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Participatory evaluation of agent-based land-use models

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A key issue facing contemporary agent-based land-use models (ABLUMs) is model evaluation. In this article, we outline some of the epistemological problems facing the evaluation of ABLUMs, including the definition of boundaries for modelling open systems. In light of these issues and given the characteristics of ABLUMs, participatory model evaluation by local stakeholders may be a preferable avenue to pursue. We present a case study of participatory model evaluation for an agent-based model designed to examine the impacts of land-use/cover change on wildfire regimes for a region of Spain. Although model output was endorsed by interviewees as credible, several alterations to model structure were suggested. Of broader interest, we found that some interviewees conflated model structure with scenario boundary conditions. If an interactive participatory modelling approach is not possible, an emphasis on ensuring that stakeholders understand the distinction between model structure and scenario boundary conditions will be particularly important.

Keywords: agent-based model; participatory research; model validation and model uncertainty; LUCC; model evaluation

1. Introduction

Agent-based land-use models (ABLUMs) are a form of simulation model currently receiving much attention by the land-use/cover change (LUCC) research community (Matthews, Gilbert, Roach, Polhill, and Gotts 2007). In simulation modelling, a model structure (i.e. the combination of model objects, relationships, parameters, rules, etc.) is derived from empirical observations and expert judgement, and then used with boundary conditions (often specified so as to represent some scenario of change) to investigate alternative system states. The structure of an ABLUM is attractive because it provides the potential to examine human decision-making at multiple levels (from individuals to households to firms), to represent social processes and non-monetary influences on decision-making, and to represent the interaction of social and environmental processes (Matthews *et al.* 2007). A key challenge facing contemporary ABLUMs is evaluating how well model structure represents the real world it simulates. This is a fundamental challenge for any kind of modelling concerned with systems that are both open and peopled. In this article, we present

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the results of an experiment with participatory model evaluation methods and reflect on the potential and problems of this approach.

1.1. Testing models of open systems

In contrast to the controlled and closed systems created and examined by laboratory science, the empirical systems studied by land-use science are ‘open’ (*sensu*, von Bertalanffy 1950). Open systems are those in a state of disequilibrium with flows of mass and energy both into and out of them (Kay, Regier, Boyle, and Francis 1999). Furthermore, anthropic land-use systems are open not only in terms of conservation of energy and mass but also in terms of information and values (Naveh 2001). Flows of information and values into the system can lead to changes in political, economic, social and cultural meanings, processes and states. As a result, the behaviour of these systems is open to modification by events and phenomena impinging from outside.

The very concept of an open system (as just described) implies a system boundary has been defined by an observer. In land-use science, system boundaries must be delineated for modelling, as it is seldom that we want to consider all land-use change around the world simultaneously. The delineation of system boundaries for modelling – establishing the temporal, spatial and process domain of what is to be considered by a model structure – is known as model ‘closure’ (Lane 2001; Brown 2004). Once the model has been ‘closed’, the influence of phenomena and events outside the model system boundary can then be represented through scenarios of boundary conditions that perturb the model system.

A problem associated with model closure is the issue of equifinality. Equifinality is a characteristic of all open systems, whereby an identical final system state may be reached from multiple initial conditions and through different sequences of system states (i.e. pathways, von Bertalanffy 1950). In modelling terms, equifinality implies that there are multiple closed model structures that may reproduce empirically observed behaviour of an open system. This generates uncertainty in the appropriateness of model structure and the potential for the mistaken assumption of ‘affirming the consequent’ – the fallacy of declaring a model structure correct or valid if it successfully reproduces observed data for the system being modelled (Oreskes, Shrader-Frechette, and Belitz 1994).

The problem of ‘affirming the consequent’ indicates that *mimetic accuracy* (the mimetic reproduction of empirical events by a model) is not a guarantee of *structural accuracy* (model specification and parameterization that appropriately represent empirical processes). Confronting a model’s predictions with empirical events, for example by comparing observed and predicted model LUCC maps, is therefore unlikely to be an adequate test of ABLUM structure if ancillary information about underlying processes is not also considered. Given that ABLUMs are still relatively new and building their theoretical foundations, focusing on achieving structural accuracy will be a more relevant near-term goal than ‘merely’ achieving mimetic accuracy (e.g. Lynam 2002).

1.2. Participatory approaches to agent-based land-use modelling

Participatory research approaches seek to draw on the knowledge and expertise of citizens and stakeholders not usually consulted by the traditional scientific method. These approaches are being increasingly used in environmental research generally (e.g. Chilvers 2009) and specifically in ABLUM (e.g. Matthews *et al*. 2007). Stirling (2006) has suggested three general classes of motivation for why scientists would consider using participatory research approaches:

(1) *normative democratic* – an end in itself; 'I think consulting you is the right thing to do';
(2) *instrumental* – a means to a particular ends; 'consulting you gives me legitimacy and builds the credibility of my work';
(3) *substantive* – a means to better ends; 'I am consulting you because there might be things I haven't considered but which you know or are concerned about, and can improve my work.'

Here, we are interested in how participatory approaches can make a 'substantive' contribution to the evaluation of the structural accuracy of ABLUMs given the uncertainties inherent in modelling open, anthropic land-use systems outlined above.

From the substantive perspective, stakeholders (farmers, land-use planners, real estate agents, etc.) have a form of non-certified, experience-based expertise about LUCC that allows them to contribute to the knowledge-making activities of certified scientists (i.e. agent-based land-use modellers). These stakeholders are non-certified in the sense that they do not possess relevant scientific qualifications from an accredited institution, but have expertise that is derived from their day-to-day experience and activities (Collins and Evans 2002). Stakeholders with experience-based expertise are likely to offer land-use scientists novel knowledge and information about the characteristics and function of both the physical environment and the social system acting within it. Such knowledge may be vital to ensure appropriate understanding and representation of the system being investigated, as demonstrated by Brian Wynne's seminal study of the inadequate consultation of Cumbrian sheep farmers by UK government scientists investigating and making policy recommendations on the ecological impacts of the Chernobyl nuclear disaster (Wynne 1989). In that case, the farmers' detailed knowledge of local environmental conditions and sheep life cycle and reproduction, combined with their flexible decision-making practices, was at odds with the 'universal' knowledge of the scientists who recommended uniform restrictions on farming practices in all areas. Both farmers and scientists possessed their own forms of relevant expertise about the likely pathways for radioactive contamination in upland pastures, but neither had the ability (or opportunity) to communicate it to the other. As a result, the certified expertise of the government scientists was given vastly more weight than the non-certified expertise of the farmers to the detriment of the policy recommendations. In the case of ABLUM, the experience-based expertise of stakeholders can provide pertinent knowledge about the behaviour and decision-making of the actors represented as agents in the model (e.g. Robinson *et al.* 2007).

Developing and evaluating ABLUM structure may therefore be pursued through a participatory approach that involves the stakeholders in the landscape being represented by the model. For example, the 'co-construction' or 'companion' modelling work of the CORMAS research group incorporates intensive interactive methods such as role-playing games throughout model development and analysis (e.g. Barreteau 2003b). By participating in role-playing games (e.g. Castella, Trung, and Boissau 2005) or by interacting with simulation agents themselves (e.g. Nguyen-Duc and Drogoul 2007), this approach allows actors to communicate with agent-based modellers and provide direct input to the development of model agent behaviours. However, the companion modelling approach also comes with high resource demands and its own unique difficulties (e.g. Barreteau 2003a), and many ABLUM projects cannot, or do not, involve high levels of stakeholder participation to co-construct their models. Other researchers, notably in behavioural economics, have developed laboratory experiments with human subjects to identify decision-making behaviours or empirically calibrate and test models (e.g. Evans, Sun, and Kelley 2006; Camilo Cárdenas 2009). However, when ABLUMs are not co-constructed or developed from laboratory-type experiments (i.e. there is limited stakeholder input during model construction and closure), participatory approaches may still be useful to evaluate model structure. These approaches may capitalise on information and knowledge from local stakeholders and experience-based experts, additional to that provided by empirical maps of LUCC derived from remotely sensed data.

If 'the prime challenge facing agent-based modellers is to show that they can provide new insights into complex natural resource systems and their management that traditional approaches are not able to' (Matthews *et al.* 2007, p. 1457), ensuring appropriate ABLUM structure will be a key first step. There has been a lack of research to date examining the potential benefits and pitfalls of participatory approaches to evaluate ABLUM structure in cases where models have not been co-constructed. In this article, we present a case study of such a situation and examine how well the output and structure of an ABLUM fits the 'mental model' (i.e. understanding) of local stakeholders for a region of central Spain. Alongside some specific questions about our own particular model and results, we ask; 'when an ABLUM has not been co-constructed, what factors might influence the ability of stakeholders to evaluate model output and structure?'

2. Methods

2.1. Overview

Our participatory model evaluation case study concerns an ABLUM developed to represent impacts of LUCC on wildfire regimes in the Madrid region of central Spain. The model we worked with during interviews is based on the agent-based model described by Millington, Romero-Calcerrada, Wainwright, and Perry (2008), with functions integrated from the landscape fire-succession model presented by Millington, Wainwright, Perry, Romero-Calcerrada, and Malamud (2009). The model represents two 'types' of land-use decision-making agent with differing attitudes towards the reasons to farm; 'commercial' agents that are perfectly economically rational, and 'traditional' agents that represent part-time or 'traditional' farmers who manage their land because of its cultural, rather than economic, value. Commercial agents' land-use decisions are based on several factors related to profitability: market conditions, land-tenure fragmentation, transport costs and land productivity. Each of these factors influences the relative values and costs of crop and livestock products (valueC, valueP, costC and costP parameters in Table 1). Commercial agents seek to maximise profit by optimising land use (arable or pasture) and farm size (buying and selling land from neighbours) and retire at 65 years of age, potentially leaving their land to an heir (determined by the *personal choice* parameter in Table 1). Traditional agents follow similar rules regarding inheritance following death but: (1) do not retire if there is no heir, (2) do not consider profit-making activities and (3) do not seek to exchange land with neighbours. Agents may switch between types, and age also influences decision-making in the model (Table 2). We represented the spatial pattern of land-tenure and transport costs in commercial agents' decision-making (Table 3) because the spatial biophysical heterogeneity and land-tenure history of the study area has resulted in a fragmented agricultural landscape. Furthermore, incorporating these spatial decision-making rules was important to us as modellers because one of the primary motivations of the model was to investigate how heterogeneous LUCC influenced wildfire regimes. In simulations presented to stakeholders, we did not simulate fire but did represent secondary vegetation succession following agricultural abandonment (Figure 1a). We presented interviewees with results from model simulations of five scenarios of economic and demographic change (driven by factors not represented by the model structure, Table 1) for 20 years hence (to 2026).

Table 1. Model scenarios.

Model scenarios
Market scenarios: These scenarios examine how the state of the agricultural market influences LUCC alone:
M1 – Declining agricultural profitability (valueC = 2.50, valueP = 1.25, costC = 1.0, costP = 1.0)
M2 – Maintenance of the *status quo* (valueC = 5.0, valueP = 2.5, costC = 1.0, costP = 1.0)
M3 – Increasing agricultural profitability (valueC = 10.00, valueP = 5.00, costC = 1.0, costP = 1.0)
Demographic scenarios: These scenarios assume processes of free-market suburbanisation and increasing access to the study area from the nearby city of Madrid:
D1 – Declining agricultural markets (i.e. scenario M1) plus increasing non-agricultural population
D2 – Maintenance of market *status quo* (i.e. scenario M2) with decreasing propensity of sons to inherit farms from fathers (*personal choice* parameter normally distributed [mean = –1.0, SD = 1] resulting in ageing and declining agricultural population)

Scenarios reflect either changing markets or human population demographics. See Millington *et al.* (2008) for definition of variables.

Table 2. Model assumptions regarding agents' age.

Agent age
There are three impacts of increasing age on agent behaviour:
(1) older agents are more likely to shift to traditional activities if market weakens
(2) agents' ability to maintain land decreases with age
(3) if an agent has no son at the age of retirement (65 years), commercial agents become traditional

This table was presented to interviewees when explaining the behaviour of model agents.

Table 3. Comparison of profitability and costs of land-use types.

	Crops	Pasture
Relative profitability (per unit area)	Higher return and costs	Lower returns and costs
Spatial configuration	Economies of scale reduce costs of larger fields located more centrally within farm	Costs not influenced by size of field but increase with distance from centre farm

This table was presented to interviewees when explaining the economic rationale of the model.

We undertook individual interviews with seven local LUCC stakeholders in November 2006, before the onset of the deep recession currently affecting Spain. These stakeholders had knowledge of specific regions of our study area due to their occupation and, in many cases, place of residence. Interviewees were selected from a range of institutional contexts including private land owners, local agricultural co-operative officials, municipality-level planning officials and local council (ayuntamiento) officials. Three of the seven interviewees had previously been interviewed during development of the agent-based model (see

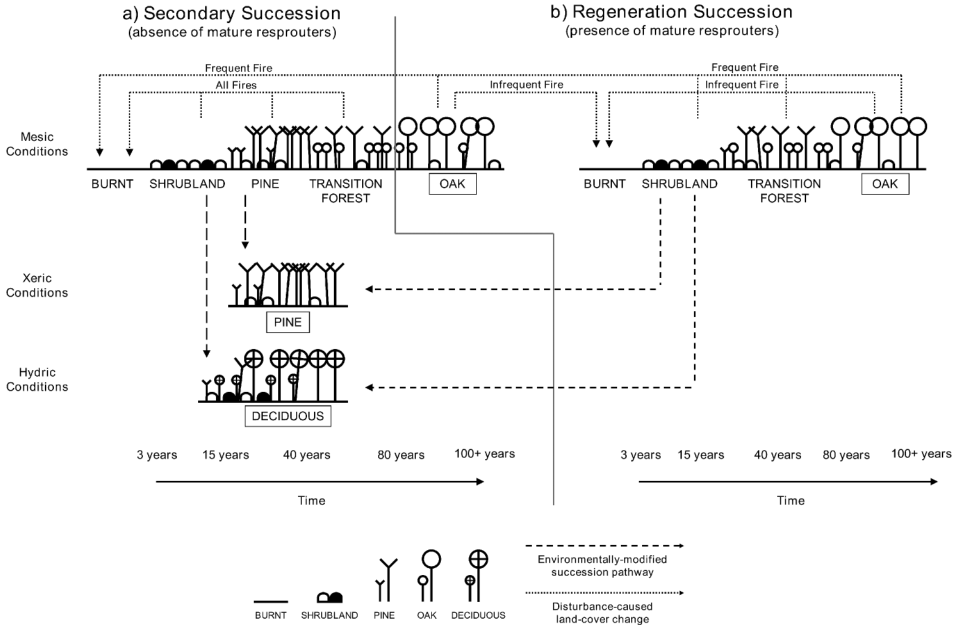

Figure 1. Succession pathways assumed to drive vegetation dynamics in the model for (a) secondary succession; and (b) regeneration succession. Directions and rates of land cover transition are shown for various environmental conditions. This diagram was shown and explained to interviewees. Reprinted from Millington *et al.* (2009) with kind permission from Elsevier (see therein for more details about the model assumptions this diagram illustrates).

Millington *et al.* 2008). The semi-structured interviews contained four distinct sections, each motivated by an explicit research question (addressed in turn below). Interviewees were free to discuss whatever points they deemed relevant to the questions asked. The main focus of the model evaluation process was on the agricultural decision-making processes represented (i.e. Millington *et al.* 2008). Interviews took approximately 1 hour and were audio recorded. Notes were also taken throughout. Subsequently, recordings were reviewed and the pertinent passages transcribed and translated into English.

2.2. Stakeholder expectations

Interviewees were asked to discuss how they think LUCC in their local area will proceed over the next 20 years. They were also given outline maps of their municipality on which to sketch their projected LUCC for the year 2026 (e.g. Figure 2) as well as maps of initial land cover used in the model (i.e. land cover in 1999) as a starting point to anchor their discussions. Interviewees were then introduced to the five model scenarios for which they were to be shown model results (Table 1) and asked if they could envisage what LUCC would occur given those scenarios of change. These questions were asked to establish interviewees' understanding of what LUCC will most likely occur over the next 20 years to 2026 *before* contact with the simulation model. This allows us to contrast simulated LUCC from the ABLUM with what our informants expected would occur.

2.3. Model output

Interviewees were next presented with the results of the simulation model for each of the scenarios specified in Table 1. These results took the form of maps (e.g. Figure 3) and

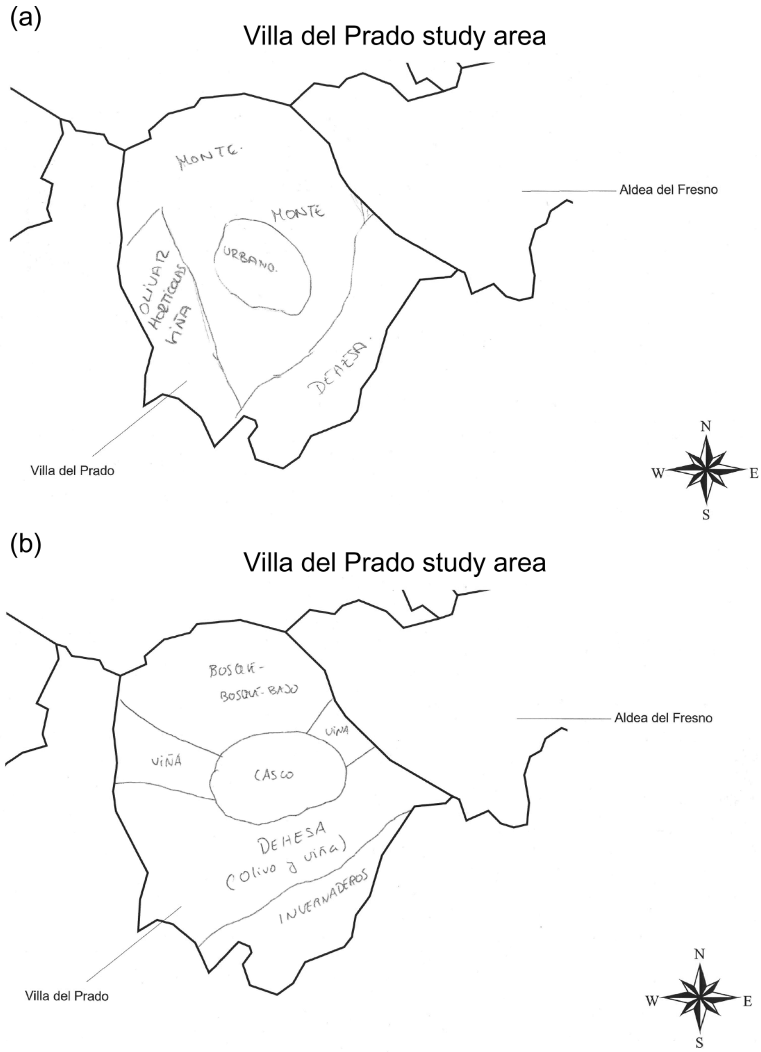

Figure 2. Example sketch maps of two interviewees' expectations of LUCC in the study area by 2026. Parts (a) and (b) were by different individuals for the same study area and projected time period.

movies of LUCC over the period 1999–2026. Interviewees were also asked to comment on the plausibility of the model results, given the scenarios that were simulated. We asked interviewees to consider (if they did not make the comparison themselves) how the simulation model projections matched those they had suggested at the outset of the interview (Section 2.2). This section was intended to gauge interviewees' opinions of the simulation model and its output before they knew anything about its structure or how/why it produced those outputs.

2.4. Model assumptions

Interviewees were then presented with the key assumptions of the simulation model so that they might assess and evaluate their pertinence and accuracy. The key assumptions presented were:

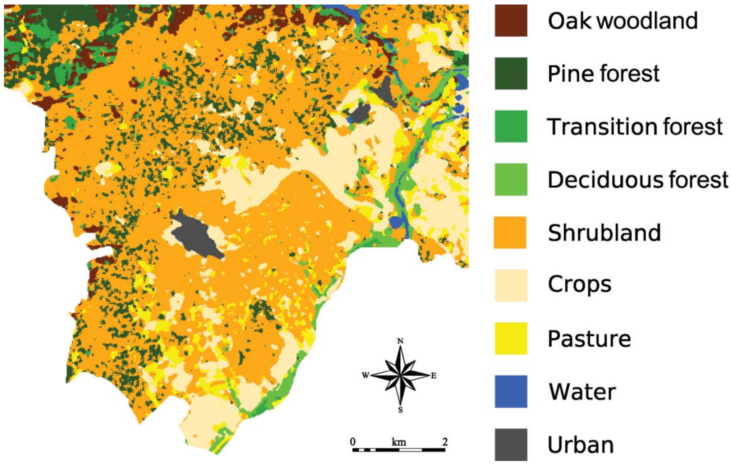

Figure 3. Example model output (land-use map) shown to interviewees. For location and more details on the study area, see Millington *et al.* (2007).

(1) Ecology diagrams with durations and times to change (Figure 1);
(2) Agent behaviour.
   (i) Agent perspective (Table 1 in Millington *et al.* 2008);
   (ii) Agent age (Table 2);
   (iii) Land uses (Table 3).

Interviewees were also presented with the initial land-tenure map used in the model to stimulate a discussion of the land-tenure structure of the study area (and possibly how it has and will change over time). This discussion was followed up with a question regarding one of the key findings from exploration of the agent-based model, namely that spatial land-tenure structure is an important driver of LUCC (Millington *et al.* 2008). Interviewees were explicitly asked if they agree with this finding.

This section of the interview aimed to elucidate how well ABLUM structure agrees with stakeholders' understanding of LUCC. Both model structure and initial conditions (i.e. input data) are uncertain and should be assessed relative to the interviewees' responses. In this part of the interview, the research team considered how detailed responses were, and noted how the aspects of the model that were focussed on were related to interviewees' experience and relationship with the landscape.

2.5. Model modification

Interviewees were asked to identify shortcomings of the ABLUM and asked how they would modify its structure to improve its representation of LUCC. Implicit in this question is the assumption that the stakeholder would modify the simulation model such that it would match more closely with their understanding of LUCC processes. Other relevant questions here were: Is this model and/or its results useful to the stakeholder? If not, how could the model be modified to become useful? Specifically, which assumptions/rules need to be changed, and how? What new assumptions need to be introduced (and why)? These questions directly address the adequacy of model structure.

3. Results

3.1. Stakeholder expectations

Interviewees stressed the importance of economic conditions on land-use decision-making. They emphasised that if agriculture is the sole income for farmers, then they will take whatever land-use measures are required to ensure profitability. For instance:

> Where production has the organic stamp; yes, agricultural activity is profitable. There are a few organic farmers here who are competitive businessmen and live well. But traditional [forms of] agriculture are disappearing because of a lack of profitability and low product prices . . . .
>
> If you have a livestock operation producing cheese, you need to have commercial links with supermarkets to be profitable. Or, you need to associate your agricultural activity with other commercial activities on your land. Then you can be profitable and all the family is involved. If not, livestock operations are abandoned. [Q1] (Local Government Official)

This comment was typical of many, highlighting the implications of changes in agricultural markets (e.g. purchasing power of large supermarkets) and the wider Spanish economy (e.g. requiring diversification to enter into emerging markets) for farmers' decision-making and hence LUCC. Linked to this theme were comments about the importance of agricultural subsidies through the EU Common Agricultural Policy:

> I don't believe agricultural activities in this municipality are [economically] sustainable. Vineyards are in decline – either abandoned or those that are not often remain un-harvested – and, in the future, the removal of subsidies is going to make the situation worse. I'd say more than half [of vineyards] will disappear. [Q2] (Regional Government Official)

Generally however, interviewees discussed the wider impacts of changes in lifestyle as the national economy grows and diversifies away from the primary agricultural sector towards the service sector. For example, from 2000 to 2006 Gross National Income per capita increased 37% in Spain (compared with 26% in the United States and 33% in the United Kingdom) and the contribution of agriculture to Gross Domestic Product dropped 25% over the same period (World Bank 2009). Interviewees implied that national economic changes were a major external driver of change in the study area. These changes directly influence the profitability of agriculture and thus land-use decision-making, but perhaps even more important is their effect on social attitudes. Several interviewees spoke about the trend of younger people within the study area seeking employment in construction and the service sector so as to secure what they perceived as a more 'modern' lifestyle:

> . . . most farmers are part-time, maintaining the traditional agriculture. The children or grand-children of those [farmers] do not have interest [in agriculture] because is it not profitable and requires dedication. The youths go or they seek other work. [Q3] (Local Government Official)

This more 'modern' lifestyle is one that affords leisure time at specified times of the week and at regular intervals (i.e. the weekends and paid holidays). Many interviewees adopted a tone that suggested they believed this trajectory of change was largely inevitable. This feeling of inevitability also had consequences for the interviewees' projections of change.

Although all interviewees shared the same general understanding of the underlying trajectory of social and economic change, this common understanding did not manifest itself in identical projections of the spatial distribution of future LUCC (e.g. Figure 2a and b). However, it did preclude the willingness or ability of interviewees to suggest how the different scenarios (Table 1) would play out in terms of spatial LUCC. Interviewees were more at ease projecting the spatial LUCC they expected from their own understanding of the drivers (i.e. their own scenario of drivers). Sketch maps were coarsely drawn (e.g. Figure 2). Some individuals initially had problems envisaging how change would occur spatially and needed prompting before they could discuss the spatial dynamics of LUCC within the study area. Those who had planning experience were best suited to this exercise, likely because their work demands they deal with maps and think in spatial terms.

3.2. Model output

Comparisons of simulated maps with sketches showed that interviewees' projections of LUCC consistently corresponded (at a coarse spatial scale) with model output from the scenario that most closely matched their expectations of social and economic change. Interviewees chose scenarios M1, D1 or D2 but never M2 or M3 (Table 1), indicating that they expected a continuing decline in the profitability of the agricultural sector and/or declines in the working agricultural population. The coarse spatial resolution of interviewees' sketches makes direct quantitative comparison with model maps impractical on a pixel-by-pixel basis. Although interviewees were encouraging about the feasibility and accuracy of the model output (relative to their expectations), rigorous spatial criticism of the maps at a fine resolution was less forthcoming. One interviewee did highlight an area of his municipality that he 'knew' would make a transition from agriculture to a private hunting concession, which the model did not project:

> In the north east of the municipality agricultural activity is going to disappear. There are large properties that were cultivated for cereals or [traditional oak woodland]. One will become a hunting area now for sure. This has already happened in one other property. [Q4] (Regional Government Official)

Some other interviewees made minor comments along these lines, but generally interviewees examined the resulting model maps in a holistic manner and were satisfied that the maps looked realistic and credible. Interviewees (possibly inevitably) made the strongest comparisons with model output for the scenario which best reflected their own expectations of LUCC (Section 3.1). In some cases, interviewees identified one of the five maps presented as being the 'right' one. At this point in the interview process, the model's structure had not been introduced. It was clear however, that it was the processes of change rather than the resulting landscape patterns (in 2026) that interviewees were interested in talking about, and about which they had a more detailed understanding.

3.3. Model structure

Although all interviewees indicated that they viewed model assumptions and process representation as adequate, most highlighted caveats. First, consistent with their views on important drivers of change (Section 3.1), interviewees suggested that market mechanisms and the influence of subsidies required more explicit representation in the model than had been possible given limitations of data:

> If you leave out variables like land prices, you will be missing data that explain why crops are lost [i.e. abandoned]. These [variables] are tied – abandonment is mainly in the zone next to the urban areas. The immediate profit [of selling the land for urban development] means that people sell those agricultural properties. [Q5] (Local Government Official)

Second, the categorization of agent types as commercial or traditional (Millington *et al.* 2008) was endorsed as a sensible representation of the attitudes and perspectives of actors in the study area. One interviewee even made such a distinction between two similar types of actor in the study area in the first section of the interview (Section 3.1), before the model structure and assumptions had been introduced:

> Those that work and can live on the land really are only three or four persons. The others work part time, for additional income, or do it as cultural occupation, inherited from parents or grandparents." [Q6] (Local Council Official)

Other interviewees suggested that such a straightforward dichotomy of agents was too simple. They pointed out that there would be differences between farmers cultivating olive groves, almond orchards and vineyards, for example. However, it was accepted that a limit on the number of agent types must be placed in any model and that the two used in the model here were an appropriate dichotomy.

Third, some interviewees did not believe the influence of farm fragmentation and distance to the nearest road (Equations (1)–(3) in Millington *et al.* 2008) were of much importance in agricultural land-use decision-making:

> Vineyard abandonment is not a distance question; it is a question of whether it is productive or not. And the town is not a market centre . . . in fact, there could be a reverse effect. The closer areas to town will be abandoned first [due to higher land prices for urban development], whereas land further away will be maintained production. [Q7] (Local Council Official)

Rather, absolute prices of products were deemed to be more important. If a product could be sold at a high price, interviewees suggested that the locations and configuration of fields would not hinder or prevent production of those products:

> I do not think the distance rules are very useful. Distance does not influence decisions here. Everything is so close; it's a maximum of 7 km [from field to town]. That's no distance. [Q8] (Agricultural Co-operative Official)

This comment suggests spatial rules for agricultural decision-making could be removed from the model, or at least modified such that the influence of spatial configuration is reduced. It also highlights that the interviewees think about the landscape and drivers of change in predominantly non-spatial terms.

When asked about the importance of land tenure within the study area, some interviewees responded that it was not important for land-use decision-making, but others suggested that the size of ownership parcels would have an influence. For example, one interviewee suggested a transition from agricultural land-use to private hunting concessions would occur in a particular area because land-tenure patches were large enough there to make such a leisure-based enterprise financially feasible:

> Those that have large properties can maintain activity through economies of scale. [Q9] (Local Council Official)

Generally however, responses suggested that an emphasis on spatial influences of change is unwarranted when modelling land-use decision-making. Rather, interviewees implied that the focus should be on establishing and representing explicitly the economic and social drivers of change.

3.4. Model modification

Our ABLUM was developed with the intent of examining the potential impact of LUCC on future wildfire regimes. However, when interviewees were asked how they thought the model could be improved, it was clear that their responses were couched in terms of their own interests, experience and expertise. A universal suggestion by all interviewees was the consideration of urban growth and development, for example:

> [What have you not considered in the model that is important?] "The urban aspect; urban speculation. The price of land has risen. I would like to buy land, but it is very expensive and I

> can't afford to. If somebody wants land to cultivate, often they cannot buy because it is being sold with urban speculation in mind." [Q10] (Local Vintner)

Urban growth and its influence on land prices were seen as major concerns that, again, were linked to the wider economic and social changes occurring across Spain and already observed across the study area (Romero-Calcerrada and Perry 2004). Individual land owners indicated that they thought the model would be useful, but probably not to the same degree as their own personal knowledge of the study area:

> [These models are useful,] yes. But when you are the subject of the model, already you have an idea of what is happening. You are already anticipating the change yourself. [Q11] (Agricultural Co-operative Official)

This point exemplifies Hacking's (1999) discussion about 'interactive kinds'. That is, the agricultural decision-making agents may be aware of their classification and representation within the model and therefore modify their behaviour based upon the results of the model. However, the implication of this quote is that initially many actors in the landscape will value their own knowledge more highly than the results of the model. How this perspective changes is open to further investigation in later iterations of model development and use.

4. Discussion

From the outset of interviews, it was clear that many interviewees' fatalistic view of wider future economic and social change would be a strong influence on their evaluation of our ABLUM of local LUCC. All interviewees considered some aspect of this wider change when they discussed their expectations of future LUCC in their area (Section 3.1), and several made it clear that they believed individual decision-making is strongly constrained by the boundary conditions of wider social and economic change (e.g. Q3). When specifically asked about individual components of the model structure (Section 3.3), they were able to comment constructively, but often their discussion quickly returned to factors considered by the boundary conditions of the model. When asked to compare model output with their own sketches of future LUCC, several interviewees indicated that the 'correct model' was the map resulting from the scenario that fitted best with their expectations of future change. Such a comment, made *before* model structure had been introduced, suggests interviewees' concern for wider conditions also seemingly influenced their understanding of the difference between model structure and scenario boundary conditions. When stakeholders view structure and scenario as synonymous like this, assessment becomes a process of establishing which scenario matches their expectation of future driving boundary conditions, rather than considering how well the model structure matches their understanding of the processes driven by external conditions. Modellers should ensure stakeholders understand the distinction between model structure and scenario before model evaluations are accepted as useful or pertinent.

Interviewees opined that the current model structure was an acceptable representation of the processes of change occurring in the study area. With regards to the three specific areas of model structure, interviewees were able to provide input that confirmed the modellers' understanding, highlighted areas for refinement, and indicated mismatches in understanding between modellers and stakeholders. First, the majority of interviewees indicated that they would like to see a more detailed representation of market mechanisms, including the consideration of agricultural subsidies. The modellers viewed this as a shortcoming themselves before entering this evaluation process, but stakeholders' comments highlight that this is a primary aspect of model structure that needs refinement.

Second, interviewees indicated that the categorization of agent types (between 'traditional' and 'commercial' – see Millington *et al.* 2008) is appropriate and confirmed that the non-monetary influences on actor behaviour represented by the traditional agents is pertinent (one of the benefits of agent-based approaches suggested by Matthews *et al.* 2007). However, it was pointed out by some interviewees that this categorization could be further refined to consider specific crop and livestock types (in conjunction with more detailed representation of market mechanisms). Third, interviewees provided useful comments on the role of farm fragmentation and spatial configuration on agricultural decision-making. These comments both provide information otherwise inaccessible to the modellers and highlight a potential mismatch between the modellers' theoretical understanding of spatial drivers of LUCC (couched in the literature – see Millington *et al.* 2008) and stakeholders' spatial understanding. Many stakeholders again stressed that social and economic drivers (mostly due to wider changes in Spain and beyond) would be more important than spatial characteristics of the local landscape (e.g. Q8), although in some cases stakeholders did link economic processes to local land tenure (e.g. Q9). The perspective of stakeholders suggests that a broader analysis that examines regional dynamics may be more pertinent than a spatial ABLUM.

However, our model was developed with the intention of examining local spatial interactions between LUCC and the wildfire regime (Millington 2007), something a regional analysis would prevent. One way to further investigate the importance of the local spatial drivers of land-use change would be by adopting the protocols of the approach that Grimm *et al.* (2005) termed 'pattern-oriented modelling' (POM). This approach aims to overcome problems of equifinality and 'affirming the consequent' (Section 1.2) by taking an iterative approach to compare empirical and model output patterns at multiple levels for multiple model structures. In 'stakeholder-driven pattern-oriented modelling', stakeholders' input would drive modifications of model structure and scientists would perform the quantitative pattern comparison. For example, if, after removing the spatial rules from our model, model behaviour is unaffected and output matches observations, then clearly these rules are unnecessary. However, if model behaviour changes markedly after removal and model output does not match observations, the next step would be to go back to stakeholders to discuss the importance of different spatial rules. This discussion would focus more carefully on what spatial drivers of LUCC do exist and how they can be represented in the model. In this way the tension between modellers' and stakeholders' views of what is important to include in the model should become more apparent. In turn, this may potentially lead to improved model structure, and may also help stakeholders to better understand the difference between model structure and scenario boundary conditions.

We asked interviewees to produce their own spatial projections of LUCC (i.e. sketch maps, Figure 2) and to compare them with maps output from the ABLUM. Interviewees with frequent experience dealing with maps and spatial planning were most comfortable performing these tasks. The comparison stakeholders made is not a true test of mimetic accuracy (and nor was it intended to be), but rather a comparison of model output with their own expectations. In our case (Section 3.2) interviewees accepted the model was a mimetically realistic representation of the changes they expected at a coarse spatial resolution. As this comparison is a test of mimetic realism from the stakeholder's perspective, it lacks the empirical rigour of comparing model output with empirical data. However, the advantage of this approach is that when the model does fail to match stakeholder's expectations (i.e. was 'wrong'), they might be able to provide reasons *why* the model would fail at these locations, and therefore contribute to understanding both model structure and processes of LUCC. Our experiment indicates interviewees may need to be encouraged to do this, but one of our interviewees did independently highlight an area of his municipality that he 'knew' would change from agricultural land use to a private hunting concession (Q4). This interviewee's projection was based on his local knowledge about the land-tenure structure and the personal relations between the land owners in that place. The ABLUM does not take account of these aspects of LUCC dynamics – whether it ever could account for these place-based nuances is a point for debate. Brown *et al.* (2005) proposed a method to examine how well a model performs in mimetic versus structural terms, by evaluating which areas of (spatial) model output would be more or less likely to vary due to path dependence or stochastic uncertainty. The stakeholder comparison we have presented is similar to such analysis, with the difference that we use the knowledge and experience of stakeholders to identify areas that are likely to have strong path dependency. The method of Brown *et al.* (2005) offers promise for greater understanding about the roles of historical and geographical contingencies in landscape change, but has limited use for models with high resource requirements (and so cannot be replicated many, many times) and it does not necessarily address the specific source of either path dependencies or stochastic uncertainties. A stakeholder evaluation as we have pursued addresses both these issues.

With regards to our experimental design, we found the first step (Section 2.2) was useful to initiate discussion and put interviewees at ease by inviting them to talk about a subject of which they have intimate knowledge, before embarking upon discussion about a potentially alien way of understanding LUCC (i.e. simulation modelling). In hindsight, it was also a vital step in our particular study area, given the tenacity of views regarding the importance of wider social and economic drivers for local LUCC. Presenting interviewees with model output before model structure was also useful in our case to identify the potential conflation of model structure with scenarios of boundary conditions. Presenting model structure before output (i.e. switching Sections 2.3 and 2.4) may help to overcome this issue and could be examined in other studies of this type. Furthermore, in our case it would be interesting to examine how interviewees' views on wider social and economic drivers of LUCC have changed given the recent global economic downturn. Our interviewees were able only to criticise the model in general terms as the relatively short duration of the interviews (1–1½ hours) did not allow a detailed presentation of the model. The value of a lengthy, detailed presentation of all model assumptions and parameters (as found in relevant peer-reviewed articles – e.g. Millington *et al.* 2008, 2009) is questionable. We expect it is unlikely that a formal presentation of these details (over the course of a couple of hours) would have helped increase interviewee understanding of the ABLUM, and its distinction from the scenarios. To ensure a better understanding of model structure and scenarios, it would be preferable for stakeholders to use and interact with the model and its parameters for different scenarios. This would likely be more efficient and result in greater insight than the approach we have presented. However, if high computational demand prevents such an interactive experience, our case study indicates that a focus on the distinction between model structure and scenario boundary conditions is important.

5. Conclusions

A key issue facing contemporary ABLUMs is model evaluation. In this article, we outlined some of the epistemological problems facing the evaluation of ABLUMs and presented a case study of participatory evaluation of a model that was not co-constructed. We found that interviewees were able to provide spatial criticism of model output, but that many needed to be encouraged to make analyses of a larger spatial area than which they experience on a day-to-day basis. We also found that interviewees were able offer reasons for why the model might not accurately forecast LUCC, but that their fatalistic views on the importance of wider social and economic change for local LUCC influenced many aspects of their model evaluation. For example, these views may have driven some interviewees to conflate model structure with scenario boundary conditions. The order in which model output and structure were presented may also have been an influence and an interaction with the model during evaluation may help to overcome this confusion. However, if resource availability prevents an interactive approach, we suggest modellers should seek to ensure that stakeholders understand the distinction between model structure and scenario boundary conditions before accepting their evaluations.

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