Participatory land use modelling, pathways to an integrated approach

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Abstract

The increasing adoption of land use models in planning and policy development highlights the need for an integrated approach that combines analytical modelling techniques with discursive 'soft-science' methodologies. Recent scientific contributions to the discipline have tended to focus on analytical problems such as statistical assessment of model goodness of fit through map comparison techniques, while the problem of integrating stakeholder information into land use models has received little attention. Using the example of a land use model developed for the Guadiamar basin in South West Spain, location of the emblematic Doñana natural area, an integrated methodology for participatory calibration and evaluation of model results is presented which combines information from key stakeholders across a range of sectors with analytical model calibration techniques. Both discursive and analytical techniques are presented side by side to demonstrate that including participatory approaches is likely to improve both calibration results and model applicability. Integration of participatory methods into land use models is more likely to be successful if stakeholders are selected carefully so as to make best possible use of their time and knowledge, and are involved in the modelling process from the beginning of the project cycle.

1 INTRODUCTION

1.1 Research Background

Over the past decades the adoption of land use models in planning and policy making has increased dramatically (Seaton 2001; Oxley et al 2004; Encinas et al, 2006; Engelen et al 2007). This has required the deployment of methods that cross disciplines and research communities, linking "soft" (humanistic, discursive) and "hard" (analytical, natural) science approaches. Soft-science approaches try to take into account the inherent unpredictability of human behaviour and the capacity of human agents to change the system from within. Hard-science approaches assume the collection of beliefs and perceptions which make up our view of the world as static for the purpose of investigating a particular theory or problem (Winder 2004). Soft-science methods are useful in cases where human behaviour or interaction is important (e.g. land use policy), and may often involve participatory or social enquiry techniques which provide qualitative or approximate information (Lemon et al 1994). Hard-science approaches are relevant to the study of natural phenomena (e.g. degradation of a natural resource), and involve mathematical and quantitative methods which provide precise, numerical data. In cases of human-environment interaction, as in a land use change model, both kinds of information are necessary and integrative approaches that try to combine hard and soft-science methodologies are therefore important.

As land use models have become more widely used, spatial modelling frameworks such as Metronamica (RIKS 2011, Van Delden and Hurkens, 2011) and CLUE (Veldkamp and Fresco 1996, Verburg et al 2008) have been developed, obviating the need to design a new system every time. Apart from the clear advantage of time-saving, the principal benefit of applying existing modelling frameworks to new regions rather than developing models from scratch for each new research project is that the model concepts and mechanisms tend to become better tested over time.

Thus, the emphasis has come to rest on calibration, that is, the adaptation of these existing frameworks to a particular case study region and data,rather than on the development of new model suites. As policy support-oriented models making use of existing architecture have proliferated, so too has literature on calibration methods and techniques; the evaluation of the results of land use simulations through various kinds of spatial metrics has practically become a sub-discipline in itself (e.g. Hagen 2003, Pontius and Malanson 2005, White 2006), map comparison techniques such as cluster analysis, rank size metrics, and the kappa statistic have been developed from existing approaches in statistics, geography and remote sensing. However, the recent literature tends to be over-balanced towards 'hard-science' approaches to calibration with little or no consideration given to the role of stakeholders as genuine contributors of knowledge that helps to define model parameters. In general, land use models do not incorporate stakeholder information at the model development phase, but rather later, for scenario development (e.g. Hernandez-Jimenez and Winder 2006, Volkery et al 2008, Van Delden and

Hagen-Zanker 2009, Kok and Van Delden 2009) or evaluation of model results (e.g. Millington et al 2011).

1.2 Aims of the research

The research takes place in the context of a wider project to use a land use model in support of finding appropriate pathways to mitigate the problem of land use change in the vicinity of a natural protected area in Spain. This research focuses on the application and calibration of the land use model which will afterwards be used to simulate the potential impact of different change processes and land planning interventions through scenarios in the wider project (for a discussion of scenario development for the Doñana natural area see Palomo et al 2011).

In developing a model for policy support the needs of both the stakeholders and the land use modelling community need to be addressed. A poorly calibrated model is likely to be less useful for discussion support purposes, since it is less easy to convince stakeholders of its intrinsic value (e.g. by showing that the model is able to simulate land use change at approximately the right locations given the appropriate rules). At the same time, calibration results need to be expressed in the language of the existing non-participatory land use modelling community (e.g. through statistical map comparison techniques) if peers are to be convinced that the approach offers advantages. The intention of this article is therefore to propose a methodology for applying and calibrating land use models in which analytical and discursive modelling steps are applied in parallel, and show that the approach presented can both improve model calibration in quantifiable terms, and contribute productively to understanding of land change dynamics in natural areas by bringing together stakeholders from different communities (scientists, conservationists, local authorities, natural park managers, farmers) and combining different disciplinary perspectives (soft and hard-science).

In order to achieve this aim three sub-objectives have been defined:

1. To engage key local stakeholders in a process of reflection and discussion about land use change in Doñana and its hydrological catchment (the Guadiamar basin), in order to build and calibrate a model of land use change in which the stakeholder community identified is explicitly involved at all stages of the development process.

2. To review existing methods for applying and calibrating land use models and participatory approaches, combining these to develop a methodology that incorporates both hard and soft science elements; and to test this methodology.

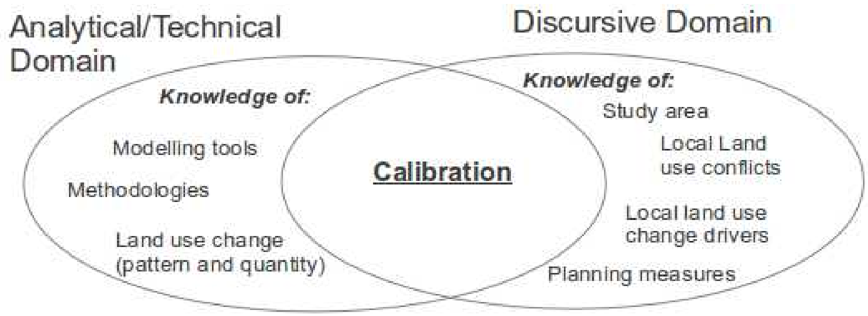
3. To demonstrate that the approach described offers important advantages over traditional non-participatory land use modelling application and calibration approaches (e.g. Van Vliet et al 2013, Wickramasuriya et al 2009) for use in planning policy context.

The first of these three research aims is addressed in detail in section 3 of this paper (results), and provides the necessary foundation for achieving aims 2 and 3, as discussed in detail in section 4 of the paper (discussion and lessons learnt).

1.3 Calibration

Rykiel (1996) defines calibration as "the estimation and adjustment of the model parameters and constraints to improve the agreement between model output and a data set".

To calibrate a land use model, a range of types of knowledge from different sources must be brought together. Unless the model is very simple, it seems unrealistic to expect a single actor or group of actors from a single domain (usually the scientist/s or researcher/s), no matter how knowledgeable, to have a complete understanding of all of these at the outset. Nonetheless, the possession of such knowledge on the part of the researcher is often tacitly assumed, leading to the misconception that discursive knowledge-sharing processes are superfluous or "value-added". A broader definition of calibration than that given abovecan therefore be proposed, incorporating knowledge from both hard and soft-science domains (Figure 1).



[Figure 1: calibration of a land use model through knowledge sharing across domains]

The key, therefore, to adequate calibration of the model is likely to reside in finding the balance between knowledge domains, not only statistical goodness of fit to available data (analytical domain), but also acceptance among the relevant stakeholder community that the model incorporates the appropriate parameters for its intended use within the area of study considered (discursive domain). For this reason we have integrated participatory information with analytical-technical activities as closely as possible.

1.4 Cellular automata models of land use change

The model employed in this research is a Cellular Automata (CA) based land use model. CA models integrate mathematical theories of self-reproduction in automata (Von Neumann 1966) and stochasticity (Ulam 1950) with the 2 dimensional cellular-grid or raster cartographic space familiar to present-day users of Geographical Information Systems (GIS). The concept of a dynamic geographical cellular automata was proposed by Tobler (1979) and developed during the 1990's by researchers interested in modelling urban growth and change (e.g. White and Engelen 1993; Batty and Xie 1994; Clarke et al 1997; Phipps and Langlois 1997).

Though land use change can in theory be attributed to particular agents, they are not normally directly represented in CA land use models, unlike in Agent Based Models (ABMs) or Multi-agent Systems (MAS). Well-known examples of CA modelling frameworks include SLEUTH (Clarke et al 1997), and those of the Metronamica family, e.g. SimLucia (White et al 2000), Xplorah (Van Delden et al

2008). CA modelling systems aim to simulate the aggregate behaviour of multiple change agents by developing land use transition rules and testing these rules against data. Model performance is estimated by determining the spatial similarity, respect to pattern and location, of the simulated map and the real map (Van Vliet et al 2013). By aggregating behavioural aspects of land change processes and combining this aggregate data with local information, it is possible to explore land use dynamics of large areas without the need to collect detailed data on actor behaviour.

1.5 Participatory modelling

Voinov and Bousquet (2010) find early examples of participation in modelling in the work of Forrester (e.g. 1961) and also in environmental assessment from the 1970s (Wagner and Ortolando 1975, 1976). Recent approaches such as companion modelling, or ComMod (Barreteau et al 2003, Bousquet and Trebuil 2005), develop this idea further. In ComMod the scientist is regarded as one stakeholder among many, whose primary role is to feed the system with evidence-based knowledge and to motivate the community to develop possible alternatives. It is possible to distinguish between purely discursive participatory approaches where a conceptual model is constructed together with stakeholders to assist in the solution of a problem (e.g. de Boer and Bressers 2011) and those in which analytical data or "hard science" information is also incorporated, as in the case of the work presented here. In the first case the modeller aims to share techniques she/he may have to contribute to the solution of a problem that must be resolved through collective action. In the second case, it is understood that the modeller may also have analytical data which she/he wishes to feed into the system, which, it is felt, may improve all stakeholders' understanding of the problem and (in the best possible case) lead to eventual changes in policy or approach to management of the resource in question. In both cases a mutual process of information exchange is initiated, in which all stakeholders may have their perceptions challenged, leading to convergence of perspectives around the issue, or *social learning* (de Kraker and van de Wal, 2012).

1.6 The case study: The Guadiamar basin, South West Spain

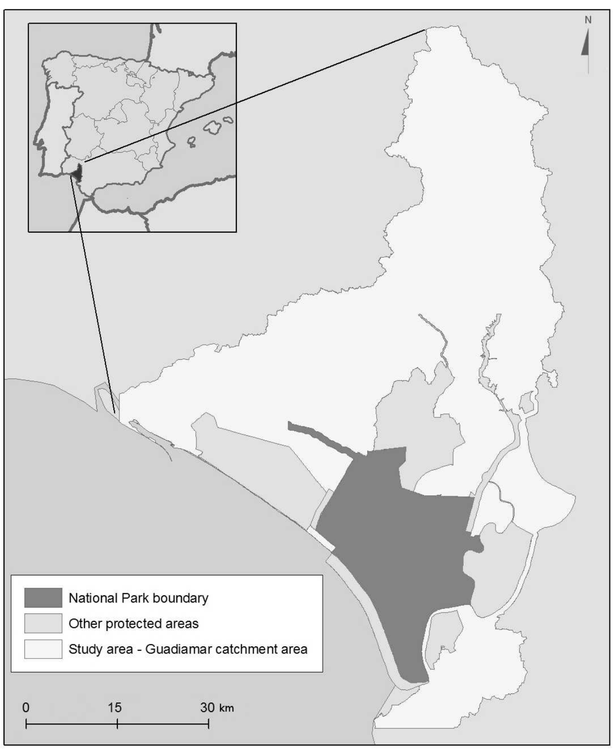
The study area addressed by this research (Figure 2), the Guadiamar basin, in South West Spain, is chiefly of interest in the following study on account of Doñana, a coastal dune and marshland ecosystem of outstanding international importance for biodiversity. Doñana lies at the mouth of the

River Guadalquivir, close to where this river is joined by the Guadiamar, principal water supply for the Doñana marshes. The socio-economic development of the area has been mainly based on intensive agriculture and tourism and is responsible for its transformation over 60 years from one of the poorest areas of Spain to a region where per-capita income is above the national average (Montes 2007). In parallel, recognition of the importance of Doñana as a natural area and provider of ecosystem services has increased, leading to the establishment of a series of natural protection measures (National Park, Natural Park, UNESCO world heritage natural property, amongst others). Unfortunately, during the same time period, the land bordering the protected area has become degraded, to the extent where environmental impacts are felt within the protected area itself (e.g., see Muñoz-Reinoso 2001). The project under which the research presented here was carried out deals specifically with land use change, and the way in which land use change modelling may be able to contribute to a more sustainable management of the natural area.

1.7 The contribution of land use modelling

Top-down management of Doñana and its hinterland through protected area restrictions has clearly been very successful in preventing outright destruction of this valuable natural area. There is no doubt that without the protected area restrictions, in place since the 1960's, much more serious degradation of the natural area would have taken place, including draining of the marshes for tree plantation (planned in the 1950's) and coastal urban development, which has been widespread in Andalusia and has led to a generalized degradation of fragile ecosystems and services along the whole coastline (Chica Ruiz and Barragán Muñoz 2011). However, the unique dune and marshland ecosystem at the confluence of the Guadiamar and Guadalquivir rivers is sensitive to land use changes throughout the entire watershed, an area which is not itself protected (Guadiamar catchment area, Figure 2) making it impossible to establish a traditional "command and control" approach to natural protection (see Palomo et al 2011). Since the 1950's, major land use change has taken place in the watershed, mainly agricultural intensification and urban and infrastructure development, and habitats and ecosystems are degrading as direct result (Zorrilla Miras et al 2013). The protected areas are becoming isolated islands, something that seriously threatens their survival (Palomo et al 2013). The only solution seems to be to involve the local community and its representatives as widely as possible to initiate a series of bottom-up actions leading to the voluntary adoption of a more environmentally sustainable approach to development

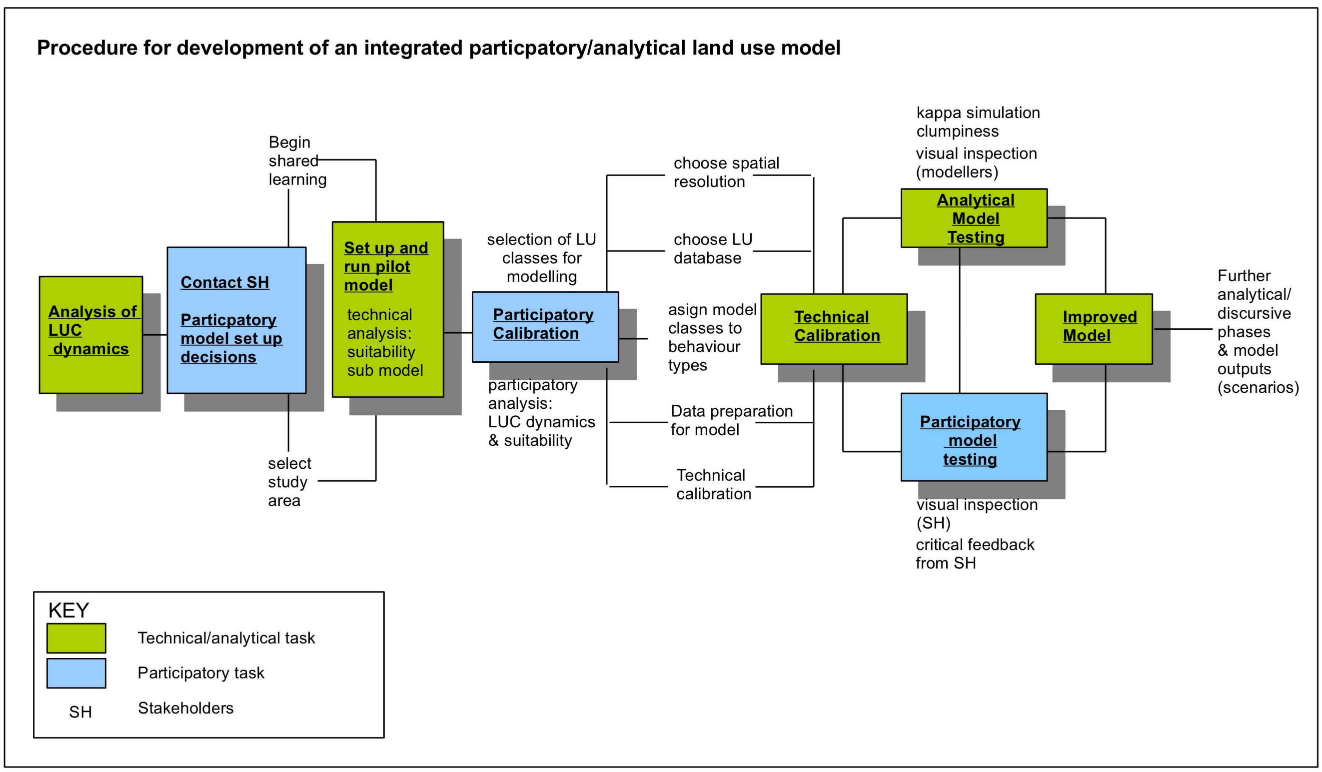
(Montes 2007, Palomo et al 2011). Environmental degradation is a societal problem, something that cannot be solved by traditional scientific methods but rather through a combination of analytical science and social enquiry techniques (see Lemon et al 1994). By initiating a participatory land use modelling process, local stakeholders can be brought to the table to discuss the specific effects of land use change on the natural area and their likely consequences. CA models are highly appropriate for this task on account of their ability to provide realistic simulations of land use change by representing pressure and competition for land use through cell transition rules (see section 2.1). The strong visual element of CA representations of land use change serves as a focus for discussion and debate. In this way, understanding of the threats that the future may pose for the natural area can be increased, and "policy option spaces" can be generated (Oxley et al 2002) to allow stakeholders to confront these threats.



[Figure 2, (left) Guadiamar basin case study area, Spain]

2. METHODS

The model calibration process comprises a series of intercalated participatory and analytical model building tasks which can be formalised as a fully integrated procedure for participatory land use model development (Figure 3). This procedure, with the relevant participatory and analytical tasks presented side-by-side for each step, is shown in table 1. The analytical-technical method is based on the application and calibration procedure of the selected land use model (see e.g. Wickramasuriya, et al 2009; RIKS, 2011 and Van Delden et al 2013) and will be described in more detail in section 2.1. The participatory components are based on the Participation Action Research (PAR) methodology and took the form of two 1 day workshop sessions with a group of 14 stakeholders. Detailed discussion of the participatory method is given in section 2.2.



[Figure 3: Procedure for development of an integrated participatory/analytical land use model, showing the cycle of alternating participatory and analytical-technical tasks]

Modelling step #	**Modelling step**	**Sub-step**	**Participatory method**	**Analytical-technical method**
1	Decisions on setting up an application	Delineation of modelled region	Workshop 1: stakeholder assessment of most suitable study area to reflect dynamics	Researchers decision based on dynamics observed and own understanding
		Selection of land use classes for modelling	Workshop 1: stakeholders select and reclassify land use categories based on their understanding of land use in the natural area.	Selection of land use classes according to land change dynamics observed in cross-tab analysis, process understanding and expected model use
		Assign land use classes to behaviour types: dynamic vs. static	Workshop 1: stakeholder evaluation of dynamics (drivers of LUC). stakeholder responses help to understand which classes are most important for dynamic modelling	Assignation of land use classes to types according to land change dynamics observed in cross-tab analysis
		Choose spatial resolution	No consultation	Chosen by researchers on the basis of own knowledge and available datasets
2	Analysis of dynamics of land use change in the territory to be modelled.		Workshop 1: stakeholder evaluation of dynamics (drivers of LUC, category losses and gains, assessment of map quality)	Cross-tabulation analysis of LUC, neighbourhood analysis and landscape pattern analysis
3	Data preparation and setting up the model for the calibration period	Input land use maps Prepare accessibility, suitability and zoning layers.	No consultation until parameters need to be defined (stage 4, below)	Data preparation and incorporation of above defined parameters into modelling environment
4	Calibration	Set neighbourhood rules	Parameters defined by	Model manipulation

		Set random parameter Set accessibility parameters, Set suitability parameters.	stakeholders from information gathered in workshop 1	and data handling, statistical testing (kappa sim, clumpiness, visual inspection)
5	Analytical testing/evaluation of calibration		Workshop 2: participatory visual inspection of cell-by-cell accuracy & spatial patterning.	Statistical testing of model goodness of fit (cell-by-cell accuracy & spatial patterning)
6	Fine-tune calibration	Adjust parameter set in step 4	Apply results of participatory model evaluation to reconfigure model	Re-configure model with new datasets or parameters.

[Table 1: Step-by-step model procedure, together with the relevant participatory and analytical-technical tasks]

2.1 The Metronamica modelling framework

The modelling software adopted is Metronamica, a "off the shelf" software framework for land use change (LUC) modelling developed using the Geonamica software environment for model integration and DSS development with numerous applications worldwide (RIKS 2011; Van Delden and Hurkens, 2011). See www.metronamica.nl for an overview.

At the core of the model is the transition potential (TP) computation which determines the future state (land use) of the cells. TP is a function of a set of model drivers which interact to update the state of the cell in every time step (one year). The yearly time step is chosen as the smallest temporal resolution at which land use change can be adequately represented.

The model drivers from which TP is computed are as follows; *neighbourhood rules*, which determine the relationship between different land use classes in terms of attraction and repulsion; *accessibility* to facilitate or constrain land use conversions depending on the distance from the cells to the network and the importance of land uses to be close to elements of the network; *zoning*, that is, existing or proposed land planning regulations; a set of *suitability* maps (biophysical characteristics of a land area which determine its aptness for occupation by a particular land use class); and a *stochasticity* variable in order to avoid over-determinism in the model. This TP function determines the likelihood of each cell in the model to change from one use to another. The Total TP is computed as follows:

Where: $({}^{t}P_{f,c})$ is the Total Transition Potential:

$({}^{t}R_{f,c})$ is the neighbourhood effect

$({}^{t}A_{f,c})$ is accessibility

$({}^{t}Z_{f,c})$ is zoning

$({}^{t}S_{f,c})$ is suitability, then;

for land use function *f* in cell *c* at time *t*

$$({}^{t}P_{f,c}) = \begin{cases} {}^{t}V_{f,c} \cdot {}^{t}A_{f,c} \cdot {}^{t}Z_{f,c} \cdot {}^{t}S_{f,c} & \text{if } {}^{t}V_{f,c} \geq 0 \\ {}^{t}V_{f,c} \cdot (2 - {}^{t}A_{f,c} \cdot {}^{t}Z_{f,c} \cdot {}^{t}S_{f,c}) & \text{else} \end{cases}$$

where ${}^{t}V_{f,c}$ is the Neighbourhood effect (including stochastic factor), found by:

$$({}^{t}V_{f,c}) = \begin{cases} {}^{t}R_{f,c} \cdot (1 + e) & \text{if } \alpha > 0 \\ {}^{t}R_{f,c} & \text{else} \end{cases}$$

for the two cases of the stochastic factor (stochastic effect and no stochastic effect)

$e = (-ln(1-ran))^{\alpha}$

where *ran* is a number from the uniform distribution in the range 0-1,

and α is the scale of the stochastic effect, where 0 = no effect [Eqn. 1]

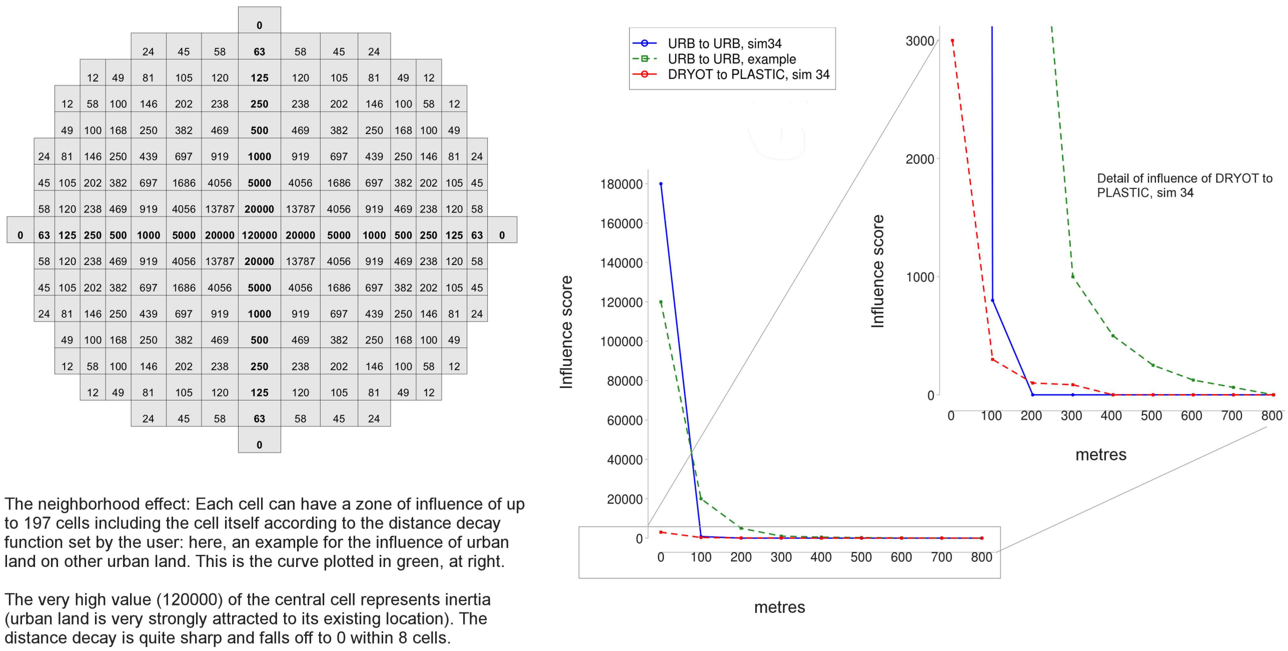
[Equation 1: Total transition potential computation in Metronamica]

In Metronamica, the Moore neighbourhood is used; each cell has a circular zone of influence comprising up to 197 cells including itself. Not all land uses are modelled in the same way, individual land use classes must be assigned to one of three land use *states*. They may be either *active,* (dynamic, changing as a result of external demands) , generally assigned to “aggressive” land uses such as intensive crops or urban land which take over other land areas, *passive* (dynamic, does not change due to an external demand, but does change as a result of changes to the active land uses), generally natural vegetation classes and some agricultural types, or *static.* Static land use classes (e.g. large bodies of water) remain inert throughout the model runtime and neither occupy other land areas nor are occupied themselves.

The model was applied and calibrated following the standard procedure for Metronamica described in detail by RIKS (2011) and Van Delden et al (2012) and according to the stepwise approach given in Table 1.

To calibrate the model, parameter values for the neighbourhood, suitability, zoning and accessibility drivers are set and the model is run from an initial map t_1 (1956 in this case) to a second date *n* time steps (i.e. years) forward for which a map is available for comparison (1999 in this case), which can be denoted t_2. The number of cells which are to be allocated for each land use at each time step t_n is known as the *demand*. Once the total number of cells corresponding to land use *demand* has been allocated to all suitable locations (TP > 0) at model time step t_n, the next step (t_{n+1}) is computed from t_n and so on until time t_2 is reached.

The time period between t_1 and t_2 is known as the calibration period. In our research the time period between t_1 and t_2 (43 years), chosen principally on the basis of the available data, is longer than that used in many similar studies (though see Clarke et al 1997). Engelen et al (2007) note that an "historic calibration will require a sufficiently long calibration period, typically some 10 years, so that the underlying processes in the system have time to manifest themselves in a representative manner". However, a very long calibration period may risk amalgamating unrelated change episodes and thus provide a poor understanding of process. On the other hand, a short calibration period may "tie" the model to a particular unrepresentative change episode and lead to a highly path-dependent model (Brown et al 2005).



[Figure 4: the cell neighbourhood and the attraction and repulsion effect]

Technical calibration (task 4, table 1) and assessment of the quality of the technical calibration (task 5, table 1) was a continuous and iterative process managed around a series of milestones relating to the determination of parameters for the key model drivers, Neighbourhood, Accessibility, Suitability and Zoning (see also Van Delden et al 2012). Firstly, land use *demand* was established for the calibration dates by subtracting the number of cells for each land use in map *t2* from the number of cells for each land use in map *t1* (linear interpolation between land use map periods). Then the model was run with simple neighbourhood rules only, reflecting the allocation of land use change according to demand without any specific location criteria, in order to establish a benchmark for comparison (milestone 1). Then, neighbourhood rules were defined in conjunction with the stochasticity variable (milestone 2), next, accessibility parameters (milestone 3), next, suitability parameters (milestone 4), and finally the zoning information was introduced (milestone 5). The *neighbourhood rules* are the main calibration parameters in the model. They are user-defined forces of attraction and repulsion that decay over distance (Figure 4). Attraction and repulsion effects are collectively known as the influence score and are defined using a neighbourhood influence graph similar to those shown in Figure 4. The influence score for the neighbourhood effect (N) is shown on the y axis of the graph; it is a relative, not an absolute measure and is unbounded ($-\infty \leq N \leq \infty$). The stochastic effect can be varied by modifying the value of the scale factor α (see Eqn. 1), where $0 < \alpha < 1$. Very low values for α lead to a high level of determinism in the model; a stochastic scaling effect of 0 gives a completely deterministic model where the Transition Potential of each cell is simply the product of Neighbourhood, Accessibility, Suitability and Zoning. A completely deterministic model is probably not appropriate for simulating the aggregate effect of human activity in the territory, so in the usual case $\alpha > 0$. In situations where there are many unplanned or chaotic land use transitions, as was the case for the city of Lagos, Nigeria (Barredo et al 2004), values of α higher than 0.5 may be useful. For further discussion, see RIKS (2011). The calibration was assessed at each milestone, in order to carefully monitor the changes in model behaviour in response to the introduction and adjustment of each parameter. Three standard methods, visual inspection, the kappa simulation statistic, and the clumpiness index were used by researchers to assess the technical calibration (see also Van Delden et al, 2012).

Visual inspection: Thorough visual inspection of all the simulations was carried out before any statistical evaluation was undertaken. Visual inspection is considered important for evaluation of simulation model results as the human eye is highly competent at pattern detection and probably outperforms automated procedures in most respects (Hagen 2003, Pontius et al 2004). The drawback, which gives rise to the need for statistical procedures, is that visual inspection is subjective and unrepeatable in practice (Hagen 2003). Visual inspection was the principal method used for pre-selection of calibration results for statistical evaluation.

Kappa simulation statistic: The kappa simulation statistic (hereafter K_{sim}) is a modified form of the kappa index of agreement (see Van Vliet et al, 2011) that takes into account persistence (areas of no change between the maps). K_{sim} assesses the changes between two maps and was used to compare the simulated map for the four calibration maps for 1999 with the real map for 1999 at each milestone point.

Clumpiness index: A standard algorithm known as the clumpiness index (McGarigal et al 2002) was used to assess structural similarity between real maps and simulations of the same map. First the clumpiness algorithm was applied to analyse the degree of aggregation of the calibration target map (lu99). The same analysis was carried out for each of the simulated maps, and the results were compared, arriving at a measure of deviation of patch aggregation between simulations and the real map for each of the land use classes. The clumpiness index is only applicable to individual categories and is not affected by changes in class area; values range from -1 (maximally disaggregated) to 1 (maximally clumped), with 0 indicating random distribution.

An additional map, known as a *simple rules* map, was used as a benchmark for estimation of simulation performance. In the simple rules map all land use changes were simply allocated next to existing land of the same category. Improving the benchmark was the minimal requirement for the technical calibration.

2.2 Participatory methods

The participatory process undertaken 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 and participant, in order to involve local people in research to solve the problems identified. PAR methodologies were applied here to identify and engage stakeholders, and to utilize their local knowledge as fully as possible by involving them in parametrization, calibration and performance evaluation of a land use model (see "aims of the research", section 1.2). For stakeholders to have confidence in model's ability to simulate the land use change processes under discussion, it was necessary to demonstrate that the model was well-calibrated according to standard evaluation techniques (as used in the technical assessment described above) and to involve stakeholders in evaluating the model themselves. The discussion and reflection process and the land use model calibration procedure are therefore equally important and inseparably intertwined (Figure 3). The methodology described here is comparable to the series of "repetitive back and forth steps between the model and the field situation" described by Barreteau et al 2003 that are integral to the ComMod approach.

Following an initial process of identifying the most appropriate local stakeholders (Hewitt et al 2012) Direct stakeholder input was sought in two participatory workshops for (1) model parameter definition and (2) to explain and evaluate model performance and behaviour on the basis of the parameters previously defined. Stakeholders were selected from 7 key sectors, Conservation, Regional

Government, Local Government, Agriculture, Tourism, Environmentalism and Science and Academia (Table 2). In both workshops, stakeholders were organised into groups defined with the aim of distributing the different perspectives and skills of the participants as evenly as possible throughout the group. Not all participants were able to attend both workshops, but many stakeholders did do so. Both workshops had 14 participants. Detailed additional information about both workshops is available at: http://www.geogra.uah.es/duspanac/taller_en.html

Key stakeholders	Roles and Responsibilities	Level of action
Doñana Natural Protected Area body (END)	Managers, public use, conservation and traditional resources.	Local
Doñana Biological Station, National Science Council (EBD – CSIC)	Researchers and specialists, remote sensing and cartography	Local and national
Doñana 21 Foundation,	Management body for local municipalities, responsibility for biosphere conservation in Doñana area (FD21)	Local
National government management organisation for national parks (OAPN)	Technician in charge of project development	National
Young farmers association (ASAJA)	Local farmer	Local
Moguer municipal government (Ayto. MOGUER)	Local Authority Planner (Environment)	Local
Rice Producers Association	Manager of agricultural producers' association in Doñana area (ARROZ)	Local
Madrid Autonomous University	Researchers in Doñana (ecosystem services and biodiversity)	Local and national
Seville University	Researcher, water exploitation and its effects on Doñana	Local
Ecologists in Action Environmental Action Group	Left wing Conservationist Association.	National

[Table 2, table of workshop participants and affiliations]

Workshop 1

The first workshop was dedicated to the definition of the appropriate area of study and parametrization of the model. Three key aspects for construction of the land use model were investigated: land use classification, landscape dynamics, and suitability. In the first exercise, stakeholders discussed in groups the most appropriate land use categories for explaining environmental change processes in the Doñana natural area, arriving at a land use categorisation for each group. The three land use categorisations for individual groups were then converted into a single list of land use categories through a process of consensus based on open discussion.

Following the land use classification exercise, participants discussed land use dynamics on the basis of a series of 9 land use change maps produced by researchers from the only cartographic source available to them prior to the first workshop (Corine Land Cover 1990-2000-2006).The nine land use dynamics analysed, were as follows:

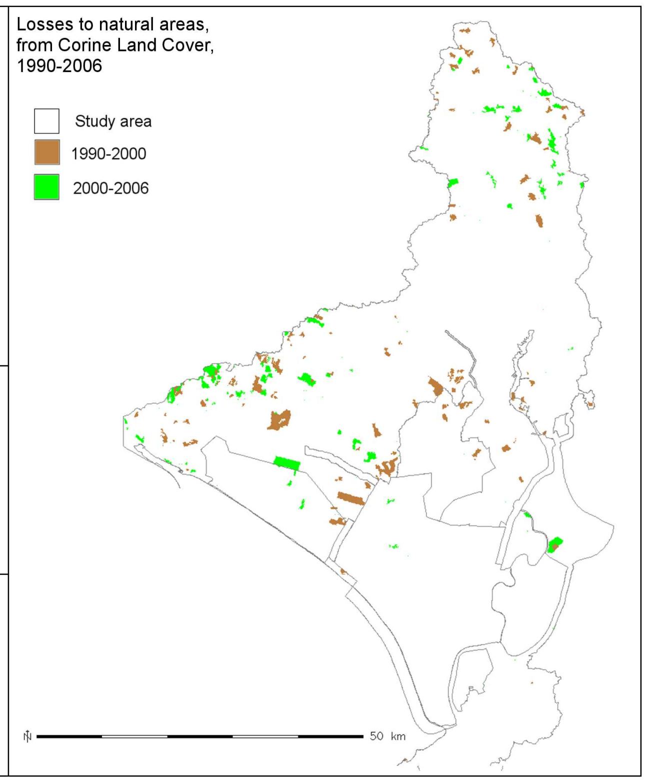
1. Loss of natural areas.
2. Increase of natural areas.
3. Increase in artificial surfaces.
4. Increase in irrigated crops.
5. Increase in pasture and dryland crops.
6. Change from shrubland into Woodland (all types).
7. Change from woodland to shrubland (all types).
8. Changes (losses and gains) to wetlands and marshlands.
9. Burned areas.

DYNAMIC 1. LOSS OF NATURAL AREAS 1990-2006

1. Land change drivers

2. Gains/Losses

3. Degree of reliability of this dynamic as represented on the map



[Figure 5, *pro-forma* worksheet for analysing land use dynamics]

Each group responded to a series of questions about these land use dynamics contained in a *pro-forma* worksheet (Figure 5). In the afternoon, participants evaluated suitability with respect to a series of suitability factors (rainfall, slope, temperature etc), and transferred the information to a *pro-forma* worksheet. For each factor (e.g. elevation, slope, rainfall, temperature), participants were asked to define its influence on each land use class as strong (*mucho*), weak (*poco*), or no influence at all (*nada*). On the basis of this information, an agreement or confidence index (C) was calculated by allocating a value of 0 where all three groups disagreed, a value of 1 where two groups disagreed with the third group, and 2 where all groups agreed. These values were then be summed to give total agreement index for each suitability factor. The categorical responses *strong, weak* and *no influence* given by the stakeholders for each land use against a given factor were translated into a simple scoring system referred to here as the influence index (I) of 2 (strong), 1 (little) and 0 (no influence). Finally, the confidence index (C) was multiplied by the influence index (I) to give a total overall score by land use for each suitability factor. Thus, for example, in assessing the PLASTIC (forced crops under plastic) land use, all three groups felt slope to be important and responded *strong*, a score of 2 for each group, giving (2+2+2) = 6. Since all groups were agreed about the importance of slope for this land use, the highest confidence score (2) was allocated. Thus the total score for the slope factor for the PLASTIC land use was 12 (6 x 2), indicating that the stakeholders felt, with a high degree of confidence that slope was influential in determining the location of forced crops under plastic, lesser slopes being preferred locations.

The first participatory workshop allowed the most fundamental model parameters to be defined. These were: the study area, the land use dataset, the land use categories (reclassification), the drivers of land use change and the susceptibility of land areas to change in response to distance effects and biophysical suitability factors. Following workshop 1, the model was developed in accordance with these parameters.

Workshop 2

In the second workshop, stakeholders were given direct contact with the model calibration results. The aim of this workshop was twofold:

(1) To communicate with stakeholders that the land use simulation model is a *process*, in which they are actively involved, not a mechanical computation producing a single right or wrong answer.

(2) To increase the validity of the model by submitting raw results to the scrutiny of external actors with knowledge of the area and problem domain but without detailed knowledge of or investment in the model itself.

Following an oral presentation providing an introduction to the model, aimed at those stakeholders who had not attended the first workshop, participants were given detailed feedback about how the information they had provided had been incorporated into the model. In some cases (the land use dataset, the land use categories) the information that the model contained had been directly selected by stakeholders in the first workshop, in other cases, i.e. land use dynamics and suitability, their input conditioned the way in which model parameters were set (see section 3.3). Stakeholders were tasked with undertaking a visual assessment of 4 calibrated maps. The task was structured by means of a *pro-forma* questionnaire (See table 3).

Technical calibration results (kappa simulation, clumpiness) were not shared with stakeholders so as not to influence their decisions.

Similarity of the location of land uses in the calibration map, compared to the real map of 1999:	**Final form (clumpiness) of land use patches:**	**Evolution of the land uses in the model, according to the animation:**
0: not very similar	A: Adequate (reflects reality)	0: I don't think it's very realistic
1: more or less similar	DD: Too scattered	1: Seems acceptable as far as I know
2: very similar	DA: Too clumped	2: Seems realistic

[Table 3. Questionnaire for activity 1, completed by participants for each *active* land use for 2 simulations of the calibration date].

Of these three questions shown above, only similarity of location and final form were successfully evaluated due to time constraints. Stakeholder estimations of location accuracy were summed (see Figure 7). For "final form", (which is in reality an assessment of the degree of aggregation or clumpiness), total scores were determined using a tally system, that is, a score of 1 was marked each time one of the five types of response given (Adequate, Too Scattered, Too Clumped, Not defined, Other response) was selected. Tallied responses from each group were summed for each land use class, for example, if two groups classified land use class URB as Adequate in one particular simulation, one group felt this class was too clumped, and one group left the box unfilled, "Adequate" would score 2, "Too Clumped" would score 1, and "Not Defined" would score 1, with the remaining two responses scoring 0. Scores obtained in this way for all 11 land use classes were summed to give total scores for each response category for each simulation and plotted by response category (see Figure 8).

Additional information about both workshops is available at http://www.geogra.uah.es/duspanac/taller_en.html

3. RESULTS

Results are presented chronologically. Results for workshop 1, which were used in the technical calibration procedure, are presented first, followed by the results of the technical calibration procedure, the results of workshop 2, and finally, a section detailing overall results of the modelling exercise

3.1 Workshop 1, results

In the first workshop it became clear that the majority of participants considered that the limited area defined by the natural protected area boundary was insufficient for understanding the land use change processes that had taken place in the region. After discussion of the advantages and disadvantages as well as the possible implications of five possible different areas it was decided to adopt the whole of the Guadiamar basin region as the model study area, instead of the more limited zone comprising the protected area that had originally been proposed(Figure 2).

For the land use classification activity, a final series of land use categories for use in the model was agreed in open group discussion (Table 4).

CLC (Corine Land Cover) level 3 class	**Dynamic**	**Model LU class**	**Abrev.**
Continuous urban fabric	3	Urban areas and leisure facilities	URB
Discontinuous urban fabric	3	Urban areas and leisure facilities	URB
Industrial or commercial units	3	Industrial areas	IND
Port areas	3	Industrial areas	IND
Mineral extraction sites	3	Mining areas and construction sites	MINECON
Construction sites	3	Mining areas and construction sites	MINECON
Green urban areas	3	Urban areas and leisure facilities	URB
Sport and leisure facilities	3	Urban areas and leisure facilities	URB
Non-irrigated arable land	5	Non-irrigated (dryland) crops	DRYOT
Permanently irrigated land	4	Other intensive crops	INTOT
Rice fields	4	Rice	RICE
Vineyards	5	Vine, Olive or VO mosaic	VINOL
Fruit trees and berry plantations	4	Intensive woody crops, Crops under plastic	INTWOOD, PLASTIC
Olive groves	5	Vine, Olive or VO mosaic	VINOL
Pastures	5	Grassland	GRASS
Annual crops associated with permanent crops	5	Non-irrigated (dryland) crops	DRYOT
Complex cultivation patterns	5	Non-irrigated (dryland) crops	DRYOT

Land principally occupied by agriculture etc	5	Non-irrigated (dryland) crops	DRYOT
Agro-forestry areas	5	Non-irrigated (dryland) crops	DRYOT
Broad-leaved forest	1, 2, 6, 7	Eucalyptus Other woodland and mixed woodland	EUCFOR OTFOR
Coniferous forest	1, 2, 6, 7	Conifer woodland	CONFOR
Mixed forest	1, 2, 6, 7	Other woodland and mixed woodland	OTFOR
Natural grasslands	1, 2	Grassland	GRASS
Sclerophyllous vegetation	1, 2	Shrubland	SHRUB
Transitional woodland-shrub	1, 2, 6, 7	Shrubland	SHRUB
Beaches, dunes, sands	1, 2	Beach	BEACH
Burnt areas	1, 2, 9	Altered, eroded, and burned areas	ALTER
Inland marshes	8	Non-tidal marshland	MARSHNT
Salt marshes	8	Tidal marshland	MARSHT
Salines	8	Hydraulic Infrastructures	INFWATER
Intertidal flats	8	Tidal marshland	MARSHT

[Table 4. Original CLC (Corine Land Cover) analysis categories and the 9 land change dynamics, together with the new model categories to which they relate.]

Land use dynamic investigated	**Results of researchers own analysis**	**Stakeholder evaluation**	**Researcher's response**
Loss of natural areas	This dynamic is represented by the transfer of woodland (principally broad-leaved; and coniferous, grassland, shrubland and	Stakeholders identified the following drivers of LUC for this dynamic: 1. Elimination of eucalyptus plantations. Although these appeared in cartographic sources originally consulted as natural and semi-natural areas category, stakeholders did not feel that elimination of eucalyptus (an	New land use maps were needed for the model, it was clearly important to separate eucalyptus from other tree species. The final model included eucalyptus as a separate dynamic category, allowing it to grow and expand, and also

	sclerophyllus vegetation land covers to agricultural land uses like dryland (rainfed) crops, permanently irrigated crops and fruit and berry plantations.	invasive fast-growing tree species planted for timber) should be considered as loss of "natural areas" 2. Agricultural expansion (particularly intensive crops like strawberries and citrus) 3. Urban development 4. Public development policy 5. Illegal occupation, lack of effective control from land planners 6. Land planning directive for Doñana and hinterland (PDTC) 7. Doñana environmental management plan (POTAD)	be eliminated by the right combination of rules. Intensive crops and urban development were also clearly important dynamic categories. The importance of PDTC and POTAD for the development of future policy scenarios from the model was noted.
Increase of natural areas	Despite the dynamic observed above, there were also some areas where natural vegetation actually increased, according to Corine land cover. This tendency was especially notable along the banks of the Guadiamar, where a long strip of land previously under non-irrigated cultivation transformed to shrubland between 2000 and 2006.	Stakeholders identified the following drivers of LUC for this dynamic: 1. Aznalcóllar mining disaster. Stakeholders pointed out that the most likely explanation for the transformation of cultivated land to natural land along the Guadiamar was the Aznalcóllar mining disaster of April 25, 1998, where the collapse of part of a tailings dam flooded the Agrio and Guadiamar rivers with high pyrite content mine tailings and acid water filled with dissolved heavy metals. The spill affected a branch of the Guadiamar river basin measuring 62 kilometres long with a width of between 500 and 1000 meters between the village of Aznalcóllar and the border of the Doñana National Park. Aside from the catastrophic effects on flora and fauna, the disaster caused the abandonment of 3,000 hectares of agricultural lands (Hernández et al 2004). 2. Inclusion in the Caracoles protected area. 3. Elimination of Eucalyptus, replaced by cork oak. 4. Protection and restoration of degraded areas. 5. Protection legislation (conservation policy)	This shows that increase of natural areas may not reflect long-term land change dynamics, rather, it is a one-off event. This dynamic was therefore not specifically modelled. The specific information obtained from stakeholders about conservation policy and the date of establishment of new protected areas is likely to help with development of future policy scenarios from the model.

[Table 5. Detailed stakeholder responses for the first two LUC dynamics, loss of natural areas and increase of natural areas]

Stakeholders also evaluated the cartographic dataset proposed for use in the model (Corine Land Cover). Although they considered that the land use changes identified with this source were for the most part reliable, it became clear that Corine was not suitable for reasons of thematic classification; for example, no distinction was made between woody irrigated crops such as irrigated olive and citrus, and other types of irrigated crop which are common in the region such as cotton or maize. Also, intensive crops grown in greenhouses and polytunnels, such as the strawberry, a flagship crop in the Huelva region, could not be separated from other fruit crop types, and eucalyptus plantations, an invasive species that conservation managers are trying to eliminate, was grouped together with native broad-leaved tree species like oak. Thus, by analysing land change dynamics on the basis of Corine, and by reclassifying the Andalusian government map series, it became clear that the latter presented the only viable option for accurate modelling.

Stakeholders provided very detailed information about land use dynamics (Table 5, above), and identified drivers of change for each of the 9 land use dynamics. This guided the decisions on the most important dynamics to be included in the model. These were: losses to vegetation or natural areas of all types, growth of artificial areas, growth and decline of both intensive and non-intensive crops, eucalyptus expansion and control, changes to coniferous and other forest types. These land use classes therefore became the driving forces of the model, the *active* land use categories.

Neither analytical change analysis (cross-tabulation) nor stakeholder opinion about land use change dynamics were considered irrefutable, since errors and inaccuracies in the CLC (Corine Land Cover) dataset are known to exist in some areas (e.g. Catalá Mateo et al, 2008, Díaz Pacheco and Gutiérrez 2013), and, on the other hand, stakeholder knowledge of land change dynamics was likely to be incomplete or biased in some cases. However, one information source generally served as a check or counterweight to the other, and disagreement between stakeholders and map sources provoked discussion, allowing researchers and stakeholders to question their beliefs and broaden their understanding of land change processes. Results of stakeholder assessment of suitability are shown in Table 6 (below).

Land use class	Suitability Factor IC score			
	Elevation	Soils	Slope	Rainfall
URB	0	2	4	1
IND	2	1	12	1
RICE	4	12	12	5
PLASTIC	4	2	12	12
INTWOOD	1	4	12	5
INTOT	1	4	5	5
DRYOT	0	12	5	12
VINOL	1	5	4	12
EUCFOR	0	1	0	5
CONFOR	1	0	0	5
OTFOR	1	4	2	5

[Table 6: results of stakeholder assessment for suitability as calculated Influence/Confidence (IC) scores]

Suitability parameter settings inside the model were estimated on the basis of the information shown in Table 6. For example, in the case of the classes IND, RICE, PLASTIC and INTWOOD, high suitability parameter values were given to areas with slopes of less than 5%. These values were subsequently modified using an iterative trial and error approach which involved experimenting with various different suitability values for different slope categories respect to these land use classes until some improvement could be seen in the location and spatial pattern according to the analytical assessment methods employed.

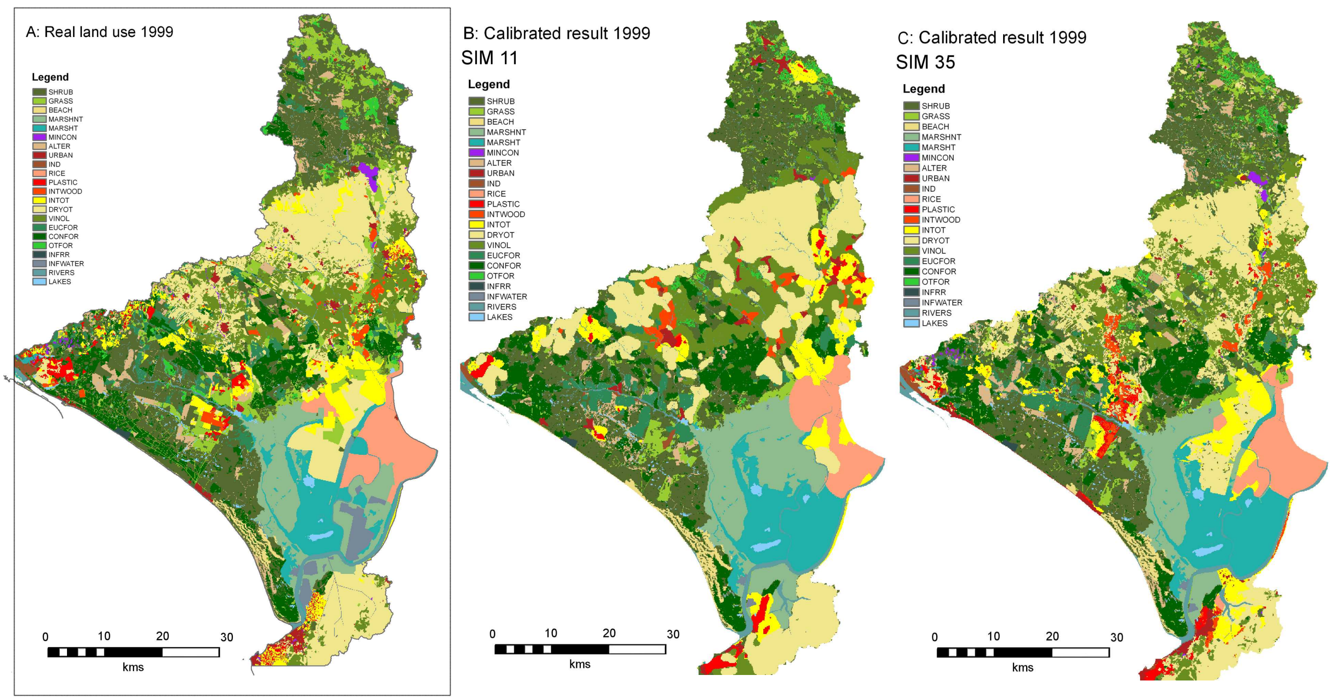
3.2 Technical Calibration results

The technical calibration and analytical calibration assessment process (section 2.1, table 1, steps 4 and 5) produced a great number of simulations of the 1999 land use map t_2 (Figure 6a). See Figure 7 (Ksim) and Figure 8 (clumpiness) for statistical assessment results. Key milestones along this road, e.g. improvement in neighbourhood rules, establishment of accessibility criteria, introduction of suitability parameters or zoning restrictions, were allocated a unique simulation identifier. The first simulation that was broadly acceptable according to the three evaluation techniques used (below) was Simulation 11 (Figure 6b). Researchers felt that important further improvements had been attained at Simulations 23 and 34. Simulation 35 (Figure 6c) was different, but more or less equivalent to 34 (35 was successful in some areas where 34 showed weaknesses, but the opposite was also true), and represented the point at which the time required to make improvements no longer seemed to be justified by the degree of improvement attained.

Simulations 11 and Simulation 35, both of which were evaluated by all 4 stakeholder groups (see section 3.3) represent opposite ends of the calibration process. In Simulation 11, neighbourhood and accessibility parameters had been established, leading to a broadly acceptable goodness-of-fit according to the evaluation techniques used (see section 2.1), but prior to establishment of suitability and zoning and as a result omitting these drivers from the simulation. Both suitability and zoning therefore took default values of 1 in the TP computation equation (Eqn. 1)

In Simulation 35, further adjustments have been made to settings to include all remaining parameters. The suitability parameter has been set, whose principal effect is to exclude irrigated crops, rice and plastic from sloping ground and areas of high elevation. Zoning has been established for the coastline and national park areas. In the TP computation equation (Eqn. 1), suitability and zoning for this simulation therefore took values in the range 0 (unsuitable, completely restricted) to 1 (most suitable, unrestricted). For all the simulations discussed here, the random scale factor was maintained at 0.5.

The establishment of suitability and zoning parameters is important, but the most notable difference between Sim 35 and Sim 11 is that in Sim 35, the neighbourhood parameter settings have been adjusted to produce a map structure that is more similar to the real map according to all three of the evaluation methods applied. Specifically (see Figure. 4), decreasing the influence values in the cell neighbourhood at distances greater than 200, leads to a less aggregated pattern, something detectable not only visually (Fig. 6) but also perceptible in clumpiness scores (See section 3.3, Figure 8, bottom), and also emerged very strongly from stakeholder evaluation (See section 3.3, Figure 8, top; Figure 9).



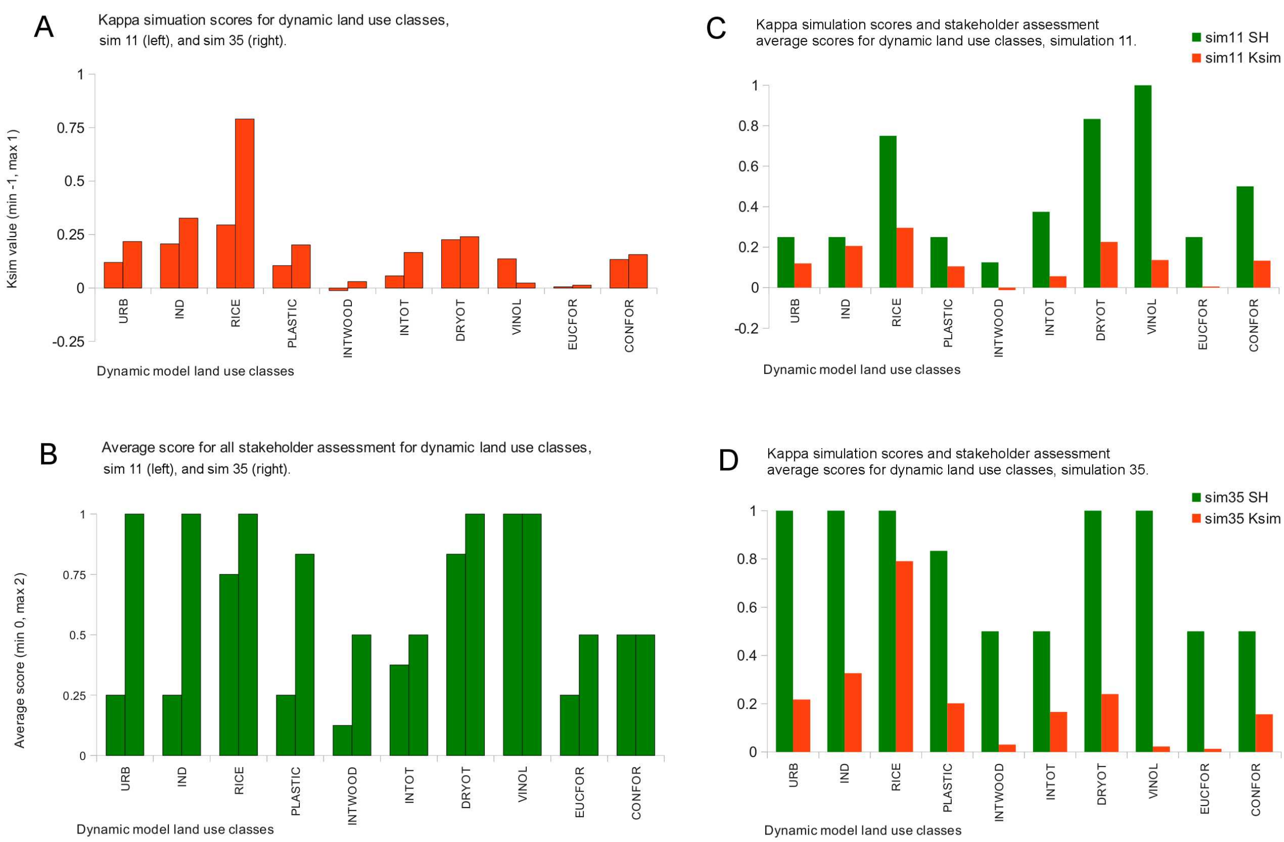
[Figure 6a: Real land use map 1999]

[Figure 6b, 6c; 2 simulations evaluated by stakeholders]

3.3 Workshop 2, results

In workshop 2, stakeholders assessed the performance of the calibration results from the model developed using parameters defined in the first workshop and the technical calibration. Participants were tasked with evaluating the four simulations that researchers felt to represent key development stages, Simulation 11 (successful development of neighbourhood rules and accessibility, hereafter sim 11, Figure 6b); Simulation 23 (first result with Neighbourhood, Accessibility, Suitability and Zoning parameters, hereafter sim 23), and simulations 34 and 35 (successful simulation stages at the end of the technical calibration process, hereafter sim 34 and sim 35, Figure 6c). Only simulations 11 (Figure 6b) and 35 (Figure 6c) were evaluated completely due to time constraints.

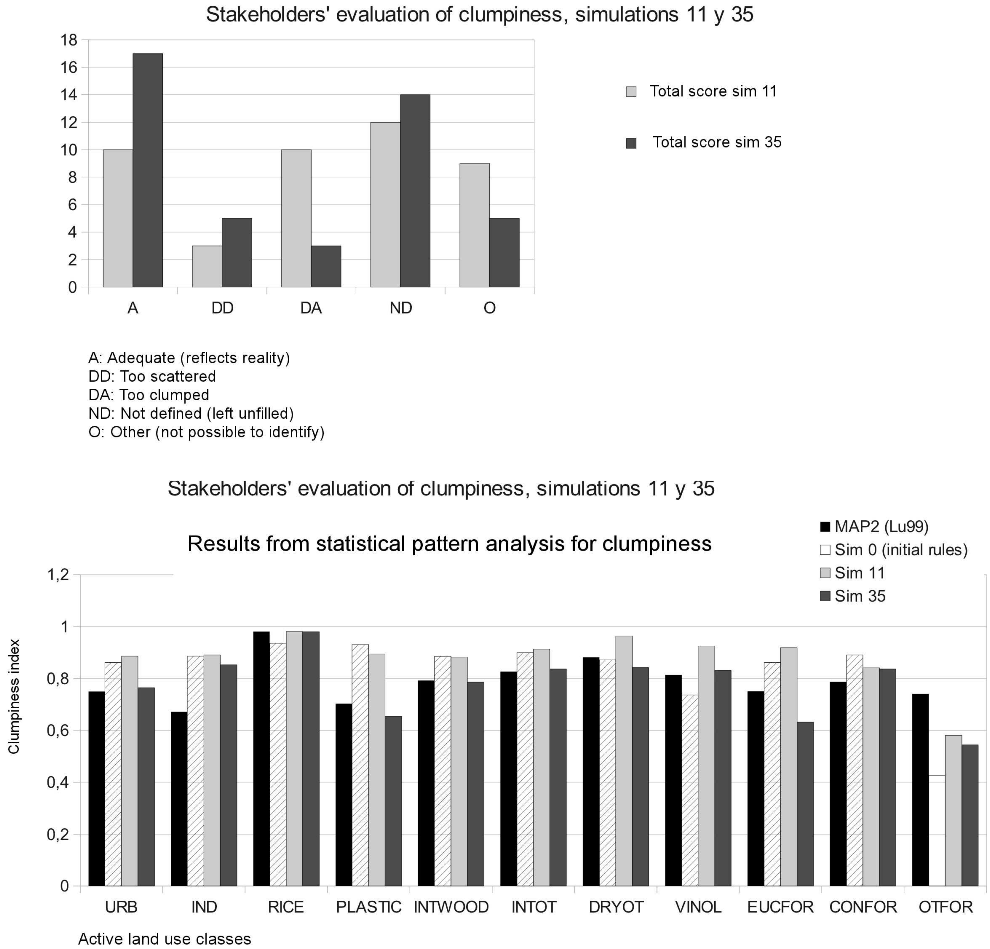
For the first part of the visual inspection activity, location, agreement between stakeholders and K_{sim} was remarkable. Aggregate results (Figure 7) show that stakeholders even captured the relative location accuracy between the land use classes. Both stakeholders and K_{sim} scores coincided that location accuracy was considerably higher for sim 35 than for sim 11. For some land classes agreement was closer than for others, for example, in sim 11 (Fig 7C) stakeholders perceived that DRYOT and RICE had been more accurately located than almost all other classes, something that is borne out by the K_{sim} scores (Fig 7C), but in the same simulation, VINOL was found by stakeholders to be much better located than indicated by K_{sim} . However, stakeholders found VINOL difficult to evaluate on account of the similarity of the legend colours between this class and SHRUB (a static land use class), so the high stakeholder assessment score here may simply be due to error.



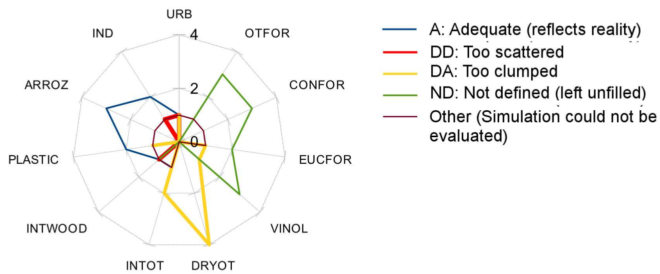
[Figure 7: graph showing kappa simulation results (A) and mean stakeholder assessment scores (B), for the two simulations evaluated. The different assessment methods are compared on the right (C, D).

High values indicate closer agreement of area and location for each category between real land use map 1999 and simulated map 1999.]

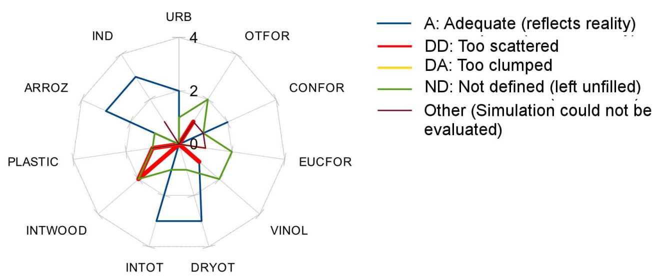
With respect to the final form of the land use classes in the simulations (patch aggregation or clumpiness), , Sim 11 scored 10 out of a possible 44 for Adequate (A), and 10 for Too Clumped (DA). The Adequate category scored far higher for sim 35 (17), while in only 3 cases for all 11 land use classes was this simulation considered too clumped. A high proportion of land uses were left unevaluated for both simulations, but there were many more answers in category “Other” (O), for simulation 11, reflecting the fact that opinions were given that did not fit the categories, reflecting the difficulty stakeholders experienced in evaluating sim 11. Over-aggregation of land use patches was clearly a problem in sim 11, an assessment which is supported by the results of the statistical pattern analysis for clumpiness (Figure 8). Figure 9 shows how the stakeholders' evaluation for each land use differed between the two simulations.



[Fig 8 – clumpiness: stakeholders evaluation versus statistical pattern analysis. The y axis in the top graph shows stakeholder evaluation scores calculated as described in section 2.2, workshop 2. These scores are in the range 0 (no group gave this response for any land use category) to 44 (all 4 groups gave this response for all 11 land use categories).]



Stakeholders' analysis of clumpiness, simulation 11



Stakeholders' analysis of clumpiness, simulation 35

[Figure 9 – Stakeholders analysis of clumpiness by land use for the two simulations evaluated]

3.4 Results of the participatory modelling process

Integration of participatory processes into the land use modelling procedure allowed the following improvements to be made:

1. Selection of a new, larger, study area not previously considered by researchers that permitted effective modelling of one of the most important LUC dynamics in the territory: the expansion of intensive crop cultivation.

2. Classification of land use categories for modelling based on the collective knowledge and experience of stakeholders.

3. Positive identification of a series of land use change drivers, including one-off catastrophic events resulting in important landscape changes (Aznalcóllar mining disaster), specific plans and policy actions responsible for the expansion of certain land uses (rice cultivation), socio-economic effects (declining profitability of non-irrigated crops) supporting the choice which processes should be included and emphasized in setting and fine-tuning the calibration parameters.

4. Input into the suitability parameters of the model and the calibration thereof in the technical-analytical part of the process.

5. An additional means (visual inspection evaluation by stakeholders) of assessing model behaviour and results that complements the traditional statistical assessment and that builds trust and improved understanding during the process. It is contended the visual inspection evaluation was more reliable than is normally that case, since, the stakeholder group was likely to be give more impartial assessments than the modellers. By taking into account multiple visual inspection estimates, problems of subjectivity can be mitigated. Statistical techniques and participatory visual inspection were seen to agree quite closely with one another, even down to the (proportional) degree of variation between the simulations.

Clearly, the inclusion of participatory processes in the development of a land use model does not necessarily translate directly into a more *precise* or more *realistic* model. This is the job of the analytical component of the calibration procedure (figure 3). However, participation, and in particular, an integrated approach that alternates analytical with discursive modelling phases, does have a strong influence on the *generality* of the model, that is, its applicability to the phenomena modelled, or real-world relevance.

4. DISCUSSION AND LESSONS LEARNT

4.1 Overfitting

There is a key difference between accurately capturing change processes in the model and producing a simulation that replicates a real land use map exactly. The two are not in any sense the same, but are frequently confused. Given the highly visual nature of the land change maps and the excitement that is felt when seeing the transition rules translated into step-by-step growth, the natural tendency is to strive for calibrations that resemble ever more closely the real map against which calibrations are compared. This approach can easily result in over-calibration or *overfitting*, especially if vocal stakeholders insist that the model is no good unless land use changes that relate to their own particular area of interest are exactly replicated. However, this problem may be alleviated in the following ways:

1. Emphasize the importance of the cellular automata neighbourhood dynamic, representing pressure and competition between land use, rather than additional information as captured in e.g. suitability and zoning.

2. Evaluate the calibrations without suitability and zoning parameters, thus forcing stakeholders to distinguish between areas of the map that are adequately simulated through neighbourhood competition effects and areas that are adequately simulated because physical and institutional constraints (as can be incorporated in suitability and zoning) leave them no-where else to go.

3. Replace the K_{sim} statistic by a fuzzy measure of cell location accuracy (eg. Fuzzy K_{sim}, Van Vliet et al 2013), and have stakeholders evaluate only the simulations that perform best according to fuzzy measures. This is likely to eliminate overfitted simulations, which typically perform poorly in fuzzy evaluation measures, before they reach the stakeholder community.

4. Have stakeholders evaluate intermediate results (i.e. transition potential maps in this case, the stage immediately prior to generation of a simulation) instead of simulated land use maps. This is likely to be less intuitive and more time-consuming, but makes it easier to evaluate probability of uptake of particular land uses in each simulation, and harder to appreciate precise eventual location.

These suggestions are not only helpful in participatory modelling situations, but are arguably good modelling practice generally.

4.2 One-off events

While CA land use models are clearly well suited to modelling tendencies that evolve over time, spontaneous one-off land change events are problematic. The extent to which this affects model performance depends not only on the extent of planning control in the study area, which affects the number of one-off events in as far as they are related to policy decisions (e.g elimination of Eucalyptus), but also on spatial and temporal scale; at smaller scales and over longer timeframes major land change processes (e.g. coastal urbanisation in Andalusia, afforestation in Europe) are likely to reduce the importance of one-off events that respond to local land policy decisions in the overall model. Stakeholder groups may be able to help distinguish between long term tendencies and one-off events, thus greatly improving the quality of the model for representing general patterns of change.

In the work presented here, two intriguing examples of one-off land change events were identified through participatory work. The first related to the loss of broad-leaved woodland, which stakeholders were able to attribute with confidence to a deliberate programme of eucalyptus elimination, and the second to the initially perplexing transition of large quantities of non-irrigated crop land to natural vegetation along the Guadiamar river, which stakeholders were able to identify as a direct consequence of the Aznalcóllar mine disaster. The first of these one-off events was initially incorrectly interpreted by researchers as due to the degradation of natural woodland areas, while the second was misunderstood as precisely the opposite sense; as a tendency towards naturalisation and away from agricultural exploitation. In both cases stakeholder information led to direct model improvements, in the first case by explicitly choosing a land use dataset which allowed eucalyptus to be kept as separate land use class, and in the second case by recognising that the conversion of agricultural land to natural land was not an identifiable land change tendency and leaving it out of the model.

These two one-off events are of two different types. The first, elimination of eucalyptus, relates to planned changes that occur in response to a policy decision and have no visible evolutionary history. The second, wholesale land conversion due to land abandonment following a catastrophe, is clearly unplanned, and by its nature, unpredictable. With respect to the first type of one-off event, the importance of local policy decisions should not be overestimated as long as major change processes can be identified. Separating the two, as we have seen, is an important job that local stakeholders can help with. One of the strengths of CA models is that they demonstrate that aggregate human activity in the landscape is not deterministic; land use changes often occur where pressure and competition for particular land uses is greatest, which does not always correspond to locations that are desirable from spatial planning or environmental point of view.

One-off events of the second type that do not correspond to planning decisions (e.g. natural or man-made disasters) cannot be explicitly modelled; however, by identifying them, stakeholders can help to avoid confusing them with tendencies, allowing them to be excluded from the model.

4.3 Advantages and disadvantages of the integrated approach

By carrying out the modelling activity in a transparent and inclusive way through participatory workshops, decisions taken about model parameters are much more easily justifiable to the wider modelling community and also to policy makers, even if such decisions do not lead immediately to a technical model improvement. This is not a justification for including variables that can be shown to have no effect or to perform poorly, but it is likely to enhance the possibility that modelling frameworks like Metronamica are employed in practice by policy makers. These kinds of models are much more likely to be successful as decision support tools if stakeholders have had reflective opportunities to intervene in the process itself (see e.g Van Delden et al 2011). By engaging stakeholders at the right point in the process, the researcher does not need to pretend to be omniscient. Instead she/he can concentrate on bringing her/his own knowledge to the table (data, perspective, methods) and shared learning can begin.

It is clear that there can also be some important disadvantages to participatory modelling work. It is very important that the stakeholder community selected is appropriate for the task at hand. In the case study presented here, there were already ongoing participatory processes related to the management of natural resources, so finding the right stakeholders was not difficult, and all participants knew what was expected of them and were interested in the model.

It is also important to recognise that additional time and resources required to carry out a fully integrated modelling project; a land change model incorporating no participatory activities can easily be developed in half the time However, this may be offset by the advantages of the participation, such as the help provided in identifying the appropriate model parameters at the outset and saving the researcher much time-consuming experimental work. In cases where stakeholders are to employ the system themselves, the chances of successful adoption are also likely to be greater if they have been involved in the modelling process.

5. OUTCOMES AND FUTURE WORK

Future work is envisaged in two main directions. Firstly, the model as presented here, calibrated and evaluated by the stakeholder community will be applied to generate future land use configurations for four scenarios for Doñana developed by an earlier research project (see Palomo et al 2011). Secondly, the participatory process itself can be submitted to evaluation by stakeholders. The success of participatory work is rarely evaluated (see Jones et al 2008), yet this is a necessary step. Not only would it help in assessing the extent to which the modelling process has contributed or is likely to contribute to the wider aims (e.g. more sustainable resource management), it is also helpful for evaluating the effectiveness of the methodology employed, in for example, making stakeholders feel comfortable interacting and exchanging opinions, integrating different forms of knowledge, and allowing decisions about collective practices to emerge (Jones et al 2008).

Key specific information to be solicited from stakeholders might include, for example:

- Has the modelling exercise affected stakeholders' willingness to support restrictions to their own activities in the vicinity of the natural protected area?
- What (if anything) do the stakeholders feel the modelling process has achieved anything that could not have emerged from an ordinary discussion process?
- Do stakeholders feel they have a better understanding of the perspectives of other workshop participants as a result of the process?

As is natural with work of this nature, which is inevitably cyclical and iterative to the extent permitted with the remit of a research project (see Barreteau 2003), important questions remain unanswered.

For example, it is unclear whether all of the stakeholders actually understood exactly how the model worked. Though researchers made great efforts to explain it as far as possible in layman's terms, some stakeholders may have lacked the background knowledge necessary to acquire a complete understanding in the short time available for participatory activities. In addition, some stakeholders clearly had preconceptions about what the model did or did not do which would have been difficult to change. All the information presented in the workshops was made available over the internet (http://www.geogra.uah.es/duspanac/pub.html), so stakeholders were and are free to consult at will the online material about aspects they did not understand. However, it can be questioned as to whether a full understanding of the model is really necessary to be able to contribute productively to the process. The most important tenets of the work, that land use change outside of the protected area may have effects inside the protected area, and that building simulations of land use change through a collective discussion process may help resolve conflicts and develop policies, seemed to have been well understood by all participants. This said, one interesting possible future line of enquiry could involve some kind of formalised assessment of stakeholder understanding.

6. CONCLUSIONS

The key to the success of any land use modelling exercise lies in finding a balance between analytical and discursive elements, something that we hope to achieve through calibration. But calibration is often rather narrowly defined as a kind of fine tuning exercise involving only adjustment of parameters (see Pontius et al 2004, citing Rykiel 1996), as if geographical models were measuring apparatus, like telescopes or surveying instruments. We contend that land use model calibration should be viewed as a process (as opposed to a technique) involving both 'hard' (quantitative, data-driven) and 'soft' (qualitative, humanistic) information flows, alternating analytical and discursive actions.

Discursive and analytical techniques have been presented together, to show that “soft-science” participatory approaches can be incorporated into the modelling process without neglecting “hard-science” technical aspects such as model calibration testing. It’s not necessary to persistently reiterate the divisions between these two overlapping scientific perspectives; better results can be obtained by methodologies that crossover into both domains. Stakeholders, policy makers and scientific peers need to know that the model meets accepted statistical standards, but at the same time, if the model is to be policy relevant, it also needs to incorporate relevant local actors and engage them as widely as possible in discussion and knowledge sharing activities. .

Finally visual inspection of model results by stakeholders can be shown to support the results obtained by statistical methods and gives a richer appreciation of model details. If models are evaluated by many pairs of eyes, the problems of subjectivity and unrepeatability (Hagen 2003) are diminished.

Land use modelling work that aims to be policy relevant should seek to integrate traditional non-participatory approaches with discursive soft-science methodologies. This is best accomplished simultaneously with technical-analytical model development as a series of phases that alternate discursive and analytical approaches, refining stakeholders' and researchers' perceptions and understanding throughout the model cycle. It is essential to begin this process early, and to incorporate participatory activities into all stages of the project.

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