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Challenges of simulating complex environmental systems at the landscape scale: A controversial dialogue between two cups of espresso

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ABSTRACT

With the advancement of computational systems and the development of model integration concepts, complexity of environmental model systems increased. In contrast to that, theory and knowledge about > environmental systems as well as the capability for environmental systems analyses remained, to a large extent, unchanged. As a consequence, model conceptualization, data gathering, and validation, have faced new challenges that hardly can be tackled by modellers alone. In this discourse-like review, we argue that modelling with reliable simulations of human-environmental interactions necessitate linking modelling and simulation research much stronger to science fields such as landscape ecology, community ecology, eco-hydrology, etc. It thus becomes more and more important to identify the adequate degree of complexity in environmental models (which is not only a technical or methodological question), to ensure data availability, and to test model performance. Even equally important, providing problem specific answers to environmental problems using simulation tools requires addressing end-user and stakeholder requirements during early stages of problem development. In doing so, we avoid modelling and simulation as an end of its own.

1. Introduction

Visions need new perspectives—and new forms from time to time. Thus, this contribution is entirely different from well-known research, perspective or review papers. Nevertheless it has elements of all of those types of publications—summarizing and thinking ahead integrated environmental modelling and systems analysis, to provide methodological support required by landscape ecological research.

2. Discussion

It was a November morning. The smell of two freshly percolated espressi dispersed in front of the large window of the cafeteria. The Zurich town centre and the river Limmat were approximately hiding from being seen from the roof of the ETH main building. Rebecca was impressed by the venerable architecture with its secret stairs to the lecturer's coffee bar. Seeing nothing but fog, she got frustrated looking through the windows.

Tony: That was hard stuff yesterday. *He was referring to a lecture Rebecca gave at his institute the day before. They both knew each other from a conference some years ago and although their viewpoints on landscapes were quite different he invited her to present her work about spatial models to the landscape ecology group of his institute.*

Rebecca, stirring her espresso: Hmm. . .

Tony: All those systems, those complex models and those math-equations you presented. . . *He was looking to the ceiling of the room desperately*. What does all that have to do with landscape ecology? I guess you lost most of the students and colleagues in your presentation yesterday. Is this systems stuff of any use for solving any real challenge in the landscape? To me it seemed pretty much like a broadcast talk directly out of the ivory tower!

Rebecca hardly avoiding choking on her espresso: Pardon me!?

Tony: I mean you are talking about very abstract physical and mathematical ideas. Isn't that approach extremely remote from species distributions, habitats and patterns? And isn't it far away from solving any environmental problem? Far away from answering any landscape-related question?

Rebecca slowly put the cup back on the table: Hmm, no. . . No! I think they are right in the focus of it.

Tony simpering: Surely you are joking. . . So you want to tell me that this is in the centre of the world?

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Rebecca: Maybe not exactly in the centre, but not at all at the periphery, as well. Environmental problems have become more and more complex. Several processes interact over large distances, they are influenced by nonlinearities, complicated feed backs of transport behaviour, and they exhibit chronically, delocalized and indirect effects. They are entangled in complex food webs and many other biotic interactions.[1] We more and more recognize that this complexity of feedbacks is crucial to come up with profound management decisions on environmental resource use. Therefore, disciplinary limits are losing significance.[2] Solving and – before that – understanding these interactions requires an interdisciplinary approach.[3] Thus, discussing disciplinary crises of scientific self-confidence and struggling for disciplinary boundaries may be counterproductive, if you refer to the huge problems waiting to be solved!

Tony: Big words, seems as you get trained in science administration and science politics in your new post. (*She was recently appointed as professor of environmental science in an interdisciplinary centre of two faculties in charge of fostering environmental modelling initiatives of the university*.) But this was no answer to my question! Even if we exceed our discipline's boundaries, the starting point of your argumentation is much too vague. Why did complexity – or at least its perception – increase? Did it really increase? I really doubt. Of course the intensity and demand of ecosystem services increases, flows are faster and stocks reduced, but where are the changes in complexity?

Rebecca: Perhaps you're right: May be one could argue that the complexity of environmental systems is more or less constant. But note, our understanding changes.[4] The more we deepen our understanding of the interacting processes the more we learn about influencing the environmental system. For instance, changing policies on subsidies in Europe leads to consequences for production system in Central Africa,[5] and for sure global financial crises do have several consequences for the environmental states of many landscapes. Therefore, we need to cope with global off-site effects as well as a lot of unspecified trade-offs.[6]

Tony: Hey, come on, you are talking about global policies! Next you'll remind me that by drinking this espresso I do import virtual water from countries that suffer from water scarcity.[7] This way you can convince your dean or ask for funding at an agency. I'm interested in scientific hypothesis and specific examples. Give me one specific example for the need of modelling in landscape ecology, for answering ecological questions and for solving environmental problems?

Rebecca: I think its not too difficult making the connection between modelling and what you said is "global politics". What I tried to exemplify is that these are processes we neither consider yet in our analysis nor in our models. We know a lot about ecosystem functioning as well as the decrease of biodiversity, however what influence has biodiversity to ecosystem functioning?[8] This is an important research issue, and one of the most complex topics at all, as it integrates biotic issues and abiotic processes as well as their drivers defined by climate change, human influence, etc. And if you broaden the view: still little is known about the dependency of landscape features from demographic development, migration and the related land use dynamics, we still need to learn a lot about the pressures to the environmental system and their effects on the provision of ecosystem services.[9] You see, there are many complex problems which have to be solved. And these problems do not stop at any landscape unit's borderline.

Tony, turning around to her and unintentionally skewed all students flyers form the table: Indeed there are those problems, and indeed we should hurry up to find solutions! And what do you guys do? Create more and more simulation models. I read in the journal Ecological Modelling[10] that "we have produced an enormous redundancy". Hey, what for? Is that your solution to the global crisis? *He stood up and started collecting all the papers*. And besides this, I do see another deficit in putting together all those different methodological approaches and concepts, not only between for example landscape ecology and systems theory. Also within systems theory itself there are different paradigms of modelling. Do we need that confusion?

Rebecca helping him pickup up the papers: Yes and no! On the one hand we have many different problems and therefore different modelling solutions can be suitable in different cases. On the other hand, you are perfectly right. There is not much to be found about model integration.[11] Anyhow, there are a lot of limitations and there are constraints of the modelling aspect, for instance start a discussion on uncertainty involved in ecological models.[12] Or just look at the questions of validation and verification.[13] Or, think about the question of integrating different model structures[14] or remember the lost optimism concerning models of whole ecosystems or take a view on the debate of the real potential of models for predictions, projections or forecasts. . . But to be honest, no, I don't have a general 3-sentence answer to your question.

Tony piling all the flyers on the table and empting his espresso: So, OK, how can we cope with your increasing complexity if your models are producing such a high amount of uncertainty? We cannot put a landscape into the lab, can we? I would recommend doing the following (*he started looking for something in his pockets*): What we need are really good tools to collect all necessary information. And before all this we need empirical data, data and data. . . We have to work in the fields! For example, initiatives on integrated monitoring of environmental processes recently started.[15] Maybe this helps because most frequently we do not have sufficient data, or we get overwhelmed from all the data obtained from remote sensing. We need suitable software tools like GIS to compile and analyse our spatial data. (*He found a pencil in his pocket and looked for an empty sheet of paper*.) I remember that you told us yesterday that modelling can be a tool for structuring and solving all these tasks (*. . .finally found one, turning around and flung the espresso cup from the table*). However, you came up with more and more complex systems, the number of model equations was increasing progressively and finally you showed us all the limits of simulations by quoting a simple example on Lotka-Volterra dynamics.[16] So, how can that approach be helpful? (*Sadly looking at the broken espresso cup on the floor*.)

[1] Ben-David et al. (1998), Phillips et al. (1999), Fath and Patten (2000), Nakano and Murakami (2001), Ernoult et al. (2003), Ricotta (2005), Schröder and Seppelt (2006), Araújo and Luoto (2007).
[2] Daschkeit (2000).
[3] Wu and Hobbs (2002), Schönthaler et al. (2003), Müller and Li (2004), Turner et al. (2007), Naidoo et al. (2008).
[4] Allen and Hoekstra (1992).
[5] Scharlemann and Laurance (2008).
[6] Millennium Ecosystem Assessment (2005).
[7] Pearce (2006).
[8] Schulze and Mooney (1993), Hooper et al. (2005), Fischer et al. (2006), Bracken et al. (2008).
[9] Steffan-Dewenter et al. (2007).
[10] Müller (1997).
[11] Jørgensen and Bendoricchio (2001), Seppelt (2003).
[12] Beven and Freer (2001), Jager et al. (2005), Dormann et al. (2008), Cressie et al. (2009), Schulz et al. (2006).
[13] Oreskes et al. (1994), Gardner and Urban (2003).
[14] Schröder et al. (2008).
[15] Biodiversity Exploratories <http://www.biodiversity-exploratories.de/>, LTER <http://www.lternet.edu/>, TERENO <http://www.tereno.net/>, NEON, Committee on the National Ecological Observatory Network (2003).
[16] Seppelt and Richter (2005).

Rebecca (*helping him collecting the broken pieces*): Yes, there are restrictions. However, I believe the core idea is excellent. A systems approach helps to cope with complexity, to reduce complexity[17] in a correct way. This is why there are that many meanings of "region" or "landscape": we just ask what the system of interest is and which processes are interlinked in this system.[18] And again, modelling, simulation and system analysis are of course interdisciplinary fields of research.[19] However, it has a proven base in systems theory[20] and this is what environmental research needs to make use of.[21]

Tony: Thus you vote for using systems science and math as a general language and as the methodology for integrating different disciplines. Sounds nice but I feel that there are multiple conceptual and methodological problems arising from this concept. How do you maintain communication in such interdisciplinary teams? Do they understand your complicated math or heaps of rules?[22] Even yesterday just a few could follow your entire lecture... (*A group of people entered the cafeteria, loudly laughing and joking, probably students that finished a seminar.*)

Rebecca gazing at the students: ...Ah what? Sorry was it really to difficult yesterday? As I mentioned yesterday the best way of tackling these problem is starting doing good education either in undergraduate or graduate classes or in Ph.D. programs. For solving present and upcoming environmental problems as well as for doing high standard research we need students that are able to understand mathematicians as well as ecologists. And this is possible only if they have joined their classes. It's a matter of organization, of organizing curricula and organizing projects. You can learn this. We have to learn this. At this point you are perfectly right. I would very much appreciate to see an international network of education for master and Ph.D. training.

Tony sketching something on the empty sheet of paper: OK this might be one part of the story. Let's get back to the applicability of system theory. I see that a systemic approach might help us with the quantitative and integrated approaches. But what I see crucial is, how do you bring the required knowledge from these integrated systems together in a consistent way?

Rebecca: There are several very good examples for the similarity of methodologies and applications in different fields, e.g. agent-based models are used to analyse population dynamics and dispersal as well as the dynamics of urban/peri-urban traffic occurrence.[23] But these are specific examples. There are more concepts that have the ability to be general, interdisciplinary theories, e.g. understanding landscapes as hierarchies,[24] quantifying connectivity,[25] searching for interactions between scales[26] or general organizational principles.[27] You can investigate landscapes as gradients of patterns and processes[28] or you describe their dynamics on the base of orientors[29] or you can turn to thermodynamic interpretations, which have the potential to aggregate many levels-of-information.[30] There are many integrative ideas, however, here we are really just at the beginning, and we are starting to develop a respective theory. Have a look at your own field of research: landscape ecology.

Tony lost in his drawing on the sheet of paper, slowly answering: ... Again, could you give some examples from practitioners? Who did pick up these results? To my understanding landscape ecology is much more problem oriented...Hmm, perhaps landscape research could benefit from incorporating more knowledge from you math folks, but... I'm not convinced yet. You know, landscape ecology protagonists claim to be integrative, but get stuck in philosophical discussions on its aims and objectives! I didn't spend much time in following all these discussions, but this is what I remember: Some people argue the major question of landscape ecology is studying pattern–process interactions.[31] Others[32] say there are a multitude of interpretations of this pattern–process-paradigm that may have caused different developments of U.S. and, e.g. European research approaches of landscape ecology. Some people say landscape ecology is necessarily interdisciplinary[33]—or more rigorously they promote trans- or multi-disciplinarity[34] as a conditio sine qua non of landscape ecology.

Rebecca: ...and others suggest landscape ecology being an advanced form of gardening! (*Both laughing*) This was a good summary of the landscape ecologist's ivory tower.[35] You have a pragmatic way to deal with it, do you? You just conduct excellent interdisciplinary research projects, always aiming at providing practical guidelines and answers to practitioners. Thus probably we could agree on the following: To cope with this diversity of meanings, let me first of all ask: is the definition of "landscape" really a prerequisite for the definition of landscape ecology? There are many scientists who would agree on this.[36] But I feel this is a scholastic question. Of course, seeking exact definitions is of importance for applying science theory to our discipline. But my fear is that these discussions detract from urgent, important and much more challenging research needs. Look, there are projects studying biodiversity and ecosystem functioning as a function of landscape structure resulting in papers that relate landscape structure on different scales to species movement[37] or species distribution.[38] This is what species distribution models and population dynamic models tell you.[39] Looking at studies[40] related to the EU Water Framework Directive (2000/60/EC),[41] the landscape is a river basin characterized by its land use and related anthropogenic impacts on waters. Other landscape scientists concentrate on energy or matter flows and storages in a certain area,[42] or they investigate disturbance regimes influencing landscape pattern.[43] In all these cases everyone has her/his own, very distinctive idea of "landscape", or let's say of her/his object of interest, which definitely should imply ecological problems and a spatiotemporal scale such as extent or grain. *She smiled at him zealously*.

[17] Wu (1999).
[18] Jørgensen (1988), Seppelt (2003), Wainwright (2004).
[19] Costanza et al. (1993), Seppelt (2003).
[20] Jørgensen (2000a,b), Jørgensen and Müller (2000).
[21] Naveh and Liebermann (1994), Schröder and Seppelt (2006), Jørgensen et al. (2007).
[22] Grimm et al. (2006).
[23] Grimm (1999), Batty et al. (2003), Topping et al. (2003), Waddell (2002).
[24] Allen and Starr (1982), O'Neill et al. (1986, 1989).
[25] Keitt et al. (1997), Tischendorf and Fahrig (2000), Chase and Ryberg (2004), Okin et al. (2009).
[26] Wiens (1989, 1999), Peters et al. (1998), Enquist et al. (2003), Seppelt and Voinov (2003).
[27] Rietkerk et al. (2004), Alados et al. (2007), Schymanski et al. (2008).
[28] Müller (2000), Wagner and Fortin (2005).
[29] Müller and Fath (1998), Jørgensen and Müller (2000).
[30] Jørgensen et al. (2007).
[31] See for instance, Forman and Godron (1986), O'Neill et al. (1992), Turner and O'Neill (2001), Ward et al. (2002), and still emphasized at the end of the conclusions section in Turner (2005a,b).
[32] Steinhardt and Volk (2003).
[33] Wu (2006, 2008).
[34] Naveh and Liebermann (1994).
[35] Milne et al. (2009).
[36] See Bastian and Steinhardt (2002) and references therein.
[37] Bowne et al. (1999), Danielson and Hubbard (2000).
[38] Patten (1992), Steffan-Dewenter et al. (2002), Söndgerath and Schröder (2002), Wintle et al. (2005).
[39] Guisan and Zimmermann (2000), Guisan and Thuiller (2005).
[40] For example, Donohue et al. (2005), Volk et al. (2009).
[41] EU, 2000. 2000/60/EC, EU Water Framework Directive. Official Journal (OJ L 327). European Parliament, Bruxelles.
[42] Mosimann (1984), Leser (1997), Müller (1998), Burke et al. (2002), Kuusemets and Mander (2002).
[43] Coffin and Lauenroth (1989), Turner et al. (1993), Haydon et al. (2000), Cousins et al. (2003), Zurlini et al. (2007).

Tony: Yes I do agree entirely. We have to. We should define it in a pragmatic way, like: "A landscape is an area that is spatially heterogeneous in at least one factor of interest."[44] May I kindly remind you that this is nothing really new and not that surprising. Wu and Hobbs focus on ". . .the science and art of studying and influencing the relationship between spatial pattern and ecological processes across hierarchical levels of biological organization and different scales in space and time."[45] But not to forget, there is a history of landscape research and there is an "endemic" landscape theory. If you look at the ideas of Troll, Neef, Haase, Leser, Haber, Forman, Urban, Turner and many others,[46] you will see that many of these theoretical ideas have been growing directly from the landscape aspect.[47] The integration with systems theory has started later. So do not worry too much about this point, there are rarely good intrinsic theories in that field of research.

Rebecca stirring in her undamaged but empty espresso cup: A good summary of the accepted theoretical background! Even if, we need to select and collect the relevant, hmm say. . . first principles from all related disciplines, such as ecology, biology, physics, hydrology, etc., there may be difficulties due to the original methodological requirements which sometimes can hardly be fulfilled, but in many cases the causalities are obvious and parallels can be formulated whenever you check the basic requirements of the theories. Look at what ecologists have made out of thermodynamics, network theory or information theory.[48] It works fine and the results are very interesting, provoking many landscape oriented questions. But referring to all this knowledge in interdisciplinary oriented landscape ecology, how do you put this into a usable box or better tool-box providing assistance to real world problem? (*Pointing at Tony with the spoon.*) Any answers? I would say, this is where modelling and simulation comes into place being the ideal framework!

Tony: Maybe, but these ideas are still far away from application, for instance in integrated assessments with a landscape or regional focus. But, how can modelling precisely help besides the systems approach? Did models really take up results from all those knowledge bases? I doubt! Are there any good examples for system approaches including integrated modelling?

Rebecca: You can find them whenever environmental processes are observed from a spatial point of view, whenever local distributions and configuration of ecosystem components are investigated. We may even go further and ask for one example of ecological interactions which is not dependent on location or space—that will be hard to find. Thus, there are lots of examples from ecology itself, meta-population biology, vegetation science, conservation biology, biogeography, hydrology, soil science or environmental management, just to give some examples.[49] They all study the flow of substances, energy, species and/or information through structured, spatially variable regions, use the concepts of connectivity, work with GIS, graph theory and spatial statistics, and try to analyse the causes and effects of spatial pattern on their response variables. You see, the world is full of such examples.

Tony: Good to see that you are happy, but up to now you have not really solved any of our problems: None of your examples tackled human–environment interactions. At least in an urban–rural landscape one should have to cope with both questions of urban land development[50] and urban ecology[51] (*smiling at her and further sketching something on this sheet of paper*).

Rebecca: You're right, no need to emphasize that mankind modifies ecosystems faster than ever and thus by far the largest amount of science that deals with environmental issues needs to cope with anthropogenic influences.[52] By this the differentiation between basic and applied research questions diminishes. Whom do I tell all this? The more crucial question is: How do we incorporate or integrate quantitative approaches of landscape ecology with qualitative knowledge on the decision making of and human behaviour?[53]

Tony breaking the tip of his pencil: Trying to answer my question with a question, hey? You as a modeller treat this much too difficult! My suggestion would be to seek for appropriate indicators that support identification of certain trends, demands, surpluses of environmental goods and services. Indicators, if properly developed, mapped and calculated together with scenario analysis, do help providing support for decision makers. At least this is my experience. This of course can go along with the development of models that support these aggregated indicators. But including human in modelling and simulation has turned out to be not very helpful for ecology, although there are so many problems. Ecological arguments and environmental problems have lost significance in the public. *He found a second pencil, continuing his drawing.*

Rebecca: True, but I'm still pretty sure: If mankind will continue drawing ecosystem goods and services from our environment in the same intensity as we do now, we'll face a 6th extinction and much more environmental problems that need to be solved more quickly.[54] This reminds me of a pretty scaring scientific documentary on ABC, called "Earth 2100"[55] which tells this story of this 6th extinction including mankind. Scenario development of any kind needs to incorporate anthroposphere and biosphere processes. No, we build the stock of knowledge that we'll need in the next years. Still badly funded, but still important.

Tony: Ah, concerning the future I have something for you, just a moment. He grabbed the laptop out of his backpack and started the database, opening a pdf-file of a Landscape Ecology paper and finally browsed to a figure in it. There was a meeting at one of the last IALE[56] conferences. Some of the big shots in landscape ecology met and discussed the top 10 research topics in landscape ecology. Jingle Wu and Richard Hobbs put this together into a perspective paper.[57] They identified many topics we have discussed before. Let me see, they put into a graph with the main axes "Methodology", "Application" and "Theory"... hmm. And these are their topics: ecological flows in landscape mosaics, causes, processes and consequences of land use and land cover change, nonlinear dynamics and landscape complexity, scaling, methodological development, relating landscape metrics to ecological processes, integrating humans and their activities into landscape ecology, optimization of landscape patterns, landscape conservation and sustainability, and data acquisition and accuracy assessment. That's quite to point, although very methodological and theoretical. How could you as a modeller support this research agenda?

[44] Turner and O'Neill (2001).
[45] Wu and Hobbs (2007, chapter 15).
[46] Troll (1950), Neef (1967, 1969), Haase (1978), Leser (1997), Haber (2004), Forman and Godron (1986), Forman (1995), Urban et al. (1987), Turner (1989), O'Neill et al. (1992).
[47] Bastian and Steinhardt (2002) provide a summary of the above quoted references (no. 45) that are mostly in German.
[48] Jørgensen (2000a,b), Ulanowicz (2000), Fath and Patten (2000), Hari and Müller (2000).
[49] For example, Levin (1992), Wiens et al. (1995), van der Maarel (1996), Poff (1997), Ward et al. (1999), de Blois et al. (2002), Pinay et al. (2002), Watson (2002), Wiens (2002), Wolanski et al. (2004), Coulston and Riitters (2005), Sivapalan (2005), Wiegand et al. (1999, 2005).
[50] Waddell (2002), Breuste (2004); Couch et al. (2005).
[51] Pickett et al. (2004).
[52] Müller and Li (2004).
[53] Lawrence (2004), Lawrence and Deprés (2004), Gunderson and Holling (2002).
[54] Millennium Ecosystem Assessment (2003).
[55] http://earth2100.tv/.
[56] International Association of Landscape Ecology.
[57] Wu and Hobbs (2002).

Rebecca: Don't you see: All these topics can be investigated by modelling, and you quoted that complexity is on the agenda. Where is the problem?

Tony: Give me an example.

Rebecca: All right, let us for instance take "scaling": This was and is still a hot topic. But there are developments. My understanding of this problem is that there are several descriptive investigations, mostly studying these log–log relationships of space and patterns of interest,[58] second there are empirical approaches that aim at processes and their respected patterns and the interrelation with scales.[59] These make use of very good empirical and expert knowledge using simulation models on different scales with different realization of the process of interest and compare the results to obtain some general pattern, as far as I know there are examples for species abundance,[60] landscape pattern and land use[61] as well as abiotic processes[62] and even for integrated agricultural systems[63]... By the way, do you listen? You are scanning your literature database, aren't you?

Tony (*looking up from his screen*): Hmm, OK look here ... "Integrating humans into landscape ecology"? This is what we discussed! And this actually does support my plea for developing reliable data based indicators. The Millennium Assessment (MA)[64] offers a concept of bridging the gap between biophysical models and the socio-economic system—it is actually pretty similar to what we know from ecosystem functioning and the multi-functionality concept,[65] and by this MA offers a connection to ecological economics,[66] if we achieve a concise methodology to derive values of the ecosystem services. But nevertheless, what we need is a concise representation of the biophysical system.

Rebecca: Yes and the approach is to use physically based models, so called "white box models"[67] that are used to study processes on different scales aiming at deriving effective parameters and based on this come up with simplified model structures.[68] Here is another one for you: if you search for "optimization" and "landscape pattern" in your database you'll find a list with very interesting papers that use optimization techniques to estimate optimum configuration of land use pattern that may be related to certain ecosystem services.[69] They use simulation models for describing the processes of interest and provide landscape patterns that are optimal with respect to a certain optimization criterion. By this, these guys not only work on the topic of optimization of landscape pattern they are also able to relate patterns and ecosystem functioning. However, related to the last topic, there is a bunch of other papers.[70]

Tony: So you mean modelling provides us with a virtual landscape lab for conducting numerical experiments?[71]

Rebecca: Yes, very ambiguous, probably nothing really new, but nowhere really finalized or even implemented! Bits and pieces, or – lets be more positive – smaller and larger parts of this large puzzle exist.[72] These pieces are mostly focused on specific problems and do not study interactions of a large bandwidth of environmental processes and thus cope with the issue of integration and these mostly not founded on physically based approaches.

I guess, our dream would be to start with a fully integrated but still very simple model covering the important processes of the considered problem, for instance hydrological processes scale-independent and physically based, but with the appropriate complexity in its model structure, e.g. a simplification or aggregation of complex systems based on first principle equations needs to be identified.[73] There is a multitude of questions and problems to be tackled: pattern–process interaction, scenario based land use cover change, changing species distribution, effects on ecosystem functioning and resilience, etc. But, the best way of proceeding seems to be following a simple constructive approach: Complexity of integrated models should be increased successively and slowly by adding processes and functions or sub-models according to the questions tackled and the data available. In doing so you will identify answers, not only to the given problem but also to these methodological questions related strong or weak interdependences; what makes the recent problems really complex; are there general methodologies to simplify or aggregate our process knowledge; what are dominant structures; what is the most simple but also most valuable approach for simulating a process? Providing knowledge and methodologies and following a constructive approach like this one can answer these questions more generally and would be a really helpful toolset for our computational landscape ecology.

Tony: Where is the relationship between this virtual lab and the real world?

Rebecca: Hey, this virtual lab was your suggestion—and I really like it. I would suggest—four answers to this question. First, you can study virtual landscapes within a virtual lab. This is something that is well known in ecological modelling[74] but probably rarely used in landscape science. Second, based on several projects we should apply real data to such a system for testing our theoretical approaches. Third, based on this, one can develop scenarios and put them into narrative stories that again can be used to transfer the knowledge to stakeholders (and vice versa). And finally such a virtual lab can provide the information for efficient strategic monitoring programmes and new observation tools.[75] It could even be combined with educational incentives!

Tony: This seems to be a really nice research agenda. But, I'm still afraid that this all might be useless, if we are not able to achieve involving practitioners, users, actually the guys that raise all the questions during the procedure at the very beginning. We have both seen that neither sophisticated modelling nor theoretical consideration on landscape ecology finds an audience outside science. Thus, I guess from a methodological point of view, you're perfectly right. But, my plea still is: let us consider the real world problems beforehand. It could make our job more complicated, or the other way round so simple that it lacks scientific challenge. But at the end of the day, you never know what rocket science is hidden in a real world problem.

Rebecca: That's a good summary. I don't want to be asked to write a perspective paper on this. And if so, I'll do this in a similar

[58] Delcourt and Delcourt (1988), Schneider (2001).
[59] Peters et al. (2007), Schooley and Branch (2007).
[60] Crawley and Harral (2001), Holland and Fahrig (2004).
[61] Seppelt and Voinov (2003), Holzkämper and Seppelt (2007).
[62] Steinhardt and Volk (2003).
[63] Dalgaard et al. (2003), van Ittersum et al. (2008), Bierkens et al. (2000).
[64] Millennium Ecosystem Assessment (2003).
[65] Helming and Wiggering (2003).
[66] Costanza et al. (1997), Boumans and Costanza (2002).
[67] Richter et al. (2002), Neef (1967).
[68] Schulz et al. (2006), Pagel et al. (2008).
[69] Bevers and Hof (1999), Seppelt and Voinov (2002, 2003), Holzkämper and Seppelt (2007), Ben Alaya et al. (2003), Haurie (2003).
[70] For example, Mladenoff et al. (1993), Loreau (2000), Poole (2002), Tscharntke et al. (2005).
[71] Peck (2004), Weiler and McDonnell (2004), Schröder and Seppelt (2006), Zurell et al. (2009).
[72] Kurz et al. (2000), Li et al. (2000), Mouillot et al. (2001), Costanza and Voinov (2003), Schröder et al. (2008).
[73] For example, Schulz et al. (2006), Boumans and Costanza (2002).
[74] Berger and Wagner (1999), Tyre et al. (2001), Wiegand et al. (2003), Reineking and Schröder (2006), Dormann et al. (2007), Zurell et al. (2009).
[75] Newham et al. (2006).

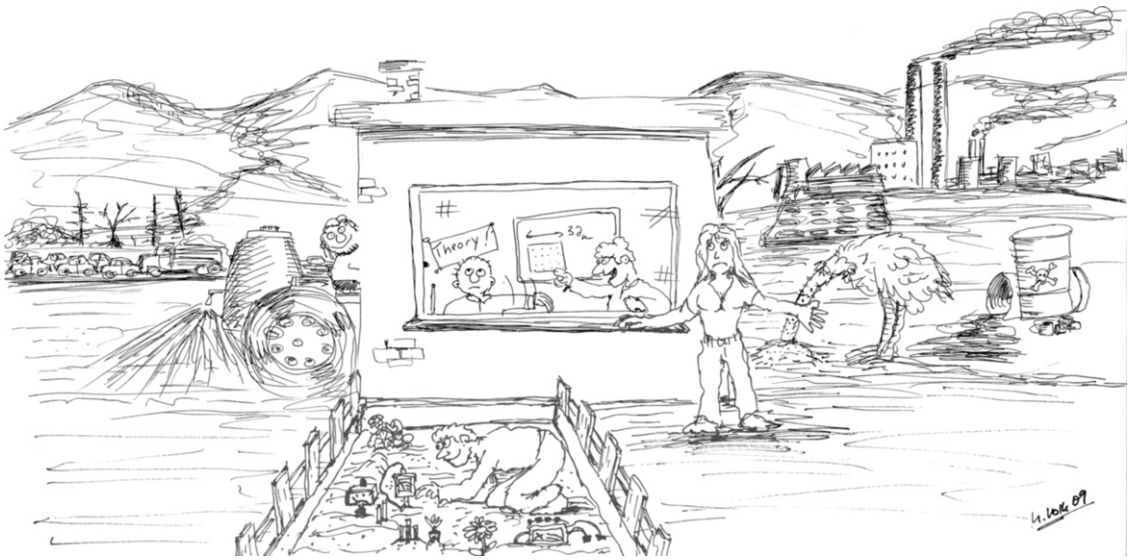

Fig. 1. Tony's way of taking minutes of the discussion: The kiosk of the ivory tower with environmental modellers hopefully producing something useful for their surrounding.

manner like August et al. did in AIR.[76] Or we can simply publish the minutes of our talk today.

Tony: OK, and what are your specific plans now?

Rebecca (*smiling*): What about another espresso? Turning to the coffee bar and asking for two espresso. She recognized that the fog outside was gone. The windows reveal the landscape with river Limmat, the lake and Zurich town centre . . . a picturesque scenery.

Tony turned around the figure he sketched during the discussion and moves it to her waiting for her reaction, c.f. Fig. 1.

Rebecca: Hmm, this could be an interesting piece of work in a scientific journal!

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Names of this dialogue are hypothetical; any similarity to living persons is truly unintended. This discussion has never taken place, albeit the location at the Swiss Federal Institute of Technology Zurich is real. All who know the place might agree that this environment would stimulate such discussions. At least it brought up the idea of writing such a paper.

Any similarity to the former publication by Galileo (1632) is intended as well as a possible association to the reasons why Galileo wrote his scientific paper in the way he did it. However, a dialogue of two contrasting opinions – here on the further development of environmental modelling – seems to be a valuable format to illustrate the different view points in recent research. And, as in real life, both parties have their stronger and weaker arguments and nobody at the end can claim the truth. This however, is the most important difference to Galileo (1632). The work was partly funded by the Helmholtz Programme "Terrestrial Environmental Research" (Seppelt et al., 2009).

[76] August et al. (1993).

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