Multi objective conflicts and environmental impact of intensive agriculture

10 Simulating greenhouse growth in urban zoning on the coast of Granada (Spain)

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Abstract
Within the last 30 years, greenhouse growth on the coast of Granada has become an environmental and territorial process of extraordinary significance, which has caused a huge transformation in the landscape and the traditional irrigated crops existing in this Mediterranean area. The creation of simulation models for generating future scenarios is focused on the evaluation of the environmental consequences of the increasing greenhouse use, mainly on non-urbanizable land according to coastal urban planning. Commonly, this land has higher environmental and heritage values. A simulation model based on cellular automata has been created, similar to those widely utilized in urban processes modelling. The agricultural use of the simulation model has followed the dynamics of urban process models of recent years, for their industrial and intensive character-istics and the significant process of diffusion and spatial contagion, with hardly taking into consideration the urban planning mechanisms.

Keywords: Greenhouses, changes in the land use, scenarios, cellular automata, urban zoning.

10.1 Introduction

The coast of Granada is located in southeast Spain. In this area, similar to the rest of the Mediterranean coast, the use of land for agricultural purposes and the consequent anthropization have historically been very significant (Fernández Ales et al. 1992). The transformation in land use, which has occurred during the last 50 years, is well known agriculturally as wells as for urban uses (Matarán and Valenzuela 2004). The first farms appeared in the 1950s; after 20 years there was broader development, and the biggest transformation has occurred since the 1970s. Nevertheless, the greenhouse growth process is clearly a new type of territorial transformation, similar to those occurring in dynamic areas such as strawberry intensive farms in Huelva (Spain) or tourism development along the coast.

In the particular case of greenhouses, the impressive expansion is mainly the result of the successful initiatives carried out by the local producers. Greenhouses are very profitable because of the climate conditions that make a year-round (non-seasonal) production possible (Castilla 2004). This new agro-industrial land use consumes high quantities of resources and produces several waste fluxes (Matarán 2005). It is also causing dramatic landscape changes because urban and spatial planning regulations are not taken into consideration and are occupying non-urbanizable land. In this land, most of the environmental and heritage values are found. However, new planning criteria are urgently needed. Moreover, the spatial and environmental conflicts could increase if the growth process continues, and this will be analyzed in this article using the implemented model and the created future scenarios.

In order to define these future scenarios for greenhouse expansion and according to many previous urban expansion research studies (White and Engelen 1997, White et al. 1997, Stefanov and Christensen 2001, Barredo et al. 2003, Cheng and Masser 2003, Aguilera 2006), this article will present an ex post predictive analysis of greenhouses on the coast of Granada, based on the spatial and temporal description of greenhouse dynamics between 1977 and 2007.

The first step of this study will be to describe the most important factors involved in this complex process by developing a simulation model based on cellular automata, similar to those widely utilized to model urban processes. For this reason, greenhouse growth processes are considered similar to urban growth processes, since this is an industrial agriculture with similar patterns of spatial dynamics such as spatial diffusion and contagion.

Using this model, a set of ex post simulations have been generated for the period of 1990 through 2007. This has allowed us to carry out a calibration of the model. Subsequently, future simulations of the possible expansion of greenhouses have been generated based on three scenarios until the year 2025. Results of such simulations can be the base for a decision-making process designed to overcome an unsustainable situation through new planning and management criteria.

10.2 Test areas and data sets

The studied area is located on the Granada coast, which is characterized by a length spanning 71 km and a particular (distinct) landscape: several deltas, hills, and huge slopes. The absolute distance from sea level to 1,000 meters altitude is 10 km. And the highest mountain of the Iberian Peninsula (Mulhacen Peak, 3,482 meters) is only 30 Km away from the coastline. This situation reduces the influence of the northern winds, which results in a subtropical microclimate unique in Europe and suitable for both subtropical farming and greenhouses (Frontana González 1984).

Since the 1970s, the mild climate situation for horticultural crops combined with the emergency use of cultivating under plastic allowed, an expansion of low cost greenhouses, utilizing low (delete space) levelled technology in comparison to other parts of the world (Castilla 2004).

From the entire, above-mentioned coastal strip of land, a constrained section of 180 km² has been selected to represent the overall situation of greenhouses, which is the main process affecting expansion and the geographical diversity of the coast (Fig. 10.1). Three units (West, Central, and East), each with their different particularities, can be distinguished in this field in order to give a representative view of the greenhouse expansion process and dynamics in any of the characteristic spatial situations of greenhouses: West Unit- greenhouses in a fertile agricultural plane, Central Unit- greenhouses in a non-fertile agricultural plane, and Eastern Unit- greenhouses in a rough valley.

Cartography for this area has been created in order to demonstrate the evolution of greenhouses throughout the last 30 years (the period of the most important growth), also to show a set of territorial variables that have influenced the expansion process of greenhouses based on previous studies (Matarán 2005, Aguilera et al. 2005, Matarán et al. 2006). Both will be used to carry out the elaborate model in the different simulations. They are shown in the following figures.

10.2.1 Greenhouse growth cartography

To begin with an analysis of the greenhouse dynamics over the last 30 years has been carried out using the growth cartography developed for the years 1977, 1984, 1990, and 2007 shown in Fig. 10.2. For the years 1977 and 1984 the cartography is based on aerial photographs. For the year 1990 it is based on the satellite image Landsat TM, we applied a non-supervised classification using the ISODATA (Chuvieco 2002) algorithm and we have also compared our results with the land use cartography of the year 1991 (Consejería de Agricultura y Pesca 1991). Finally, for the year 2007 the cartography is mainly based on a Landsat ETM+ satellite image of January 2003 corrected with the orthophotos from the Junta de Andalucía (2004) and Google Earth (2007).

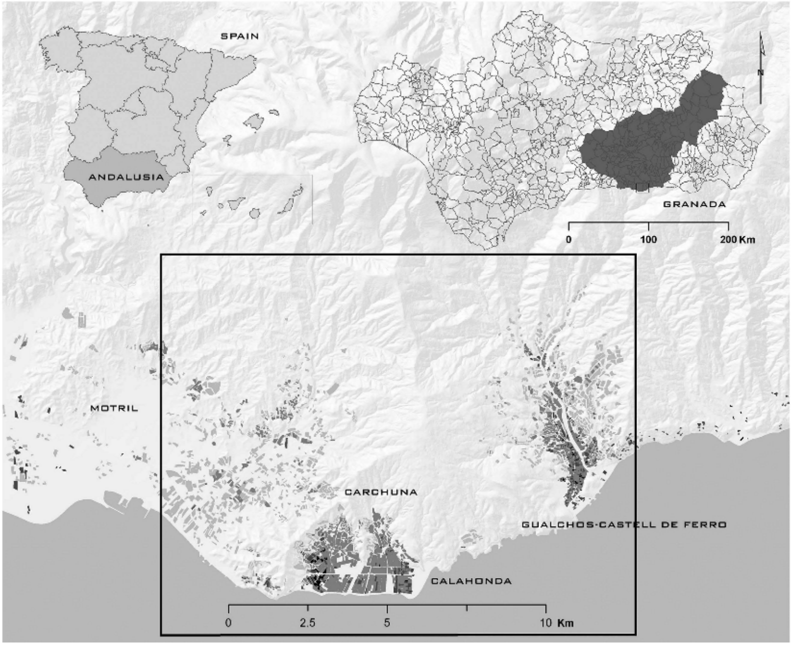

Fig. 10.1 The Coast of Granada: studied areas

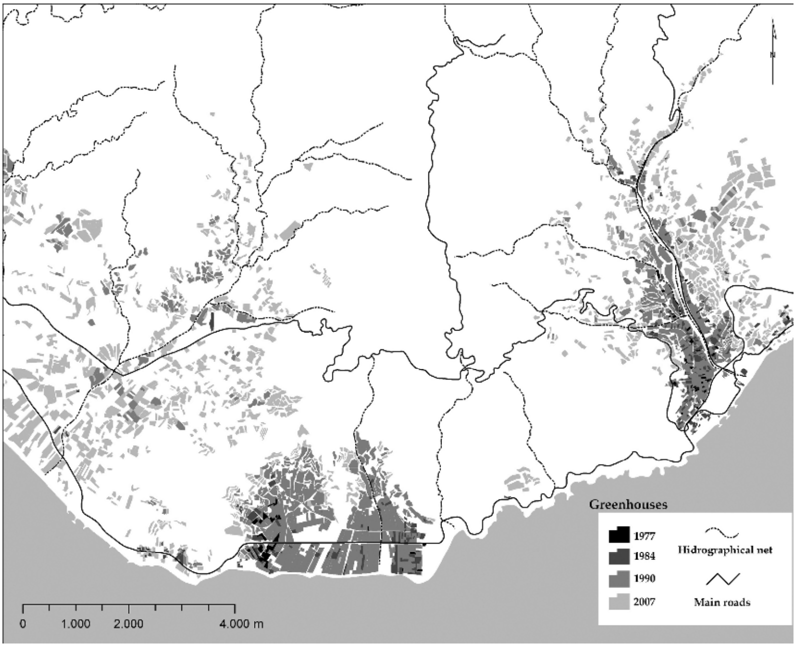

Fig. 10.2 Greenhouse growth cartography 1977-2007

As shown, the greenhouse surface development over the last 30 years has been extraordinary. The first greenhouses appeared in the 1950s, and since the 1970s greenhouse crops have gradually replaced irrigated low-land crops and non-irrigated coastal land crops.

In 1977, only 20.17 hectares existed within the studied area, and by 1984, the greenhouse surface had undergone a major growth process resulting in five times the original surface to approximately 95.44 hectares. Since 1990, as a consequence of this extraordinary growth, the greenhouse surface has reached 464.68 hectares, which will result in the saturation in most of the plane lands situated below the altitude of 100 meters along a significant part of the coast (Matarán 2005).

During the 1990s, the greenhouse surface continued expanding at a significant growth rate, especially in the West unit (Rambla del Puntalón). After the 1990s, this growth slowed down due to the stabilization of market prices and the emergence of plagues that affected the production (Matarán 2005). This has resulted in the current uncertain situation with a greenhouse surface of 1,664.26 hectares, posing the creation of scenarios that may shed light on possible future consequences of this process.

10.2.2 Territorial variables cartography

According to previous studies on the geography of greenhouses (Matarán 2005), and together with the greenhouse evolution cartography the following group of environmental and spatial factors have been charted. These factors have been considered to be the most influential in greenhouse development in a study based on logistic regression (Matarán et al. 2005, Matarán et al. 2006). The factors are as follows:

– *Land uses:* This factor represents the importance of the previous landscape structure and growing pattern.
– *Distance to central places:* The "central areas" are the centers for commercial purposes and provision of services for farmers (Matarán 2005). The distance to these places influences the set up of new greenhouses.
– *Distance to roads:* accessibility affects the expansion of greenhouses as it reduces the costs for building new lanes for the setup of greenhouses and it also facilitates the access to merchandising centers.
– *Distance to hydrographical net:* distance to the irrigation channels defines the costs of the irrigation and is the only restriction concerning water, as the new Rules dam and its irrigation net has introduced in the XXI century enough water resources for greenhouse growing. In addition to this, a price policy approach coming from the application of the

Water Framework Directive (2000) will not affect the greenhouse agriculture as it consumes less water and produces bigger benefits than the rest of agricultures (Matarán 2005).

– *Topography:* height above sea level determines the temperatures and the pumping needs for irrigation.
– *Slopes:* high slopes imply greater set up costs, whereas areas with low slopes cost less.
– *Orientation:* relates to sunlight and temperatures. Northward-orientated areas imply lower temperatures, fewer sun hours and less marine breeze.
– *Protected areas:* In Natural and National Parks, it is forbidden to build greenhouses, other regional or national restrictions are not considered in the anarchic greenhouse planning described by Matarán (2005). In addition to this, as we state in the article, in local protected areas we have found fewer restrictions.

10.3 Methodology and practical application to the data sets

The characteristics of the greenhouse expansion process described above, and the significant territorial and environmental consequences that result from these characteristics make the process quite comprehensive. The creation of future simulations from these considerations create an approach of alternative expansion scenarios in order to compare and weigh spatial possibilities. The predictive capacity of the model alone would in vain if it did not contribute to the decision process.

Our interest for modelling lies not only in knowing or creating a gradually more precise model, but also as an instrument for planning through the identification and the anticipation of possible spatial consequences that could allow us to suggest new planning criteria.

In order to carry out this task, the creation of a simulation model of greenhouse expansion has been proposed. Similar to those widely utilized in the listed bibliographies, it is based on cellular automata (CA), which is used for the simulation and evaluation of urban growth; including greenhouse expansion and many previous urban expansion research studies (White and Engelen 1997, White et al. 1997, Stefanov and Christensen 2001, Barredo et al. 2003, Cheng and Masser 2003, Aguilera 2006) as well as other natural processes, in which spatial contagion is very significant, such as in forest fires.

Applying these types of models in the field of agricultural growth could seem strange or unjustified at first glance since these tools have been widely utilized for the analysis of the spreading of urban processes. Due to the spatial characteristics of these processes, they can be "well reproduced" by the models based on CA (Batty 1997, White et al. 1997, Torrents 2000, Barredo et al. 2003, Barredo et al. 2004). These characteristics, such as the similarity through scales, spreading processes, spatial autocorrelation, contagion, attraction, repulsion, etc. can also be identified and modelled through CA for the use with greenhouses. In addition to their agricultural use, greenhouses have an intensive characteristic, which converts them into agro-industrial soil, and therefore acquire certain urban properties (Matarán 2005). These properties influence the variables that set the spatial nearness and spreading. Consequently, these properties make applying CA ideal for the construction of a predictive model (Matarán et al. 2006).

The methods used for creating simulations consist of building a model that allows the creation of an ex post simulation for the situation in 2007 using the greenhouse surface cartography from 1990, thus including the most important period of greenhouse growing and based on the knowledge of the growing process since the 1970s. Generating simulations for 2007 and comparing them with the actual situation at that time will allow the progressive calibration of the model eventually obtaining the most accurate simulations compared to the actual data in 2007 beginning with the available data for 1990. Calibrating and adjusting the model will result in the comprehension of the spatial process previously defined as the main objective of this study.

Once the ex post simulations are carried out, some perspective simulations will be generated for 2025 using the most up-to-date cartography, the map of 2007, as the base year, thus we are considering a similar interval for the calibration process (17 years) and for the modelling (18 years, not 17 years in order to round up to 2025). The proposed simulations for the same year (2025) will be based on the approach of three greenhouse expansion scenarios that consider 15 to 20 years as the best period to assess greenhouse dynamics (see Sect. 10.3.2). These simulations allow an analysis of the effects of the possible expansion of greenhouses on non-urbanizable land included in the planning.

10.3.1 The model based on cellular automata

The model based on cellular automata is theoretically inspired by those developed for urban environment by White et al. (1997). At a practical level, the model has been completely developed using IDRISI Andes. This model has been used as a base for the studies of different authors (Barredo et al. 2003, Aguilera 2006, etc). Some modifications have been introduced to this theoretical model.

From a theoretical point of view, the model is composed of three different parameters. By combining these components, a transition potential for greenhouse use will be obtained.

The three parameters are:

1. A *neighborhood parameter*, consistent on the cellular automaton, which has been defined for a regular grid whose elements or cells are represented by the cells on a raster GIS using a pixel of 50x50 meters, selected according to the average size of greenhouse farms (around 0.8 to 1 ha).
2. *A territory aptitude* value, or parameter, for each cell built by combining the set of charted territorial variables and those previously described.
3. Finally, it is also composed by the stochastic, or randomness, parameter. The objective of this parameter is to generate a “real” degree of disorder, similar to the parameter that roughly characterizes the distribution and change in spatial urban processes.

Since previous studies (Aguilera et al. 2005, Matarán et al. 2006) have revealed a low correlation between this factor and greenhouse growth[1], in this version of the model used for this case study, the accessibility parameter of the transition potential calculation is not considered (as it is in the urban theory purposed by White et al. 1997).

These parameters are combined according to the following equation:

$$P_I = v \times (1+s) \times (1+n) \tag{10.1}$$

Where:

- P_I is the transition potential of each cell in greenhouse use. It is the result of the combination of all the parameters previously described.
- n is the neighborhood parameter, also referred to as the parameter of cellular automata.
- s is the territory aptitude parameter for greenhouse use. Created using the set of charted factors, this parameter, for which correlation analysis exists from previous studies, will be presented below (Aguilera et al. 2005, Matarán et al. 2006), and has shown a significant relation to greenhouse growth. These correlation values given by the ROC (Pontius and Batchu 2003) statistic are presented in Table 10.1.

  The group of factors include: topography, slopes, orientations, uses of soil, distance to the road networks, distance to the commercialization centralities, distance to the hydrographic network, and protected areas.

[1] The values for the ROC statistic for the accessibility existing in previous studies (Matarán et al. 2006) were 0.63

They have been combined resulting in the aptitude parameter as shown below.

- v is the stochastic parameter, also referred to as the parameter of random perturbation. This parameter is used in order to try to replicate the degree of randomness inherent to social processes.

Table 10.1 ROC Values

Factors	ROC
Topography	0.8555
Distance to greenhouses	0.8355
Distance to centralities	0.8299
Slope	0.7982
Land Use	0.7257
Distance to roads	0.6291
Distance to hydrographical net	0.6106
Protected areas	0.5601
Orientation	0.5302

A detailed description of the parameters follows.

10.3.1.1 Neighborhood parameter

n refers to the neighborhood parameter, being in itself a CA parameter. The automaton is considered to work in a relatively simple way; for each cell, it obtains a value of change potentiality depending on the present greenhouses in the adjacent cells that compose its regular grid. The closer cells will attract the new greenhouses stronger than the farther cells. This decrease effect of attraction-repulsion is known in the literature as "distance-decay effect" and, as pointed out in White et al (1997), appears as a common characteristic in most of the cities.[2]

In order to be able to implement the model, a filtering matrix (9x9 cells) is used (Fig. 10.3). This matrix calculates the potentiality value for each pixel of the raster grid, depending on the number of pixels that represent the greenhouse use around it and on the distance between them. Using this matrix, the value of the neighboring pixels are multiplied by a certain factor (0 represents the absence of a greenhouse, 1 represents the existence of a greenhouse) that represents the attraction capacity of the new greenhouses

[2] This behavior is generic, and does not apply in all cases. It is possible that certain uses can show a growth in attraction after some distance, as it can occur in industrial uses, repelling in close distances to residential uses, and at longer distances can attract.

generated by the surrounding, or neighboring pixels, and shows a decay effect with distance. According to this parameter, it is assumed that those pixels, having other pixels with greenhouse use in their vicinity, will have a higher trend to turn into new greenhouses.

1	1	1	1	1	1	1	2	1
1	2	2	2	2	2	2	2	1
1	2	3	3	3	3	3	2	1
1	2	3	-50	-50	-50	3	2	1
1	2	3	-50	0	-50	3	2	1
1	2	3	-50	-50	-50	3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

Fig. 10.3 Filtering matrix

Therefore, the definition of the filtering matrix is crucial, in other words, it determines up to which range of distances the pixels will be considered as neighboring, just as in the assignment of the factor of the model calibration process. This process assigns values to the neighborhood parameter. These values determine the attraction that the greenhouse areas generate on the adjacent areas. This calibration process is carried out using approximation through different trials, until certain values are set, which al-low obtaining results as close as possible to the actual results.

Finally, all the values are summed and the resulting value is normalized between 0 and 1.

10.3.1.2 Aptitude parameter

The aptitude parameter refers to the intrinsic capacity of the territory to accommodate greenhouses. It has been defined by combining the variables, or territorial charted factors, and those variables which the existing correlation value of greenhouse growth has previously shown. In order to combine these factors, each one of them has been converted into an aptitude factor on a scale from 0 to 1, in such a way that the values close to 1 represent the most optimal values of the factor for the establishment of greenhouses. The values close to 0 represent the worst values of the expansion variable. For instance, for the slopes, the higher values will have an aptitude value close to 0 and the lower values will have a higher aptitude value.

Utilizing IDRISI Andes software, the factors expressed in aptitude values from 0 to 1, and the correlation values for each one of them, have been combined using the methodology of multi-criteria evaluation (Malczewski

1999, Gómez and Barredo 2006) in order to determine the global aptitude factor. By means of a pair comparison matrix, in which the different factors have been prioritized according to the correlation values previously obtained (Aguilera et al. 2005, Matarán et al. 2006), the different weights assigned have been determined in order to carry out the weighting system of the multi-criteria evaluation.

Table 10.2 shows the correlation values obtained from the ROC statistic, as well as the value of the weight assigned in the MCE for the different factors, used in the determination of the aptitude.

Table 10.2 ROC and MCE weight values

Factors	ROC	MCE weight
Topography	0.8555	0.40
Distance to greenhouses	0.8355	-
Distance to centralities	0.8299	0.25
Slope	0.7982	0.13
Land Use	0.7257	0.12
Distance to roads	0.6291	-
Distance to hydrographical net	0.6106	-
Protected areas	0.5601	-
Orientation	0.5302	-

Once these factors are combined depending on the weights presented in the previous table, the aptitude factor is obtained and used as a raster surface that shows the territorial aptitude for the location of the new, intensive agricultural crops. This surface is shown in the Fig. 10.4.

Areas having a higher aptitude (depending on the available variables) for the occupation of agricultural areas used for greenhouses are shown in lighter tones.

10.3.1.3 Randomness parameter

As pointed out previously, v is the stochastic or random perturbation, parameter. This parameter is used to try to replicate the randomness degree inherent to social processes. It is obtained for each of the pixels in the studied area applying the equation proposed by White and Engelen (1997).

$$v = 1 + (-\ln(rand))^{\partial} \tag{10.2}$$

rand is a random number between 0 and 1.

∂ is a parameter that permits the adjustment of the degree of perturbation. After carrying out different simulations, with varying calibrations of this parameter, we have adjusted the value of α to 0.55 in this study. As this parameter increases, a larger degree of disorder is introduced. The simulations generated with high values of this parameter will tend to show more scattered forms of occupation than those simulations generated with lower values of this parameter.

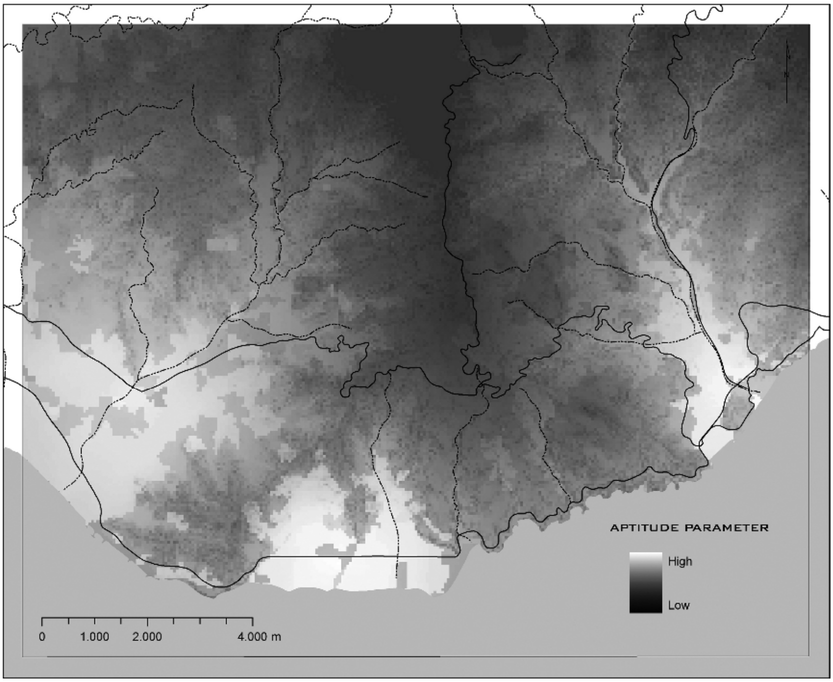

Fig. 10.4 Aptitude parameter

10.3.1.4 The implementation of the model

After the different parameters had been theoretically defined, they were implemented in the model constructor IDRISI Andes resulting in the greenhouse growth model. It is worth noting that the model has been completely implemented in a widely extended GIS, without having to resort to connections between geographic input data stored in the GIS and an external model. This has the advantage of not having to carry out programming tasks, which makes the model easily reproducible. It also eases its use for geographic fields, once it is calibrated. In this sense, this fact is a breakthrough, since the models proposed in previous literature consist of specific software and are usually complex. These previous models are developed just for this purpose and are highly complex when implementing their use.

The model works through a series of iterations, each iteration corresponding with a year in the simulation, and obtains a transition potential for each one of the pixels of the studied area and selects those with the highest potential. These pixels will be included as new greenhouses for the next iteration of the model.

The amount of pixels which are selected by the model in each iteration for the ex post simulation for the period of 1990-2007 will correspond with the annual growth rate of the greenhouses for that same period of time. For future simulations created and based on the 2007 greenhouse cartography; the selected surfaces in each iteration of the model as new greenhouses will be established by 3 future growth scenarios. These scenarios will be explained below and will take into consideration different situations of occupancy demand for new greenhouses.

10.3.2 The calibration of the model

As previously explained, the simulations carried out for the future, using the 2007 cartography as the base year, will require the establishment of certain surfaces and growth rates in order to allow the model to select a specific set of pixels with the highest potential. This occurs because the model can only spatially identify those pixels with the highest potential, but can not identify how many must change.

Three scenarios for the possible evolution of greenhouse agriculture in future years have been created, taking into account the socio-economical factor which determine greenhouse surface growth. These scenarios have been created in order to raise different future growth hypotheses, each hypothesis with certain demands for growth of greenhouse surface, which can be included in the model. Each one of these scenarios will be projected to the year 2025, starting from the existing situation in 2007. This 18-year interval has been chosen in order to maintain some similarity between the studied intervals in the period of 1990-2007 and, likewise, in order to consider enough time as to make it representative of the average values for factors that affect the localization of greenhouses.

Among the main factors that determine the dynamics of the 3 proposed scenarios, there is the profitability of crops, dependent on the market prices of these crops, based on the analysis carried out for the period of 1990-2003, obtained from Matarán (2005).

Dynamics will also be affected by other factors such as urban planning. According to what has been observed in the analysis of the last 30 years in the coastal region of Granada, urban planning is substantially modified at least every 15 years (and at most every 20 years), unless political decisions set different regulations. Up to the present, it has been observed that the greenhouses located on urbanizable land tend to be abandoned. This process has gone almost unnoticed in the recent years. However, the new planning in the early 21st century and the extraordinary dynamics of urban growth in this decade may lead to a significant transformation of some of the lands that are currently occupied by greenhouses.

Finally, the environmental factors and the availability of natural resources remain more or less constant in time, in other words, there is an amount of resources suitable to maintain different growth rates; for instance, what happened with water after the Rules Dam started working in the river Guadalfeo, (Valenzuela and Matarán 2008), the main river in the studied area.

Hence, according to these factors, 3 future growth scenarios have been proposed:

– *Stabilization*: This scenario represents stagnation in the greenhouse growth process, which would yield to the pressure of the incipient tourist sector. For this reason, the greenhouse surface remains more or less constant. However, a relocation process in which greenhouses are being urbanized occurs. Therefore, a growth in the greenhouse surface in the non-urbanizable areas has occurred, occupying about 208.35 hectares. This means a transformation of almost 1% per year, which is equivalent to the percentage of greenhouse areas that will be used for urbanization.
– *Tendential Growth:* In this scenario the average growth rates in the last 23 years (1984-2007) remain constant. In these years a process of occupation has taken place and it has resulted in the current saturated landscapes. This is related to the relocation process due to urbanization of existing areas, and to the existence of an average profitability similar to the average of the last 23 years that guarantees new growths at the previous pace. Therefore, the growth of the land occupied by greenhouses has increased by 1,274 hectares, representing an annual growth rate of over 4%.
– *Moderate growth:* In between the two extreme scenarios described, there is a scenario of moderate growth in which the average growth rates of the last 23 years (1984-2007) are reduced. It is related to the relocation process, because of the expansion of urban areas, and related to overcoming the current crisis scenario. This favors the existence of the average profitability, which could be lower than those of the last 23 years, lowering the capacity of the farmers´ ability to occupy new lands. The annual growth rate in this case could reach 2% (around 29 hectares per year), representing around 524.29 hectares of growth. This number and the total 208.35 relocated hectares, through the 18 years, add up to 732.94 hectares.

10.4 Results

Results for the ex post simulations used in order to carry out the calibration of the model during the period 1990-2007 and the future scenarios for the year 2025 will be presented next. The results for the ex post simulations will be presented first, followed by the results of the prospective simulations.

10.4.1 Results of the ex post simulation process in period 1990-2007

In order to calibrate the model, many ex post simulations have been carried out for the period 1990-2007 using the presented model. Hence, the feedback mechanism allows for the optimization of the results, narrowing in on the situation in 2007. Three of the simulations obtained, which were used in the model calibration process will be presented next in Fig. 10.5.

Through each simulation, a model that better resembles the current situation is obtained. In order to obtain better results in each of the simulations, the calibration values for the filtering matrix of the neighborhood parameter have been modified, as well as the randomness degree obtained from the stochastic parameter.

Simulation 6, visually, has the highest degree of similarity with the existing situation in 2007. This is corroborated by different tests used and described in the validation and discussion of the results epigraph. In this simulation, the existing “disorder” degree is lower than in previous simulations, which appear to have a dispersion degree higher than the actual one. This fact gives it a less “real” aspect due to the presence of multiple dispersed pixels. Other simulations, when trying to attenuate this effect, created masses in the areas planned as new greenhouses, which also reduced the ¨reality¨ effect. On the contrary, in simulation 6, a distribution of the greenhouse growth much more similar to the actual one can be observed. It has some “packages” that are not as compact as in some of the first simulations or as dispersed as in the other simulations.

For the Central unit, the result resembles the actual existing situation, although with a slightly higher degree of saturation. The West unit shows a similar structure, although the actual situation seems to show a lower degree of aggregation, tending to occupy areas of higher altitude than in the situation simulated by the model. Finally, the least similarity is found in the East unit. In this studied area, the obtained results are less satisfactory since the simulation shows a much more compact situation than the reality. These results show different situations in the different units, which suggest that the three can be found in different stages of the expansion dynamic, making it difficult to calibrate them simultaneously. In any case, simulation 6 shows that it is possible to generate a simulation that can be similar to the actual situation, as will be discussed in the validation of results.

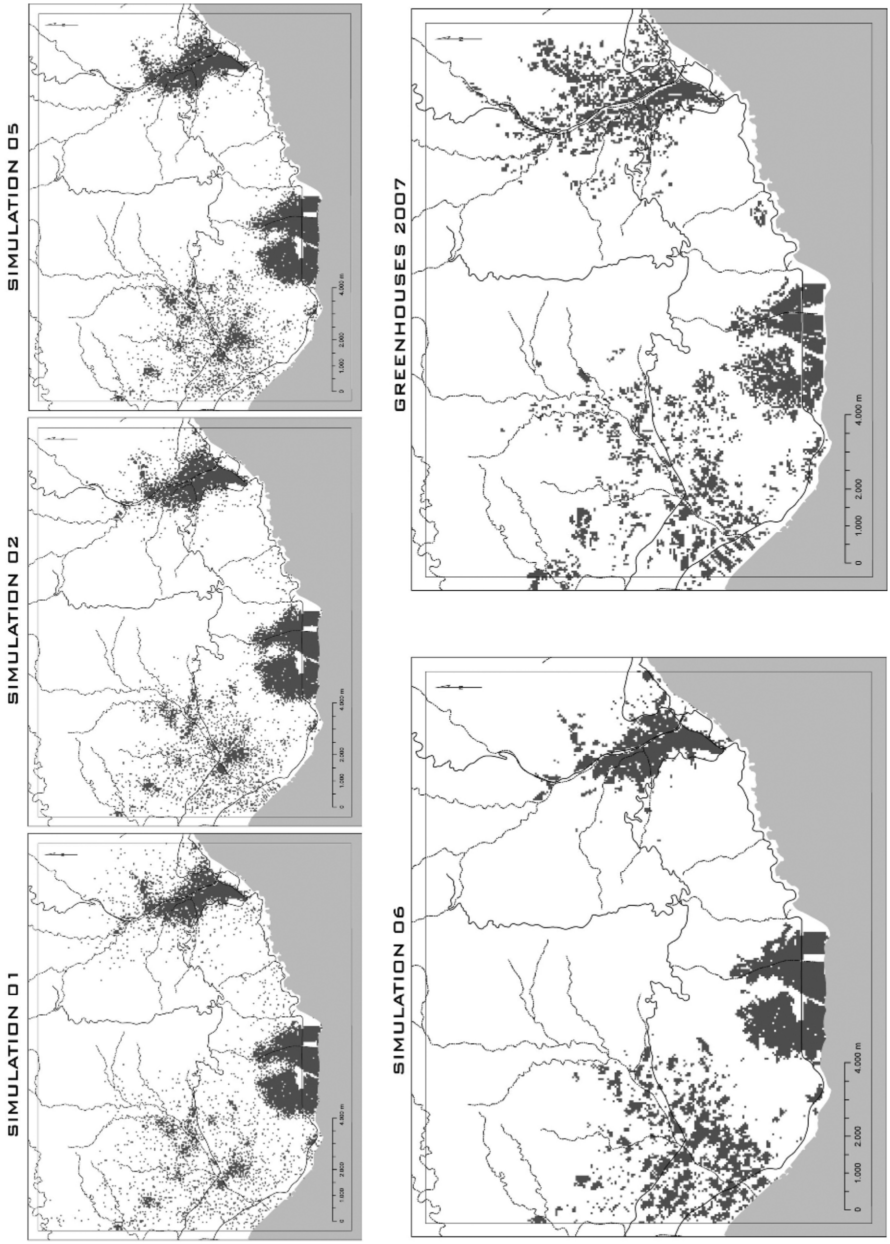

Fig. 10.5 Simulations obtained using the model

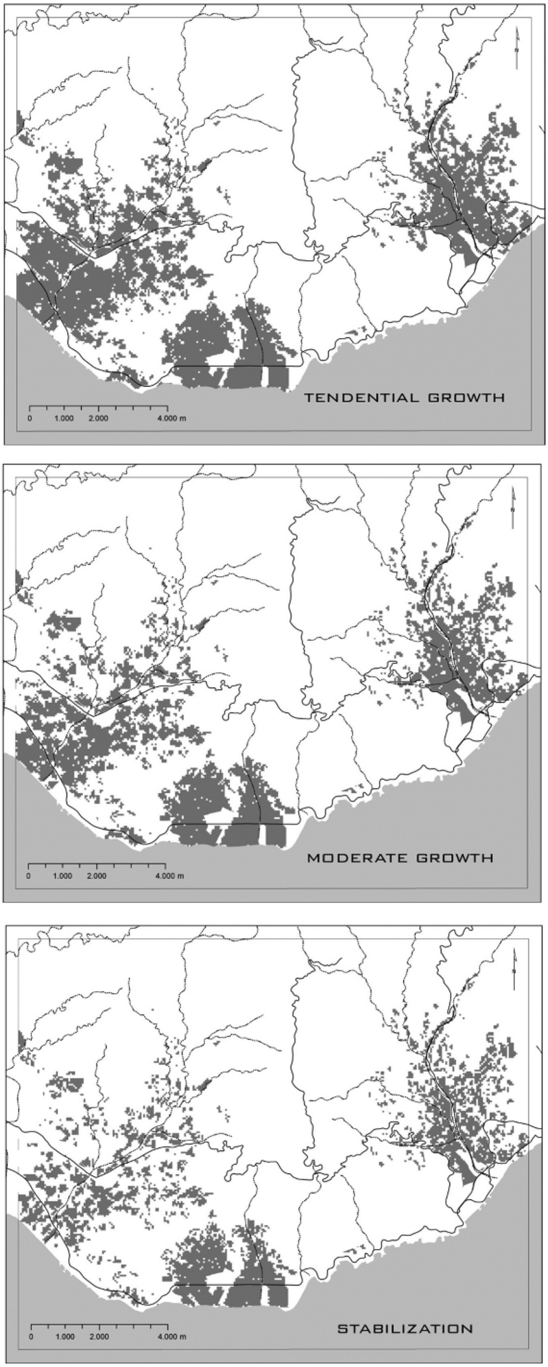

Fig. 10.6 Future scenarios generated

10.4.2 Results of the future scenarios

After the model has been calibrated according to the ex post simulations and the calibration used to generate simulation 6 (identified as the one which best represents the growth patterns of greenhouses, according to the tests applied in the next epigraph) has been applied, simulations for each one of the three proposed scenarios were carried out (stabilization, tendential growth, and moderate growth). The results for each one of these generated scenarios, using the base of the 2007 cartography, are shown in Fig. 10.6

From the top to the bottom, the figure shows the scenarios for tendential growth, moderate growth, and stabilization. The first scenario shows a greenhouse growth process that maintains the pace of the last years, which generates a massive occupation of the coastal plains, with a significant aggregation of new growth. The scenario for moderate growth shows a growth that is mainly the result of the relocation of greenhouses, which will be replaced by new tourist development, which does not cause such a pronounced saturation as in the first scenario. The stabilization scenario shows how only a slight relocation of some surfaces, that would transfer greenhouses to areas of lower tourist demand, would result in little change in the existing situation.

In the three scenarios, the occupation structure is very similar, changing generally the degree of saturation that reaches those areas which show acceptable aptitude values for being cultivated. This occurs because the areas of higher capacity are already occupied; hence the new growths have to compete for those areas that are not suitable for being occupied with new greenhouse agriculture.

In any case presented below, the different scenarios described show different possible degrees of development for the expansion processes of greenhouse agriculture along the coast of Granada.

10.5 Validation and discussion of results

After describing both the ex post simulations generated in order to calibrate the model and the different future simulations of the greenhouse expansion scenarios, a validation of the results of the ex post simulations for 2007 was carried out. Different comparison techniques have been applied, as well as an evaluation of the future scenarios and consequences that those scenarios could imply for the non-urbanizable lands, included the planning.

10.5.1 Validation of ex post simulations

Firstly, the validation of the ex post simulations generated through the cellular automaton model, should be considered. In order to do this, several methods for comparison have been selected to evaluate the different simulations with the existing situation in 2007. Besides the visual comparison previously shown, these methods include the already classic, pair comparison matrix, as well as a comparison through landscape ecology metrics, such as the patch number (PN) and their average size (MPS) (Botequilha and Ahern 2002, Botequilha et al. 2006). The pair comparison matrixes have been widely utilized as a method of comparison in simulations and actual situations, as in the models based in cellular automata used in the simulation of urban processes (White and Engelen 1997, Barredo et al. 2003, Aguilera 2006). However, these matrixes have been criticized for not being able to compare patterns at a landscape mosaic structure level (White et al 1997). Hence, a set of landscape ecology metrics that allows a comparison of the situation in the greenhouse landscape mosaic, has been selected. Since it is not so important to determine whether one or the other pixel will turn into a greenhouse, the use of this type of landscape and spatial pattern metrics as a measurement of validation of the simulations is much more valuable. This type of test is much more valid for the objective of this study because it can better identify the patterns and shapes of future occupations.

10.5.1.1 Comparison through matrixes; cross tabulation

Validation through pair comparison matrixes shows, by using the kappa index, the degree of similarity between two images by comparing pixel by pixel. Each one of the simulations can be compared to the actual situation, hence a coincidence value can be obtained for the paired maps. The main problem of this comparison method, as previously pointed out, is that is not able to identify occupation patterns. In any case, the following table (Table 10.3) shows the values for the kappa index for the next 4 selected simulations.

Table 10.3 Value for Kappa index for the selected simulations

SCENARIO	Kappa index
Simulation 1	0.5062
Simulation 2	0.5195
Simulation 5	0.5208
Simulation 6	0.5368

The previous table shows how the values are very similar for all the simulations and it can be noted that they are low values. In other words, pixel by pixel, the simulations do not correspond very accurately with the results (reality). For the first three simulations, which visually do not accurately resemble the actual situation, the results do not seem to be too illogical. However, for simulation 6, which at least at a visual level seemed to resemble the actual situation, the results are not very encouraging, since the values for the kappa index are only slightly higher. The different behaviours of the different units distinguishable in the studied area explain these results (Fig. 10.7). For the West and Central units, at a visual level, the results seem to be satisfactory. However, for the East unit the results are less satisfactory. It is possible that the results of the East unit affect the kappa index by lowering it for all the studied areas.

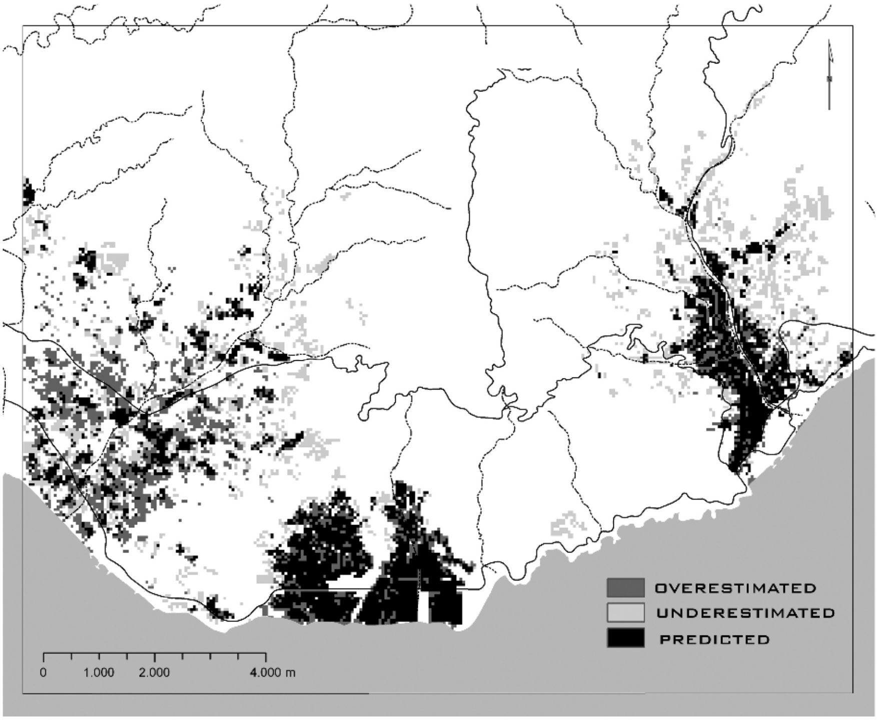

Fig. 10.7 Cross tabulation for simulation 6

An individual calibration would probably show more accurate results, taking only one of the three units as a field of study. In order to consider the possible particularities of each of the existing units (West, Central and East), subsequent developments of the model and its calibration could work in this way, as it was developed for a logistic regression model (Aguilera et al 2005). Regardless of calibration type, in this article we wanted to assess the process at a subregional scale, which means that we have to consider at least an area large enough to represent the main situations.

10.5.1.2 Comparison through landscape ecology metrics

The other method selected in order to validate the results, consisted of the comparison through landscape ecology metrics. These are non-dimensional (only comparable) metrics (Table 10.4, Fig. 10.8), whose exhaustive description can be found in McGarigal and Marks (1995) and in Botequilha et al. (2006), and among them we have selected the following:

PN: The *patch number* is the simplest metric in the landscape ecology and can hint to how much a use is divided or fragmented.

MPS: From *the medium patch size*, the average surface of individual spots of a certain use will be obtained (McGarigal and Marks 1995). In this study, the average values of the different patches will be obtained.

Table 10.4 PN and MPS value for the 4 simulations and the real situation

SCENARIO	PN	MPS
Simulation 1	833	2.00
Simulation 2	903	1.84
Simulation 5	1,238	1.35
Simulation 6	238	6.79
Greenhouses 2007	356	4.70

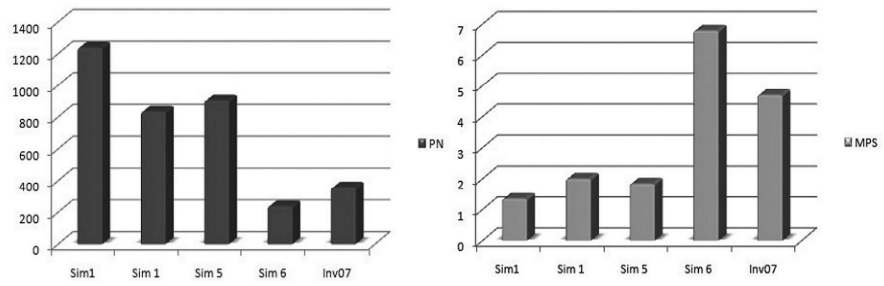

Fig. 10.8 PN and MPS result

In accordance with this comparison method, simulation 6 shows values much more similar to the actual situation than the previous simulations, despite having similar values for the kappa index. These values show that simulation 6 is able to roughly reproduce the occupancy structures that greenhouses showed for the period of 1990-2007. The comparison through matrixes and kappa index is less suitable in trying to identify those simulations that show a pattern similar to the actual one.

Likewise, in spite of the fact that there is not a total degree of coincidence (perfect agreement), this simulation is considered capable of generating future scenarios fairly representative of the greenhouse growth dynamic that might occur. Hence, it has been selected for the simulation of the previously described simulations.

10.5.2 The valuation of future scenarios; the growth on non-urbanizable land

Finally, generated future scenarios have been valued, with special attention to the occupancy of the lands included in the planning. In this sense, the location of the greenhouses would take place on non-urbanizable land in the tendential and moderate growth scenarios, in which a net increase of the greenhouse surface occurs, as well as in the relocation scenario.

The higher growth in the tendential scenario represents a densification of the greenhouse surface in the studied area. This compactness mainly appears in both the West and East units.

The other two scenarios, the moderate and the stabilization scenarios, involve a higher presence of areas free of greenhouses in an interstitial manner in the three units. Lower compactness represents better drainage and water infiltration, especially for the aquifer located in the West unit, as well as a more distant location from the dry watercourse that lowers the risk of flooding.

Other consequences of lesser compactness in greenhouse use would be environmental infiltration related to ecologic connectivity, the possibility of diversification of uses, and the decrease of the visual impact of greenhouses.

Because of the intensive use, which is closer to the industrial use than to the traditional agricultural use, municipal planning should establish certain control mechanisms regarding the different categories that can be established for non-urbanizable land. In the example of Motril, located in the West unit, the greenhouse expansion would be restricted to two areas (in gray) located in Fig. 10.9 (according to the municipal town planning of from 2003).

Fig. 10.9, corresponding to the tendential scenario, shows how a large quantity of greenhouses would be located in non-urbanizable land, especially when protected because of its forest and archeological values or its high slopes.

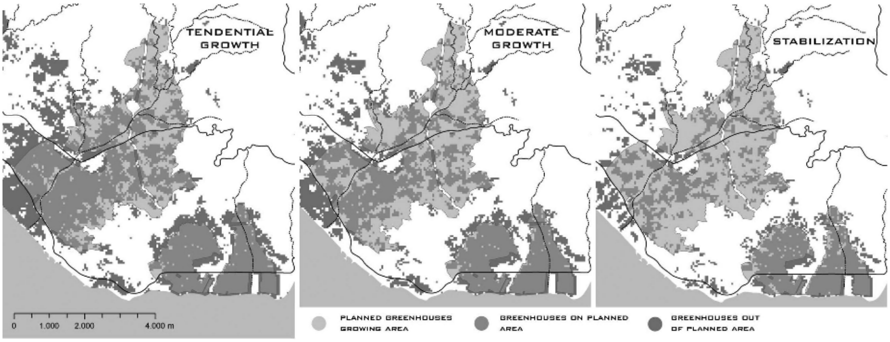

Fig. 10.9 Future Scenarios and Non-urbanizable land

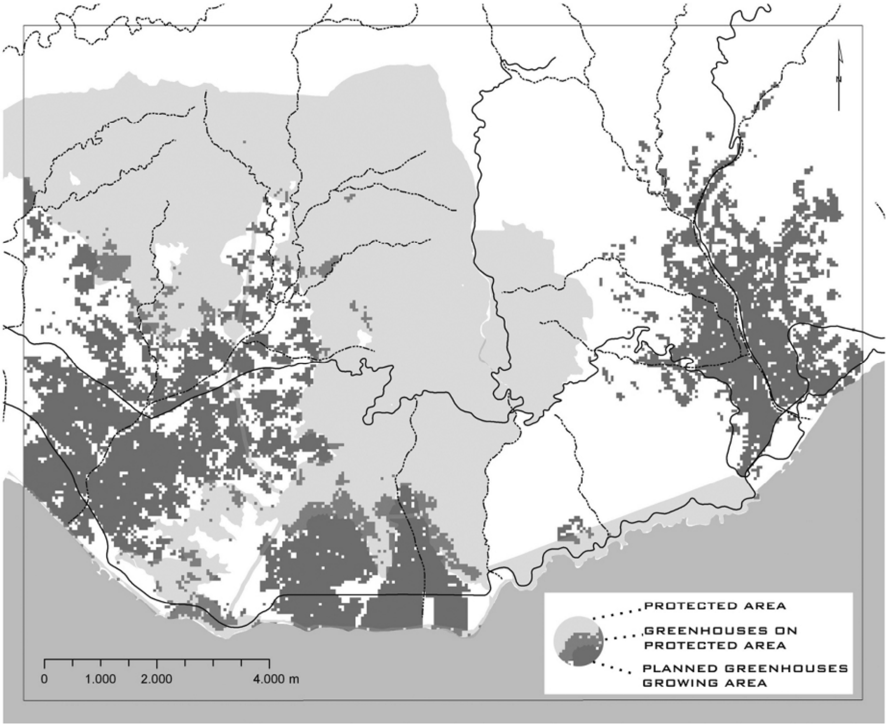

Fig. 10.10 Greenhouses located in protected areas. Tendential scenario

Therefore, it is necessary to establish adequate control mechanisms for greenhouse growth, taking into consideration the criteria based on environmental and landscape functions in the planning of non-urbanizable land. Using these functions, the suitability of certain areas for organized greenhouse growth can be established.

10.6 Conclusion and outlook

Analyzing, modelling, calibrating, predicting, interpreting, planning, and managing spatial change should represent a constant and unitary sequence in planning, feeding back models and territory management systems. In such a manner that predictions can be used in order to make informed decisions and not the other way around. Models should adapt to territories, helping to understand and describe complex processes with a clear territorial significance, such as this case of intensive greenhouse agricultural growth on the coast of Granada (Matarán 2005). In this case the model developed, although it did not obtain spectacular values of similarity (average values for the kappa index and approximated values for the spatial ecology metrics) in the ex post simulations, fulfills the desired objectives. It advances knowledge both in the comprehension of the greenhouse expansion territorial process, as well as in the creation of future scenarios, which could be incorporated into the planning and decision-making process. Since 2004 a sub-regional plan has been in development, unfortunately the regional authority in charge of this plan is currently the sole user of the model. Local authorities could also use the model, seeing as they are in charge of urban planning and zoning, and greenhouses need to be included in these regulations as they are considered an agro-urban land use. Finally, other administrations such us the environmental and the water administrations (both regional and national) could use the model, for example to assess the possible environmental impacts produced by greenhouse wastes (Matarán 2005) or to predict the increasing hydrological risk due to the impervious surface of new greenhouses.

On the other hand, results obtained from future scenarios, with significant growth of non-urbanizable land (some under special protection), raise some questions about planning, optimizing the use of the results of the simulations.

- Which significant parameters exist in order to identify the environmental and financial impacts originated from the spatial diffusion of greenhouses?
- Which monitoring instruments exist that can utilize parameters, or indexes, capable of planning and managing the diffusion of a certain activity?
- Is it possible to generate environmental and territorial suitability criteria for the greenhouse spatial diffusion process?

These questions arise as consequence of: the analysis of the process, the attempt of modelling of the process, and the creation of possible future scenarios that start to take into consideration the planning process. For that precise reason, the modelling and comprehension process of the greenhouse diffusion per se, should be advanced. In this sense, some of the proposed challenges are:

– *Incorporating new factors which can effect the process.*

Many of the factors analyzed and utilized in the model described are territorial factors that are easy to chart and obtain information from. However, other factors are more diffuse and difficult to value, such as landscape inertia (Matarán 2005). This concept is related to the existence of changing motor forces in the land use, linked to facts including social, financial, cultural, and spatial origin of the conditioning processes. These other factors can be decisive, because lands that have conditions suitable for expansion a priori, will remain unaltered and vice versa.

– *The space-time perspective of the model and future scenarios.*

Regarding the time and space scale, predictive dependency should be mentioned first. The field, the selected variables, and the understanding of the process end up conditioning the results, also conditioned by the chosen technique (Verburg et al. 2004). In this sense, new proposals must be developed in order to improve the modelling process. In any case, an added complexity such as the spatial process should be considered. It responds to an original and accelerated expansion process (around 30 years), unprecedented in the international literature or in analysis on this spatial process.

– *Validation methods and use of spatial ecology metrics.*

Validation methods are an additional main challenge that arises from the design of these models. Spatial ecology metrics can end up representing not just an alternative method, but also a complementary method to other classic methods, such as the comparison matrixes method. These classic methods have been criticized for not being able to take the spatial pattern into account (White et al. 1997). In this sense, the exploration of other metrics that have understanding of compactness and shape can be, and must be, explored in future studies.

These metrics can also be utilized in order to value possible future scenarios and determine environmental consequences of growths that are more disperse, compact, aggregated, etc.

All these factors must be explored in new studies in order to maintain the advancement in the knowledge of the greenhouse expansion process on the Mediterranean coastal areas and to incorporate the results of the simulations created in the decision-making process, with the objective of planning and valuing consequences of possible future situations.

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