Qualitative Modeling in the Landscape Development Monitoring

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Abstract: - The paper introduces an architecture of qualitative models for monitoring of the landscape development. There are introduced data model, class, state, sequence models, process, emergent and matroid models. The architecture and the interaction of models allows to form a global view to ecosystem needed for qualified assessment of human activities in landscape. The first goal of the paper is to model situations associated with violations of the Small Water Cycle (SWC) in the modeled ecosystem, and to contribute to formation of acceptable solutions. The second goal of the paper is to present qualitative models for monitoring the stability of the landscape development and to support approaches of integrated environmental modeling.

Key-Words: - Database system, architecture of models, monitoring, stability of landscape, integrated environmental modeling

1 Introduction

Considering about modeling activities in the field of ecology we note four main lines of interests:

- Functional description. How the system functions as a whole and how function its parts.
- Operational dangers – from exceeding of technological limits till the functional instability. (Some human activities belong to causes of such dangers.)
- Dangers of violation of structural stability. (Re-structuring of the system from inside, self organization of the system, cooperative phenomena and emergent situations are causes of such dangers. Here we find unexpected negative coincidences and as well as a gradual decrease of species diversification.)
- How expensive is the operation of the ecosystem and where are the balances of energy and emergy (System emergy analysis.)

In this paper we start with data and database models acquired by experimental way. These data and database models contain state of ecosystem (including negative phenomena and processes). With regard to the fact that we have rather incomplete data of many variables it is non reasonable to apply the quantitative techniques of regression analysis (though it had been done many times before). Qualitative models introduced in this paper overcome experience with quantitative models namely in these items:

- They provide compression of information contained in large volumes of numerical data.
- On the contrary of individual quantitative modeling qualitative models enable to describe the function and properties of the whole ecosystem.
- Conclusions from qualitative models are in many cases better than are the generalizations of results from quantitative models.

Qualitative modeling were, in its beginning, introduced as a tool for simplification of complex quantitative reality, e.g., [15], [13]. Though this goal is actual still, some lines of the research very soon achieved to sophisticated methods and concepts.

In our paper we will prefer decomposition of complex reality of ecosystems into simple concepts and models and into a few modeling strata. We propose the methodology how to develop this structure of models. In works [3], [2] we introduced four types of qualitative models – data (database), state, emergent and matroid models. These models are included in this proposed paper into context of another three models – class, sequential and process models.

2 State of Art

Before we devote our full attention to qualitative models we introduce a wider context of modeling of ecosystems and living environments.

The application of classical models in the form of so-called ”oriented elements” (or ”input/output elements”) seems to be problematic for most ecosystems. The number of measurable inputs is rather high, and some potential inputs are unavailable or not measurable. Input/output models are used with success, e.g., for modeling of the energy flows in an ecosystem [23], [17] and modeling for emergy analysis [5].

In the field of modeling of ecosystem functions appear reductionist models, that represent behavior of ecosystems by means of relations among a small number of measurable variables. Well known is the model ”Temperature/Moisture” or the model ”Temperature/Moisture/Radiation” [19]. The success of these local models depends on defining their area of validity, and on knowledge of the actual quantities of the constants and parameters.

Author of [20] investigated the usability of concepts from the field of complex adaptive systems for individual modeling. In addition to using classical concepts for individual modeling (e.g., Adaptation, Fitness and Strategy, Prediction), he devoted great attention to the concept of Emergence. Unfortunately – the position of I/O models with danger of emergent phenomena will become even worse. The systems with emergent phenomena need special modeling tools. Classical balance models are violated by self-organization processes and the goals of such processes are usually unknown and can be negative for us. We quote in this context works [25], [10], [22].

Formulation and computation problems introduced for I/O models in ecological field were partially simplified in recent time by new computation means, as are artificial neural networks and genetic algorithms [11], but have not been completely solved. The question arises whether ecological models have the potential to form a new computation paradigm [12], similarly as in the case of so-called chemical programming [16]. If a new paradigm can be formed, it would also affect the position of our qualitative models.

Discussing the landscape stability development we need models for integrating enormous volumes of data measured in ecosystem functions. An important issue here concerns concentrating the density of information and integrated models that can also be utilized for higher executive levels (districts, regions, countries). There are two development ways for it:

- *Visualization approaches* are very simple and effective. Visualization is either done directly or some associated formal means are applied (e.g., cellular automata - [28], [6]. These examples investigated the influence of man on changes in landscapes.
- The development of special software utilizing modern information technologies (especially software engineering), [24], [1], [8]. We can refer to long files of systems that combine special methodologies for the development of software systems with means for integrated assessment of landscape changes [27], [29] [26].

3 Types of applied models

Before we describe details of relevant models we emphasize one substantial difference between quantitative and qualitative models.

The formulation of problems in case of quantitative models is very typical. We ask, e.g., for the speed of a car. The sequence of steps to the solution is standard: equation of motion, substitution of parameters and a mechanic solution (by a preformed solver). The result is: ”the speed of the car = xy.z”.

In case of a part of qualitative models we will speak about in this paper, the formulation of the problem is more extensive, e.g., ”how functions this ecosystem”? We need for it the functional description of the whole system, not a collection of equations.

Comparing with quantitative models - in qualitative modeling we solve the problem directly in formation of models and of their architecture. No substitution, no solvers. The solution is acquired by reading, understanding and practicing of the developed models (e.g., class model and state models). (More in subsections 3.2 and 3.3).

3.1 Data (database) model

The essential pre-model for developing some of our qualitative models is the database model (implemented in some database program system). This model stores the values of landscape variables (of the type - temperature at height of 30cm above the surface of the landscape, radiation received from the sun, radiation reflected from the surface of the landscape, etc.) measured at selected points of the landscape at certain time intervals.

Database model says which quantities achieved selected variables in certain time and in certain space. This model represents a data background for the formation of these qualitative models: state, sequence, process models and of the model for the detection of emergent situations.

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3.2 Class model

For the formation of Class model is usually used some special methodology, e.g., Object Modeling Technique (OMT) [21] and some special functional language, e.g., Unified Modeling language (UML) [14]. The result is the structure of abstract modules, (classes, objects) and their bonds

$$\boldsymbol{CM} = \langle C, Att, Op, B, Q, ST_{CM} \rangle, \qquad (1)$$

where C is the set of class names, Att is the set of attribute names, Op is the set of class operation, B is the set of bonds, Q is the set of qualifications of bonds and ST_{CM} is the structure of the class model.
For the development of the class model we need an expert that knows the function of the system, uses an proper knowledge methodology (e.g., OMT) and knows how to write it in a proper functional language (e.g., UML).
From the class diagram is possible to acquire: which are the main classes of the system, which classes are interconnected, which bonds are between classes, which attributes are substantial and which operations will work with values and manifestations of these attributes. (Within the frameworks of classes are then developed *state models*.)

3.3 State model

One type of state model has been introduced in [3]. Other type of state models differs in the concepts of states and transitions. In general the state model has the following structure:

$$\boldsymbol{SM} = \langle S, I, O, Ac, \lambda, \delta, ST_{SM} \rangle, \qquad (2)$$

where S is the set of state names, I … are names of inputs, O are names of outputs, Ac is the set of actions, events and activities that are executed during staying the system in the given state, λ…is the state function, δ … is the output function and ST_{SM} is the structure of the state model.
State model contains information about activities and processes that are executed and performed when the system is in the given state and which conditions (events or actions) release the transitions between the states.

3.4 Sequence model

As an another means for the description of the dynamic phenomena and processes we use sequence model. Development of sequence model is done in the following context

$$\boldsymbol{SQM} = \langle C, Att, Op, Ac, ST_{SQM} \rangle, \qquad (3)$$

where C is the set of class names, Att is the set of attribute names, Op is the set of class operation, Ac is the set of actions, events and activities that are executed during the system stays in relevant state, and ST_{SQM} is the structure of the sequence model.
Comparing with state model the sequence models is oriented according the tasks and describes interaction of classes within the framework of given task. An example of the task is, e.g., ”the decrease of evaporation in the region with measurement stations S11, S12”.
The sequence models answer questions of the type: “Which stable sequences of operations, actions and events form the given task and how they participate on the task? ”.

3.5 Process model

Process model contains in its qualitative part *processes* and *transformations*. In case of ecosystems is difficult to describe quantitative properties of processes with sufficient precision and hence the qualitative part of the model is much more important. Process model will be used in our case for modeling of energy flows in the landscape, for ecological evaluation of the landscape and for emergy analysis. One of variants of a Process model has the following form

$$\boldsymbol{PM} = \langle E, A, S, P, T \rangle, \qquad (4)$$

where E … is the set of events, A … is the set of actions which combine the events into processes, S … is the set of states, P … is the set of processes and T … is the set of transformations.

3.6 Model for the detection of Emergent situations

In works [2], [3] has been proposed method for the detection of emergent situation by structural invariants. The completion of this method by dual concepts is introduced in our recent works. General form of model for detection of emergent situations has the following form

$$EM = \langle SS, \langle \Gamma_1(SS), \ldots, \Gamma_n(SS) \rangle, \langle Inv(\Gamma_i), \ldots, Inv(\Gamma_p) \rangle, COND_{VInv} \rangle, \qquad (5)$$

where SS … is the set of situations, $\Gamma_1(SS), \ldots, \Gamma_n(SS)$ ... are appropriate structures on the set SS, $Inv(\Gamma_i), \ldots, Inv(\Gamma_p)$... are structural invariants discovered or formed on structures $\Gamma_1(SS), \ldots, \Gamma_n(SS)$ and $COND_{VInv}$ are conditions of violation of structural invariants. Typical structural invariants are, e.g., the triplet (Matroid Basis, Matroid Cover, Emergent Zone) or the twofold (Dulmage-Mendelsohn decomposition, Set of evaluated rules) or Algebra of transformations. Emergent situations are detected as the violations of structural invariants or as a appearance of dual system invariants (dual invariants).

Model for the detection of emergent situations answers the question: Are structural detection invariants violated? Will appear an emergent situation in near time?

3.7 Matroid model

Matroid model uses matroid structure formed on the sets of classes, states, events or processes and use for relevant purposes the properties derived in Matroid Theory, e.g., properties of bases, properties of binary matroids, properties of dual matroids, etc. A matroid, e.g., in [18] is introduced in this paper as the structure

$$M = \langle X, IND, \{N_1, N_2, \ldots, N_n\}\rangle = \langle X, IND, \Gamma\rangle, \quad (6)$$

where X ... is a set of elements (e.g., classes, states, events, processes), IND is the relation of Independence, and $N_1, N_2, \ldots, N_n$ are independent sets ($\Gamma = \{N_1, N_2, \ldots, N_n\}$). Matroid introduced in this paper is goal oriented. It means that individual pairs of X are evaluated according to their influence on the attainment of some goal in the model (e.g., the intensification of Small Water Cycle). Matroid model has the following form

$$\boldsymbol{MM} = \langle X, B, Int\rangle, \quad (7)$$

where X ... is a set of elements, B... is the set of matroid bases and Int ... is an interpretation function that explains the influence of elements of bases on the achievement of the defined goal. Matroid model contains information about most important classes (states, events) for the attainment of some goal in the model.

4 Case study

We turn back to situation of violation of Small Water Cycle (SWC) in Trebon basin (South Bohemia, Czech Republic) we informed about in papers [3], [2]. In the mentioned ecosystem is evaporated water quickly brought up in the zone in which does not condense yet and in this height zone is transported outside the ecosystem till distanced mountains where spontaneously condenses in rising air streams. (With regard to enormous volumes of brought vapor the condensation is very dynamic and the rain is sometimes of downpour form.)

In further text we describe this ecosystem and its interconnected subsystems from a points of view of the introduced models. Respecting limited number of pages of the paper we introduce in details only models: class model, state model and matroid model.

4.1 Data (database) model

The structure of database model with data for violation of Small Water Cycle (SWC) in Trebon basin (South Bohemia, Czech Republic) was introduced, e.g., in [3]. The database is still actual, completed with measured data for last two years and analyzed by program for knowledge discovery especially for the detection of emergent situations.

4.2 Class Model of the ecosystem

The classes of this model determined expert (in our case by methodology OMT).

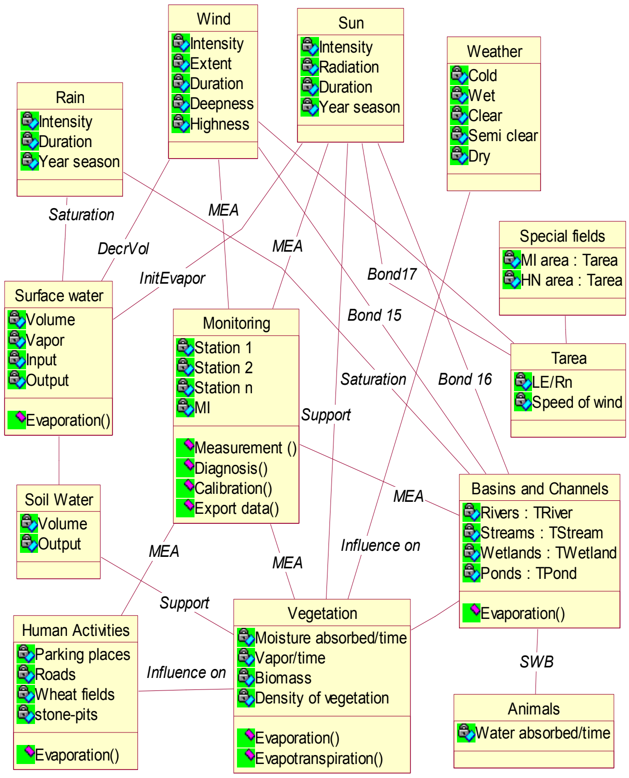


Fig. 1 Class diagram for Trebon basin.

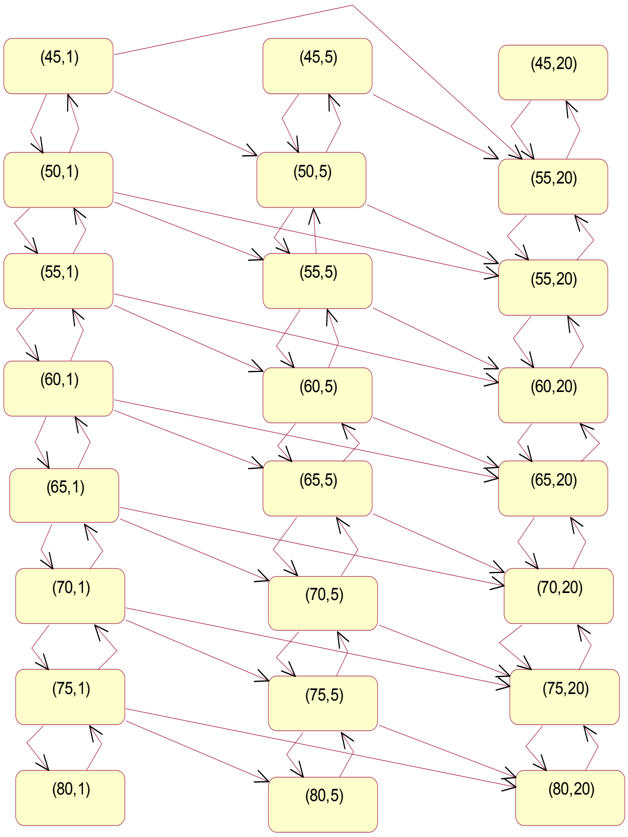
The preliminary result of this activity was the list of classes that was gradually tuned till the final form. The same process was done for attributes, bonds, operations and their qualification. The class diagram of a part of Trebon basin is in Fig. 1.

4.3. State model for the class MI area

We describe states (S_i) of this class by pairs of numbers

$$S_i \approx (\nu , \omega), \qquad (8)$$

where ν [%] is a relative latent heat used for evapotranspiration by ecosystem (in a considered area) and ω is an average speed of the wind in the



given area [m/s].

Fig. 2 State diagram for the area MI.

Relative latent heat used for evapotranspiration is computed as a ratio

$$\nu = LE / Rn, [\%], \qquad (9)$$

where LE is a flow of a latent heat used for evapotranspiration in considered area [kWh/m^2], and Rn is a pure complete radiation in considered area [kWh/m^2].
Relative latent heat used for evapotranspiration ν in the considered area was measured in the interval $\langle 45, 80 \rangle$ % and the average speed of the wind in the considered area was measured in the interval $\langle 1, 20 \rangle$ [m/s]. In the scale of relative latent heat used for evapotranspiration we mark (with help of expert) 8 points (45, 50, …, 80) % and in the scale of the speed 3 points (1, 5, 20) [m/s].
Hence the state model has 24 states. The transitions between states were extracted from database.
State model in Figure. 2 concentrates information about possible motions in state diagram during a part of year (e.g., June, …, September). The possibility of transitions can be done qualitatively (Possible, Impossible), non deterministically (transition is sometimes available, sometimes no available – this is our case), can be done by fuzzy variable or by quantity of probability.

4.4. Sequence model

Sequence models for problems with violation of SWC were developed for selected operational tasks. As an example of such a task we introduce ”Increasing of moisture turning back to Trebon basin”. On this task are engaged classes: Wind, Sun, Weather, Surface water, Basins and Channels and Vegetation.

4.5. Process model

As a process model was developed qualitative system model for emergy analysis of ecosystem in Trebon basin. This qualitative model allows to continue with computations of expenses for the ”operation” of the whole ecosystem in Trebon basin. There was used methodology presented in [5].

4.6 Model for detection of Emergent situations

The method for development of model for the detection of emergent situations, introduced, e.g., in [2], [3] was adapted. The original method that used Hasse diagram synthesis and the extraction of rules from Hasse diagram has been extended by the development of dual system of rules.

4.7 Matroid model

The technique for the synthesis of matroid model has been illustrated in [2], [3] for the set of ecosystem states. In this paper we apply the method of the synthesis of matroid model on classes of the class model (Figure 1). From Figure 1 we consider 15 classes for construction of matroid model:

X = {Rain, Wind, Sun, Weather, Surface Water, Soil Water, Rivers, Streams, Wetlands, Ponds, Vegetation, Animals, Monitoring, Human Activities, Special Fields}. (10)

On this set is executed a questionnaire procedure (done by experts). The goal of this procedure is to find the responses for question ”Does effect the class x_i on improvement of violation of SWC in dependence (DNT) on class x_j”, where x_i, $x_j \in X$. Dependence relation (DNT) was introduced in [2], [3] and relation IND is dual to DNT.
There were discovered two bases with 5 elements:

B1 = {Rain, Wind, Sun, Monitoring, Human Activities }. (11)

B2 = {Rain, Wind, Animals, Monitoring, Human Activities }. (12)

Hence we have matroid model

$$\boldsymbol{MM} = \langle X, \{B1, B2\}, Int \rangle. \qquad (13)$$

Interpretation of B1, B2 in the context of classes *X* is done similarly, as in [2], [3].
Int: Matroid bases contain classes that are most important for improvement of violation of SWC.

5 Conclusions

This paper has reported on an investigation of qualitative models destined for a monitoring system oriented to an integrated assessment of landscape changes. Seven qualitative models were proposed: data, class, state, sequence, process models, model for the detection of emergent situations and matroid model.
The development of these models requires cooperation with a qualified experts. The advantages of application of these models are in quick responses and comprehensive results (assuming standard software equipment). Our paper aims to evoke interest in qualitative modeling of ecosystem functions and in integrated environmental assessment.

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References

[1] Argent, R.M., Grayson, R.B., Design of information system for environmental managers an example using interface prototyping. *Environ. Model. Software* 16, 2001, pp. 433–438.
[2] Bila, J., Pokorny, J., Jura, J. and Bukovsky, I., Qualitative Modeling and Monitoring of Selected Ecosystem Functions. (Submitted in *Ecological Modeling* (Elsevier) in 2010).
[3] Bila, J., Jura, J., Bukovsky, I., Qualitative Modeling and Monitoring of the Selected Ecosystem Violated with Parasitic Dehumidifying and Dehydrating. In: *Proc. of 10th WSEAS Int. Conf. on Automation and Information,* Prague, 2009, pp. 211-219.
[4] Bila, J., Jura, J., Unexpected versus ill separable situations, In: *Proc. of 4th IMECO International Symposium on Measurement, Analysis and Modeling of Human Functions – ISHF 2010*, Prague, 2010, pp. 96-101.
[5] Brown, M.T., Martínez, A. and Uche, J., Emergy analysis applied to the estimation of the recovery of costs for water services under European Water framework Directive, *Ecological Modeling*, 221, 2010, pp. 2123.
[6] Flamm, R.O., Turner, M.G., Alternative model formulations for a stochastic simulation and landscape change*, Landscape Ecology*, 9, 1994, pp. 37–46.
[7] Forrest, S., Emergent computation: self organizing, collective, and cooperative behavior in natural and artificial computing networks, *Introduction to the proceedings of the ninth annual CNLS conference. Physica D 42*, 1990, pp. 1–11.
[8] Grimm, V., Ten years of individual-based modeling in ecology: what have we learned and what could we learn in the future? *Ecol. Model.* 115, 1999, pp. 129–148.
[9] Hinkel, J., The PIAM approach to modular integrated assessment modeling. *Environ. Model. Software* 24, 2009, pp. 739–748.
[10] Holland, J.H., *Emergence: From Chaos to Order*, Helix Books, Reading, Massachusetts, 1998.
[11] Huse, G., Strand, E., Giske, J., Implementing behavior in individual-based models using artificial neural network and genetic algorithms. *Evol. Ecol.* 13, 1999, pp. 469–483.
[12] Huston, M., DeAngelis, D., Post, W., 1988. New computer models unify ecological theory. *BioScience* 38, 1998, pp. 682–691.
[13] Ishida, Y., A Qualitative Analysis on Dynamical Systems? Sign Structure. *Mem. Fac. Eng. Kyoto Univ,* Vol.54, No.1., 1992, pp.21-32.
[14] Page-Jones, M., *Fundamentals of Object-Oriented Design in UML*, Addison Wesley Longman, 2000.

[15] Kuipers, B., Qualitative Reasoning, Modeling and Simulation with Incomplete Knowledge, *Automatica*, 4, 1989, pp. 571-578.
[16] Matsumaru, N., Lenser, T., Hinze, T., Dittrich,P, Toward Organization-Oriented Chemical Programming: A Case Study with Maximum Independent Set Problem. In: *Advances in Biologically Inspired Information Systems,* Springer, Berlin, 2007, pp. 147-164.
[17] Odum, H.T., Explanation of ecological relationships with energy systems concepts. *Ecol. Model*. 158, 2002, pp. 201-211.
[18] Oxley, J.G., 2001. *Matroid Theory*. Oxford: Oxford Science Publications.
[19] Pokorny, J., Bila, J., *et al*., Partial Report to project 2B 06023, MSMT, Czech Republic, 2008.
[20] Railsback, S.F., Concepts from complex adaptive systems as a framework for individual-based modeling. *Ecol. Model*., 139, 2001, pp. 47–62.
[21] Rumbaugh, J.E. *et al*., *Object-Oriented Modeling and Design*. Prentice Hall Int. Inc. 1991.
[22] Reid, R.G.B., An Emergence Theory. In: *Biological Emergencies. Evolution by Natural Experiment*. Massachusetts Institute of Technology, Massachusetts, USA, 2007, pp. 361- 400.
[23] Ripl, W.,. Management of Water Cycle and Energy Flows for Ecosystems Control – The Energy Transport Reaction (ETR) Model. *Ecol. Model*., 78, 1995, pp. 61-76.
[24] Rotmans, J., Dowlatabadi, H., Integrated assessment modeling. In: Raynor, S., Malone, E. (Eds.), *Human Choices & Climate Change.* Batelle Press, Columbus, 1998, pp. 291–377.
[25] Waldrop, M.M., *Complexity: The Emerging Science at the Edge of Order and Chaos*. Simon & Schuster, New York, 1992. pp. 380.
[26] Verweij, P.J *et al*., An IT perspective on integrated environmental modeling: The SIAT case. *Ecol. Modeling*, 221, 2010, pp. 2167-2178.
[27] Villa, F., Athanasiadis, I., Rizzoli, A., Modeling with knowledge: a review of emerging semantic approaches to environmental modeling. *Environ. Model. Software* 24, 2009, pp. 577–587.
[28] Wang, Y., Zhang, X., A dynamic modeling approach to simulating socioeconomic effects on landscape changes. *Ecol. Model.* 140, 2001, pp. 141–162.
[29] Wien, J.J.F., *et al.*, A web-based software system for model integration in agro-environmental impact assessments. In: F. Brouwer, M.K. Van Ittersum (Eds.), *Environmental and Agricultural Modeling: Integrated Approaches for Policy Impact Assessment*. Springer Academic Publishing, in press.

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