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Knowledge analysis in coupled social-ecological systems

What do stakeholders in sub Saharan Africa know about the dynamic complexity of climate change, agriculture and food security?

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Abstract

Climate change will lead to significant yield reductions in maize dominated farming systems in sub Saharan Africa. Agriculture in this region thus faces the challenge of undergoing considerable transformation in order to adapt to climate change and become more food secure. Stakeholders who are directly affected by the challenge to adapt to changing conditions, however, neither have an overview of existing adaptation options and their impacts, nor do they have sufficient knowledge for prioritizing and implementing these options. This paper proposes a methodology for evaluating stakeholders' knowledge of and learning in complex dynamic systems such as agri-food systems. This methodology emphasizes the analysis of how stakeholders affected by climate change and food insecurity perceive the current situation, how they acquire new knowledge in the course of a system dynamics-based intervention and how their existing knowledge hinders or contributes to the acquisition of new knowledge. In a pilot study, we apply this methodology to the case of agri-food systems in Zambia and we report data concerning farmers' conceptions about the challenges offered by climate change and the effectiveness of different policy options to meet these challenges. Our preliminary data indicates that adaptation seems to require a combination of science-based knowledge and traditional knowledge. Traditional ways of predicting hunger and climate define the need to respond and prepare, whereas science-based knowledge defines how to proceed, that is, the particular methods to use and how to go about them.

Introduction

Climate change will lead to significant yield reductions in maize dominated farming systems in sub Saharan Africa (Lobell et al., 2008). Agriculture in this region thus faces the challenge of undergoing a considerable transformation in order to meet the challenges of achieving food security and adapting to climate change. Adaptive practices are manifold and they can occur at multiple levels and at different scales. They range from technological developments and government policies to farm production practices, farm financial management as well as on and off farm diversification. A considerable body of research explores adaptive practices for food systems (reviewed e.g., in Below, Artner, Siebert, & Sieber, 2010; FAO, 2010; Easterling et al., 2007; Ngigi, 2009; Vermeulen et al., 2010).

Food systems are social-ecological systems that consist of biophysical and social factors which are linked through feedback mechanisms and thus display complexity (Berkes, Colding, & Folke, 2003; Ericksen, 2008b). As social-ecological systems are both complex and adaptive, they require stakeholders to continuously test, learn about, and develop knowledge and understanding in order to cope with change and uncertainty (Carpenter & Gunderson, 2001; Darnhofer, Bellon, Dedieu, & Milestad, 2010; Darnhofer, Fairweather, & Moller, 2010; Ericksen, 2008a; Folke, Hahn, Olsson, & Norberg, 2005).

This complexity makes it difficult for stakeholders affected by the challenge to adapt to changing conditions and to assess the short- and long-term impacts of adaptive practices. This is already the case for individual practices and even more so when practices need to be prioritized and combined into comprehensive adaptation and food security strategies. Knowledge acquisition in social-ecological systems is a dynamic learning process that requires institutional frameworks and social networks to be nested across several levels and scales (Berkes, et al., 2003; Cash et al., 2006; Gunderson & Holling, 2002). Stakeholders who interact with food systems on a daily basis and over long periods of time thus possess crucial knowledge of food system dynamics, together with associated management practices (Berkes, Colding, & Folke, 2000). The design, diffusion and implementation of effective adaptation and food security strategies may thus benefit from the combination of different knowledge types, that is, from intuitive or traditional knowledge to more science-based knowledge (McLain & Lee, 1996; Ludwig, Mangel, & Haddad, 2001; Mackinson & Nøttestad, 1998).

The diffusion of effective adaptation and food security strategies thus calls for a new generation of learning tools, applicable not just to educated Western professionals in complex industries, but also to target audiences with little or no scientific and formal education. A new generation of learning tools is particularly important because learning in complex dynamic systems such as climate change, agriculture, and food security is typically slow and hampered by the difficulty to assess the dynamic impact of policies (e.g., Moxnes, 2004; Sterman, 2008). One of the main goals of system dynamics is to improve decision-making in complex dynamic systems. Over the years, a variety of strategies have been proposed that aim at improving decision-making by supporting learning processes. Such strategies either focus on gaming-oriented simulations such as simulators and planning games (Maier & Größler, 2000), group model building (Vennix, 1996) or classroom teaching (Kunc, 2012; Saldarriaga, 2011; Sterman, 2010; Wheat, 2007).

Improving decision-making in, that is, learning about complex dynamic systems, involves restructuring of existing knowledge, integration of existing and science-based knowledge and not only adding new, science-based knowledge. Evaluating learning about complex dynamic systems thus requires investigating how intuitive knowledge changes and integrates with science-based ideas or expert knowledge (Brown & Clement, 1989; Clark, 2006; Clement, 1993; diSessa, 2007a; Duit, Roth, Komorek, & Wilbers, 2001; Masson & Vázquez-Abad, 2006; Parnafes, 2007). A recent review of studies assessing system dynamics-based learning tools, however, revealed that most studies either measure understanding and learning indirectly though performance or in terms of distance between novice and expert understanding (Kopainsky & Saldarriaga, 2012). They thus provide a benchmark for expert knowledge and give indications about the gap between novices and experts. However, they do not provide a theory for further investigating how this gap can be closed.

The purpose of this paper is to develop a framework for evaluating knowledge of and learning in coupled social-ecological systems. For this purpose we draw on work from system dynamics, social sciences, cognitive psychology and learning sciences research. These fields define four learning factors: performance, analytic strategies, self-reactive influences, and knowledge. In the remainder of this paper we give an overview of the four factors in the evaluation framework and describe the knowledge factor in more detail. We introduce the general principles and methods of knowledge analysis and then turn to the specific case of stakeholders' knowledge about the dynamic complexity of climate change, agriculture and food security in sub Saharan Africa. The paper presents results from a pilot study where we applied the framework with a small number of farmers in Zambia. We use insights from the pilot study to revise the evaluation framework and reflect on the implications for the design and assessment of system dynamics-based interventions in the field of dynamic decision-making in climate change, agriculture and food security.

Overall evaluation framework

The evaluation framework spans four learning factors: performance, analytic strategies, self-reactive influences, and knowledge. These factors are evaluated in four research stages that we call the exploratory stage, pre-intervention, teaching and post-intervention.

Factors of the evaluation framework

Figure 1 provides an overview of the factors of the evaluation framework. The decision to focus on these particular factors, namely performance, analytic strategies, self-reflective influences, and knowledge, is based on existing work from complex decision-making (Cervone, Jiwani, & Wood, 1991; Osman, 2010; Vollmeyer, Burns, & Holoyak, 1996), decision-making in climate change (Grothmann & Patt, 2005; Hansen, Marx, & Weber, 2004; Marx et al., 2007; O'Connor, Bord, & Fisher, 1999; Weber, 2010; Weber & Stern, 2011) and previous studies in system dynamics that build on cognitive psychology approaches (e.g., Cavaleri & Sterman, 1997; Doyle, Radzicki, & Trees, 2008; Groesser & Schaffernicht, 2012; Kopainsky, Pirnay-Dummer, & Alessi, 2012; Rouwette, Vennix, & Mullekom, 2002; Schaffernicht & Groesser, 2011) or learning science literature (e.g., Bakken, 1993; Larsson, 2009; Mulder, Lazonder, & de Jong, 2009; Saldarriaga, 2011).

To study the knowledge factor, we merge two fields of research coming from rather different disciplines: Traditional Ecological Knowledge (TEK) and Knowledge Analysis (KA) research. Together, these approaches define our theoretical and methodological stance. TEK research combines social and ecological perspectives to study local people's knowledge of their ecosystems and of the interface between humans and their environment. TEK is defined as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes, 2008: 7). This approach to studying human-environment systems assumes that traditional knowledge may be as valuable as scientific knowledge in the search for practices for adapting to climate change. As a consequence, adaptation efforts need to emphasize *integration* of scientific and TEK-based practices, rather than the *imposition* of scientific practices on local communities. The capacity to successfully adapt to change may require integrating external knowledge from agencies and researchers with locally generated knowledge (e.g., Gadgil, Olsson, Berkes, & Folke, 2003; Klubnikin, Annet, Cherkasova, Shishin, & Fotieva, 2000; Fernandez-Gimenez, 2000; Leonard, Parsons, Olawsky, & Kofod, 2013).

While recognizing the value of local knowledge of climate change and food security problems, we are also interested in *tracking* this knowledge as it changes during a system dynamics-based intervention. By tracking these changes, we hope to understand how system dynamics-based interventions can help local communities find effective adaptive practices, and how system dynamics knowledge integrates with local knowledge. Knowledge Analysis (KA) research combines cognitive psychology and learning sciences perspectives to study the structure of knowledge, the relationships among its components, and its change over time. To accomplish this, knowledge analysts identify meaningful units from a particular body of knowledge and develop descriptive theories of the content and change of these units based on external evidence such as learners' actions and speech (Parnafes, 2005).

KA has mainly being used to study the integration between people's intuitive knowledge of basic world-phenomena and scientific knowledge (e.g., Brown & Clement, 1989; Clark, 2006; Clement, 1993; diSessa, 2007a; Duit, et al., 2001; Masson & Vázquez-Abad, 2006; Parnafes, 2007). There is not a unique methodology to knowledge analysis. In general, the analysis consists of systematically coding people's utterances (explanations and actions) during an episode of inquiry or learning. These utterances are generally elicited during semi-structured clinical interviewing. According to Parnafes, (2005), two levels of analysis are involved in knowledge analysis: (1) a description of what happens during the episode, and (2) an explanation (e.g., explanatory theory) that accounts for why people act or reason in the ways they do. The elements of causal knowledge and readouts in the knowledge factor are our units of analysis. In what follows we explain how each factor is defined, and later, in the methodological section, we explain how we implement the KA approach to study the role that each of these factors plays in stakeholders' decision-making for adaptation.

Figure 1: Factors of analysis.

Performance	The outcome of stakeholders' decisions in terms of the gap between desired outcomes and those generated by the adaptive practices
Analytic strategies	
Adaptive practices	Practices (e.g., farming techniques) that stakeholders may choose among for coping with changes and uncertainty in climate, and for solving food security problems
Goals	The outcomes that stakeholders expect from particular adaptive practices, e.g., the effects that a farmer believes a particular technique will have on productivity
Self-reactive influences	
Risk perception	Stakeholders' perceptions of the likelihood of negative consequences from climate change to oneself and to society's food security
Perceived adaptive capacity	Stakeholders' perceptions of the likely effectiveness of particular adaptive practices for solving food security problems, and their ability to adopt such practices
Knowledge	
Readouts	Information attended to and used by stakeholders for predicting changes in their environment and adopting preventive or adaptive practices
Causal knowledge	Assumptions about cause-effect relationships used by stakeholders to interpret readout information and to further support their practices

Performance

Performance is a quantitative measurement of the outcome of stakeholders' decisions (practices), that is, of how well stakeholders solve a particular dynamic decision-making problem in a particular learning context (in our case, climate change, agriculture and food security).

The system dynamics literature describes numerous studies measuring performance in complex dynamic decision-making tasks (for an overview see e.g., Rouwette, Größler, & Vennix, 2004). Measurements of performance allow answering questions such as "How does people's performance change with system dynamics-based interventions?" "Does performance get better, worse or does it stay the same?" "Do particular interventions affect performance in different ways?"

Analytic strategies

This factor investigates why stakeholders choose particular *adaptive practices* for coping with changes and uncertainty in climate, and for solving food security problems. It emphasizes stakeholders' decision-making preferences that lead them to perform in the way they do. In addition to analyzing the content of practices, it is also important to know what stakeholders' think these practices can accomplish. We call these *goals*. Goals are indicators of the stakeholders' priorities. Farmers frequently have non-economic priorities and those priorities tend to differ from those of other stakeholders, e.g., decision makers or technical advisors (Hansen, et al., 2004)**.** Moreover, goals are indicators of stakeholders' ability to anticipate the effect of adaptive practices on the system's behavior. Improvement in the ability to make such predictions has been shown to be associated with knowledge revision and change (Osman, 2010). We group the components of adaptive practices and goals into analytic strategies (Cervone, et al., 1991) to emphasize that these components reflect stakeholders' inquiry efforts to make decisions.

Self-reactive influences

People's perceptions of the severity and importance of climate change has been shown not only to differ from those of experts (Weber, 2010), but also to be one of the main determinants of the motivation to take climate change adaptation actions (Grothmann & Patt, 2005). *Risk perception* has been found to account for behavioral intentions regarding climate change (O'Connor, et al., 1999). Thus, tracking risk perception is fundamental not only for understanding the particular conditions stakeholders perceive as more or less risky, but also to determine how particular teaching tools (or adaptive practices) change risk perception. Another self-reactive influence that affects decision-making is *perceived adaptive capacity:* stakeholders' belief in the effectiveness of particular adaptive practices to solve food security problems (Grothmann & Patt, 2005), and their ability to adopt such practices (Cervone, et al., 1991). Availability and access to resources do not always determine whether an adaptive action is taken; political, social, and cultural factors may limit stakeholders' willingness and ability to adapt. Perceived adaptive capacity is known to improve with learning: "Individuals with a strong sense of self-efficacy develop more effective strategies ...They learn more from feedback, respond more adaptively to the decision environment, and, over time, are better able to translate their learning into improved performance" (Cervone, et al., 1991: 259). We group the components of risk perception, and perceived adaptive capacity into self-reactive influences (Cervone, et al., 1991) to emphasize that these components reflect stakeholders' subjective motivations affecting decision-making.

Cognitive psychology extensively measures analytic strategies and self-reactive influences in controlled experiments. Such experiments can help answer questions such as "Why do people perform in a certain way?" "Why do people choose a particular adaptive practice over others?" "What competing practices do people contemplate before choosing one?" "What goals do people have in mind when choosing a practice?" "How does people's confidence in their capacity to control the system affect their performance?"

Knowledge

Finally, we have the group of components associated with stakeholders' knowledge resources. Knowledge is a key determinant of decision-making in climate change (Weber, 2010; Weber & Stern, 2011) independently of risk perceptions (O'Connor, et al., 1999). Despite its importance, not all stakeholders may have or obtain the necessary knowledge for decision-making. Scientific information about climate change do not always reach decision makers and the general public, and learning through personal experience is inefficient because it is difficult to detect and keep track of the slow and gradual modifications that characterize climate change (Weber, 2010). For the purpose of the current project, we conceptualize knowledge in two components: causal knowledge and readouts.

Causal knowledge is the knowledge of causes and effects related to climate change and food security. Causal knowledge is closely related to the concept of mental models used in system dynamics (e.g., Doyle & Ford, 1998; Schaffernicht & Groesser, 2011). The causal knowledge concept is less quantitative than that of mental models (which counts the number of pre-defined systems elements and the relationships between them) in that it focuses on studying stakeholders' beliefs in whatever form and level of aggregation they occur. The focus on conceptual beliefs as units of analysis for stakeholder knowledge has given learning research the opportunity to track the development of this knowledge during problem solving (McDermott, 1997; Sherin, 2001, 2006), conceptual change (Parnafes, 2005, 2010; Roschelle, 1991), and knowledge transfer (Brown & Clement, 1989; Clement, 1993; Duit, et al., 2001).

Readouts describe the information that people attend to for predicting changes in their environment. People's attention to particular information is influenced by general beliefs (content declarative knowledge) and causal knowledge of climate change. Furthermore, people's beliefs and causal knowledge influence people's selection and attention to information (Weber, 2010). Readouts work as rules-of-thumb to recognize changes and act on them. The rules-of-thumb require "a sensitivity to critical signs in the environment and an intuitive understanding of what they mean for the conduct of practical tasks" (Ingold & Kurttila, 2000: 192).

Ultimately, by studying these knowledge components, we hope to answer questions such as "What knowledge do stakeholders use to adopt a particular practice?" "What information do stakeholders use for making decisions?" "What knowledge affects stakeholders' preferences for particular practices over others?" "How does this knowledge change during a learning intervention?"

Other variables have been shown to be involved in decision-making in environmental issues such as demographic characteristics, age, gender and education. We focus on variables that can be affected through training (e.g., knowledge and risk perception) and use demographic characteristics and education as secondary variables for further analysis.

Research stages

The choice of the four research stages in our evaluation framework is motivated by our interest in investigating decision-making before any teaching intervention (the exploratory stage), during a dynamic decision-making task in the absence of a specific teaching intervention (the pre-intervention stage), during a teaching intervention for performing the decision-making task (the teaching stage), and after the teaching intervention (the post-intervention stage). Our purpose for collecting data at four different stages is to be able to track and describe particular changes in the learning factors and how these relate to specific features of the teaching intervention.

- Exploratory stage: The purpose of the exploratory stage is to gain a general understanding of stakeholders' initial analytic strategies, self-reactive influences and knowledge, in their natural decision-making environments. The data collected in this stage provides information about: stakeholders' existing beliefs on climate change, the consequences of these changes for food security, and current and desired adaptive practices.

- Pre-intervention: The purpose of the pre-intervention stage is to investigate stakeholders' initial performance in a dynamic decision-making task by measuring all learning factors (performance, analytic strategies, self-reactive influences and knowledge) in the absence of a specific teaching intervention. The data collected at this stage and in the exploratory stage should be used to determine *learning gaps* between stakeholders' existing and desired performance (defined in terms of gaps in analytic strategies and knowledge).
- Teaching: The purpose of the teaching stage is to help improve stakeholders' performance in decision-making on climate change, agriculture and food security by working on those particular learning factors that underlie performance in the decision-making task. Teaching should be designed based on the learning gaps identified in the previous stages.
- Post-intervention: The purpose of the post-intervention stage is to investigate, at multiple points in time, stakeholders' performance after teaching by measuring all learning factors (performance, analytic strategies, self-reactive influences and knowledge) in the presence of the teaching intervention.

Both quantitative and qualitative data will be collected throughout the four stages. Quantitative data will be based on measuring performance and administering questionnaires in the pre- and post-intervention stages. Quantitative data provides information on performance, analytic strategies and self-reactive influences. Qualitative data will be obtained using semi-structured interviews in all research stages and video recordings during the teaching stage. Qualitative data provides information on stakeholders' knowledge and further information on their analytic strategies and self-reactive influences.

Working with a comprehensive evaluation framework such as the one proposed in this paper has important implications for a research agenda. It implies the underlying assumption that the task of investigating knowledge and learning of climate change, agriculture and food security is extensive and must be done progressively and cumulatively. It also implies the need for multiple methodologies and learning to assess the validity of each methodology for answering different questions. No single methodology is likely to fit all questions. However, such a framework should not be considered a finished construct. Rather, it needs to be updated and refined progressively. In our first step, we thus focus on one research stage (the exploratory stage) and in that research stage specifically on the use of knowledge analysis to study the learning factors in our framework (Figure 1).

Exploratory stage: analysis of traditional knowledge and adaptive practices

The exploratory stage is fundamental for understanding the knowledge and information currently used by stakeholders to choose particular adaptive practices. In other words, we want to know how stakeholders *currently* make decisions on climate change, agriculture and food security issues in their usual decision-making environments.

Knowledge analysis is of central interest in the exploratory stage. Nevertheless, analytic strategies and self-reactive influences must also be considered. For example, in the exploratory stage, we are interested in investigating how knowledge is associated with decision-making. Specifically, we want to investigate whether and what particular perceptions of climate change, agriculture and food security are associated with specific adaptive practices. Also, we want to determine whether and how stakeholders differ in their knowledge and decision-making processes. By stakeholders we refer to decision makers in climate change, agriculture and food security on the national and regional level, researchers and change agents on different levels, and farmers.

The exploratory stage serves to address the research questions below. The questions build on the framework in Figure 1.

- What are stakeholders' perceptions and beliefs about: (a) Changes in climate affecting food security; and (b) what the causes of these changes are (i.e., what factors are involved and how do these factors contribute to the changes)?
- What are stakeholders' risk perception and perceived adaptive capacity?
- What are stakeholders' adaptive practices: (a) What do they think should be done (practices); and (b) how do they think these practices would work (i.e., how specifically they will affect/change food security)?
- What content declarative knowledge do stakeholders use in their decision-making process?
- Do particular stakeholders' perceptions, beliefs and prior knowledge (from the previous research questions) relate to specific adaptation preferences? This research question seeks to identify relation patterns between what stakeholders' know and their decision-making.
- Do particular stakeholders' self-reactive influences relate to specific policy choices? This research question seeks to identify relation patterns between stakeholders' perceptions of risk and adaptive capacity and their decision-making.

In the remainder of this section, we describe the procedure for answering these research questions. The main data collection method in the exploratory stage is interviewing, and more specifically the use of semi-structured clinical interviews (Clement, 2000; diSessa, 2007b; Ginsburg, 1997).

Methodological Guidelines: Interviewing

In qualitative research, interviews are used to answer questions where answers cannot be directly observed through stakeholders' behavior and/or where the potential answers (categories) are not known in advance. In cases where the categories are known, multiple-choice questionnaires using such categories as choices can be designed. In this paper, we report on the use of interviews to investigate stakeholders' perspectives (knowledge, risk perceptions, etc.) on climate change, agriculture and food security.

An interview is a one-to-one conversation between an interviewer and a stakeholder or a group of stakeholders. The aim of a semi-structured clinical interview is to allow the stakeholders to expose their "natural" way of thinking about a particular situation (diSessa, 2007b). Therefore, the role of the interviewer is to support inquiry, and to avoid exercising any judgment on the correctness or appropriateness of the stakeholder's thinking. The typical procedure of an interview consists of the interviewer posing a situation or task and encouraging the stakeholders to explore and express aloud their thinking about the situation. Interviews may involve the use of support tools such as pen and paper or computer interfaces designed to focus participants' attention and to provide a communication bridge between the interviewer and the person or persons being interviewed.

Most interviews are semi-structured. The interviewer usually has a set of predetermined situations or tasks, but particular questions may emerge during the interview according to the flow of the stakeholder's reasoning and the interviewer's understanding of this. For instance, noticing that a specific situation offers particular difficulties to the stakeholder, the interviewer may introduce variations of the situation to further understand and describe the stakeholder's reasoning. Any variation in questioning will depend on the purpose of the interview. The interviewer's constant focus on clarifying and further exploring the stakeholder's reasoning introduces an interpretative level in the interview itself. That is, during the interview, the interviewer is already analyzing the stakeholder's way of thinking and testing different hypothesis by asking clarification questions or slightly changing the situations under discussion. This differs from most common research methodologies in which performance is measured during an intervention and the resulting data is analyzed afterwards. Interviews are usually videotaped and later transcribed for further analysis or they are directly analyzed using qualitative software that allows video coding.

Semi-structured clinical interviews are often used in Traditional Ecological Knowledge (TEK) research (Huntington, 2000). In the particular context of climate change, Hansen, et al., (2004) use the data collected through interviews to build conceptual maps of stakeholders' mental models, calling the methodology *mental model interview*. This approach is closely related to semi-structured clinical interviews but has a clear coding and analysis scheme in mind—the development of conceptual maps.

Methodological Guidelines: Coding and qualitative data analysis

Interviews are usually transcribed before any analysis. Subsequently, the first step of analysis is developing a classification or coding scheme for the content of the interviews (Patton, 2009: 463). This is done by: (1) Coding the content, and (2) finding categories for the codes. Coding involves breaking the interview text down into manageable, meaningful segments and attaching one or more key words to the segments to permit later retrieval (Kvale & Brinkmann, 2008). Categorizing involves grouping coded segments into common themes (categories) and systematically coding the text around such themes allowing, if necessary, for quantification of occurrences (e.g., how many times a theme is coded). Usually, several researchers code the data separately and inter-rater agreement is evaluated to test the validity of the categories and quality of coding. Coding is both deductive (top-down) and inductive (bottom-up). It is deductive in that the data is analyzed with general categories known in advance, for instance, causal knowledge and readouts. It is inductive in the sense that the *subcategories* in which the general categories can be divided and described are not known in advance and will emerge from the data. At first, the particular causal beliefs and signs for identifying change stakeholders use are unknown to us. Coding and qualitative data analysis allows identifying and, in later research stages, tracking units of knowledge (Parnafes et al., 2008) and developing theories/models of such knowledge (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; diSessa & Cobb, 2004).

Exploratory stage: A pilot study in Zambia

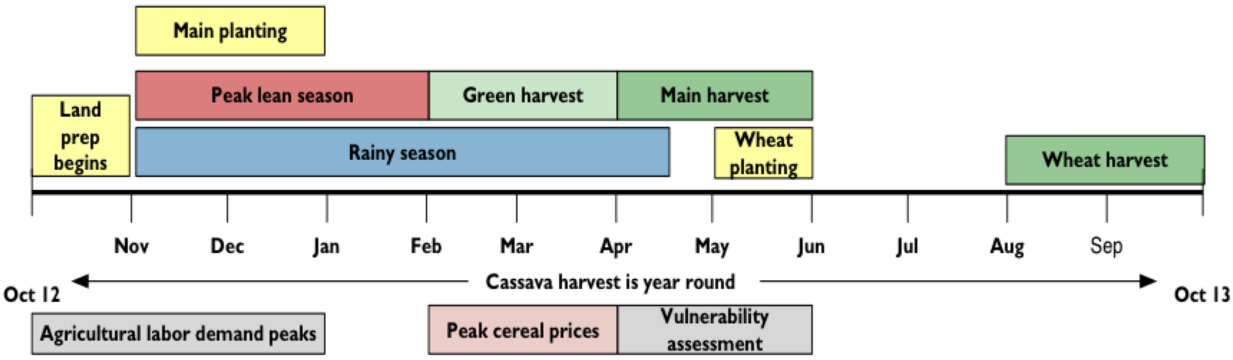
Zambia, officially the Republic of Zambia, is a landlocked country in southern Africa. The neighboring countries are the Democratic Republic of Congo to the north, Tanzania to the northeast, Malawi to the east, Mozambique, Zimbabwe, Botswana and Namibia to the south, and Angola to the west. The Zambian economy has historically been based on the copper mining industry. Zambia fell into poverty after international copper prices declined in the 1970s. Today, nearly 70% of Zambians live below the recognized national poverty line, with rural poverty rates standing at almost 80% and urban rates at around 50% (Millennium Development Goals indicators; United Nations Statistics Division). According to the Food Security Index, Zambia belongs to the 10 most food insecure countries.

Agricultural productivity in the country is held back by lack of access to input and services, as well as to transport, markets and other social infrastructure. At present small-scale farmers do not have access to financial services, and even larger enterprises lack access to long-term finance. Soil fertility is decreasing and agricultural farming systems are one sided. This is particularly the case for smallholder farmers and staple crops, mainly maize production (Neubert et al., 2011).

Smallholders account for the vast majority of farms, cropped area, maize production, and fertilizer use in Zambia. For example, as of the 2011/12 agricultural year, smallholders accounted for 99% of the farms, 94% of total cropped area, 98% of maize area planted, 95% of maize production, 75% of total fertilizer use, and 93% of the fertilizer used on maize (figures are based on the 2011/12 Crop Forecast Survey).

In addition to this, external drivers, such as climate change and economic shocks, are posing increasingly significant challenges to the agricultural sector. Rainfall patterns have changed significantly since the late 1980s and on average shifted the blue bar in Figure 2 from October to November. In the south, the rainy season is becoming so short that it is insufficient for most maize varieties except ones maturing early. Such varieties, however, mostly have smaller yields. In the north, on the other hand, rainfalls are becoming longer and often cause the maize crop to rot in the field. Planting varieties maturing late can resolve this problem, but these seeds are much more expensive than conventional ones. Crop species diversification would be necessary in addition to shifts in maize varieties (Neubert, et al., 2011).

Figure 2: Seasonal calendar for food production in Zambia (FEWS Net, 2013).



In this paper, we present data from a preliminary field study in Zambia. Using the framework described earlier, we conducted interviews with two farmers from the Mumbua district, to the northwest of the capital city of Lusaka, and one farmer from Chisamba, a town in the outskirts of Lusaka (Figure 3). We use excerpts from the interviews to illustrate what the factors in the evaluation framework look like in real data and discuss our observations on how they affect decision-making. Ultimately, our purpose is to interview a much larger sample to construct a more accurate and representative picture of current knowledge possessed by local stakeholders and their current decision-making for adaptation in the different agro-ecological regions of Zambia.

Figure 3. Mumbwa District and Chisamba town in Southern Zambia

Semi-structured interview guide

Following are the questions we used for our pilot study in Zambia. The order of the questions, however, is not predetermined. The natural way an interview develops is defined by the interviewee's ways of seeing and thinking about the issues being discussed.

1. Stakeholders are interviewed individually or with the members of their household. To begin, the stakeholder is given an explanation of the purpose of the interview. It is important that the interviewer not impose their own views and knowledge, unless the purpose of the interview is to exchange expertise on particular issues.
   a. *Our discussions and questions will touch areas like food systems, how you are farming, changes that you have experienced since your childhood in the climate and how you have responded to those changes. Also, we would like to talk about what you think the future will be like, how you see the lives of your grand- and great-grandchildren.*

This introduction helps establish a fair and transparent basis for discussion in which all participants are aware of the value of their interventions. It also helps sharpen the focus of the interview around the issues of interest—climate change, agriculture and food security.

2. The following questions focus on gaining further understanding of stakeholders' perceptions of changes in climate and food availability and the consequences for food security.
   a. *Now starting with issues relating to food, based on your experiences, is there any change in terms of food availability or abundance or sufficiency? For instance, compared to when you were young, how was the food that your parents (our grandparents' equivalent) were eating?*

b. *Apart from abundance, have you noticed any changes in terms of food diversity?*
c. *Now concerning wild foods, are there any changes that you have noticed?*
d. *What could be the cause for these changes that you have explained?*
e. *Apart from the changes related to food, have you noticed any changes related to the rains when you were still young and nowadays?*
f. *When you were still growing or in your teenage hood, when was the onset of the rain season?*

3. The following questions focus on gaining further understanding of the signals stakeholders use to predict changes in climate and food availability and of the ways in which they respond to these changes.
   a. *Now let us consider what you do in response to the changes in climate?*
   b. *Are there any indicators for a hunger year?*
   c. *What do people do when they believe that there would be hunger or to prevent hunger or prepare?*
   d. *Is there any preparation in readiness for hunger in relation to wild fruits?*
   e. *Are there any challenges that you face as you are responding to the changes?*

4. The following questions focus on gaining further understanding of stakeholders' perceptions of risk and uncertainty concerning future climate and food security.
   a. *Now based on your experience what are your feelings about the climate and food in the future? Are you worried that things may worsen or you are hopeful that things may become better?*
   b. *What would be your answer if your grandchildren were to ask you to describe how the climate will be in future when they grow to your age?*

5. An important purpose of our research is to understand how stakeholders see and think about causality. To explore this we use the following questions.
   a. *We live in other parts of the world, do you think the way we live, farm, the way we interact with nature, may affect the rains or agriculture or your lives here?*
   b. *Let us make it a bit local. Let us consider this area or place; do you think the way you farm in this village may affect the next village?*

Local ecological knowledge and adaptive practices in Zambia

As we present illustrative data for each factor below, we discuss how the data relate to the adaptive practices that farmers adopt to cope with changes and uncertainty in climate and food availability.

Readouts

Readouts are the signals people use to perceive current and predict future changes in their environment. One of the most important climate phenomena farmers in Zambia depend on is rainfall. Changes in rainfall are therefore one of the main uncertainties farmers need to deal and cope with. Farmers in Zambia use a series of sense-signals, including touch and observations, to predict rainfall shifts, abundance, and hunger. Every year, before the beginning of the planting season (Oct-Nov), farmers use the fruit forest trees and winds to predict whether food will be abundant or whether there will be hunger next year. Preparing for a hunger year requires farmers to use all the adaptive capacity available to them.

Wild fruit and vegetables are hunger foods for farmers in Zambia. They are eaten as an alternative source of energy while waiting to harvest the main crops, primarily maize, or as a survival option during hunger years in which the crops have gone bad. Some farmers believe that the amount of fruit in wild trees, particularly in Mobola plum trees (Mbula), indicate hunger. Scarcity of fruit in the trees indicates abundance of harvest; abundance of fruit indicates hunger. Farmers believe that wild trees bear more fruit when people need to cope with hunger.

Researcher	What of the bearing of fruits? Are there any changes that you have observed?
Farmer	Trees bear fruit. But during a year with hunger or drought, they bear more fruit, that is what I have seen.
Researcher	Why?
Farmer	So that people can survive on them.
Researcher	Are there any indicators for a hunger year?
Farmer	To know that this year there would be hunger?
Researcher	Yes
Farmer	The same wild trees. For example this same tree Mbula, if you noticed that the bearing of fruit was low then that is the indicator that there will be plenty of food. But if the fruit bearing was more, then it implies that there was going to be hunger.

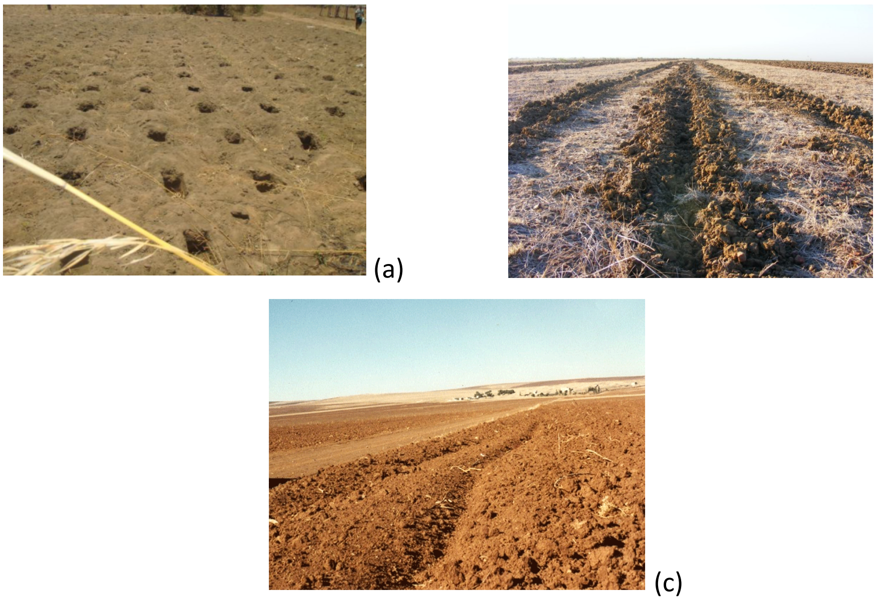
Signals like this are very important for farmers' decision making. Farmers trust them enough to adopt preventive practices to fight food scarcity in the next harvest season. For instance, if farmers suspect that a hunger year is coming, they may store food if available, borrow money to buy food, prepare early for the next farming season, or work for others to earn some money to buy extra food.

Researcher	What did people do when they saw the wind and they knew there would be hunger? What did they do to prevent or prepare? [We were told by a farmer that elders could use the wind-blow to predict hunger, however, we did not get any explanation of how exactly the signal was interpreted]

Farmer	If you had harvested some food, you would keep it, no selling. Those that had no food in store, they would start looking for money to buy food, while others would start early to prepare for the next farming season.
Researcher	Are there any other ways to prepare for hunger?
Farmer	When hunger comes it does not affect people the same way, because some people would have food while other would not. So some people would start working for others (piece-work) so that they get some food in return.

In addition to supporting predictions as described above, some readouts also seem to inform decisions about farming practices. Sense-signals are used to judge "good" or "bad" practices. For instance, one of the farmers we interviewed explained that she prepared the land combining basins and ripping—rather than plowing, because those methods "agreed" (see Figure 4 below). She perceived the basins and the ripping as agreeable because of the similar visual patterns caused by the methods on the land.

Figure 4. Land preparation methods (a) basins, (b) ripping, (c) plowing


(a) (b) (c)

Researcher	Why are you using basins?
Farmer	This is because the basins capture and retain more water. Even when it does not rain for some time the basins are often moist. The other advantage is that you harvest much earlier than in conventional agriculture.
Researcher	Why?
Farmer	Because you start land preparation much earlier. As you can see, I have already finished digging the basins and I am waiting for the first rains to plant.
Researcher	What else?

Farmer	[Basins] also help to protect the soil.
Researcher	How?
Farmer	The soil is carried away if you use a plow, [while with the basins] the crop residues that are left in this portion of soil that is not cultivated helps to prevent soil from being washed away. Plowing makes the soil be like cement (loose and powdery) as such it can easily be washed away.
Researcher	Do you have a tractor, plow or animals?
Farmer	I do not have a tractor or animals.
Researcher	So how do you plow or rip?
Farmer	I hire.
Researcher	Do you hire a tractor or oxen?
Farmer	I hire oxen.
Researcher	Now, this year you want to use a ripper on this other field [rather than preparing the entire field using basins]. Why do you want to do so?
Farmer	It is because am tired. I cannot manage to dig basins on the entire farm. So I have to hire either a tractor or oxen. I have to rest from digging basins; I cannot manage the whole farm.
Researcher	But why are you planning to hire a ripper instead of a plow which you have been hiring for years?
Farmer	It is because conservation basins and ripping are in agreement, they go together.
Researcher	How?
Farmer	Because even a ripper, it leaves some soil undisturbed between the ripped lines, just the same as in the basins, there is some undisturbed soil between the rows of basins. Also there are crop residues between rows of basins, the same as in between the rows of ripped lines.

Causal knowledge

People use other types of knowledge to convert readout-signals into predictions. For instance, using *wind-blow* as a predictor of *hunger or good harvest* is based on a chain of relations between these two events. This chain may be based on cause-and-effect or on correlational associations. A possible cause-and-effect chain could be: the stronger the wind, the more likely the rains, and the better the harvest. In contrast, an association based on correlation does not require a chain of relations linking the readout with the event being predicted. Correlation is usually based on observations of both events happening simultaneously or consecutively within a short frame of time. People usually make predictions based on such correlations. That is the case of using the wild fruit trees as predictors of hunger.

Whether farmers' knowledge is based on strict cause-and-effect chains or on correlations, we count it as *causal knowledge.* Both types of associations reflect important aspects of how farmers perceive, think of, and conceptualize the world around them. Also, it is possible that some correlations used by farmers really do have underlying cause-and-effect chains, even though they are unknown to the farmers.

One of the main functions of causal knowledge in farmers' decision-making is to help explain and organize past observations of change. For instance, farmers perceive that wild foods as well as wild trees have been decreasing over time. By associating these two phenomena, farmers not only develop an explanatory theory about the decrease of wild foods, but they also compile their observations about both phenomena:

Researcher	Now concerning wild foods, are there any changes that you have noticed?
Farmer	In the past these were common, these were plentiful, we had Mankomona, Muchingachinga, Mavhuma and many more different wild fruits. But nowadays, because of cutting down of trees, we have very few left, like Mawi, Lusala and Delele.

Farmers base their farming practices on a wide range of causal associations of this sort. To mention only a few: more population growth corresponding to more deforestation; fewer trees corresponding to less rain; more soil water retention corresponding to better likelihood of a good harvest; less disturbance of soil corresponding to more conservation of soil nutrients.

Researcher	At the beginning you mentioned changes related to food availability or abundance. But what do you think is the cause of such changes?
Farmer	Population has increased. That is why there is also an increase in hunger. When we were growing up we did not know hunger. Previously when an elderly person had harvested 10 bags of maize (10 x 90 kg) it was easily enough for the family the whole year. Nowadays it is not possible; there are more people. In response the farming systems have also changed. In the past people during this time of the year would be relaxing, but nowadays we are busy digging basins, knowledge has also increased and businesses have increased.

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Researcher	Okay there is something I had forgotten. Concerning dry spells. This past farming season, when was the onset of the rains?
Farmer	Rainfall was delayed, by the 15th of November, the time we usually plant, the rains had not yet started.
Researcher	So what do you think is the cause of this?
Farmer	Others explain that it is due to cutting down of trees for charcoal. They explain that forests capture rains. If land becomes bare without trees, it reduces the rain.

Causal knowledge seems to have a great influence on farmers' decisions concerning which specific adaptive practices to adopt.

Researcher	Now let us consider what you do in response to the changes in the weather. For example, you earlier mentioned that previously people could plant in October but now that rains do not come in October what do you do?
Farmer	The way we farm is all about preparation and rains, so I start to prepare in advance digging basins and even if the rain does not start in October, I can plant in advance so that as the rains come they find my seeds already in the ground.
Researcher	Okay.
Farmer	Yes because with basins, if there is good rainfall at the beginning, even if there is a dry spell for 2 to 3 weeks, there will still be moisture in the basins. The plant will not die because basins keep water.
Researcher	How do you know that there is moisture?
Farmer	I would know, if you lift the crop residues you would find that the soil is still moist in the basins.
Researcher	What about a plowed field with crop residues? Won't you find the same?
Farmer	Not really, maybe in the morning yes because of dew, but later during the day, it will be dry. The plowed field dries faster than in basins.

Risk perception and perceptions of adaptive capacity

Perceptions of risk and of future uncertainty are common among farmers in Zambia. It is clear that farmers are concerned about the consequences of climate change for their food security. However, an important lesson we learned from our pilot study is that farmers in Zambia seem to perceive risk at two levels: short- and long-term. Although farmers seem to be rather concerned about the effects of long-term, cumulative changes in climate, they also need to respond to the most immediate risk of going hungry *this or next year*.

The interview episodes presented in the Readouts section reflect farmers' perceptions concerning risk of imminent hunger. Long-term risk is perceived with respect to the disappearance of wild trees, and the increase in unpredictability of rainfall.

Farmer	Wild fruits have reduced.
Researcher	Why?
Farmer	Because of cutting down of trees, nowadays the wild fruits are found very far away from people.
Researcher	Could you explain the cutting down of trees?
Farmer	They are cutting down trees to make charcoal.

Researcher	What feelings do you have for the future? Are you hopeful or worried? Or when you consider the life of your grandchildren in future what do you think their food situation will be like?
Farmer	As my wife pointed out, cutting down trees, the grand children will never see or eat some of the foods in the future. They will just read about them.

***

Researcher	Now based on your experience with reference to the rainfall, what are your feelings about the future? Are you worried that things may worsen or are you hopeful that things may become better?
Farmer	If it continues raining the way it did this year, then it means death, there will be nothing good.
Researcher	Okay.
Farmer	Yes because the rains that give food are medium, not too much.

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Researcher	Or what would be your answer if your grandchildren were to ask you to describe how the rain will be in future when they grow to your age?
Farmer	I see that there will be some hardships.

This interplay between short-term and long-term perceptions of risk seem to also play an important role on the adaptive practices farmers adopt. Immediate risk of hunger may require quick actions such as doing piece-work for those whose crops are doing better in the current season. That extra money may make the difference between having access to some food and going hungry. Long-term risk in contrast may require more durable, sustainable strategies to cope with more permanent changes in climate.

Farmers in Zambia have adopted several practices to adapt to more permanent changes, not only to changes in climate, but also to changes in the food market and the environment. These adaptive practices include: preparing the land in ways that conserve moisture and nutrients to prepare for possible droughts; and doing gardening of cash crops to respond to market demands and to replace disappearing wild foods. Some farmers also seem to regard *learning* as an important practice to cope with changes.

Researcher	When you consider the future life of your grandchildren, will the food security situation be the same, better, or worse? Are you worried or hopeful about the food security situation in the future?
Farmer	If things continue there won't be a problem, if the trainings continue it will be fine.

Researcher	Okay, if the training continues
Farmer	Yes yes yes.
Researcher	What if the training does not continue?
Farmer	There will be problems.
Researcher	Could you explain on the training?
Farmer	Training concerning farming and other things.

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Researcher	In relation to the changes that we have discussed, are there any challenges that you have faced?
Farmer	The challenge is the access to inputs. You need money. If you don't have money you will always have problems.
Researcher	What do you do to respond to these challenges?
Farmer	In most cases, instead of troubling our children, we cultivate small manageable area and we buy the inputs.
Researcher	What else do you do to reduce the challenges that you are facing?
Farmer	What do you have to say my wife (bina-Joice)?
Researcher	We have discussed some changes, and these changes may have brought some challenges and my question is what do you do in response or to reduce these challenges?
Farmer	Like after harvesting field crops we start gardening, growing some vegetables like tomatoes, and when we sell them we get some money to buy some soap and other things.
Researcher	Okay so gardening
Farmer	Yes gardening also helps.
Researcher	So does it mean that also your grandparents were also engaged in gardening?
Farmer	No, a long time ago there was no gardening and no selling.
Researcher	But now gardening is a source of income.
Farmer	Yes it helps.

***

Researcher	Now, we have been discussing more of the field crops, but what of foods from the forest?
Farmer	Mbula and Masuku fruit are still present.

Researcher	Have you noticed any changes in the availability of wild foods since you were young?
Farmer	Wild foods also seem to have reduced; let us say they have reduced. What has remained mostly are fruits like oranges, pawpaw, and guavas. So instead of fruits from forests we now eat theses fruits.
Researcher	Why has forest fruit decreased?
Farmer	It's because of development, education, what we are learning. Wherever you stay you need to plant some fruits because wild fruits do not easily germinate.

Whereas practices such as learning and gardening may improve farmers' adaptive capacity, other practices, such as eating traditional foods, seem to restrict farmers' willingness to diversify their crops—for crops that are more resilient to droughts.

Researcher	Do you think the food that you eat is good for you?
Farmer	The food we eat is not quite sufficient but my idea is that I need to improve so that I get more food.
Researcher	Would you wish to have other foods?
Farmer	We eat what we have, according to our harvest, but sometimes it is not enough.
Researcher	Okay, do you think the food gives you good health?
Farmer	Yes we eat Nshima [traditional dish made with corn], beans, cowpea, ground nuts and other different types of food.
Researcher	And do you think the food gives you good health?
Farmer	For me I think they give us good life.
Researcher	What if you had to substitute these foods?
Farmer	A-a-ah I don't think so because from birth these have been our foods. I don't think you have to change to start eating foods that you do not know.

Conclusions

The purpose of this paper was to report the development and pilot testing of a comprehensive framework for analyzing learning processes in complex dynamic systems. The framework was based on the finding that current methods in system dynamics focus mainly on documenting gaps between novice and expert knowledge and that there is much less work on methods that help analyze how stakeholders acquire new knowledge during a system dynamics-based intervention and how their existing knowledge hinders or contributes to the acquisition of new knowledge. The paper focused specifically on the principles and methods for knowledge analysis and, in the pilot study, applied them to farmers' knowledge of climate change, agriculture and food security in Zambia.

Our pilot data indicate that adaptation seems to require a combination of science-based knowledge and traditional knowledge. Traditional ways of predicting hunger and climate define the need to respond and prepare, whereas science-based knowledge defines how to proceed, the particular methods to use and how to go about them. Science-based knowledge derives from extensive impact analysis to study cause-and-effect relationships. There is not a clear-cut distinction between the two types of knowledge, however. Some of the traditional farming practices are very sophisticated and suggest extensive knowledge of the environment (e.g., intercropping with pumpkins for water retention) while some science-based practices are followed without full knowledge of the underlying science (e.g., eating pumpkin leaves to supplement the diet). As farmers don't just replace their traditional knowledge but adopt a mix of traditional and science-based knowledge, it is crucial to understand stakeholders' knowledge before designing and implementing teaching interventions and adaptive practices.

The evaluation framework described in this paper considers several factors and needs to be applied in different research stages. This paper only reported on a pilot study in the very first of these stages, the exploratory stage, and with only one stakeholder group, that of farmers. No single study will be able to consider all factors in all research stages at the same time. Instead, the evaluation framework serves to organize and accumulate work over time. The knowledge analysis described in this paper is a first step towards designing system dynamics-based interventions to improve performance, decision and policy-making and knowledge concerning climate change, agriculture and food security. One suggestion for the design of such strategies can be taken from a review of documented and measured learning effects due to exposure of stakeholders to system dynamics-based gaming-oriented simulations such as simulators and planning games (Kopainsky & Saldarriaga, 2012). This review found that the most effective strategy for improving understanding was through the addition of learning tasks such as working with cognitive conflict and analogies or going through training phases with initially reduced but gradually increasing complexity. This was more effective than altering the actual design of the user interface in simulators. This finding is relevant for our project concerning climate change, agriculture and food security as many of the stakeholders involved in the necessary transformation and adaptation process have very little experience with computer simulations. It might thus be promising to design interventions that are inspired by simulation models but do not necessarily work directly with simulation models (see e.g. Moxnes & Saysel, 2009; Saldarriaga, 2011).

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