Formalizing conceptual modeling: An application to Orchard Meadows in Baden- Württemberg

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Formalizing conceptual modeling: An application to Orchard Meadows in Baden-Württemberg

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Abstract: Conceptual modeling is a decisive stage in any modeling process, but especially relevant for the analysis of complex, large systems. Here, researchers must filter out those processes that appear relevant, even before specific research questions can be posed. For this step of conceptual model reduction, we propose an explicit framework.

Our research project assessed causes for biodiversity loss in German orchard meadows. A large conceptual model was assembled using literature review and expert interviews, creating an excessively large model. Then, two different approaches were applied to simplify this model and identify policy intervention points. Both approaches yielded different cause-effect explanations and pointed to very different research questions and intervention points. We found that combining an actor-centred approach with a macro-perspective greatly improved the relevance of our conceptual model with respect to policy advice.

***Keywords**: Conceptual modelling, model reduction, Orchard Meadows, biodiversity*

1 INTRODUCTION

Conceptual model reduction is a step within every modelling process that synthesises which cause and effect linkages are relevant from all potential linkages postulated for a particular research topic. Researchers may perform model reduction using explicit rules and procedures. Alternatively, this step may be an implicit component of model building, based on an individual's expert judgement or on the combined "wisdom" of a group, e.g. in a facilitated group modelling session. Regardless, the synthesized conceptual model then becomes the assessment framework that defines scientific research questions, the selection of future research partners, and the range of policy options that are considered further.

Any model synthesized using implicit model reduction reflects the paradigm of those whose perspective is represented, and we have no indication to which extent this paradigmatic filter is reproducible independently. Scientific quality control mechanisms can verify that research questions were well-posed and answered by applying sound methodology in a proper manner. However, the earlier step of reducing a large but uncertain conceptual model creates a paradigmatic filter that determines which research questions are actually posed, based on the prevalent perspectives and values [Funtowitz 2006]. Participatory design and group modelling techniques are preferred methods to minimize this bias [Pahl-Wostl et al., 2007].

We demonstrate the impact of this paradigmatic filter, as encountered during a small research project that identified drivers of biodiversity loss in orchard meadows ("Streuobstwiesen"). Orchard meadows are traditional agricultural systems in central Europe that became islands of biodiversity within a densely urbanized landscape and supported the food security of communities for hundreds of years. To understand the decline of orchard meadows in the German state of Baden-

Wuerttemberg, we developed a conceptual model that provides a consistent explanation for the rise of the orchard meadow food system in the past, when contextual factors and public policies drove a self-enforcing feedback mechanism that increased the extent of orchard meadows. The model also explains the current situation in which the self-enforcing feedback mechanism has flipped and is now causing the decline of orchard meadows. In addition, the model places successful contemporary renewal initiatives into a larger perspective, identifying leverage points for policy interventions [Hammel and Arnold, in review].

Methodologically, causes and effects were gathered through literature review and expert interviews, creating a large and complex conceptual model of the rise, decline and renewal of orchard meadows. However, especially with the varied perspectives of the experts, this model became a “spaghetti diagram” with too many details and storylines to be of further use (Figure 1). Group modelling techniques were beyond the scope and funding of this study, so we were challenged to identify a non-biased method for this decisive modelling stage. In this paper, we present two framework-based approaches to model reduction and demonstrate that these significantly influence how research questions are posed.

1.1 Conceptual Modeling

Particularly in integrated environmental studies, where system boundaries are ambiguous, errors and omissions in the conceptual modeling stage can misguide research that builds upon it. Unfortunately, conceptual modeling usually occurs during early project stages, when knowledge of the system is at its weakest. Especially at this stage, the mental models of researchers are built on incomplete knowledge. These early system conceptualizations may not be reproducible, even though they impact the choice of research partners, research themes and paradigms [Jones et al 2011].
Conceptual modelling typically consists of seven steps:

1. Define project objective
2. Identify sources of relevant knowledge
3. Literature review
4. Selection of stakeholders or experts and facilitated pooling of knowledge [e.g. Szendimir et al 2008]
5. Integrate knowledge into a consistent ontology [Raymond et al 2010].
6. Create “Spaghetti diagram”: Translate integrated knowledge into a single and coherent conceptual model of causes and effects, without regard to the relevance of a cause-effect link and the overall model complexity
7. Model reduction/synthesis: A simplified model is extracted from the “spaghetti diagram” that meets the project objective meaningfully.

No formal approach for the last step of model reduction is common praxis in integrated modeling, but different options exist to reduce spaghetti diagrams. For example, the syndromes of global change were developed as a conceptual framework for the German Advisory Council on Global Change, defining “the most relevant aspects of the global dynamics closely related to the civilization-nature interface” [Schellnhuber 1997]. Each syndrome was characterized in a spaghetti diagram organized along disciplinary realms (e.g. population, bio-, pedo-, hydrosphere, psychosocial and organizational realm). Then, a “kernel” was extracted that captures a syndrome’s main vicious cycle, mainly using “expert analysis” and group discussions. While the approach allowed to quantify the intensity of each syndrome, it was criticized for its failure to identify policy options.

In recent years, stakeholder-based modeling projects rely on facilitated group discussions to translate knowledge into a “reasonably complex” conceptual model that becomes the basis for further research [Hare 2002, Pahl-Wostl et al 2007].

Such a process implicitly merges the creation of a "spaghetti diagram" (step 6), as integration of knowledge into one common conceptualization, and the reduction of this model to an appropriate level of complexity (step 7). However, group modeling must fulfill conditions to be successful: Experts are required to move into one room with sufficient time to establish trust and build a common understanding of terminology. Furthermore, group discussions are more difficult if experts possess different types of knowledge (e.g. formal and informal knowledge & education), experts live far from each other, the issue is contentious (e.g. different development paradigms), individuals carry emotional baggage or a lack of respect for each other (e.g. due to long-standing association with political parties), or communication abilities are disparate. To ensure unbiased outcomes, group discussions with distinguished experts ultimately require substantial funding for repeated group meetings and high-quality facilitation.

To improve project outcomes cost-effectively, practitioners have moved to a combination of approaches. For example, the "Roots of Change" project combined individual-based conceptualization with group discussions [ROC 2010]. Others promote analytical frameworks that highlight specific driving factors [Blaikie 1987, Stedman-Edwards 2000], an approach that was chosen for this project.

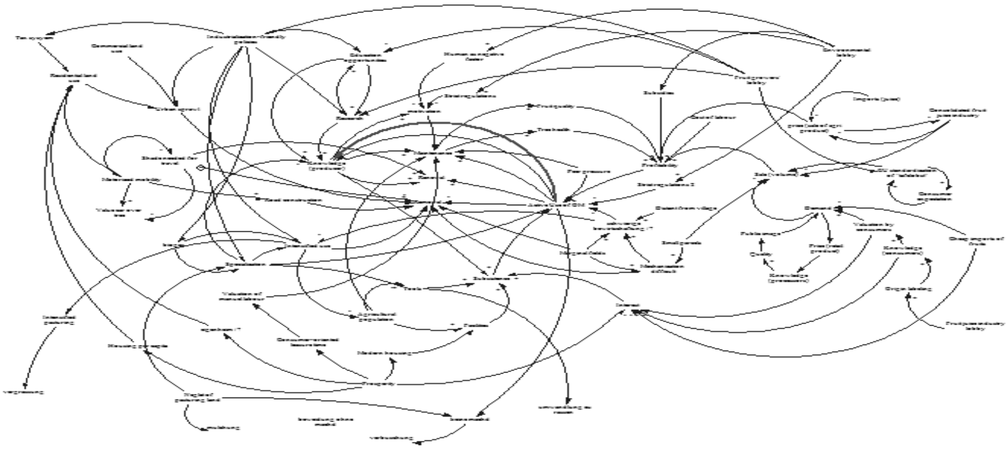

Figure 1 The "spaghetti diagram" captures all storylines described by the experts.

2 METHOD

2.1 Modeling procedure

An initial understanding and a preliminary model of macro dynamics was based on a literature review evaluated with the Root Causes Framework [Stedman-Edwards 2000], which links major socioeconomic trends to the decline of biodiversity. The Root Causes Framework involves four steps [Stedman-Edwards 2000]:

1. **Literature review and generation of cause effect hypotheses:** The literature review should be focused on the local situation while taking into consideration the national context and generally recognized causes of biodiversity loss. It should produce a set of hypotheses about the root causes of local biodiversity loss that identify possible drivers at the local, national and international scales.
2. **Initial formulation of conceptual model(s):** Taking the cause-effect chains identified in Step One, each link is refined specifying who, what, how, and why it occurs according to literature sources, noting information gaps.
3. **Data collection:** Local data is gathered to refine the initial model, and to fill information gaps.
4. **Revise and reduce the conceptual model:** With data, the initial conceptual model is refined and revised. The aim is to produce a model that will provide information about the causes of biodiversity loss, which is needed to develop strategies and policies to counter this loss.

After an initial literature research was performed and a set of initial models was formulated, fifteen experts on orchard meadow issues were interviewed. These experts included processors, extension workers, farmers, academic researchers, politicians, business people, and NGO activists. The interviews were carried out individually, rather than in a group setting. First, the resources to conduct a series of facilitated group modelling sessions were not available. Also, many disabling factors for group modelling were present: agricultural debates tend to be politicised and paradigmatic in nature, the formal education levels of our experts ranged from secondary school to university professor, and communication experience ranged from farmer, campaigner, entrepreneur, and academic, to professional politician. Thus, direct and structured interviews were chosen to gather additional information. The knowledge of interviewees was then integrated and incorporated into a large cause-effect model, creating the spaghetti diagram presented in Figure 1.

This “spaghetti diagram” was then reduced using two paradigmatic filters (see next section): (A) the chains of explanations framework of root causes analysis, and (B) the trends-actors-flows framework that combines the first with an agriecological perspective. These two paradigmatic frameworks resulted in different cause-effect models. We discuss how the reduced conceptual models impact potential research questions and potential points of intervention.

2.1 Model reduction frameworks

(A) Chains of explanation

Chains of explanation trace effects back to drivers, which are themselves the effects of deeper causes [Blaikie and Brookfield, 1987]. When applying this approach to biodiversity loss, the emphasis is on linking scales, from the local to the global, and the approach is based on the understanding that while biodiversity loss occurs at the local level, the drivers of biodiversity loss are often distant from the points of loss. Thus, chains of explanation start locally with the study subject and then move upwards and outwards to explain the influences shaping and limiting local action. While such an approach can be powerful in helping to understand the myriad forces shaping local actions, it has a few problems.

First, determining which variables must be included and at what scales is often difficult [Robbins 2007]. In the field of biodiversity loss, Stedman-Edwards [2000] presents a research framework of factors considered to be critical (compare [Olson et al 2004] for an alternative formulation of factors): macroeconomic policies & structures, poverty and inequality, public policies and regulations, markets and politics, demographic and societal change, and the development bias (Figure 2). A second problem is the difficulty in setting system boundaries and relevant scales, to limit the scope of analysis. Therefore, Stedman-Edwards suggests that a root cause be defined as a point at which successful intervention is feasible. This is in

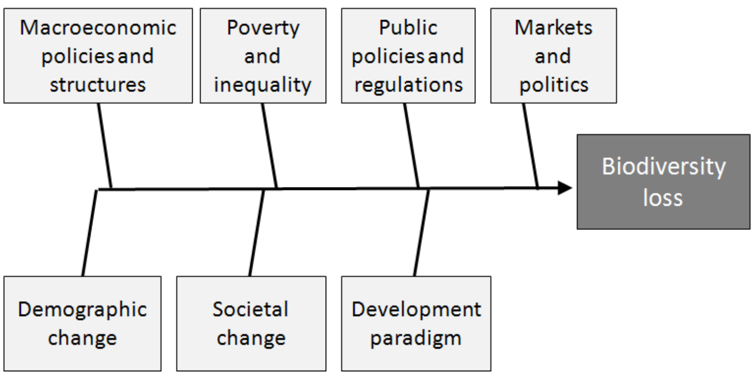

Figure 2 Chain of explanation diagram for root causes analysis (after Stedman-Edwards 2000)

contrast to contextual factors, which she defines as historical or physical facts that cannot be altered. Third, causes usually don't operate alone but in combination with other factors that may interact with each other [Stedman-Edwards 2000]. Finally, Robbins [2007] recognized that this approach tends to create a conceptual framework in which external forces are seen to drive the system from the outside, which may bias the analysis toward external drivers at the expense of internal factors. In this case, the potential intervention points identified tend to be both spatially and politically distant from the subject, and therefore not within the realm of action of local actors. Consequently, potential research questions are likely to focus on policy, international markets and trade.

(B) "Trends-actors-flows"

This second framework combines an the macroscopic approach of Stedman-Edwards and its power to elucidate symptoms, drivers and causes, with an actor-centered approach that seeks to understand the motivation that drives anindividual action. In our study of the loss of orchard meadows in southern Germany, Stedman-Edwards' major socioeconomic trends were complemented with the food systems perspective of agroecology (Figure 3). Francis et al [2003] describe actors and the context of their decision-making by tracing the flows of material, energy, values, and information throughout a food chain (production, processing, marketing, and the consumption of food and food products). The integrative framework generates a matrix of themes (demographic change, inequality/poverty /wealth, public policies, macroeconomic structures, social change) and actors (producers, processors, marketers, and consumers), through which the flows of materials, energy, values and information can be traced.

In such an analysis, the potential intervention points we identified focused on the interfaces between actors within the system, as well as the policies that limit the range of action of local actors or their motivations. As a result, potential research questions focused on how the flow of values, information, materials and energy shape the decision-making of actors within the system, on outcomes and their externalities.

3 RESULTS: TWO STORIES OF DECLINE

The knowledge of interviewees was integrated and incorporated into one large cause-effect model that captured all the interactions described by all the interviewees, which was neither useful for discussion nor analysis as it was simply overwhelming (Figure 1). Using the two model reduction frameworks, two different stories of orchard meadow decline emerged from the combined insights of the experts interviewed.

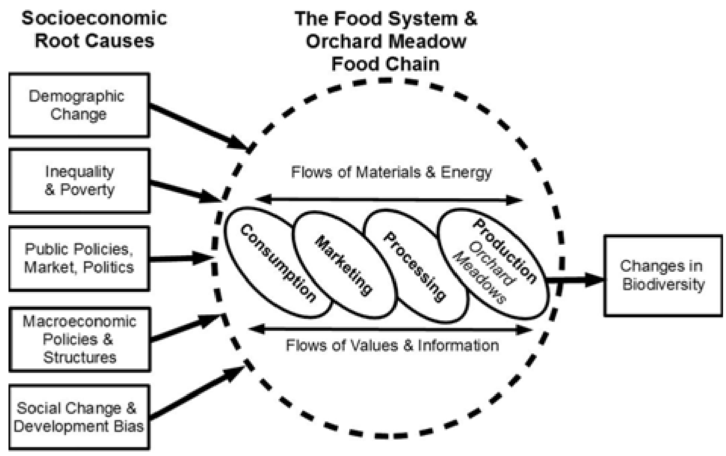

Figure 3 Schematic diagram of "trends-actors-flows" framework

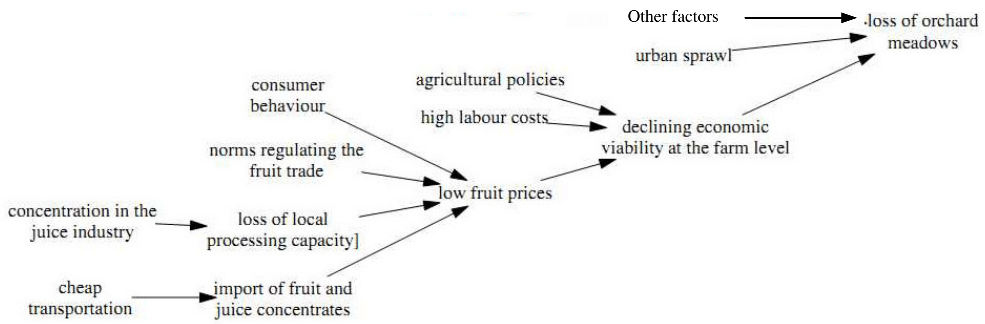

Figure 4 Chain of explanation of orchard decline (extract)

3.1 Economic progress and modernity make orchard meadows an obsolete production system

Using the chains of explanation approach, the story of orchard meadow decline emerged such that demographic change, prosperity, agriculture policies, international trade and a development bias toward the urban and industrial, all undermine the foundations of the orchard meadow food system. This happens all along the food chain, from production through to consumers. The system evolved over hundreds of years in response to the socio-economic conditions of those times and provided numerous ecological externalities, many of which are valued today. However, because times have changed, the system is inevitably obsolete and its positive environmental externalities will be lost or must be replaced through other means (see Figure 4).

Therefore, few potential intervention points exist for conserving orchard meadows as part of the food system. Instead, a 20th century approach to nature conservation is necessary and conservation efforts are directed toward parks and nature reserves for orchard meadows. The approach pointed to potential research questions that focus on the ecological functions of orchard meadows. For example, what specific ecological niches/habitats are present in orchard meadows, how can they be maintained without traditional use of the system, how many orchard meadows must be maintained in order to produce the desired ecological effect on a landscape scale, what would such protection measures cost, and are these worthwhile investments (cost-benefit analysis).

3.2 Decline and renewal driven by motivations and knowledge of core actors in the food chain

The trends-actors-flows framework emphasizes understanding the decision-making of actors within the orchard meadow system. Using such an approach, four sub-systems are identified: the orchard meadow as bio-physical system, the owners who harvest products, the processers who transform these products into marketable goods, and the consumers. Producers are linked to processors via a market and processors are linked to customers via a second market. Both producers and processors are motivated by market prices, as well as knowledge and values. Currently, a positive feedback of decline is active in which low yield and low-quality apple harvests lead to low-quality processed products and subsequently a poor public image. Along with other factors, this drives down the demand for processed orchard meadow products along with the price. In response, processing and the demand for raw products declines and therefore prices for fruits collapse, de-motivating producers to maintain their orchard meadows. Over the course of decades, the condition of orchard meadows degrades. Furthermore, knowledge of orchard meadow maintenance and the production of quality products are largely lost. At the same time, increasing prosperity and the availability of other products has resulted in the collapse of the subsistence use of the system: Even though many people still gather fruit from orchard meadows, there is currently no perceived need (motivation) to maintain or plant orchards (see Figure 5).

Notably, this model can also capture the mechanisms by which the development of orchard meadows was supported by government in the past and current examples of revival [Hammel and Arnold, in review]. This is in contrast to the previous model, which presented a linear model of decline that could not describe the system's development or cases of revival. This suggests that the former approach does not actually describe how the system operates, but rather is limited to describing the impact of external drivers on the system. This can be helpful, but it does not increase our understanding of the system itself.

Potential intervention points identified by the second method include the actors (throughout the food system), as well as the information/values/motivations that shape their decisions (markets, knowledge, skills); research, education and training institutions; and the policies governing agriculture and food. Potential research questions focus on how combinations of interventions, at various scales and acting on diverse intervention points, support or conflict with each other. Research may also identify success stories and analyze the intervention points they leverage, as well as the mechanisms that are employed, in order to test the conceptual model of the system and further conservation efforts.

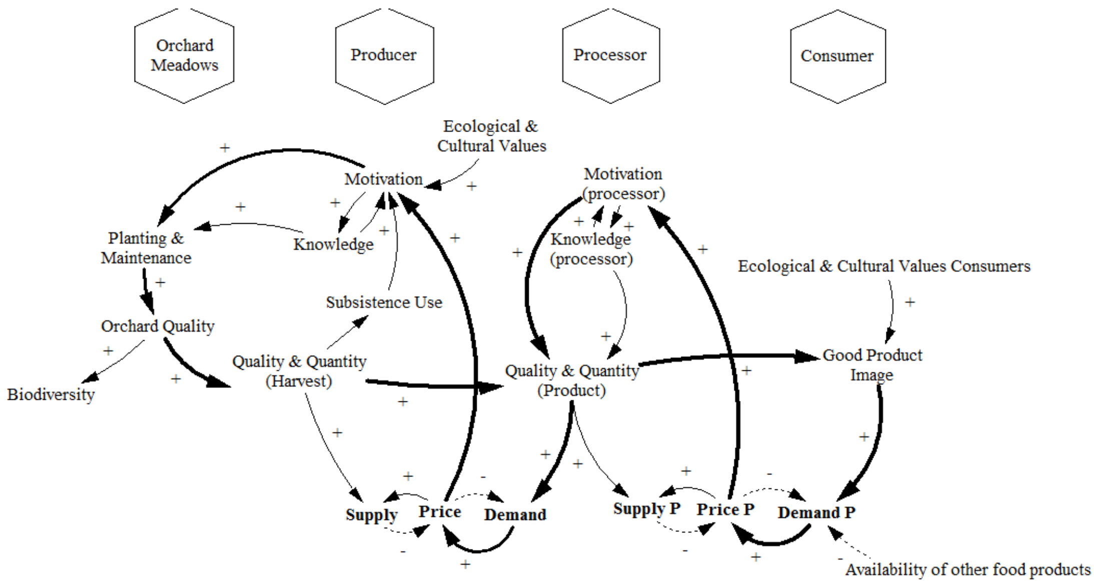

Figure 5 A conceptual model of the decline of orchard meadows, developed using the Trends-Actors-Flows framework

4 DISCUSSION AND CONCLUSION

We presented an excessively large conceptual model that is not useful for policy analysis or research. Next, the model was reduced using two frameworks. The simplified conceptual models vary in size and focus, but also in the intervention points they identify and the research questions they pose. Thus, conceptual model reduction is a decisive step and paradigmatic filter within an integrated research process. The assessment of complex systems, a focus on a sub-system or a particular paradigmatic filter may result in an early, unintended bias of research.

The "Trends-Actors-Flows" framework attempts to formalize the paradigmatic reduction of large conceptual models. Using literature and interviews of leading experts, system analysis is pursued through three perspectives: i) relevant socioeconomic trends, ii) actors involved, and iii) the flow of matter, energy, information, and values. This approach was found to be powerful at elucidating the internal functioning as well as the external drivers that govern a highly complex system. The approach can be applied if costly group modeling sessions are not feasible, but may also serve as preliminary study, or complementary to group modeling sessions.

We believe that formalized and explicit approaches for the reduction of conceptual models, such as the one suggested in this paper, have the potential to mitigate paradigmatic bias in complex systems research. We encourage further research in this vital step of conceptual modeling.

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