Gaming and simulation to explore resilience of contested agricultural landscapes

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Chapter 1

Introduction

1 Background

During the last decades, globalization and economic and institutional global change resulted in strongly increased connectivity between biophysical and governance scales and levels (Cash et al, 2006). Impacts of far-away decisions increasingly reach the local level. Consequently, local livelihoods, land-use dynamics and associated social organization became strongly affected by multi-scale intersecting processes of economic, institutional, social and agricultural change even in isolated areas of the world (Taylor, 2005). As a consequence, people are continuously challenged to respond to often conflicting drivers of change to adjust the systems they manage (e.g. Fabricius et al., 2007; Schlüter and Herrfahrdt-Pähle, 2011; Ribeiro-Palacios et al., 2013). Responding to the local impacts of global change is said to be one of the greatest challenges of this century (Eakin and Lemos, 2010). In this context, resilience thinking theory (Holling, 1973; Walker et al., 2004; Folke et al., 2010) provides a systems-oriented perspective on dealing with change.

Although the attributes that underpin a system's capacity to deal and adapt to change are widely agreed upon in literature and include flexible institutions, knowledge exchange and equitable resource access (e.g. Yohe and Tol, 2002; Folke et al., 2003; Walker et al., 2006), (i) empirical evidence on how rural communities adapt, and (ii) tools that can support stakeholders to explore opportunities and facilitate (social) learning are still scarce (e.g. Tschakert and Dietrich, 2010). This thesis addresses both issues in the context of smallholder agricultural landscapes. The following sections provide a brief theoretical background on the main concepts and methodologies used and developed throughout this thesis.

1.1 Contested agricultural landscapes

Smallholder farming systems are commonly characterized as family farmers who manage one or several small plots of land. Smallholder farmers generally pursue a variety of functions from these system e.g. to produce food, to generate income, and to satisfy religious and social needs (Speelman et al., 2006). Smallholder systems are often located in fragile agriculturally less-favorable environments in which natural, economic and social resources are under pressure (van Keulen, 2006). For long, these systems were regarded as stable and highly resistant to change due to the complex interaction between social and ecological system. However, the trend of increasing competing claims on land is now also recognized in smallholder and peasant farming systems even in relatively isolated areas (García-Barrios et al., 2009). The interests of a growing number of non-local stakeholders and global trends in policies and market dynamics have also in these agricultural landscapes, become drivers for local land-use change and associated social organization (e.g. Lambin et al., 2001; Wadley et al., 2006; Grau and Aide, 2008; Barraquand and Martinet, 2011) (Figure 1.1).

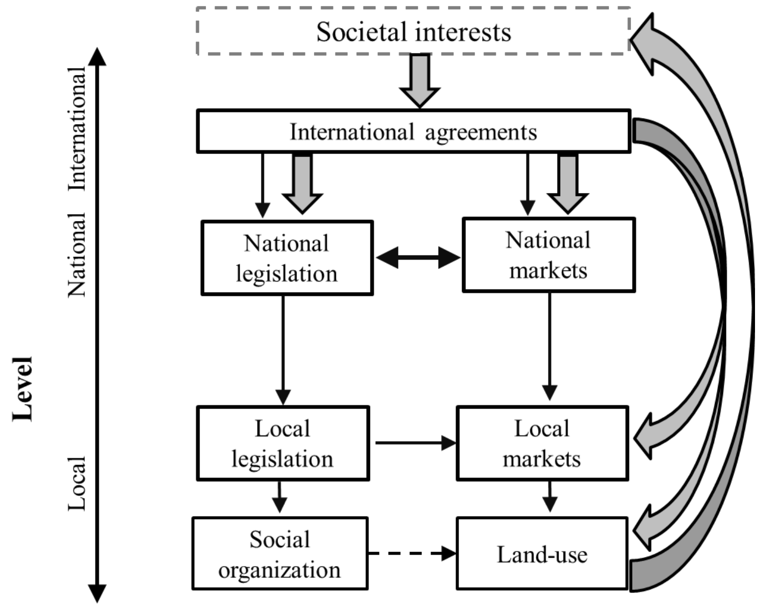

Figure 1.1: Schematic overview of an example of the influences between non-local governance, and economic drivers and local social organization and land-use. Grey arrows indicate influence that resulted or strengthened due to globalization. Whereas, the black arrows indicate influence already present before globalization.

While smallholder agricultural landscapes are commonly situated in agriculturally less-favorable environments, at the same time they hold key positions in watersheds, and in areas with high biodiversity and large forest resources (van Keulen, 2006). Global interests in nature and biodiversity conservation have resulted in attention for these previously often neglected areas. However, national agricultural production demands and local livelihoods are often at odds with nature conservation legislation. More sustainable forms of agricultural production have been proposed e.g. sustainable or ecological intensification (Pretty et al., 2011; Bommarco et al., 2013), agrodiverse farming systems (Jackson et al., 2007; Kremen and Miles, 2012), and agroforestry systems (Nguyen et al., 2013; Mbow et al., 2014). In addition, nature reserves in which natural resource conservation and (sustainable) agricultural development are jointly established were developed amongst others in the form of UNESCO's Man and Biosphere (MAB) reserves (see e.g. Nagendra, 2002; Bray et al., 2003; Berkes, 2007; Orozco-Quintero and Davidson-Hunt, 2009).

1.2 Stability, resilience and adaptive capacity

Over the last decades, the scientists' perspective of the world changed dramatically and moved from viewing the world as an organized set of parts to a complex systems view in which the sum of the parts often does not explain the behavior of the system as a whole (Kinzig et al., 2006). This new perspective, which recognizes the complexity and uncertainty in systems, originates from physics and ecology and has found its way in various fields of science. Many scholars relate its origin to the work of Holing in 1973 (Holling, 1973). Research identified that seemingly stable systems could suddenly shift to another state under specific circumstances. Perturbations or permanent changes in a driving variable of a system have been related to critical shifts in systems properties. Such critical shifts in systems have often been referred to as regime shifts that occur after a system passed a specific threshold or tipping point. Many systems are now believed to have more than one stable state or basins of attractions in addition to unstable states (Scheffer et al., 2001; 2012; Scheffer, 2010). Regime shifts have been identified in a variety of situations, ranging from lake eutrophication (Scheffer et al., 2001) to social opinion (Gladwell, 2000) and agroecosystem dynamics (Tittonell, 2013). These somewhat abstract concepts have been visualized through simple representations using graphs (Walker et al., 2010) (Figure 1.2a-b), and the so-called "cup and marble" diagram (Figure 1.2c) (Scheffer et al., 2001). In figure 1.2a, the concept of threshold is visualizes. The state of the system shows a continuous response to an underlying variable, but changes abruptly when a certain threshold is reached. Figure 1.2b shows the existence of two alternate system regimes. When a certain threshold or tipping point is passed the system will switch to the other another regime. Hysteresis is shown as the process in which the way between the two regimes are distinct. An example is deforestation, logging an area is a fast process, but the process to return to a forest is a slow process. In figure 1.2c, a cup and marble diagram is shown to represent the state of a system and its attractors. In these diagrams, the cup is used to represent the attractor into which the system, the ball is drawn (Figure 1.2c). An important feature of these diagrams is that the shape of the cup is more important than the current position of the marble (Carpenter and Gunderson, 2001). Social experiments showed that the connections and feedbacks in a system are often not random and can contribute to rapid unexpected changes (Travers and Milgram, 1969; Granovetter, 1983).

This complexity perspective on systems behavior led to the development of wide variety of concepts. The main concepts and their definitions used in this thesis are: 1) resilience thinking, 2) resilience, 3) adaptability and adaptive capacity, and 4) regime shifts. Resilience thinking theory is used as the umbrella term that refers to the complexity perspective on system's behavior of complex social-ecological systems (cf. Walker et al., 2004; Folke et al., 2010). Resilience was defined as the capacity of a system to absorb disturbance, reorganize to maintain the same function. Adaptability and adaptive capacity are identified as the capacity of actors in a system to positively influence resilience. Cross-scale and cross-level feedbacks are key in understanding resilience thinking concepts (Cash et al., 2006; Taylor, 2005).

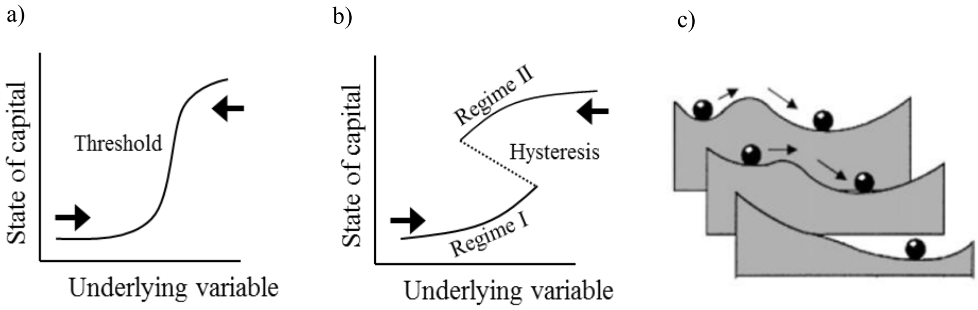

Figure 1.2: An overview of various graphical representations of : a) thresholds, b) hysteresis (Walker et al., 2010), and c) stability landscapes as proposed by Scheffer et al. (2001).

Resilience thinking theory and its related concepts have been extensively researched in the context of human impacts on natural systems (e.g. Folke et al., 2004). Over the last decade, the concept also rapidly gained importance in research on social-ecological systems in which social and ecological processes are strongly interlinked (e.g. Berkes et al., 2003; Folke, 2006). Managed natural systems such as agricultural systems and landscapes are an example of a complex social-ecological system in which processes and feedbacks cross scales and cross levels to often result in (unexpected) land-use dynamics (Bert et al., 2014). Often these systems are analyzed without explicitly incorporating human decision-making. However, when long-term behavior of social-ecological systems is analyzes, these systems behave as complex adaptive systems in which human decision-making is an integral component of the system (Walker et al., 2002).

1.3 Stakeholder participation and (social) learning

Collective governance systems in social ecological systems are of central importance to the capacity to adapt to change (Ostrom, 1990;1999; Robinson and Berkes, 2011). Current social-ecological challenges are highly complex, while individuals generally have trouble dealing with such complexity (Dörner, 1996). The diversity of knowledge that is required to understand and improve the adaptive capacity of the actors of complex social-ecological systems can generally only be found in the joint knowledge, skills and problem-solving capabilities of a group of people (Page, 2008). Therefore, stakeholder participation has become a main approach in problem-solving and solution-exploration (Walker et al., 2002; Reed, 2008; Scholz et al., 2013; Angelstam et al., 2013). With increasing pressures on resources, relationships between stakeholders have become more apparent and more intense. This has resulted in conflict among stakeholders and an increasing need for (social) learning and negotiation processes (e.g. Gurung et al., 2006; Barnaud et al., 2010; Dumrongrojwatthana et al., 2011; Villamor and van Noordwijk, 2011). Participatory approaches to enhance involvement of individual stakeholders in processes of problem-solving and solution-exploration have become available since the late 1960s (e.g. Rapid Rural Appraisal, Participatory Rural Appraisal, Participatory Action Research: e.g Biggs, 1990; Pretty, 1995, Reed, 2008). However, methods that focus specifically on collective or communal decision-making or negotiation processes remain scarce.

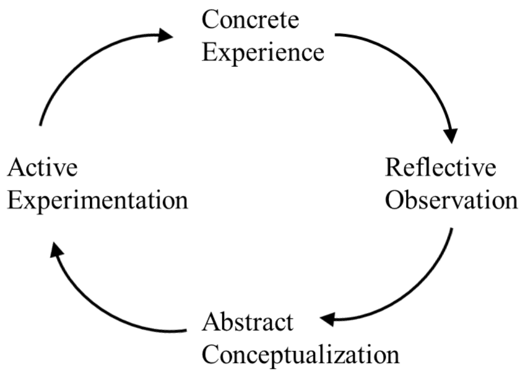

Figure 1.3: Kolb's cycle of experiential learning (Kolb, 1984).

Learning and in particular forward-looking or anticipatory learning plays a key role in the resilience and adaptive capacity of systems (Tschakert and Dietrich, 2010). Classical views on learning are strongly linked to the cognitive process of acquiring of knowledge (Sfard, 1998). Different perspectives on learning developed over time, such as experiential learning (Kolb, 1984), and social learning (Bandura, 1977). In experiential learning, people are assumed to learn from experience (Kolb, 1984). Kolb identified two dimension in the learning process, grasping and transforming experience. Grasping is done by concrete experience and abstract conceptualization, and transforming is done through reflective observation and active experimentation (Figure 1.3). Ideally any learning process consists of all four phases, but people are found to have specific learning styles in which they focus more strongly on one or two the phases of the Kolb cycle. Social learning is the process of learning form observing and interacting with others and focuses more on reframing ideas and adjusting perspectives (Pahl-Wostl et al., 2008; 2013). The concept relates to a cognitive process within a group of people in which individuals establish: (i) a change in one's understanding, (ii) a change that goes beyond the individual and affects communities of practice, and (iii) occurred through the interactions with others (Reed et al., 2010). Social learning is said amongst others to build consensus, empower among stakeholders and reduce conflicts (Lebel et al., 2010).

1.4 Simulation and gaming

Computer supported modelling tools have been developed to study and explore systems behavior in a wide variety of research fields such as social science (Gilbert and Troitzsch, 2005; Jager, 2000), agriculture (van Ittersum et al., 2003; Keating et al., 2003), land-use change (Verburg et al., 2002). Especially in the last two decades, the number of studies in which social and ecological systems have been actively coupled in simulation models increased sharply (for overviews see e.g. Parker et al., 2003; Matthews et al., 2007; Schlűter et al., 2012; An, 2012). Agent-based modelling (ABM) has become one of the main modelling approaches in the field social-ecological simulation. ABM is a modelling approach that allows to explicitly simulate the interactions among (heterogeneous) agents and their environment (Grimm, 1999). In the of modelling social-ecological systems, agents commonly represent autonomous decision-makers that can be heterogeneous in terms of their properties and abilities, and/or their resource endowment. In these coupled approaches, agent's decision-making processes have been mostly grounded on a variety of approaches e.g. statistical, probabilities, microeconomics, space theory, heuristic or empirical rules, institutions or stakeholder participation (for an overview see: An, 2012). Many of these studies resulted in a more systemic and comprehensive view on land-use dynamics and an increased understanding system's behavior as a result of interacting heterogeneous individuals (e.g. Acosta-Michlik and Espaldon, 2008; Gotts and Polhill, 2009; Valbuena et al., 2010).

Computer supported modelling tools that aim to facilitate learning on complex systems behavior have often been simple stylized models. It has been proposed these educational models should simplify things as much as possible, but not to the point where the interesting characteristics of the phenomenon are lost (Gilbert, 2005). Complexity is not about details; it is about the variety of nonlinear behaviors a system may exhibit. In the field of agriculture and natural resource management, educational models have been developed often in combination with games as discussion and decision support tools often in combination with simulation tools e.g. Barreteau et al., 2003; Bousquet and Le Page, 2004; Collectif ComMod, 2014.

Since the first development of games as tools to facilitate learning in business education (Duke, 1974), games have been developed and used in a variety of settings for distinct goals such as data collection on social-ecological systems modelling (Washington-Ottombre et al., 2010), climate negotiation (Sterman et al., 2014) and complex systems awareness/education (Dörner, 1996; Peppler et al., 2013). Role-playing can have significant influence on the way the players will behave in the future (Gurung et al., 2006). Role-play has become a common feature in workshops with these types of games. These methods allow stakeholders to engage in discussions, clarify their views and jointly discuss and find solutions. Games have also been used for testing hypotheses especially on the management of common pool resources (Janssen and Anderies, 2011) and cooperation and coordination dilemmas around rural land-use (García-Barrios et al., 2011).

2 Objectives

The capacity of agricultural communities to develop resilient systems and adapt to social-ecological change is key in securing the continuation of livelihoods in rural parts of the world. Although the attributes that underpin system's resilience and adaptive capacity are widely agreed upon in literature, (i) empirical evidence on how rural communities adapt, and (ii) tools that explore and facilitate (social) learning on related concepts remain scarce. This thesis addresses both issues.

The main objective of this thesis was to explore and apply concepts of resilience theory to contested agricultural landscapes in particular the concept of adaptive capacity, by means of innovative gaming and simulation methodologies to facilitate (social) learning related to these concepts. The specific objectives were:

1. To identify how and under which circumstances smallholder communities adapt to social-ecological change (*Chapter 2*).
2. To develop a gaming methodology to facilitate the active involvement of stakeholders and to assess factors and patterns of communal decision-making (*Chapter 3*).
3. To develop computer simulation tools to enable (social) learning on complex concepts related to sustainable management of social-ecological systems in agricultural landscapes (*Chapter 4 and 5*).

4. To improve the current understanding of land-use dynamics in agricultural landscapes in response to economic and institutional change through applying social psychology theory to farmer decision-making processes (*Chapter 6*).

The objective was based on a set of underlying hypotheses. These included amongst others: (i) Depending on the specific circumstances, smallholder communities can adapt to social-ecological change; (ii) Gaming and simulation can facilitate (social) learning among stakeholders through creating a space in which stakeholders can openly discuss their interests and ideas; and (iii) Simple simulation models can greatly assist learning on complex concepts by generating emergent outcomes through a limited set of interlinked understandable processes.

3 Empirical data

The research questions were explored through analysis of: 1) empirical data from a case study area, 2) empirical data from workshops with various groups of stakeholders, and 3) simulated data from a series of simulation experiments. The smallholder community Tierra y Libertad (TyL) in Chiapas, Mexico, was specifically selected as a case study for this research for its history in the context of contested agricultural landscapes and pre-identified signs of adaptation.

3.1 Case study area

The smallholder community Tierra y Libertad is situated near the ridge of the Sierra Madre de Chiapas mountain range in the upmost part of a watershed in one of the poorest states of Mexico, Chiapas at an altitude between 900-1500 meters above sea level (Figure 1.4). Over the past fifty years, this community was confronted with frequent and large economic and institutional pressures at the global, national and local levels. These pressures included (i) a strong decline in the price of their main produce as a result of trade liberalization, and (ii) land-use limitations associated with the establishment of an UNESCO's Man and Biosphere (MAB) Reserve in the region. Since 1995, TyL is situated in the buffer-zone of the La Sepultura Reserve (6°00'18" and 16°29'01"N and 93°24'34" and 94°07'35"W) (INE, 1999).

The area became populated in the early 1960's and the community was officially established in 1972 as an *ejido*, a landholding peasant community in legal terms common in Mexico. The current young population has an average age of 24 years, SD = 18) (Chapter 2).

The community is remote and poorly connected to the nearest urban center and market, but has basic facilities, e.g. a small health clinic and rural schools from kindergarten up to lower-secondary school. The territory of the community is hilly with average slopes of 20° and extremes of 60° and accounts for some 3200 ha (Toupet, 2010). The climate is sub-humid tropical with an average temperature of 20-22°C. Annual precipitation is around 2000 mm of which nearly all occurs between May and October (INE, 1999). Soils are characterized by a shallow sandy clay loam top layer (60% less than 10 cm deep) (Toupet 2010), under which sandy clay is found on a granite bedrock (INE, 1999).

Figure 1.4: Location of the smallholder community Tierra y Libertad, Chiapas, Mexico.

Current land-use types include staple food production (maize and beans), pasture-based livestock production and coffee and palm cultivation. An estimated 80% of the territory is under forest cover (Dahringer, 2004). This also includes parcels with agricultural production such as forest-based production of coffee and palm cultivation in the understory of the existing forest, but also livestock ranching is performed in partially forested pastures. Staple food (maize and beans) is grown for home-consumption, whereas coffee and livestock are produced for home-consumption as well as sales purposes. The wild Camedor Palm (*Chamaedorea spp.*) is a pure cash crop. The ornamental leaves of this plant are sold directly to an exported who exports the product to the U.S.A. There is no regular local market for any of these products. Palm leaves are sold directly to an exporting company who sells the product to the U.S.A., coffee is sold in one of the nearest towns, whereas livestock is usually sold to visiting middlemen. Only under special circumstances e.g. family celebrations, sickness of a family member, failed harvest, excess produce is shared, sold or exchanged with those who need.

4 Thesis outline

This thesis consists of seven chapters of which chapters two to six form the core of the thesis. The chapters are ordered according to three themes: i) assessing the current situation – *Chapter* 2, 3, and 6; ii) learning for the future – *Chapters* 4 and 5; and iii) exploring the future – *Chapter* 6 (Figure 1.5).

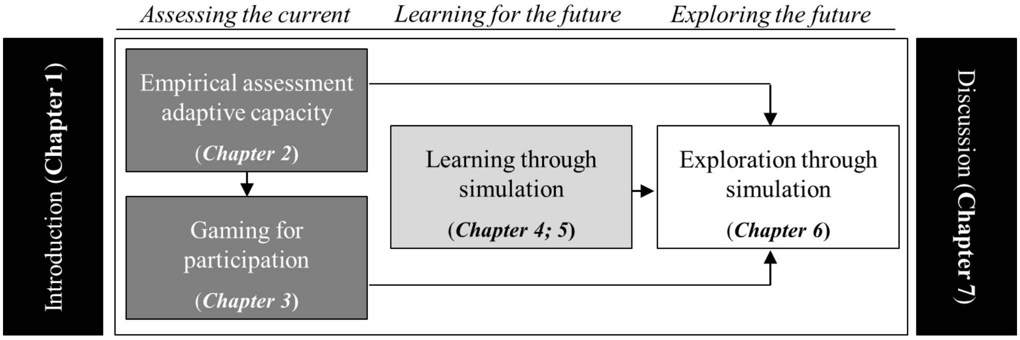

Figure 1.5: Schematic outline of the thesis.

Chapter 2 presents an empirical assessment of social-ecological change through a comprehensive driver-response reconstruction in the study area. Local effects of global, national and local economic and institutional changes on land-use and associated social organization are evaluated to assess the change in adaptive capacity. This chapter also formed the basis for chapters 3 and 6. Chapter 3 describes a gaming methodology to actively involve smallholders in land-use planning and landscape design. The chapter presents results of four pilot sessions and the developed hypotheses on factors and patterns of communal decision-making during game strategies deployed by participants.

Chapter 4 and 5 describe educational simulation tools to facilitate (social) learning on complex concepts and train discussion and negotiation skills. Chapter 4 describes a simple simulation tool that facilitates learning on concepts related to agrodiversity. In addition, the chapter presents an in-depth assessment on the effectiveness of using this simple simulation tool to learning among BSc Students. Chapter 5 presents a more complex game on the management of a rural landscape, which contains computer simulations, group discussion, role-play and negotiation among participants. The different features of the game and feedback of users of a series of workshops are described.

In chapter 6, the findings from previous chapters are integrated in the development of an agent-based modelling tool for the simulation of social-ecological change in an agricultural landscape. This chapter describes the first steps of the development of an agent-based model and its qualitative validation with empirical data land-use dynamics in the study area.

Chapter 7 presents a discussion on the main findings of this thesis in relation to the overall objective of the thesis. The contribution of this thesis to current research is discussed, future research opportunities are proposed and conclusions are drawn.

Chapter 2

Assessing social-ecological change: an empirical evaluation of adaptive capacity

Smallholder farming communities are increasingly affected by local effects of international market dynamics, and (inter)governmental economic and nature conservation policies to which they respond through coping or adaptation. Although the attributes that underpin the capacity to adapt are widely agreed upon in literature, empirical evidence on how rural communities can develop adaptations are still scarce. Here, we provide such evidence based on a comprehensive driver-response reconstruction of a community in the buffer-zone of a Biosphere Reserve in Chiapas, Mexico. We found that coping (between 1990 and 2000) was gradually replaced by adaptations (1995-2010) based on: (i) diversification of land-use, (ii) improved social organization, (iii) improved communal decision-making, and (iv) more sustainable forms of land management. The diversification of local farming systems through inclusion of organic forest-based palm and coffee cultivation and the establishment of associated organizations, formed the basis of these changes. These adaptations were mainly supported by improved social, institutional and political capital. Communal forest resources, long-term support of an NGO and a highly motivated population, were essential circumstances that allowed these trajectories to develop. However, current unequal land and power distribution could undermine and debilitate adaptive capacity. Communities and supportive organizations need to be aware and capable to adjust continuously to prevent today's adaptation strategies from becoming tomorrow's coping responses.

Based on: Speelman, E.N., Groot, J.C.J., García-Barrios, L.E., Kok, K., van Keulen, H., Tittonell, P., under review. From coping to adaptation to economic and institutional change - Trajectories of change in land-use management and social organization in a Biosphere Reserve community, Mexico. Land Use Policy

1 Introduction

Global change challenges rural households and communities all around the world to respond to secure the continuation of their livelihoods (Fabricius et al., 2007). The capacity to respond to e.g. climatic and demographic change and international market dynamics is mainly dependent on natural, economic and social resource availability and the capability to utilize these resources (Wall and Marzall, 2006; Nelson et al., 2007). Smallholder farming communities are thought to be relatively more challenged by change (Eakin and Lemos, 2010), due to the fragile environments they are often located in, and their limited natural, economic and social resources (van Keulen, 2006). Natural resource management and social organization of smallholder communities are largely determined by the often conflicting local effects of global economic and institutional change (e.g. Lambin et al., 2001; Wadley et al., 2006; Grau and Aide, 2008; Barraquand and Martinet, 2011). Price drops associated with trade liberalization, subsidy abolishment and cheap imports that push farmers to intensify production, or limitations imposed by governmental policies to protect natural resources are just some common examples of such changes (e.g. Nagendra et al., 2006; Milgroom and Spierenburg, 2008; García-Barrios et al., 2009; Ribeiro Palacios et al., 2013). Improving the capacity of farmers and communities to respond to global and local drivers in a sustainable manner is deemed essential for the future of rural livelihoods. This is especially the case, as the frequency and severity of (unexpected) changes e.g. climate events and market dynamics, are expected to increase (Eakin and Lemos, 2010).

The adaptive capacity of a system is the foundation for the development of adaptation strategies and has been defined as the ability of individuals and communities to modify natural resource management in a sustainable way in response to actual, perceived, or expected drivers or pressures (Folke et al., 2003; Armitage, 2005). Adaptive capacity is thought to improve the resilience of a system and reduce its vulnerability. It allows the system to avoid or move out of an undesirable state and towards a desirable one (Folke, 2006). Improving system's adaptive capacity allows initial coping responses to be transformed into adaptation strategies. The basis for adaptive capacity has been described and agreed upon extensively in literature and includes e.g. flexible institutions, knowledge exchange and equitable resource access (see e.g. Yohe and Tol, 2002; Folke et al., 2003; Walker et al., 2006). However, understanding on how rural communities can improve their adaptive capacity still needs sufficient empirical data (Eakin and Lemos, 2006).

When faced with global, national or local changes with (expected) major impacts at the local level, rural households generally respond by changing land-use practices while communities might adjust organizational structures. Resulting trajectories of change vary and can be categorized as: 1) Coping: characterized as a re-action response triggered by past or current drivers, and 2) Adaptation: characterized as deliberate management adjustments in response to past, current and future drivers (Nelson et al., 2007; Fabricius et al., 2007). Coping is a common immediate response to change, but does not necessarily prepare a system for future changes and is therefore mainly effective in the short-term. Adaptation deliberately anticipates future or expected changes and is therefore generally effective in the long-term. Coping responses may include (temporary) out-migration and increasing off-farm income sources (e.g. Robson and Berkes, 2011; Ribeiro Palacios et al., 2013). Adaptation strategies are often based on (strengthened) social networks, re-orientation of agricultural production, improvement of infrastructure, improving (local) organizational structures or diversification of production systems (e.g. Saldaña-Zorrilla, 2008; Huber-Sannwald et al., 2012). However, these strategies strongly differ depending on the initial resource availability and potential within the system or household.

We aimed to contribute new empirical evidence and insights around the pivotal research question: how and under which circumstances do households and communities improve their capacity to strengthen adaptation to an increasingly changing and demanding economic and institutional environment. We addressed this question through a thorough analysis of past responses to multi-level drivers of change and an assessment of adaptive capacity in the smallholder farming community of Tierra y Libertad (TyL), in Chiapas, Mexico. Over the past fifty years, this relatively young community was confronted with frequent and large economic and institutional pressures at the global, national and local levels. These pressures included a strong decline in the price of their main produce as a result of (i) trade liberalization, and (ii) land-use limitations associated with the establishment of an UNESCO's Man and Biosphere (MAB) Reserve in the region. MAB Reserves were developed as mechanisms that aim to combine natural resource conservation and (sustainable) agriculture (see e.g. Nagendra, 2002; Bray et al., 2003; Berkes, 2007; Orozco-Quintero and Davidson-Hunt, 2009). We assessed the local adaptive capacity by examining changes in multi-level economic and institutional drivers (Section 4.1.1) and the associated community responses in social organization (Section 4.1.2), and land management (Section 4.1.3). Subsequently, we evaluated the response mechanisms (Section 4.2) and assessed the development of adaptive capacity through a resource-based framework (adapted from; Yohe and Toll, 2002; Wall and Marzall, 2006; Eakin and Lemos, 2006) (Section 4.3). We discuss the findings of this research in relation to previous studies and analyze their implication for our current knowledge on social organization and institutional change (Section 5).

2 Case study background

2.1 Economic and institutional policies

Between 1950 and 1982, Mexican agricultural policies were aimed at protecting the national market and achieving self-sufficiency in staple foods, in particular maize. In 1965, a secure market with guaranteed prices was established, by which the whole market chain was managed by the state-owned Compañía Nacional de Subsistencias Populares (CONASUPO). In 1982, the Latin-American debt crisis started and Mexico was pressured to implement neoliberal policies towards (open) market-driven governance, which resulted in the dismantling of CONASUPO in 1989. Consequently, staple food prices became more dependent on the international market. In 1994, the North American Free Trade Agreement (NAFTA) between USA, Canada and Mexico was ratified with devastating effects on the farm-gate price of maize (e.g. Nadal, 2002; Yunez-Naude, 2003; Appendini, 2008; Keleman et al., 2009). In a response, national and local governments developed policies such as subsidies and credits for alternative land-use types, to assist farmers to adjust their production systems.

In 1992, Mexico signed the legally binding Convention on Biological Diversity (CBD) at the Earth Summit in Rio de Janeiro. This initiated active national conservation policies. Mexico's natural protected areas program (1995-2000) was developed to expand protected natural areas (INE, 1999). The Mexican government established the 'La Sepultura' MAB Reserve as one of the pilot areas of the program in the northeastern part of the Sierra Madre de Chiapas, in 1995 (6°00'18" and 16°29'01"N and 93°24'34" and 94°07'35"W) (INE, 1999). MAB Reserves consist of core zones – in which human activity is strictly forbidden - and buffer-zones – where farming is allowed under a set of restrictions to protect the environment. Large-scale land clearing, timber and non-timber extraction except the collection of firewood, and the use of fire to clear and prepare fields for sowing are prohibited in the buffer-zone. La Sepultura Reserve (167 309 ha) consists of less than 10 % (13 759 ha) of core zone, fragmented in five patches, and the rest of the area (153 550 ha) is buffer-zone (Figure 1.3).

2.2 Mexican land tenure

Land reform that was promised after the Mexican revolution of 1910, only really began after the official re-introduction of the old Aztec *ejido* system in the mid 1930's. The *ejido* system is based on shared management of communal resources in which a fixed number of households have rights to land within an *ejido* - so-called *ejidatarios*. Households without such rights are called *pobladores* in this part of Mexico. An *ejido* is, in legal terms, a usufruct landholding peasant community in which land management is bound by government rules:

land cannot be sold, land and rights to land cannot be separated, and land and connected rights are transferred from father to one of his children - most commonly the oldest son (de Ita, 2006). Two democratically elected committees chaired by the village head perform the daily management of an *ejido*. Community decisions are made jointly by all *ejidatarios* during monthly meetings. *Pobladores* can participate in the meetings but do not have any official decision-making power within the *ejido*.

Within the neoliberal political view, *ejidos* were identified as inefficient low-productive units. Private ownership was assumed to lead to higher efficiency and productivity (see e.g.: Heath, 1992; Johnson, 2001). As part of the political transformation towards neoliberal politics, the Mexican land tenure system was changed to allow *ejidos* to pursue individual property rights, in 1992. In 1993, the Program for Certifications of *Ejidal* Rights (PROCEDE) was developed to establish and facilitate this change. The program allowed *ejidos* e.g. to choose property arrangements, measure and certify individual plots (Vázquez Castillo, 2004; de Ita, 2006). However, Reserve communities were excluded from this new legislation.

3 Material and methods

3.1 Study area

The smallholder community Tierra y Libertad (TyL) is near the ridge of the Sierra Madre de Chiapas mountain range in the upmost part of a watershed at an altitude between 900-1500 meter above sea level (Figure 1.4). The territory of the community is hilly with average slopes of 20° and extremes of 60° and accounts for some 3200 ha (Toupet, 2010). The climate is sub-humid tropical with an average temperature of 20-22°C. Annual precipitation is around 2000 mm of which nearly all occurs between May and October (INE, 1999). Soils are characterized by a shallow sandy clay loam top layer (60% less than 10 cm deep) (Toupet, 2010), under which sandy clay is found on a granite bedrock (INE 1999).

In the early 1960s, people arrived to the area as laborers in a private sawmill. These laborers developed forest-based livelihoods consisting of wage labor in the exploitation of timber and individual exploitation of non-timber products. The ornamental leaves of the wild Camedor Palm (*Chamaedorea spp.*) complemented very low wages at the sawmill in the initial phase of settlement. After the closing of the sawmill in 1972, the National government officially gave 101 households the right to use the land (2200 ha) in social usufruct, under the legal form of the Mexican *ejido*. In 1986, the National government granted the community a one-time only expansion of 1000 ha and 22 *ejidatario* positions. Soon after, land was de facto parceled and some people started to cultivate the lands cleared by the sawmill for agricultural activities, mainly maize cultivation for home consumption. However, the extraction of wild palm leaves persisted for many years and formed an important source of income for another part of the community. At the time of land allocation, the group of households that up to then had fully relied on palm extraction gave little attention and importance to the land they were granted. Consequently, they obtained less (and relatively more forested) land. On the other hand, those who focused on agricultural activities obtained more (and less forested) land. The distinct values attached to forest and the differences in landholdings, status and income has somewhat polarized these two groups over time. Since the closing of the sawmill, forest logging has become a complex issue led mainly by non-local actors. Therefore, it will not be extensively discussed in this chapter (for additional reading see: Dahringer, 2004).

In 1995, the 'La Sepultura' MAB Reserve was established with minimal involvement and consideration of the interests of the communities in the area. This together with the restrictions of the community's new Reserve-status, led to a conflict over land-use between TyL and the Reserve authorities between 2000 and 2004. In 2004, the Reserve authorities engaged researchers from Universidad Autónoma Chapingo to assess the situation and to suggest improvement opportunities. As a result, the NGO Pronatura-Sur A.C. started a participatory project on improving local social organizational structures and collective decision-making, which received some financial assistance of the Reserve. The NGO is the regional office of the internationally connected Mexican NGO Pronatura Sur A.C. and combines a conservationist approach focusing on the protection of flora and fauna with promoting community participation and social development (Pronatur-sur A.C., 2013). The community developed strong relations with the NGO and requested their assistance in several other projects such as on the development of alternative sources of income through sustainable land-use such as cultivation of the Camedor Palm and controlled sustainable timber extraction. The ornamental leaves of the palm are a key high-value product from the region.

Current land-use types include pasture-based livestock production, staple food production (maize and beans) and shade-coffee and palm cultivation in the understory of the existing forest. Three farming systems can be distinguished (i) cleared-field land-use type (livestock herding); (ii) forest-based land-use type (organic palm and coffee cultivation); (iii) a combination of cleared-field and forest-based land-use types. The former group of palm leaf extractors is now mainly devoted to forest-based farming systems. Maize production is a small-scale activity of all groups, but more common among (i) and (iii). An estimated 80% of the territory is under forest cover (Dahringer, 2004). This includes parcels with agricultural production such as shade-coffee and palm cultivation. Also livestock grazes in (partially) forested areas, especially during the dry season. Staple foods (maize and beans) are grown for home-consumption, whereas coffee and livestock are produced primarily for sales purposes and secondarily for home-consumption. Palm is cultivated as a cash crop. There is no regular local market for any of these products. Palm leaves are sold directly to an export company who sells the product to the U.S.A., coffee is sold in one of the nearest towns, whereas livestock is usually sold to visiting middlemen. Only under special circumstances e.g. family celebrations, sickness of a family member, or a failed harvest, excess produce is shared, sold or exchanged with those in need. The population of TyL was estimated at 750 persons with an average age of 24 years (SD = 18). The community has basic facilities, e.g. a small health clinic and rural schools from kindergarten up to lower-secondary school. Yet, it is remote and poorly connected to the nearest urban center and market.

3.2 Adaptive capacity assessment

Nowadays, adaptive capacity is most commonly analyzed and discussed in the context of climate change, however the term can be used more broadly to include responses to economic and institutional drivers affecting social-ecological systems (Olsson et al., 2004; Adger, 2006; Smit and Wandel, 2006). Adaptive capacity is fundamentally dependent on resource availability and the capability to utilize these resources (Nelson et al., 2007). However, resource availability is not an indicator of adaptive capacity but merely provides the potential for its development. Hence direct assessment of adaptive capacity is a challenge (Engle, 2011). Therefore, a wide range of methods is currently used to assess adaptive capacity including case studies, survey techniques, modeling, indicators and indices (e.g. Wall and Marzall, 2006; Plummer and Armitage, 2007; Huber-Sannwald et al., 2012). Here, we base our assessment on a comprehensive reconstruction of the community's driver-response history mainly focused on changes in land-use and associated social organization (1960-2010) through identifying a number of multi-scale intersecting processes of economic, institutional, social and agricultural change (Taylor, 2005). We identified and evaluated these responses using two criteria: (1) the type(s) of driver(s) that triggered response – past, current or expected, and (2) the intended objective of the response. Reponses triggered by past or current drivers and aimed at buffering the effects of only those drivers, were identified as coping mechanisms. Responses that were motivated (also) by expected drivers and that were aimed to develop resilient systems in view of these drivers, were classified as adaptation strategies. Finally, we evaluated the dynamics of adaptive capacity over time (1960-2010) based on the detailed driver-response history through a resource-based assessment framework (adapted from Yohe and Toll, 2002; Eakin and Lemos, 2006; Wall and Marzall, 2006). The framework consisted of a set of attributes that reflect six main resources of adaptive capacity, namely 1) social, 2) institutional and organizational, 3) political, 4) human, 5) natural, and 6) economic capital.

3.3 Primary data collection

This research was aligned with plans for a local participatory project on communal landscape planning supported by the NGO Pronatura-sur A.C. However, the research was performed without active collaboration of the NGO. Throughout the stay in the community, researchers did not show a preference for specific groups within the community nor for a specific land-use type. This and previous research projects were carried out with all groups of the local population and were of a neutral and descriptive nature. Before the start of the data collection, the objective and methods of the research were introduced and permission to execute data collection was asked during one of the monthly community meetings. At the start of each interview, the aim of the study and scope of the questions were briefly explained. After which the interviewee was asked if he/she was willing to participate.

3.3.1 Key stakeholder interviews

We performed open interviews with 17 key stakeholders to identify qualitative changes in land-use, land management and social organization at community level and their drivers. We identified key stakeholders as persons with a thorough understanding of: 1) land-use and social organization change in TyL e.g. farmers involved in the management of the *ejido* and/or producers groups, 2) economic and institutional drivers and land-use change in smallholder communities in Chiapas e.g. researchers, NGO staff, and 3) those involved in implementing local effects of global and national drivers e.g. reserve staff. We identified 17 key stakeholders through the snowball sampling method (Goodman, 1961), namely three researchers, three NGO workers, two Reserve employees, and nine farmers. In this method, interviewees are asked to identify one or several other potential interviewees. This method is commonly used to identify persons of interests unknown to the researcher. During the interviews, a variety of topics and subtopics related to the local historical changes and non-local drivers were discussed (Table 2.1). Interviews were performed in April 2010.

3.3.2 Household survey

We performed a household survey using a 50% sample to identify within a time frame 1960-2010): 1) drivers of local land-use, land management and social organizational change to complement and/or confirm those identified by key stakeholders, 2) land-use change, 3) changes in land management, and 4) changes in local social organization.

Table 2.1: Overview of interview topics applied to key stakeholders and household heads (50% samples of registered household N=151) performed in April and October 2010. All topics related to the time period since the first people arrived in the area in the early 1960s.

Topics	**Subtopics**
Topics discussed with key stakeholders and household heads	
Drivers and impacts	History of international, national and local policy changes affecting land-use in TyL
	Effects of policies on social organization and land-use
	History of land-use related projects in TyL
	Effects of projects on social organization and land-use
Local organization	History of social organization at *ejido* level
	History of producer groups
	Functioning and size of producer groups
Land-use change	Land-use change at *ejido* level
Additional topics included in survey with household heads	
Land ownership	Number of land units owned
	Area of each land unit
	When and how land units were acquired/lost
Land-use at field level	Land-use per land unit per year
Reasons for land-use change	Reason for land-use change at farm level using six options pre-identified through key stakeholders interviews: 1) product price, 2) subsidy program, 3) project, 4) biophysical aspects of the land unit, 5) social influences such as advise, imitation behavior and 6) other reason

We used a 50% proportional stratified systematic sampling method to identify the households to be interviewed. We used the local registration list of *ejidatarios* and *pobladores*. Off all 178 persons on that list, 27 were temporarily out-migrated at the time of the interviews. These were excluded from the sample for practical reasons. Then, with the assistance of the village head, we stratified the list based on the production focus of each household. After a random start in each of the strata on the stratified list, we systematically sampled every second person listed for each strata. This led to the following sample (N=151; n=75): 1) Staple foods n=16; 2) Coffee n=16; 3) Palm n= 6; 4) Livestock n=8; 5) Coffee & palm n=11; and 6) Coffee & palm & livestock n=18. The sample consisted of 54 *ejidatarios* and 21 *pobladores*.

The survey involved semi-structured interviews, in which we reconstructed a detailed land-use history at the field level of fields currently and previously owned by the interviewee. Basic field characteristics e.g. size, location, and the reasons to change land-use were also included (Table 2.1). The survey was performed in April and October 2010 by the first author and one field assistant. With permission of the interviewee, the interviews were recorded with a voice-recorder and data were registered on data sheets.

3.4 Data analysis

For the development of the comprehensive driver-response reconstruction, we first identified the main drivers as seen by the key stakeholders and household heads. Subsequently, we identified responses to these drivers in terms of: 1) changes in social organization, with sub-topics 1a) land tenure, 1b) producer groups, 1c) communal decision-making, and 1d) social cohesion, and 2) land-use and land management. Based on data gathered from key stakeholders, we developed a qualitative overview of the local driver-response history by plotting drivers, qualitative land-use and social organizational change on the same time line. Data collected through household surveys allowed us to quantify land-use change at the household and the community level by adding land-use change of the individual land units per household and then summing this information of all households. We further analyzed these driver-response relations by plotting drivers and the cumulative proportion of households performing a specific land-use activity – so-called adopters S-curve (Rogers, 1995). We analyzed household response trajectories to economic and institutional drivers by plotting the various land-use types (ha) over time. We qualitatively analyzed and described management and organizational changes mentioned by representatives of local producer groups, farmers and other key stakeholders.

For the assessment and identification of responses as coping or adaptation, we used two criteria namely (1) the type(s) of driver(s) that triggered change – past, current or expected, and (2) the intended objective of the response. Reponses triggered by past or current drivers and merely buffer the effects of those drivers, where identified as coping responses. Responses that were motivated by past and/or potential future drivers and that were aimed to develop systems resilience in view of these drivers, were classified as adaptation strategies.

Finally, we evaluated the dynamics of adaptive capacity through a set of attributes reflecting six capitals - social, institutional and organizational, political, human, natural, and economic capital - over time (1960-2010). This assessment was based on the driver-response reconstruction and the identified coping or adaptation mechanisms.

All except two attributes were assessed qualitatively. The attributes, 1) distribution of natural resources and 2) property rights arrangements were assessed (also) through quantitative household landholding data. We plotted landholdings of *ejidatarios* and *pobladores* - those that have legal rights to land and those who do not – against their age. In addition, we analyzed equality of land distribution using a Lorenz curve at three moments in time (Lorenz, 1905). Lorenz curves are commonly used to present the distribution of assets over a population. It forms a visual measure of (social) inequality. We developed these curves for three characteristic moments in time with equal time intervals: 1) 1980 – when both farming and social systems stabilized after the first establishment phase of the community, 2) 1995 – when conflicting drivers coincided, and 3) 2010 – current situation in which sustainable land-use and collaboration were initiated. Also, we calculated an additional curve to assess the effect of the locally developed property rights arrangements on land distribution. Therefore, we used data from 2010 and excluded landholdings from the officially landless. The landholdings that were excluded were: (i) land of *pobladores*, (ii) land of farmers who bought legal rights to land, (iii) land of farmers whose father still had rights to land, and (iv) land of farmers with landholdings brothers. In the last case, landholdings of the oldest son remained unaltered, whereas landholdings of all other brothers were excluded in the calculations of the curve.

4 Results

4.1 Driver-response relations

Over the 50-yr period considered, the complexity in the driver-response history of TyL increased substantially. A gradual increase in the number of multi-level drivers of change, both economic and institutional, led to concomitant diversification of types of land-use and the development of social organizational structures, as described in the following paragraphs (Figure 2.1).

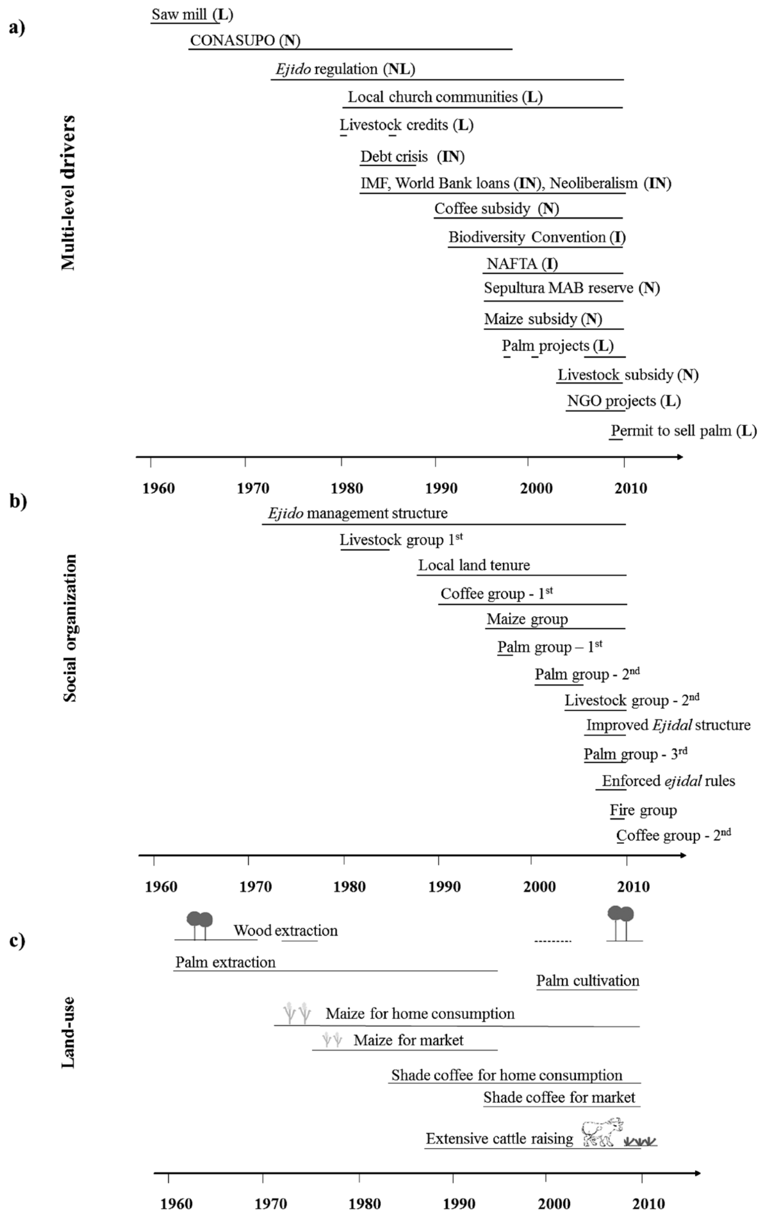

Figure 2.1: Historical overview of: a) multi-level drivers and the level: L- Local, N- National, I- International level drivers, b) social organization, and c) qualitative land-use change in Tierra y Libertad as identified by key stakeholders (1960-2010). Dashed and solid lines refer to illegal and legal land-use activities.

4.1.1 Economic and institutional drivers

Key stakeholders and household heads jointly identified 23 economic and institutional drivers for local land-use, management and social organizational change (Figure 2.1a). Almost all identified economic drivers, were connected to institutional changes.

The implementation of neo-liberal policies and the ratification of NAFTA led to a dramatic decline (by 35%) in local maize prices between 1986 to 1994 as identified by households and supported by local data. Farmers mentioned that during the same period, fertilizer prices strongly increased. Farmers mentioned that while before NAFTA one ton of maize could be used to buy two tons of fertilizer, after NAFTA two tons of maize were needed to buy only one ton of fertilizer. The establishment of the Reserve and the connected forest protection regulations were identified as a strong driver that limited land-use options. Credits from local governments became (temporarily) available to assist farmers to adjust their farming systems to new neoliberal market dynamics and to reduce the negative effects of NAFTA on rural livelihoods. Credits to establish livestock production were obtained by a group of farmers in 1980 and 1985. Since the early 1990s, the National government developed and implemented subsidy schemes for specific land-use types for the same reasons. These subsidy schemes were meant to be phased out after a few years. However, all schemes remained functional for many years. In 2010, annual subsidies ranged around MX$ 950 (=US$80) for a hectare of maize (PROCAMPO), MX$ 350 (=US$30) per animal (PROGRAN), and MX$ 1500 (=US$125) for a hectare of coffee.

Farmers did not mention changes in product prices due to economic market dynamics as drivers of change for most products except for maize. Local coffee prices were reported low for until 2004. Since 2004, prices tripled due to access to certified organic coffee markets (see Section 4.1.2.). Livestock prices gradually decreased since 2001. The prices for palm leaves increased as a consequence of shortening commercialization channels, and contracting and selling directly to a wholesaler.

4.1.2 Changes in social organization

Changes in social organization throughout the period considered were shaped by four intersecting processes: (i) The establishment of the *ejido* structure and its implications on the land tenure system, (ii) the creation of producer groups, (iii) the gradual emergence of communal decision-making (cf. Figure 2.1b), and (iv) an increasing social cohesion.

Land tenure system

In response to official land access under *ejido* law, the community developed local land tenure, to allow more households access to land. These arrangements included: (1) land in long-term use became locally regarded as full ownership, (2) land-use rights and land "owned" became separable, (3) both land and land-use rights became tradable, and (4) *pobladores* and other people without legal rights to land were allowed to buy land and/or land-use rights. Where officially only *ejidatarios* had access to land, land became accessible to any member of the community. In 2010, 60% of officially landless (*pobladores*) owned land (Figure 2.2a). Land distribution grew more unequal between 1980, 1995 and 2010. In 2010, 10% of households jointly owned 40% of the land. However, locally developed land tenure arrangements seemed to have dampened the growing inequality (Figure 2.2b).

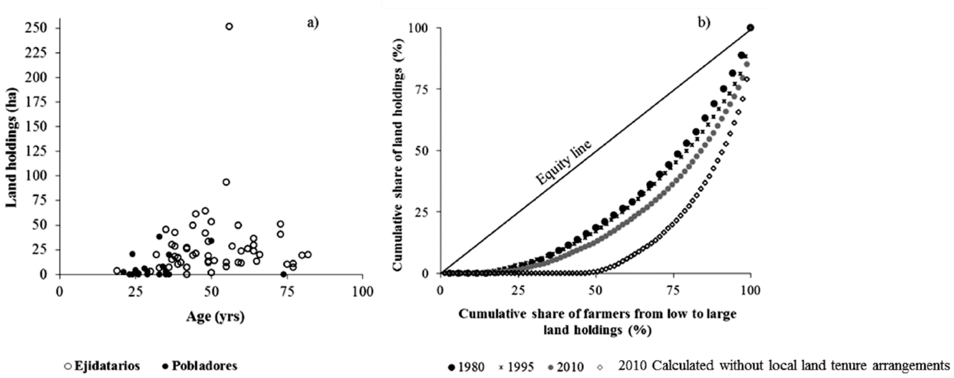

Figure 2.2: a) Individual landholdings (ha) plotted against age of ejidatarios and pobladores; b) Land distribution equality in three characteristic moments in time with equal time intervals (1980, 1995 and 2010), and a calculated land distribution curve based on 2010 without land holdings obtained through local land tenure arrangements. Data were based on a 50% sample of all registered household heads (N=151) collected in 2010 in Tierra y Libertad.

As a result of the changes in National land tenure in 1992, PROCEDE initiated land mapping activities in the mid-1990s. However, these land mapping activities were never finalized. Nonetheless, PROCEDE changed the documents that showed the location of the parcels held in long-term use by the *ejidatarios*, for documents with merely a percentage of the *ejido* territory that could be used by the *ejidatario*. Parcels were no longer identified on these documents. Several farmers mentioned that they were confused and worried about this change. Nonetheless, locally developed land tenure arrangements continued to be respected.

Producer groups

Since 1980, groups of farmers jointly developed so-called producer groups. These producer groups were commonly based on and focused towards the management of a particular land-use type and the production and/or sale of the associated products. Objectives, rules, regulations, goals, criteria for membership differed strongly among groups. In 1980 and 1985, the first producer groups were established to obtain livestock credits, which were only available to groups of farmers. These groups were developed to obtain credits for livestock production, which were only available to groups of farmers. Farmers in these groups collaborated in livestock management and in repaying the credits. After one or two years credits were paid off, and these groups fell apart. Collaboration of livestock management also stopped. The development of these first livestock producer groups initiated large-scale land-use change (Figure 2.3a; 2.3b). In the early 1990s, producer groups for coffee and maize production were initiated to apply for governmental subsidy schemes which were only available through a community-based application. In 2003, a producer group for livestock was established for the same reason. Members of the coffee, maize and livestock producer groups only collaborated in the application and distribution of the benefits of the respective subsidy schemes. Only farmers that were already involved in the respective land-use were allowed to apply within the first application for the subsidy. The establishment of these subsidy-based producer groups was not reflected in land-use changes (Figure 2.3a; 2.3b).

In 1997, 2000 and 2005, producer groups for palm cultivation were initiated. The first two palm groups were initiated and financed by the local municipality through a project to establish alternative production systems based on cultivation of palm and dissolved soon after establishment. The third group emerged from the community and was supported by the NGO and was more persistent. The cultivation of palm was a new activity started by one local farmer in the early 1990s, while other farmers were not interested. When the first project started in 1997, there was no legal permission to sell palm leaves from reserve grounds. Consequently, farmers were not interested in the cultivation of palm and only participated in the project for the initial wage labor to establish a palm nursery. Once the nursery was established and wage labor stopped, the group fell apart. After 2000, a few farmers had started palm cultivation with young palm seedlings from the nursery in the forested parts of their landholdings. In 2005, a new producer group for palm cultivation was developed with the help of the NGO Pronatura-sur A.C.. The reserve supported the project through partially funding the project. Farmers could join the producer group irrespective of palm cultivation activities, if they were committed to participate according to rules and regulations developed by the group. Group members collaborated in the seedlings preparation in the nursery and post-harvest and sales activities. Farmers participated in workshops on cultivation practices for palm, but managed and harvested palm individually. As a result, product quality improved and the community obtained a permit for sustainable harvesting and selling non-timber products from forest plots including palm leaves, in 2008.

In 2010, an additional producer group for coffee was established. This groups developed rules and regulations to establish collaboration among its members similar to those developed by the palm producer group. Through this collaborative effort, the group obtained organic certification and consequently higher prices. Since 2000, the relative area cultivated with palm and coffee gradually increased (Figure 2.3b). In 2010, five producer groups were present; 1) maize group with 90 members, 2) coffee group to receive coffee subsidy with 83 members, 3) coffee group established in 2010 with 56 members, 4) livestock group with 34 members, and 5) palm group with 55 members.

Communal decision-making

At the beginning of the settlement, no communal decisions were made. With the establishment of the *ejido*, the associated organizational structures that guide communal decision-making were implemented i.e. two managing committees and monthly meetings. However, these structures were ill-developed and land-use decision-making resided almost entirely at the household level. For example, the extraction of palm leaves was not regulated which resulted in the near extinction of palm plants in a large area surrounding the community. Communal decision-making was substantially strengthened by a project initiated by the NGO Pronatura-sur A.C. in 2004. Participation in local decision-making improved through increased active participation of households in: 1) monthly *ejido* meetings- these meetings became obligatory for all *ejidatarios* and *pobladores*, 2) management of the *ejido* and its various committees, and 3) regular planning meetings to prepare the monthly *ejido* meeting. The latter strongly improved the structure and focus of discussions during the *ejido* meeting. The community agreed on the establishment and implementation of stronger local rules and regulations. These included the enforcement of penalties for absence during the meetings and the breaking of agreements e.g. illegal logging and fire use. The improved communal decision-making increased the community's credibility with non-local actors such as the Reserve authorities. As a result, the Reserve and the community agreed on re-introducing selective fire use to clear fields under strict regulations and enforced penalties, in 2010.

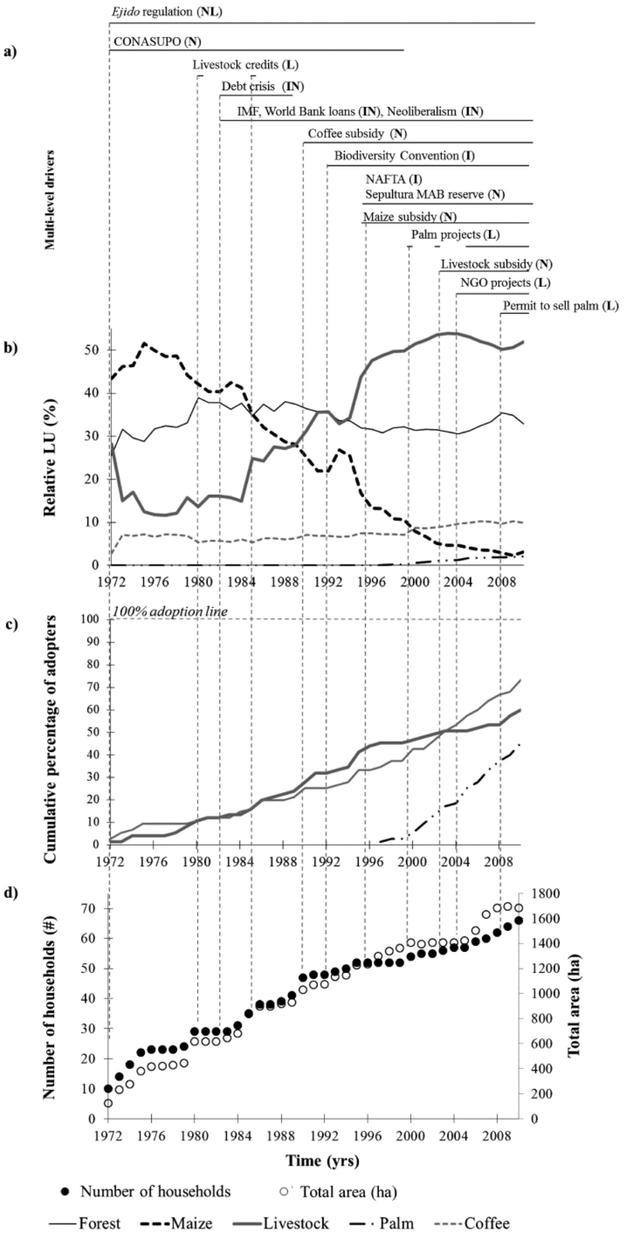

Figure 2.3: Multi-level drivers and land-use change in Tierra y Libertad between 1972-2010 based on 50% (n= 75) sample of all registered household heads (N=151), showing: a) multi-level drivers - b) relative land-use change, c) cumulative percentage of farmers per land-use type, and d) total area and number of households reporting over time. The level of the drivers is indicates between brackets as: L- Local, N- National, I- International level drivers.

Social cohesion

From the early 1960s until the early 1980s, there was little social cohesion in the population. Initially the community consisted primarily of men who had arrived mostly without their families. The living conditions were described as extremely harsh. The settlement was isolated without roads, bridges or other infrastructure to connect it to a village or urban center. Reaching an urban center required a 1.5 days walk and involved crossing the local river 28 times. Under these conditions, many people left while also new people arrived. In 1972, the sawmill closed and wage labor was no longer available. As a result, many people left and those who remained were forced to change their life style dramatically, from laborers to self-sufficient smallholder farmers. Most of the families of those who decided to stay arrived. Social cohesion slowly increased among the remaining households. However, the outmigration of households created available *ejidatario* positions, which in turn resulted people migrating into the *ejido*. In the early 1980s, all *ejidatario* positions were occupied and migration rates decreased. During the same period, several church communities were established. These attracted many members and increased trust, faith and tolerance.

The improvement of community life was only briefly disrupted in the mid-1990s, when temporary out-migration increased strongly. In 2010, almost every household reported that one or several household members were or had been temporarily out-migrated to the USA in response to the implementation of land-use restrictions by the MAB Reserve, and the devastating effects of neoliberal agricultural policies. Mainly men emigrated, which disrupted the male-dominated *ejido* decision-making and management. Most emigrants returned after a few years without the expected economic gains.

Social cohesion in the community was also demonstrated by the organized resistance to the establishment of the Reserve and its limitations on land-use (period 2000-2004). The development of various local (producer) groups and improved *ejido* management was a sign of improved social cohesion. At the same time, these local organizational structures stimulated social cohesion even further. The unequal land distribution and the large discrepancy between official and local land rights led to discussion on potential re-distribution of land among like-minded community members i.e. landless, farmers with large landholdings.

4.1.3 Changes in land management

Land management and the production of agricultural products were predominantly unsustainable from the early 1960s until 2004. The extraction of forest products was not compensated by a sufficient resting period for regeneration. Initial agriculture focused on small-scale staple food production with low external inputs. Between the late 1970s and

1980s, maize production was intensified with increasing amounts of external inputs e.g. artificial fertilizers and pesticides purchased with (local) loans. Maize became a cash crop produced at large-scale. Fallow periods were shortened and fire was introduced to facilitate sowing and germination. However, no clear protocol developed on the use of fire. Consequently, the risk for bush-fires increased. In addition, the use of fire left the land bare at the start of the rainy season and thereby increased run-off and erosion. Farmers used increasing amounts of fertilizers and chemical pesticides to maintain production levels in order to pay off loans in the form of fertilizers, seeds and/or money received to initiate production. Since 1995 when the use of fire became prohibited, farmers increased the use of chemical herbicides to clear fields from weeds for the next cropping season.

When livestock was first introduced, livestock numbers were low. Local livestock production was primarily focused on livestock rearing. Young male animals were sold, while the female calves remained in the herd. Consequently, the number of livestock increased fast, grazing pressure increased steeply and pastures were overgrazed. Signs of soil degradation e.g. soil compaction, formation of trenches, and bare soil, were seen throughout the pastures. Since 2009, some farmers experimented on an individual basis with the production of grass that was suitable to feed livestock through cut-and-carry and reduce the grazing pressure in their pastures.

Under guidance of producer groups and with the help of the NGO, alternative land-use types such as palm and shade-coffee were established and/or expanded. Coffee and palm were managed organically in the understory of the existing forest, with minimal manipulation of the existing forest and without external inputs.

Stated reasons for land-use change

Reasons for land-use change as stated by farmers differed strongly (Table 2.2). Product prices could only partially explain land-use change. Product price was only identified as a strong driver of land-use change in the case of the large decrease in farm-gate price of maize as a result of neoliberal policies and the ratification of NAFTA. Farmers did not identify the gradual decrease in livestock prices since 2001 as drivers of land-use change, nor was this found in data (Figure 2.3a). When coffee prices were low, the relative area with shade-coffee expanded. Whereas only marginal increases were seen when coffee prices increased strongly between 2004 and 2010 (Figure 2.3b, 2.3c). Until 2008, there was no official market for palm leaves or permission to sell them. However, the number of palm producers increased strongly since 2000. After 2008, when selling palm leaves was officially permitted and prices shortly increased, the number of palm producers continued to increase at a similar rate (Figure 2.3c).

Table 2.2: Stated reasons for land-use change at household level. Household heads were asked to state the reasons for their land-use change. They were allowed to give more than one reason per land-use change.

Reason	Maize	Livestock	Coffee	Palm
Household needs	8	1	9	0
Land characteristics	1	5	9	3
Price	2	8	11	9
Recommendations from others	0	1	18	2
Participatory local project	0	0	0	20
Subsidy	0	0	1	0
Other	0	6	5	3
TOTAL	**11**	**21**	**53**	**37**
Total households producing (#)	36	37	55	36
Households that gave reason (#)	9	16	38	27

4.2 Coping and adaptation

Based on the detailed driver-response history, we identified two coping and five adaptation mechanisms. Within the analyzed time frame, coping mechanisms were gradually replaced by adaptation strategies (Table 2.3). The identification and assessment of the response mechanisms are described chronologically in the following paragraphs.

In the late 1980s, the community developed local land tenure arrangements in response to the rejected request for expansion of the *ejido*. These arrangements differed from the official *ejido* land tenure and were aimed to allow future access to land to more households. As such, we identified the arrangements as an adaptation strategy. These arrangements seemed to have dampened the growing inequality in land distribution (Figure 2.2b) and 60% of *pobladores* owned land at the time of the survey (Figure 2.2a). However, *pobladores* owned on average 9 ha of land, whereas *ejidatarios* owned on average 28 ha. Prices for land were not regulated within the new arrangements. This resulted in large difference in prices being paid for land and/or land-use rights. In addition, land inheritance and division of land among children was also not regulated. In short, the locally developed land tenure arrangements allowed more households to have access to land, but landholdings remained largely determined by the inheritance of land, use rights and/or monetary assets, which in turn could be used to purchase land and/or use rights.

In the mid-1990s, large-scale land conversions and temporary migration were the immediate response mechanisms to past drivers. Especially farmers that had specialized in

Table 2.3: Overview of identified driver-response relations in Tierra y Libertad (1960-2010); showing: 1) the time period, 2) description and level of driver(s): **L**- Local, **N**- National, **I**- International level drivers, 3) description of response, 4) response type, and 5) resources that facilitated the response. The level from which the driver originates

Time	Description and level of driver(s)	Response	Response type	Resource
Late 1980s to 1990	Rejected request for expansion of the *ejido* (N)	Local land tenure	Adaptation	Social capital
	Availability of livestock credits (L), Local impacts of : - National implementation of neoliberal policies (N) - Ratification of the international NAFTA (I)	- Large-scale land conversion from maize to livestock production	Coping	Natural and economic capital
1995 to 2000	Local impacts of the following coinciding drivers: National implementation of neoliberal policies (N) - Ratification of the international NAFTA (I) - Signing of the Convention on Biological Diversity (I) - Implementation of National biodiversity conservation policies (N) - Establishment of the La Sepultura Reserve (NL) - Land-use restrictions (L)	- Large-scale land conversion from maize to livestock production	Coping	Natural and economic capital
		- Temporary out-migration	Coping	
2005 to 2010	Local impacts of the following coinciding drivers: - National implementation of neoliberal policies (N) - Ratification of the international NAFTA (I) - Signing of the Convention on Biological Diversity (I) - Implementation of National biodiversity conservation policies (N) - Establishment of the La Sepultura Reserve (NL) - Land-use restrictions (L) - Conflict with Reserve authorities (L)	- Land-use diversification	Adaptation	Natural capital
		- Strengthened community decision-making	Adaptation	Human resources
		- Improved social organization	Adaptation	Human resources
		- More sustainable land-use	Adaptation	Natural and human capital

maize production swiftly converted their farming systems from maize production to livestock herding. However, an immediate shift in production system was not possible for households that had based their livelihoods on palm extraction. This group owned relatively more forested land, which no longer could be deforested. From this group, many responded by temporary out-migration to provide their families that remained in TyL with (additional) cash income. However, temporary out-migration became also common practice in the households that shifted to livestock rearing. Livestock rearing was less labor-intensive than maize production and especially the sons of these households left temporarily to the U.S.A. All migrants planned to return to their families after a few years and almost all did. After their return, farmers invested their (minor) economic gain in land, livestock and/or the building of a house. We identified both large-scale land conversion and temporary out-migration as coping mechanism.

We identified the following response mechanisms in relation to the impact of past and future (coinciding) economic and institutional drivers since 2000: (i) diversification of land-use, (ii) improved social organization, (iii) improved communal decision-making, and (iv) more sustainable land management.

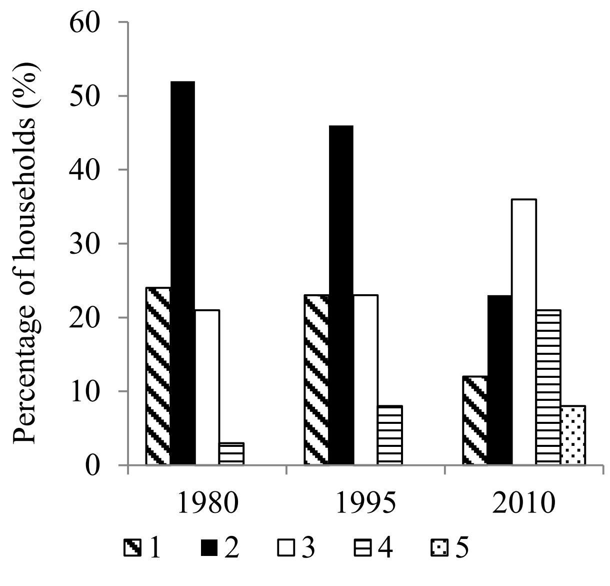

Figure 2.4: Overview of land-use diversification at household level over time. We show the percentage of households with 1 to 5 land-use types (LU) at three moments in time, namely 1980, 1995, 2010.

Land-use change at farm level was characterized by diversification through the introduction of alternative land-use types such as palm and organic coffee cultivation. Farmers steadily increased the number of land-use types managed in their farms from 1980 to 1995 and 2010 (Figure 2.4).

Many farmers stated that they diversified to deliberately increase their system's resilience and safeguard their income in case of future irregularities such as price drops or institutional limitations a possible future change in profitability of one product due to climate, policy or market changes. They mentioned that the sudden decline in maize price and their sole reliance on maize, taught them that diversified farming increased their changes to be able to provide for their families in the long-term. At the same time, it reduced the risk that they would have to leave their families to find wage labor elsewhere. At community level, land-use was marginally diversified. Only a little over 10% of the area in production was devoted to agricultural activities other than livestock herding.

Diversification differed among households. In general, the former group of palm leaf extractors, continued to focus mainly on forest-based land-use types, shade-coffee and/or palm cultivation (Figure 2.5a). Farmers with intermediate landholdings diversified most by producing livestock, palm, and coffee. Many of these farmers had returned from abroad with some savings (Figure 2.5b). In contrast, farmers with the largest landholdings who converted their maize production areas to pastures remained mainly focused on livestock with sometimes some shade-coffee production for home-consumption (Figure 2.5). As such diversification was an adaptation strategy with differed numbers of land-use types incorporated into their farming systems for all households except few farmers with very large landholdings. Both *ejidatarios* and *pobladores* diversified their farming systems. However, in general *pobladores* owned less land, which often meant that they had fewer options for diversification.

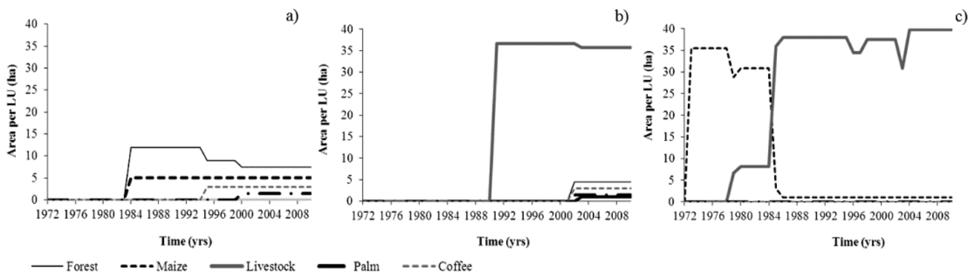

Figure 2.5: Three land-use change trajectories showing household division of land-use types in ha over time of: a) early diversification, b) late diversification, and c) specialization.

Several farmers explained the implementation of more sustainable land management as originating from a necessity to protect and maintain local natural resources for future generations. The protection of clean drinking water, and maintaining forest cover to reduce risk of mud- and landslides were pointed out most commonly. Many of these households also talked about the community's responsibility through the unique location of their territory at the top of the watershed towards other downstream communities. Mainly farmers involved in shade-coffee and/or palm cultivation mentioned these views. As a result of the conflict between reserve staff and TyL, the NGO supported project on communal decision-making, strengthened the credibility of *ejido* management within and outside the community. While participation of all registered heads of household in communal decision-making increased, the management of the *ejido* and its organizational structures remained with a relatively small group. This group consisted mainly of *ejidatarios* with diversified farming systems with both cleared-field and forest-based land-use types. We identified all four response mechanisms as adaptation strategies, which gradually replaced coping.

4.3 Adaptive capacity assessment

We found that 8 of 13 evaluated attributes improved, two attributes deteriorated and the remaining three remained unchanged (Table 2.4). The improvements in adaptive capacity coincided with the identified gradual shift from coping to adaptation.

Social, institutional and organizational, and political capital increased due to a mixture of factors: the arrival and presence of the protestant church improved governance and property rights transfer and the emergence of producer groups. Facilitated by the participatory NGO project, local social organization became more decentralized and democratic, and community participation increased. These changes resulted in the development of commonly respected rules and the implementation of penalties for violation of regulations. The *ejido* governance became more effective in collective land-use management, subsequently decision-makers in *ejido* and producer group management became more credible within the *ejido* as well as with non-local actors. These projects assisted the community to self-organize and empowered the community in their internal and external affairs with others. The developed organizational structures and functioning of producer groups (especially those of palm and coffee producer groups) improved by self-enforced rules to increase participation, shared decision-making and gain better prices for their produce. In addition, the resulting self-organization allowed the community to access and use their natural forest resources in a sustainable manner.

Table 2.4: Evaluation of adaptive capacity in Tierra y Libertad between 1960-2010 using a resource-based framework (adapted from literature; Yohe and Toll, 2002; Wall and Marzall, 2006; Eakin and Lemos, 2006).

	Attributes	Change
Social capital	Social cohesion in the community	+
	Credibility of decision-makers	+
Institutional and	Structure of institutions	+
organizational capital	Effectiveness of organizational structures	+
	Property rights arrangements	+
Political capital	Participation	+
	Decentralization	+
Human capital	Formal education	+/-
	Capacity building	+
Natural capital	Availability of natural resources	+/-
	Distribution of natural resources across population	-
Economic capital	Availability of financial instruments (credits, subsidies)	-
	Income	-

The improvements in human capital were less prominent. Although the enrolment in formal education (up to secondary school) increased, the incidence of illiteracy and functional illiteracy remained high. However, the organizational and management skills of some community members increased through capacity building by NGO projects.

Natural capital was under pressure, especially in the non-forested agricultural fields. In 2010, the number of households was 40% larger than the official *ejidatario* positions so that more households had to live of the same amount of land. Since the establishment of the Reserve, the use of the existing cleared land available for agriculture land had become more intensive. The erosion risk had first declined after the strong reduction in the cultivated area of maize on the sloped fields, which were converted to grassland with a permanent ground cover, but later the erosion risk increased again due to increasing grazing pressure in those pastures. Controlled timber harvesting and alternative forest-based production systems can potentially be beneficial for biodiversity and ecosystem services, if planting and harvesting are carried out responsibly.

Economic capital was under pressure. Although income was not specifically measured in this study, many farmers mentioned that their financial status deteriorated. Financial security was reduced due to the loss of the secure income of maize. Palm production was identified as an alternative secure source of income, with high and stable prices. During the last few years also revenues of coffee were good. However, coffee prices were perceived as more volatile and less secure. The available subsidies were too low to significantly increase income. Also, credits were no longer available after livestock credits in 1980 and 1985 (Table 2.4).

5 Discussion

This study contributes new and grounded evidence on how land-use and natural resource management by smallholder communities are shaped by intersecting multi-scale processes of economic, institutional, social and land-use change. Major adaptations to the economic and institutional drivers examined here were based on diversified and more sustainable land-use types, and on the development of diverse institutions in which decision-making processes became more inclusive, democratic and decentralized. Between 1980 and 2010, the percentage of households specialized in one land-use type dropped from 24% to 12%; and the percentage of households with more than three land-use types increased from 24% to 65% (Figure 2.4). Land management became more sustainable with the introduction of organic palm and later the expansion of organic coffee cultivation in the existing forest. Producer groups were formed to further improve management, product quality and price. Communal rules and regulations were developed and enforced, including fines for breaking of the communal agreements such as absence from community meetings or unauthorized timber harvest. The nature and responsiveness of the adaptations developed were determined by the community's improved adaptive capacity, in particular improved social, institutional and political attributes of adaptive capacity. Natural, economic and human capital remained weak and under pressure.

The main drivers identified by key stakeholders and farmers were consistent with literature (Nadal, 2002; Yunez-Naude, 2003; Appendini, 2008; Keleman et al., 2009) and price databases (ICO, 2010; SIAP, 2010). Diversification of production and income, as developed in our study area, has often been shown to reduce the vulnerability to external drivers and improve adaptive capacity, as reported for case studies in Vietnam (Adger et al., 2002), Tanzania (Enfors and Gordon, 2007), Argentina (Easdale and Rosso, 2010), Mexico (García-Barrios and García-Barrios, 1990, 1992; Ribeiro Palacios et al., 2013), Brazil (Simões et al., 2010) and a wide range of case studies from Latin-America (Speelman et al., 2008; Astier et al., 2011). The development of more sustainable land management practices in itself has been reported to have long-term positive effects on the adaptive capacity of communities. In the highlands of Chiapas, farmers developed innovative soil conservation practices after the devastating hurricane Stan that passed through the area in 2005 (Cruz-Bello et al., 2011). However, diversification and/or sustainable natural resource management practices may not be able to ensure adaptive capacity per se in the absence of effective communal decision-making institutions. The existence of strong social organizational structures or institutions is deemed to be essential for improving adaptive capacity and developing long-term adaptations (Ostrom, 1990, 1999; Adger 2006). The importance of strong networks and producer groups was demonstrated in a neighboring community of TyL, in which the development of these networks led to increased resilience of the social-ecological systems (García-Amado et al., 2012). Assistance from external sources to empower and assist the local community to self-organize, as seen in TyL, was deemed essential for responding to change in a sustainable manner (e.g. Fabricius and Collins, 2007).

The circumstances that allowed for the development of adaptation strategies were characterized by three concurring elements: (i) the long-term support of a NGO, (ii) access to vast forest resources that allowed for the development of sustainable forest-based alternative land-use types, and (iii) a local population highly motivated to improve the resilience of their system. The NGO served as an intermediate, seemingly neutral organization to bridge the gap between interests of the community and of non-local actors. The role of such intermediaries can be crucial and has also been shown in other cases (e.g. Berkes, 2008). The presence of ample forest resources suitable for alternative non-timber production systems was found important to reconcile competing claims on land resources in various other cases (cf. Kusters et al., 2006; Campbell et al., 2010). The motivation of the local population to improve the sustainability of their systems was confirmed by many members of the community who referred to their "obligation" vis-à-vis the conservation of natural resources for future generations. We believe that this strong intrinsic motivation could be partly explained by the history of the community. The *ejido* was for all households the first and only opportunity to own land and build on a long-term future. Leaving the *ejido* due to a lack of capacity to adapt to a new and changing situation was felt to be equivalent to giving up their security. The minimal economic gains of the temporary emigration wave that resulted from coinciding drivers – drop in maize price and land-use restrictions (Figure 2.4) – might have further increased motivation for local adaptation, as also leaving the *ejido* seemed barely attractive.

This study was based on a detailed research in one community, which was specifically selected for its history, location and pre-identified signs of adaptation. Consequently, local responses to drivers and improvements in adaptive capacity were highly site-specific. Such site-specificity often prevents a comparative analysis and generalizations on adaptive capacity (Engle, 2011). However, we believe this case study allows for some generalizable observations. The drivers identified in this study all originate from global trends that are affecting many (smallholder) farming communities all over the globe, namely liberalization of economies and increasing claims for nature conservation (Kiers et al., 2008). The complexity of the multi-scale intersecting processes of economic, institutional, social and agricultural change, analyzed here, shows the need for more comprehensive integrated studies, to fully understand the interplay between coping and adaptation. Diversification and the development of strong social organization and institutions appeared to be key in improving adaptive capacity.

6 Conclusions

The capacity of agricultural communities to adapt to the current fast-changing social-ecological environment is key in securing the continuation of livelihoods in rural parts of the world. Although the attributes that underpin resilience of social-ecological systems are widely agreed upon in literature empirical evidence on how rural communities adapt to this changing environment is still scarce. This study provided an example of a community that managed to transform itself from a situation in which non-local drivers led to serious conflicts, to an example community similar to other Mexican ones famous for their sustainable resource management such as Sierra Morena in Chiapas (García-Amado et al., 2012), San Juan Nuevo Parangaricutiro in Michoacán (Orozco-Quintero and Davidson-Hunt, 2009) and a collective of *ejidos* in Quintana Roo (Bray et al., 2003). The approaches taken by the community studied here were based on: (1) land-use diversification, (2) more sustainable land management, (3) improved social organization, and (4) strengthened communal decision-making. Communal forest resources, long-term support of an NGO and a highly motivated population, were essential circumstances that allowed for these trajectories of change. However, in spite of the emergence of seemingly solid mechanisms of communal decision-making in TyL, we identified issues that could undermine future communal decision-making and seriously debilitate the dynamics of adaptive capacity. Natural resources remained under pressure with a fast-growing population. There was discrepancy between official land tenure and local land tenure arrangements. In addition, land was unequally distributed among households with 10% of farmers who jointly owned 40% of the land. We showed that under the current situation the number of actual and official landless increased. This trend could undermine the current move towards improved communal decision-making. Unequal power distributions within communities could negatively affect social cohesion, effectiveness of local institutions, poverty reduction and lead to environmental degradation (Boyce, 1994; Boyce et al., 1999; Pérez-Cicera and Lovett, 2006; García-Amado et al., 2011). Improving adaptive capacity is an ongoing process in which communities and supportive organizations need to be aware and capable to adjust continuously to prevent today's adaptation strategies from becoming tomorrow's coping responses.

Chapter 3

Participation through gaming: a land-use board game

Smallholder farming systems often consist of a mosaic of interlinked forested and cleared-field patches that together provide a diversity of services to local and non-local stakeholders. Designing and adopting more sushtainable farming systems for such mosaic landscapes involves communal decision-making and active participation of local smallholders. Currently, a wide variety of participatory approaches to involve individual farmers in such design processes are available. However, methodologies that address communal decision-making processes as seen in complex smallholder agricultural landscapes are still rare. Here, we present a gaming methodology developed to (i) actively involve farmers in the process of agroecosystem design, and (ii) to identify factors and patterns of communal decision-making through an in-depth analysis of game strategies deployed by participants. At the basis of this methodology is the RESORTES board game; a stylized yet complex land-use game rich in ecological and social outcomes. Results of four pilot sessions in a usufruct community in the buffer zone of a Man and Biosphere Reserve in Chiapas, Mexico, showed that the game sessions created an open and active discussion among participants. Discussions concerned land-use issues in the game and in real-life. It allowed participants that were new to active involvement in communal decision-making to openly discuss and share their ideas. The highly structured monitoring and analysis scheme for ex-ante/ex-post analysis was easy in use and identified communication, leadership and relatedness among participants as influential factors that smoothened the collective decision-making process. The RESORTES board game and related games can shed light on farmer´s actual views on and responses to multifunctional agricultural landscape planning and the land sharing vs. land sparing dilemmas currently in debate in academic and policy-making settings. The findings of this chapter can be useful to inform strategies for community involvement in agroecosystem design in a broader set of complex socio-environmental context, using serious game to guide agricultural landscape planning processes.

Based on: Speelman, E.N., García-Barrios, L.E., Groot, J.C.J., Tittonell, P., 2014. Gaming for smallholders' participation in the design of more sustainable agricultural landscapes. Agricultural Systems 126, 62-75.

1 Introduction

Smallholder farming systems often consist of a mosaic of interlinked forested and cleared-field patches that together provide a multitude of services to local and non-local stakeholders (e.g. Speelman et al., 2006; Jackson et al., 2007). Over the last decades, many of these ecosystem services degraded due to unsustainable land-use change triggered by institutional, market and policy drivers (Wadley et al., 2006; García-Barrios et al., 2009; Ribeiro-Palacios et al., 2013; Chapter 2). Consequently, the design of more sustainable agricultural landscapes gained importance among a wide range of institutes and organizations (Wegner and Pascual, 2011; Astier et al., 2012). Increased societal awareness on the negative externalities of agriculture pushed governments and markets to develop mechanisms that directly and/or indirectly reward farmers for developing and/or adopting more sustainable agricultural systems that maintain ecosystem services within an agricultural landscape e.g. shade coffee certification, Payment for Ecosystem Services (PES) and carbon sequestration (Antle et al., 2003; Perfecto et al., 2005; García-Amado, et al., 2011). Nowadays, farmers are influenced in their decision-making by often conflicting schemes. The associated economic incentives can deteriorate local social norms and institutions by inducing or increasing competition and individualism among community members (Gómez-Baggethun et al., 2010). However, the requirements and the environmental effects of many of these schemes extend beyond farm level and thereby challenge farmers to coordinate their activities. Coordination is particularly important in smallholder farming where a multitude of farmers manage a mosaic of plots (van Keulen, 2006; Herrero et al., 2010). Therefore, the study of the design of more sustainable agricultural landscapes and institutions for their stewardship requires the active participation of local farmer groups as a first step towards adoption of the designed landscapes and institutions, especially where landscape planning includes coordination among individual farmer's decisions.

Participatory approaches to enhance stakeholder involvement in agroecosystem design and implementation processes have been available for some time now (e.g. Rapid Rural Appraisal, Participatory Rural Appraisal, Participatory Action Research – cf. Pretty, 1995). However, methodologies that specifically allow participants to safely enact and explore the benefits and challenges of complex collective land-use decision-making during the learning process are scant. Since the first development of games as tools to facilitate learning in business education (Duke, 1974), games have been developed and used in a variety of settings for distinct goals (e.g. Dörner, 1996; ISAGA, 2013; Chapter 4). In the field of agriculture and natural resource management, games have in particular been developed as discussion and decision support tools (e.g. Barreteau et al., 2003; Collectif ComMod, 2014).

These games are commonly developed as open-ended board games in which goals and rules have many degrees of freedom and therefore the solution space of the game is mostly unknown. Games with an unknown solution space are difficult to reproduce and options for systematic comparison of results are limited (Bousquet et al., 2002). Some of these games are closed games, in which the goals and rules define a large but countable set of solutions which can be revealed through analytical and simulation methods. These generally simpler and more stylized games are used in an experimental set up that allows replication of results with various groups of participants (Falk and Heckman, 2009; Janssen et al., 2010) and allow the testing of specific experimental hypotheses about the relation between game outcomes and the attributes and behaviors of players (Janssen, 2010; García-Barrios et al., 2011).

However, analysis of communal decision-making through games has mainly been conducted within relatively simple settings of joint management of a single common pool resource (e.g. Ostrom, 2006; Janssen et al., 2010) without capturing the complexity of the coordination of communal agricultural landscape planning - even in a very stylized manner. Some stylized natural resource games are now moving towards two or more resources, multiple choice decision-making with many interactions, both positive and negative externalities and stakeholder participation (e.g. Chapter 5; García-Barrios et al, 2011; Janssen, 2010; Villamor and van Noordwijk, 2011; Castillo et al., 2011). Stylized yet complex land-use games have shown their potential for stakeholder engagement especially when stakeholders are in conflict, but at the same time they show difficulties for interpreting their richness of ecological and social outcomes. Therefore, the properties, behaviors, outcomes and possible analysis schemes of such games need to be explored through pilot sessions, before embarking on performing game sessions at large scale.

Here, we present a gaming methodology specifically developed to actively involve smallholders with conflicting interests and activities in the process of designing more sustainable agricultural landscapes. We use the role-playing board game RESORTES (literally coil-springs in Spanish), which is the Spanish acronym for Social Networks and Sustainable Land-use Planning (Speelman and García-Barrios, 2010a), embedded in a highly structured monitoring and analysis scheme. The RESORTES game is a closed and realistic land-use decision-making game that depicts an agricultural landscape and captures some of the current challenges in complex smallholder farming. We present explorative results of four pilot game sessions with local smallholders in a usufruct community in the buffer-zone of a Man and Biosphere (MAB) Reserve in Chiapas, Mexico. Game development and implementation were aligned with an ongoing NGO supported local participatory project on communal landscape planning. It also contributed to a larger multi-institutional research program on participatory development of innovative tools to create and expand social knowledge for more sustainable agricultural smallholder landscapes in the Sierra Madre de Chiapas, México and similar tropical mountainous territories (for a synopsis, see García-Barrios et al., 2012).

Over the past fifty years, our case study community has been confronted with economic and institutional pressures that strongly influenced social organization and land-use change. The tension between market pressures favoring cleared-field rather than forest-based land-use types led to distinct farm strategies based on one or both land-use types (Chapter 2). Recently, the community has taken the first steps to more active communal land-use planning through the participatory project. Such planning processes can induce or unveil tensions among farmers who belong to different social networks and who have different preferences for cleared-field and forest-based land-use types with distinct incentive schemes.

Through individual discussions with local stakeholders, we previously identified land-use decisions that require or could benefit from coordination among farmers to jointly meeting requirements of incentive schemes such as Payment for Environmental Services (PES), and reaching production quantities to obtain benefits through Economies of Scale (EoS). In both types of land choice (i.e. cleared-field and forest-based) there are land-use types with different levels of market risk (high and low volatility). In the RESORTES game farmers choose among high and low risk forest-based and cleared-field land-uses, and where coordination among farmers concerning land-use decisions at the landscape level affect the returns to ecosystem service provisioning or scape-related benefits. Our main research questions for the highly structured and monitored pilot sessions were: 1) To what extent does this gaming method actively engage smallholders in jointly reflecting over the issues of collective agroecosystem design and landscape planning, and 2) Which key factors seem to allow or impede successful coordination among farmers, and conduce to hypothesis that could be formally tested in future trials with more elaborate experimental protocols?

2 Material and Methods

2.1 Study area

The smallholder community Tierra y Libertad (TyL) is situated in a MAB Reserve near the ridge of the Sierra Madre de Chiapas mountain range in the upmost part of a watershed. This community of circa 750 persons owns 3200 ha of land and has a young population (average age of 24 years SD = 18). The community is remote and poorly connected to the nearest urban center and market, but has basic facilities, e.g. a small health clinic and rural schools from kindergarten up to lower-secondary school.

In the early 1960's, people arrived to the area as laborers in a private sawmill. These laborers developed forest-based livelihoods consisting of wage labor in the exploitation of timber and individual exploitation of non-timber products. The ornamental leaves of the wild Camedor Palm (*Chamaedorea spp.*) complemented very low wages at the sawmill in the initial phase of settlement. After the closing of the sawmill in 1972, the National government officially gave people the right to use the land in social usufruct, under the legal form of the Mexican *ejido*, Soon after, land was de facto parceled and some people started to cultivate the lands cleared by the sawmill for agricultural activities, mainly for maize cultivation. However, forest-based activities and especially the extraction of wild palm leaves persisted for many years and formed an important source of income for another group of people within the community. At the time of land allocation, households that up to then had fully relied on palm extraction gave little attention and importance to the land they were granted. Consequently, they obtained less (and relatively more forested) land. On the other hand, those who focused on agricultural activities obtained more (and less forested) land. The distinct values attached to forest and the differences in landholdings, status and income has somewhat polarized these two groups over time.

During the mid-1990's, global economic and institutional drivers strongly limited livelihood strategies based on either maize cultivation or palm extraction. Due to the Latin-American debt crisis, Mexico was forced to reform its policies and markets under the neoliberal Washington Consensus (Yunez-Naude, 2003). The implementation of the North American Free Trade Agreement (NAFTA) caused a further dramatic decline in the Mexican maize price. Monetary returns of some other cleared-field products became volatile. The potential return on investments for these land-use types became highly uncertain. At the same time, the interest of global governance agencies in nature and biodiversity conservation grew. This resulted in international agreements and conventions to protect biodiversity and ecosystem service hotspots. Mexico signed the legally binding Convention on Biological Diversity (CBD), which was followed by the initiation of active national conservation policies. As one of the pilot areas of the protected natural areas program (1995-2000), the Mexican government established the UNESCO's MAB Reserve 'La Sepultura' in the northeastern part of the Sierra Madre de Chiapas (6°00'18" and 16°29'01"N and 93°24'34" and 94°07'35"W) (INE, 1999). As of 1995, land-use became strongly restricted and extraction of timber and non-timber products became prohibited. In some of the recent years, the *ejido* as a whole received PES from the National government for maintaining forest flora and fauna within the *ejido* territory. So far, the *ejido* always divided PES among all households without consideration if and how much forested area was maintained per household. However, there is continued debate over PES sharing.

In a response to this new economic and institutional setting, people in TyL (and elsewhere) were forced to develop alternative farming systems. Meager governmental subsidies and credits became available to assist farmers to convert their maize fields into livestock rangelands. In TyL, the local municipality and a national NGO have promoted alternative forest-based farming systems through the introduction of organic palm cultivation in the understory of the forested fields. Communal decision-making was also reinforced and social organization concerning land-use improved through the development of producer groups. Currently, farming is based on forest-based and/or cleared-field land-use types. Three farming systems can be distinguished (i) cleared-field land-use type (livestock herding); (ii) forest-based land-use type (organic palm and coffee cultivation); (iii) a combination of cleared-field and forest-based land-use types. The former group of palm leave extractors is now mainly devoted to forest-based farming systems. Maize production is a small-scale activity of all groups, but more common among (i) and (iii). Maize production and organic coffee currently have less market risk than livestock and palm.

Farmers that focus mainly on cleared-land or forest-based land-use activities have conflicting interests over the use of forest in the *ejido*. Recently, through a NGO supported project the community has taken its first steps towards active communal landscape planning. This project consists of: (i) developing a comprehensive view of the distribution of land-use activities within the territory, (ii) understanding the history that led to the current agricultural landscape, (iii) identifying key factors in communal land-use decision-making, and (iv) actively engaging farmers in local agricultural landscape planning.

2.2 Game description

The RESORTES board game (Speelman and García-Barrios, 2010a) revolves around land-use planning in an agricultural landscape. The game includes some of the issues smallholders are currently challenged with, namely 1) risk and uncertainty in monetary returns from land-use types, and 2) coordination of land-use activities among farmers to obtain financial benefits from payment schemes that reward the provisioning of ecosystem services from unfragmented forested areas (PES) or scale-related additional returns or reduced costs for cleared-field land-use (EoS). Negative externalities are deliberately not included in this first version of the game, in order to keep it simple and to focus on the willingness or unwillingness of players to coordinate with other community members in the face of benefits and incentives subject to moral and economic risks. Box 1 describes the main features of the game; a succinct explanation of its rationale, goals, rules and mechanics follows.

Box 1: Basic game information

Name: RESORTES Redes Sociales y Ordenamiento Territorial Sustentable - the Spanish acronym for "social networks and sustainable land use planning SPRINGS (Speelman and García-Barrios, 2010b)

Objective: To practice, discuss and evaluate the land use planning process

Goal: To win the game by accumulating the largest number of points.

Type: Cooperative; non-zero-sum; goal-seeking; common access game (See classification of Klabbers, 2009 p.42)

Form: Non-electronic intellectual skill game - Board game (See classification of Ellington et al., 1982 adapted by Klabbers, 2009 p.37). Computer facilitated version of the game in Netlogo 4.2 (Wilensky, 1999) is available by contacting the corresponding author.

Time: Preparation - 15 minutes; Playing – 30-60 minutes; Debriefing – 45-90 minutes

Actors

Target audience: Smallholder farmers and/or communities that are planning their agricultural landscape; researchers; NGO offices; students that work on land use cooperation issues

Number of actors: Participants – six; Facilitator – one; Assistant - one

Resources

Game board consisting of 37 connected hexagons divided in four equally-sized quadrants; Field cards – 24; Land use cards – 4 sets of 24 cards; Dice – 2 with one small range and one large range of numbers but with same average; Scoreboard; Monopoly money; Computer

Mechanics

A typical game session starts off with extensive game explanation through trial rounds. Once the facilitator has assured him or herself that all players understand the game, field allocation starts. Players take turns and select one field location per round. When all fields have been selected land uses are added to the fields, one per field. When all players are satisfied with their selected land uses, both dice are thrown and the facilitator and the players jointly check if any additional points through the planning schemes are earned. Then, that round's points are calculated and all players receive their points. Then, the facilitator highlights the current state for obtaining additional points through one or two of the planning schemes. The game continues as long as the players want. After the game, the game debriefed in the form of group discussion.

Rules

Turn taking: turn-taking is required when fields are allocated

Planning schemes: two incentive schemes for landscape planning can lead to additional points: 1- Payment of Environmental Services (PES) and 2 - Economies of Scale (EoS). The PES scheme requires eight fields per quadrant with forest-cover (virgin or forest-based land use) and rewards all who hold a field in the respective quadrant five additional points per round. The EoS scheme requires a minimum of ten of the same cleared-field land uses on the whole board and rewards every cleared-field land use four additional points per round. *Point system*: At the end of every round, players receive that round's points. Points result from standard points dependent on risk-level of current land use choices, and additional points from one or both planning schemes.

A mountainous landscape is represented on the game board by four quadrants each with nine contiguous hexagon fields (Figure 3.1). Six players enact farmers, each of whom owns four fields. At the start of the game, players take turns in selecting a location for their fields - one field per round - but without developing them yet. The fields that remain unselected represent virgin forest. During the remainder of the game field allocation remains fixed. In the subsequent rounds, players select the land-use type of each of their four fields. Land-use in all fields can be selected and/or changed without limitations within every round. The four land-use types in the game are described generically as cleared-field or forest-based with either low- or high-risk.

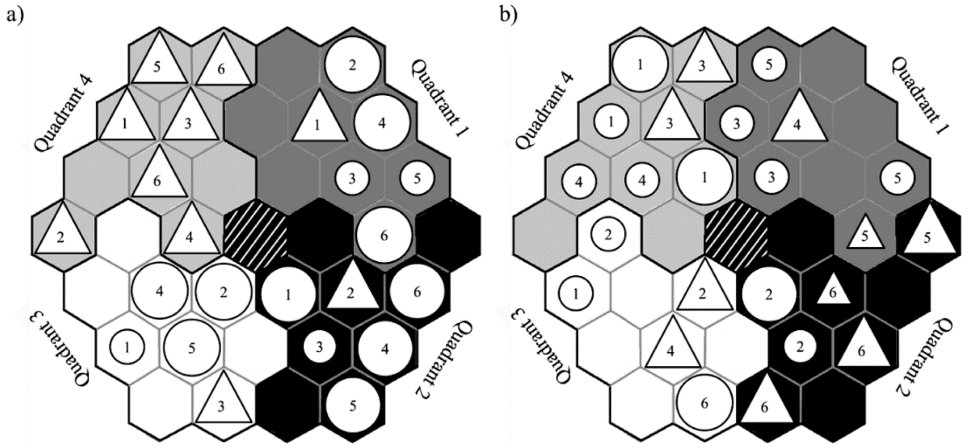

Figure 3.1: Schematic representation of the RESORTES game board with the field locations in four quadrants in distinct colors and the settlement in the center of the board (striped). Two contrasting examples of participant's field and land-use allocations; a) best possible coordination leading to maximum additional points board-wide, and b) little coordination leading to no additional points. Participants' field and land-use choices are shown by different tokens: forest-based land-uses are represented by circles; cleared-field land-uses by triangles. The size of the land-use tokens reflect risk–level of the land-use, small for low-risk and large for high-risk land-uses. Participants' fields are represented by numbers.

Each player receives or loses points at the end of every round based on: 1) the status of his current land-use choices, and 2) the benefits ensuing from coordinating choices with others. Points related to the current land-use choices are determined by the risk level of the selected land-use types. These points are not fixed, but determined every round by rolling a low-risk and high-risk dice. The range of values on the low-risk dice (-1 to +11) is smaller than on the high-risk dice (-10 to +20). However, the average of the six values is the same on each dice in order to eliminate a systematic bias towards any land-use type and risk level. A positive dice value results in receiving points from the game master; a negative value on the dice would lead to a player returning points to the game master.

In each round, additional points can be obtained by players through PES and / or EoS payment schemes: (i) PES additional points are granted to those players who own fields in any quadrant that holds virgin forest or forest-based land-use types in eight of its nine fields (PES additional points are spatially conditioned), (ii) EoS additional points are granted to those players who have chosen a land-use type that is present in at least 10 cleared fields over the whole territory (EoS is therefore scale dependent but not spatially conditioned). When condition (i) is met, every player that holds at least one field in a benefited quadrant(s) receives five additional points per round – even if the player's field in that quadrant does not have forest cover. When condition (ii) is met, every player with the benefited cleared-field land-use(s) receives four additional points per benefited cleared-field land-use per round. At the end of every round, participants receive or return points in play money. Players run the game for as many rounds as they collectively decide until they reach an equilibrium where none of the players desires further land-use changes. At the end of the game, the player who has accumulated the most points over the full course of the game is announced the winner.

When considered individually, points from any of the four randomly scored land-use types have the same statistical expectancy (i.e. any land-use type produces in the long run the same average number of points). Participants can only really exert influence on their scores by attempting to gain additional points through coordinating with others. Players can do so by following or being followed by other players in their choice of field locations and land-use types. Influence can be exerted implicitly and in silence or through active discussion prior to any round or move. According to the literature on social experiments held mainly in the university lab and sometimes in rural settings (Janssen et al., 2010; Castillo et al., 2011), such influence can be based on relatedness and leadership among players, either developed previously, or in the context of the gaming session and stimulated by communication during the session. In field allocation rounds, players implicitly select who will be the immediate neighbors, whose decisions and willingness to cooperate might allow or impede attaining coordination benefits.

The optimum strategy for a single player can only be reached by one player per round through a smart allocation of fields (one field per quadrant), and obtaining benefits from the EoS scheme for all four fields while free-riding the PES benefits created by the other participants in three quadrants through a high level of coordination (Figure 3.1a). This optimum strategy for a single player renders 31 additional points per round. If one player follows the individual optimum strategy, the group as a whole can also obtain the highest joint score (125 additional points for all 6 payers together). However, this maximum group score will be unevenly divided among the players (four players with 18 additional points per round, one with 19 and one with 31 additional points per round). Homogenous landscapes in which PES or only EoS incentives are reached by selecting at least 83% forest-based or only cleared-field land-use types result in (slightly) less attractive but evenly distributed joint scores of a maximum of 125 and 89 additional points per round, respectively. Many other field and land-use configurations lead to attractive but sub-optimal scores (Figure 3.1b). In short, the level of group coordination during field allocation determines the individual and group optimum strategies which can be biased towards diversified or homogeneous landscapes and equal or unequal division of additional points.

Thorough simulation of outcomes on our agent-based version of RESORTES (Speelman and García-Barrios, 2010b) revealed that almost any level of whole territory forest cover can lead to a wide range of total additional points. This very low correlation warrants that the games incentive structure does not bias players towards forest-based land-use types (Figure 3.2).

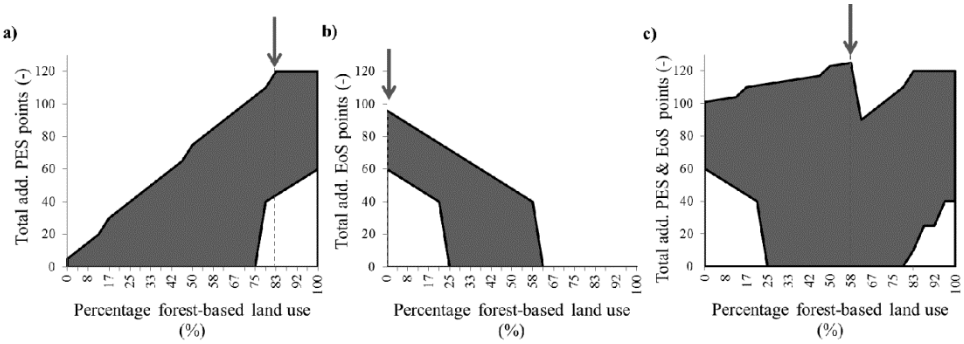

Figure 3.2: Schematic representation of the solution space for total additional points in the RESORTES board game employing a strategy based on: a) only forest-based land-use incentives, b) only cleared-field land-use incentives, and c) both incentives. The grey area represents the range of possible total additional points that the players can jointly obtain with a specific percentage of forest-based land-uses of all players jointly. The arrows show the highest total additional point with the lowest forest-cover.

Before starting the game, players were informed about the set-up and rules of the game, namely that (1) they will colonize this territory with four possible land-use types – one land-use per field, (2) that each land-use results in benefits with either a high or a low level of uncertainty/risk due to price fluctuations or production, (3) that both spatial and non-spatial coordination of similar land-use types can produce additional benefits, and (4) that the player with most points will be declared the winner. Also, after each round, participants are informed of the points and additional points obtained per player to inform decisions to be made in the next round. We created a slightly competitive setting for the game by clearly stating that the game would have a winner to: 1) stimulate the interest in obtaining additional points through coordinating with other participants, and 2) reflect the current competitive setting in complex smallholder systems due to a variety of economic incentives (Gómez-Baggethun et al., 2010). Ideally, the six players have distinct farming system preferences in real-life (e.g. diversified or more inclined to cleared or forested lands), which can trigger more meaningful communication and discussion on the design of this imaginary landscape.

2.3 Monitoring and analysis scheme

We developed an in-depth monitoring and analysis scheme to evaluate the level of active participation and to identify key factors that were hypothesized to influence coordination of land-use decisions (see section 2.3.2), as expressed indirectly and safely in a gaming context. This scheme consists of: (i) pre- and post-game surveys, (ii) quantitative and qualitative communication analysis during and after the game through video-observations, (iii) post-game group discussion, and (iv) follow-up individual interviews. The pre-game survey included a structured questionnaire to identify: 1) the social acquaintance of a player with all other players (relatedness), and 2) the player's preferred field allocation on the board in the absence of other players. The post-game survey explored who advised, commented and suggested the most (to all and to the player), and who was a role model during the game. During group discussions, we posed questions to assess the playability, functionality, and fun of the game. During follow-up interviews, a few days after playing the game, individual players were posed similar questions.

2.3.1 Active participation

We assessed the game's capacity to actively involve smallholders through recording and analyzing communication during and after the game. We assumed that active participation was characterized by the occurrence of in-depth discussions on issues relevant to landscape planning, whereas relative passive participation would be characterized by little communication and communication about topics that were less relevant to landscape planning. Also, we assumed that active participation would lead to more detailed game information in the group discussions and follow-up interviews after the game.

We analyzed communication during the game qualitatively by filtering relevant content of the communication during the game. We identified relevant content as e.g. in-depth land-use discussions on the state of the game, discussions on real-life land-use planning issues, active persuasion of other players to change the land-use selected by them. In addition, we measured the individual verbal input to the game by counting the number of comments made by every player. The length and content of the comment were not taken into account. Group discussions after the game and follow-up interviews were analyzed qualitatively through the observer impression method (see Patton, 2001).

2.3.2 Key decision-making factors

For the identification of key factors in communal decision-making on coordination of land-use decisions, we pre-identified communication, leadership and trust as potentially influential factors (Biel, 2000; Cárdenas and Ostrom, 2004; Ostrom, 1998; 2006; van Vugt, 2006; Janssen et al., 2010; García-Barrios et al. 2011). Communication during the game was analyzed quantitatively and qualitatively (see section 2.3.1).

We assessed leadership in three ways, namely: (i) leadership roles of player in the community, (ii) leadership during the game as observed by researchers, and (iii) leadership during the game, as perceived and later informed by players. Leadership in the community was assessed through thorough field knowledge of each player's role in local society by the first author (Chapter 2). We used two indicators to identify societal leadership, namely: (i) leader or member of producer group or community management, (ii) spiritual leading roles i.e. vicar or pastor. Leadership during the game was estimated quantitatively by counting the number of suggestions made per player. The length and nature of the suggestions were recorded and stored in our databases, but were not taken into account in this chapter. Perceived leadership was assessed by counting the number of times a player was mentioned in the post-survey.

Due to the difficulty and sensitivity of assessing the level of trust among players, we identified the strength of the social relationships between any two players in the social network among the players. In the pre-game survey, players self-reported the nature of the acquaintance they had with all other players in the group. They identified family, friendship, and religion-related ties. We used network graphs to visualize the social network per group of players and calculated the relatedness index per player as the normalized node strength (Boccaletti et al., 2006), based on the number of high valued relationships i.e. family, friendship, religion-related, divided by the number of players minus one.

We assessed the potential influence of these three factors on coordination during both field and land-use allocation. The PES and EoS schemes in the game were used to assess the effect of leadership and self-reported relatedness on field and land-use pattern. Therefore, we estimated how much a player´s preferred field locations - as reported during the pre-game survey - deviated from the field locations he actually selected once interacting with other players.

We measured the effect of coordination among players by assessing the trajectory of additional points obtained by the group during the playing session. We displayed these trajectories in a binomial table with high vs. low values in the axes for X = communication & relatedness and Y = leadership to visualize the qualitative relation of these two axis with the outcome of interactions among players.

2.4 Pilot game sessions

Before performing the pilot sessions, we ran four game sessions with school children aged between 12 and 16 years from the same community to assess the playability of the game in this context. Results from these sessions were positive and led to only minor practical adjustments. Adult participants in the pilot sessions that followed understood the game and its mechanics well and had fun while discussing the management of their fields and the planning of their very stylized rural landscape.

The four pilot game sessions took place in October and November 2010. We selected prospective participants for the sessions from a random proportionate stratified sample of all registered household heads in the community in chapter 2. These prospective participants were all smallholders. In TyL, farming is performed exclusively by men, as such all selected (prospective) participants were male. The participants were selected in a way to include all three different farm strategies and a variety of societal leadership roles. However, when we started with the first group, it became clear that the desired mixture of participants was unattainable. Severable prospective participants were unable or unwilling to join at all in spite of being invited personally by the first author, who had lived in the locality and worked with them for over a year. Therefore, we adjusted the initial participants scheme using the snowballing method (Goodman, 1961) while attempting to maintain all farm strategies and at least one societal leader per group of players (Table 3.1). Also, the first two pilot sessions were played with only four and five smallholders respectively. A student, who was familiar with the game, played with a low profile the role of missing farmer(s) in these sessions. All smallholders participated on a voluntary basis. Follow-up interviews were performed with 15 of the total 21 smallholders that participated.

3 Results

3.1 Game outcome

Game outcomes in terms of landscape configurations and additional points differed between the four pilot sessions and seemed to depend largely on the presence of clearly identified objectives such as reaching a specific landscape configuration, maximizing additional points, or reaching and maintaining consensus of individual goals among players. During and after the game, most participants explained that their decisions of field and land-use allocation were based on the farming systems they had in real life. However, few players explained decisions made in the game to be inspired by what they would like to have in real-life.

Table 3.1: Participants characteristics per group i.e. farming system, societal leadership, age (#), land holdings (ha), relatedness index (%), and the average comments made per player during the game (#).

	Group	Description
Farming systems	Group 1	Cleared-field based: 1; Forest-based: 1; Mixed: 2
	Group 2	Cleared-field based: 2; Forest-based: 1; Mixed: 2
	Group 3	Forest-based: 4; Mixed: 2
	Group 4	Cleared-field based: 1; Forest-based: 2; Mixed: 3
Societal leadership roles	Group 1	1 player with religious and 1 with community/ producer group management roles
	Group 2	3 players with community/producer group management roles
	Group 3	3 players with community/producer group management roles
	Group 4	1 player with a community/producer group management role

		Mean	SD	Range
Age	Group 1	41	± 9.60	25-50
	Group 2	44	± 22.15	18-78
	Group 3	41	± 9.26	25-50
	Group 4	44	± 13.00	29-69
Land holdings (ha)	Group 1	30	± 18.35	19-62
	Group 2	29	± 25.95	2-77
	Group 3	20	± 15.26	4-46
	Group 4	19	± 7.69	6-27
Relatedness index (%)	Group 1	108	± 14.29	100-133
	Group 2	75	± 35.36	25-125
	Group 3	107	± 9.43	100-120
	Group 4	113	± 18.86	100-140
Comments (#)	Group 1	77	± 46.19	32-151
	Group 2	32	± 12.25	20-51
	Group 3	78 [a]	± 51.44	26-173
	Group 4	65	± 44.31	27-138

[a] The average number of comments per player was corrected for the additional round played by group three.

Table 3.2: Outcome of the four pilot game sessions showing the player's individual quadrant occupation (QO) and percentage of selected forest-based land-uses types.

Group	Player	QO	Round 1	Round 2	Round 3	Round 4	Round 5	Average
1	1	2	75	75	100	100		88
	2	3	75	75	75	100		81
	3	3	75	50	100	100		81
	4	2	75	75	100	100		88
	Average	3	75	69	94	100		
2	5	4	50	50	50	50		50
	6	3	50	75	75	25		56
	7	3	50	75	75	75		69
	8	3	50	75	50	75		63
	9	2	50	75	25	25		44
	Average	3	50	70	55	50		
3	10	3	75	75	50	50	50	60
	11	2	100	100	75	75	75	85
	12	2	75	100	75	75	75	80
	13	2	50	50	50	50	50	50
	14	2	75	75	50	50	50	60
	15	3	50	50	50	50	50	50
	Average	2	71	75	58	58	58	
4	16	4	75	75	100	75		81
	17	2	100	100	100	100		100
	18	3	100	100	100	100		100
	19	3	75	75	75	100		81
	20	2	75	100	100	100		94
	21	3	75	100	100	100		94
	Average	3	83	92	96	96		

Most players allocated their fields in three of the four quadrants on the board. Only two players distributed their fields in all four quadrants - the optimum individual strategy. Consequently, none of the groups reached the unique optimal field configuration. In some groups, however, players occupied more quadrants than in other groups (Table 3.2). During land-use allocation rounds, none of the players maintained their initial land-use choice - selected during the first round. Groups one and four gradually increased the percentage of forest-based land-use types over the different rounds. These groups started with 75 and 83% forest-based land-use types in the first round and ended with 100 and 96%, respectively. Groups two and three first increased the percentage of forest-based land-uses from round one to round two and then decreased the percentage of forest-based land-uses on the board after round two. The latter two groups also started with slightly less forest-based land-use types (Table 3.2). In groups one and four the relative higher percentages of forest-based land-use types during the game were related to relatively more participants with a forest-based or mixed farming strategy in reality. Group two had most participants with a real-life farming strategy focused on cleared-field activities, which coincided with relatively more cleared-field based activities on the board. However, in group three a mixed strategy was played on the board, whereas real life farming strategies of the group of players leaned more towards forest-based land-use types (Table 3.1 and 3.2). During the game, all groups discussed their need to grow maize (a cleared-field activity) to feed their families. Only in group one towards the end of the game, players jointly decided that they could buy maize to feed their families instead of growing it themselves. In groups one, three and four, all players selected predominantly low-risk land-use types throughout the game. In these groups, the final landscape was nearly completely made up of low-risk land-use types. However, participants in group two selected relatively more high-risk land-use types (Table 3.3). No relation was found between the points of low- and high-risk land-use types in previous rounds and the risk-level of the land-use types selected by the players.

All players obtained additional points through one or both of the incentive schemes, over the course of the game. The total accumulated additional points per player ranged from 16 to 75. Group four jointly accumulated significantly more additional points than the other three (Table 3.4).

Groups one and four only obtained additional points through the forest-based land-use planning scheme, whereas groups two and three obtained additional points through both cleared-field and forest-based land-use planning schemes. Only in group four a player free-rode the PES benefits created by his fellow players in the quadrant. This led to a strong discussion with another player. Interestingly, the discussion was not focused on the PES benefits the player was free-riding, but on the potential real-life consequences of having a maize or grassland plot within a forested area.

We found no relation between free-riding behavior and measured factors relatedness, communication, leadership. The final land-use configuration at the end of the game sessions showed large differences in the percentage of forest-based land-use types, and land-use allocation over the four quadrants. However, the amount of additional points was comparable in groups one, two and three (Tables 3.2 and 3.4).

3.2 Active participation

All players in all groups commented during the game, but the individual differences between players in quantified communication were large, ranging from 11 to 151 comments per player. The number of comments made per group was similar in groups one, three and four. In group two, significantly less comments were made than in other groups (Table 3.1).

Most comments were made during the land-use allocation rounds, and only 6 to 10% during the field allocation rounds.

Table 3.3: Outcome of the four pilot game sessions showing the player's individual quadrant occupation (QO) and percentage of selected high-risk land-use types.

Group	Player	QO	Round 1	Round 2	Round 3	Round 4	Round 5	Average
1	1	2	0	25	25	0		13
	2	3	0	0	0	0		0
	3	3	25	25	0	0		13
	4	2	0	0	0	0		0
	Average	3	6	13	6	0		
2	5	4	0	0	25	50		19
	6	3	75	50	50	100		69
	7	3	50	25	75	50		50
	8	3	50	25	75	50		50
	9	2	0	0	75	75		38
	Average	3	35	20	60	65		
3	10	3	25	25	0	0	25	15
	11	2	25	25	0	0	25	15
	12	2	0	0	0	0	0	0
	13	2	0	25	0	0	0	5
	14	2	25	25	0	0	0	10
	15	3	0	0	25	0	0	5
	Average	2	13	17	4	0	8	
4	16	4	0	25	50	0		19
	17	2	25	50	25	25		31
	18	3	25	25	25	0		19
	19	3	0	0	0	0		0
	20	2	0	50	75	0		31
	21	3	0	0	0	0		0
	Average	3	8	25	29	4		

In group two, communication was characterized by scarce comments on topics unrelated to land-use choice and landscape planning. In groups one, three and four, individual land-use choices were discussed openly and frequently. Discussions were often related to actual preferences and real-life land-use choices of players. As an example, in group four an intense discussion started on the selection of a cleared-field land-use in a quadrant dominated by forest-based land-use types. Several players urged the respective owner to change the land-use type of his field. They supported their plea with arguments on the increased risk of bushfires (not a feature of the game) by the management of a maize field. "Your maize field represents a risk for our coffee fields. They will be ruined if your fire causes a bushfire!! You must change land-use in that field!" Such pressing discussions were, again, not observed in group two. In group one, players even jointly agreed to offer a fellow player a payment of the play money they personally earned during the game to pursue the player to change land-use of one of his fields. Interestingly, their objective was not to meet the requirements of the PES and/or EoS planning schemes to gain additional points, but to reach a specific landscape configuration they jointly preferred. The desired land-use configuration was characterized by the concentration of cleared-field-based land-use types in one quadrant and forest-based land-use or virgin forest in the other three. Few comments and no discussion or persuasion of players were made in group two. In short, there was more land-use discussion, pressure and coordination among players in the two groups (group 1 and 4) that eventually attained higher forest-based land-use over the whole territory. Mixed strategies emerged where there was little communication (group 2) or less pressure on players willing to clear land (group 3).

Table 3.4: Outcome of the four pilot sessions showing the additional points obtained per player and total additional points per round and per group.

Group	Player	Round 1	Round 2	Round 3	Round 4	Round 5	Sum
1	1	5	5	5	10		25
	2	5	10	10	15		35
	3	5	5	10	15		35
	4	0	5	0	10		15
	Sum	15	25	25	50		110
2	5	5	15	9	18		47
	6	5	10	4	12		31
	7	5	5	9	14		33
	8	5	10	8	9		32
	9	0	5	12	12		29
	Sum	20	45	42	65		172
3	10	5	5	5	13	13	41
	11	5	5	5	9	9	33
	12	5	10	10	14	14	53
	13	0	5	5	13	13	36
	14	0	0	0	8	8	16
	15	5	10	10	18	18	61
	Sum	20	35	35	75	75	240
4	16	15	20	20	20		75
	17	5	10	10	10		35
	18	10	15	15	15		55
	19	10	15	15	15		55
	20	5	10	10	10		35
	21	15	15	15	15		60
	Sum	60	85	85	85		315

During the group discussions after the game, players reflected on the decisions they made or could have made during the game. Especially in groups one, three and four, discussions on specific choices were re-initiated or continued. During the discussion in group two, one player shared with the other players that only while filling out the post-game survey, he realized that the game was "about collective decision-making". The player's realization led to similar comments by the other players.

Several players mentioned that they enjoyed playing the game and that they appreciated the in-depth discussion on land-use issues that developed from playing the game, in particular players in groups one, three and four. Players especially appreciated the participation of community members that were usually not actively involved in communal landscape planning. During the follow-up interviews, most players reflected on the game session in a similar way. One of the players described how he in the days after the game discussed his experience with several family members and friends. He mentioned it had led to interesting in-depth exchange of ideas on real-life individual land-use decisions and communal landscape planning.

3.3 Key decision-making factors

3.3.1 Communication

Communication was assessed quantitatively and qualitatively. Communication was frequent and relevant in groups one, three and four and scarce and unrelated in group two (see section 3.2 and Table 3.1).

3.3.2 Leadership

In total, 9 of the 21 participants were pre-identified by the first author as societal leaders based on their role in the community; none of them remained silent and/or played a marginal role in the games with the exception of the religious leader in group one (Figure 3.3).

Regarding leadership during the game, in group one, a single player made 80% of all suggestions. In all other groups, there were generally two or three players that made similar numbers of suggestions. Players identified between two and four influential players per group. In groups one and four (where forest-based strategies dominated), measured leadership during the game was consistent with perceived leadership and actual leadership. This pattern was less consistent in groups two and three (where mixed strategies dominated) due to a mismatch between how players performed and how they were perceived by others (Figure 3.3).

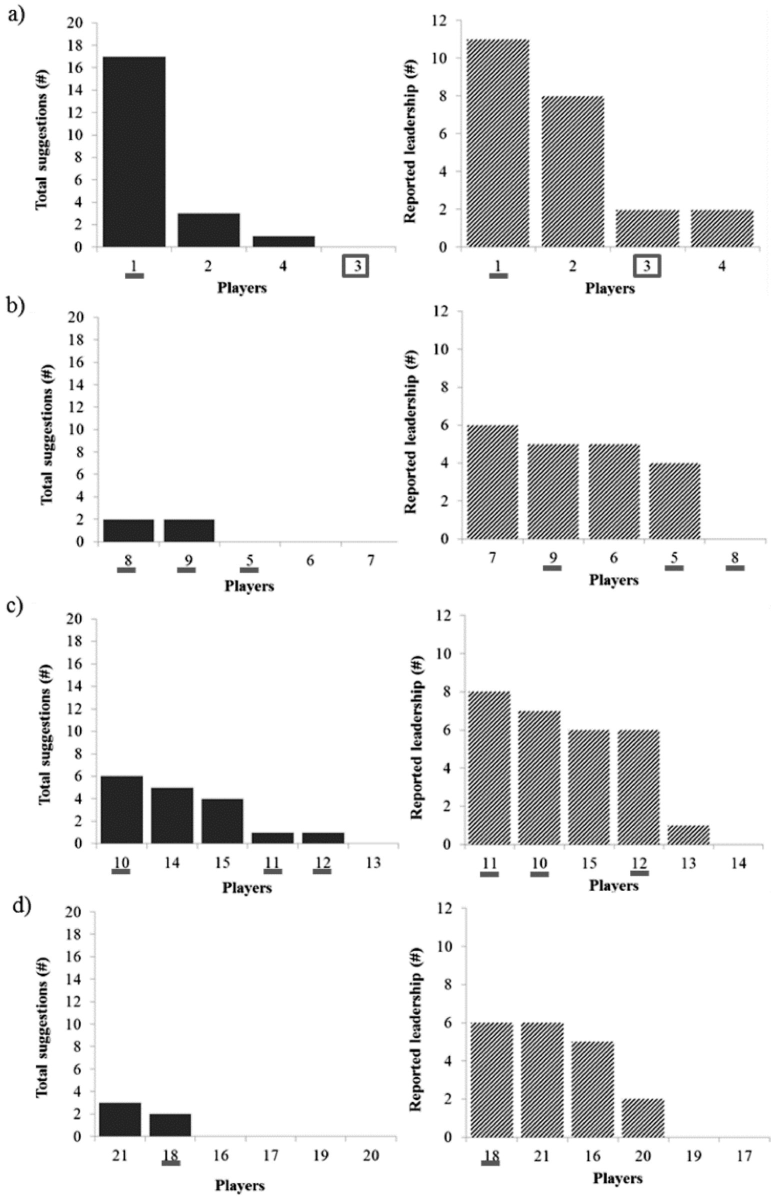

Figure 3.3: Leadership of players during the game assessed through measured number of suggestions (*left*) and perceived leadership (*right*) of the four pilot game groups; a) group one, b) group two, c) group three, and d) group four. Societal leadership of participants is shown by a box around the participant's number for religious leadership and a line underneath participant's number for leadership in producer group(s) and/or community management.

3.3.3 Relatedness

In three of the four groups, the social networks among the players were characterized by high valued relationships such as friendship and family (Figure 3.4) and perception of closeness was symmetrical (You consider me a friend, and I do as well). Consequently, the individual relatedness index was relatively high for all players in groups one, three and four, but low for three players in group two (Table 3.1).

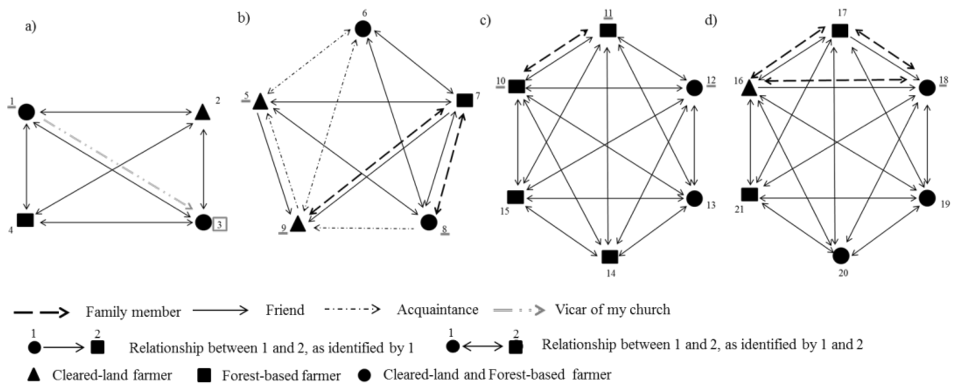

Figure 3.4: Social network graphs of the self-indicated social relationships among the participants of the four groups with smallholders in Tierra y Libertad, a) group one, b) group two, c) group three, and d) group four. In addition, the shape of the farmer node shows the farming strategy in real-life. Societal leadership of participants is shown by a box around the participant's number for religious leadership and a line underneath participant's number for leadership in producer group(s) and/or community management.

3.4 Key decision-making factors and coordination

We identified a moderately significant positive relation (p=0.06) between a player's individual relatedness index and the number of adjusted field allocations, expressed as the number of changes between the preferred and the actual field location on the board (Figure 3.5). In all groups, a pattern in field allocation was identified in which the participants occupied one quadrant to a lesser extent than the other three quadrants. However, we did not identify a clear relation between the field allocation pattern and relatedness among players. In group one, players agreed at the beginning of the game upon a clear goal in terms of landscape configuration. This was reflected in the field allocation pattern.

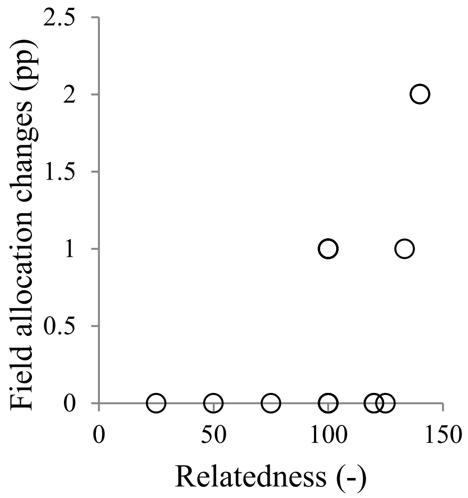

Figure 3.5: Relation between the individual relatedness of players and the number of deviations in field allocation between preferred and the actual field allocation on the game board.

Measured decision-making factors - communication, leadership and relatedness – seemed to be positively connected to the smoothness of the trajectory of accumulated additional points. Sessions one, three and four, in which these three factors were present, showed a gradual increase of additional points. In session two, these factors were low or absent and the additional points trajectory was more erratic. The accumulated additional points trajectory of group one was characterized by a continuous increase of PES-related additional points. Session three and four showed intermediate trajectories, where session three resembled session two and session four was similar to session one (Figure 3.6). The total additional points obtained per round were similar in all four groups (Table 3.2).

Leadership by a single player seemed to have stimulated goal development and led to a goal-oriented approach in group one, where a clear goal in terms of landscape configuration was agreed upon by all players before the start of the game. This landscape configuration was characterized by a land-use pattern of three quadrants of virgin forest or forest-based land-use types and one quadrant with cleared-field land-use. In subsequent rounds, players tried to achieve this by persuading and even offering rewards to a reluctant player. Towards the end of the game, the additional goal of meeting PES requirements in all four quadrants was set, and reached within a single round. However, the goal-oriented approach did not lead to more additional points. Especially in groups three and four, players tried to reach and maintain consensus among all players on the goals they tried to reach. A strong social network and high relatedness among players was correlated to in-depth communication among participants. The risk-level of land-use types was not often discussed in any session. Some players commented on their choice of risk-level, but no in-depth discussions and attempts to pursue other players to change the risk-level of the selected land-use types were identified.

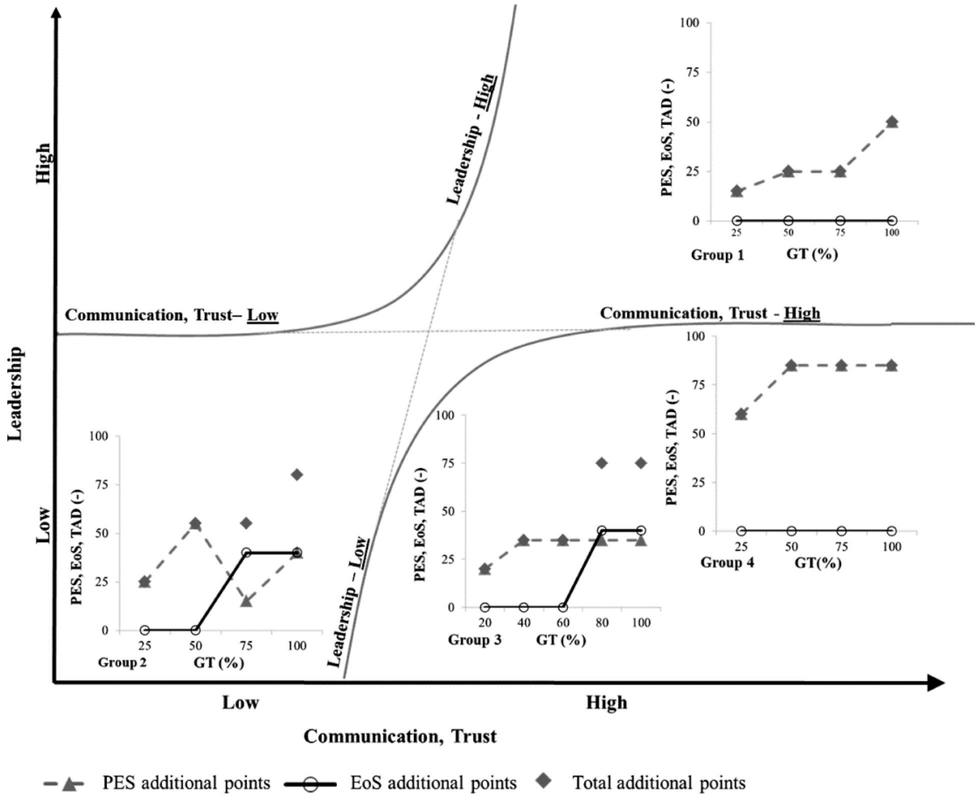

Figure 3.6: Graphic representation of the impact of the interplay of communication, trust, and leadership on the process of collective decision-making, reflected by obtaining PES, EoS and total additional points (TAD) in pilot sessions with the RESORTES board game with four groups of smallholders. The points presented here were calculated by adding the individual additional point obtained per player and were plotted against the relative progression of the game, expressed as game time (GT). The number of players was four in group 1, five in group 2 and six in group 3 and group 4.

4 Discussion

The results of the four pilot game sessions with the RESORTES land-use planning board game confirmed the explorative model runs with the agent-based version of the RESORTES game (Speelman and García-Barrios, 2010b) and did not show any structural bias in the game that could lead to a specific land-use outcome, or preference towards any incentive scheme. The large solution space allowed all groups in the pilot game sessions to create different agricultural landscapes throughout the game. Final landscapes were characterized by a combination of cleared and forested fields in half of the groups, whereas the other half were dominated by forest-based land-use types (Tables 3.1 and 3.3). In all except one group, participants selected more low-risk land-use types (Table 3.2). In three of the four pilot sessions, participants communicated constantly and had in-depth discussions on land-use choices. Interestingly, discussion and decisions seemed to have been driven more strongly by general (and previous) preferences of players towards forest-based or clear-field uses than by the incentive schemes and risk levels associated to them in the design of the game. Most participants commented that field and land-use allocation in real life formed the basis for decisions in the game. In addition, real-life land-use decisions and their consequences were taken to the board and discussed openly. We identified a positive relation between the amount of communication and the process and outcome of communal decision-making during the game (Table 3.3). Communication and relatedness were positively associated. Measured leadership coincided in some groups with leadership as perceived by the other players, but not in others (Figure 3.3). Higher relatedness characterized by stronger social relationships among players, influenced field allocation decisions (Figure 3.5). The RESORTES board game and the corresponding monitoring and analysis scheme, proved to be useful tools to involve smallholders in an exercise that has motivated them to be more interested and active in the ongoing local design of more sustainable agricultural landscapes and institutions. Active participation of players was characterized by constant communications and in the three of the four sessions (Table 3.3). Participants appreciated the game's capacity to actively involve a variety of community members, in particular those participants that were usually not involved in real-life communal land-use planning. According to participants, the game created a fun setting in which serious issues could be openly discussed (cf. Schrage, 2000). Active participation in the design of more sustainable landscapes and institutions is the first step towards adoption of the designed landscapes and institutions. The results of the four pilot sessions concerning the effects of communication, leadership and relatedness on the process of coordinating land-use planning decisions led us to develop some generalized hypothesis to be tested in the future in this and similar territories, namely (i) communication smoothens communal decision-making, (ii) leadership stimulates the development of goals in the decision-making process, (iii) leadership of single players conduces to an imposed land-use pattern, whereas a process led by several people allows for more consensus building and a diversity of possible outcomes, (iv) strong social network and high relatedness among players facilitates communication during the communal decision-making process, (v) high relatedness positively affects communal decision-making, and (iv) relatedness increases the influence people have on each other's decisions (Figure 3.6).

Several studies showed the capacity of role-playing games to engage stakeholders in a discussion or learning experiences in a variety of situations, especially through the Companion modeling approach (e.g. water management - Dray et al., 2005; Gurung et al., 2006; Ferrand et al., 2009; Barreteau et al., 2012; erosion - Souchère et al., 2010; collective awareness - Mathevet et al., 2007). Other authors demonstrated that more complex games that depict more realistic systems could be used to identify various influential factors of collective decision-making (e.g. Vieira Pak and Castillo Brievo, 2010; Villamor and van Noordwijk, 2011; García -Barrios et al., 2011). In addition, Castillo et al. (2011) showed the capacity of closed games commonly used in social experiments to test specific hypothesis on the underlying factors and processes of communal decision-making to engage local stakeholders and to identify effects of the case study specific contexts on communal decision-making processes.

The proposed RESORTES monitoring and analysis scheme attempts to meet the requirements of more in-depth and structured analysis of collective decision-making processes during social experiments with games as proposed by e.g. Anderies et al. (2011), García-Barrios et al. (2011), Janssen and Anderies (2011) and Perez et al. (2011). The analysis scheme allowed for a simple and clear-cut preliminary assessment of the factors communication, leadership and relatedness per game session. The RESORTES pre-game survey to identify player's preferences for field location is similar to those developed by Worrapimphong et al. (2010) and Castillo et al. (2011). However, the RESORTES analysis-scheme went one step further and compared the preferred to the actual selected field locations on the board to assess the influence of the interaction among players on the decisions they made. We quantified and analyzed communication during game sessions in a manner similar to Janssen (2010), whereas García-Barrios et al. (2011) used similar self-reporting on cooperation and leadership in post-game surveys. Post-game individual interviews were also developed in some if the COMMOD case studies (e.g. Perez et al., 2011).

We found a strong relation between the player's real-life and the game which was also identified by Levitt and List (2007), Villamor and van Noordwijk (2011) and Castillo et al. (2011). The positive effect of communication on collective decision-making as found in the pilot game sessions seemed to confirm results of e.g. Ostrom (2000), Castillo and Saysel (2005), Jansen (2010), Anderies et al. (2011). Ostrom (2000) found that communication among players was key in collective decision-making processes as it helped players clarify their intentions and created possibilities to build consensus for agreements. Low volumes of communication were linked to lower game outcomes as identified by Janssen (2010). Other authors found that when players met during subsequent sessions, collective decision-making was smoothened due to trust developed among people, which is similar to our findings on the positive relation between communication and relatedness (e.g. McAllister et al., 2006). The identified discrepancy between measured and perceived leadership could be explained by leadership theory of e.g. De Cremer and Van Vugt (2002) and van Vugt (2006), who state that leadership is shaped by the interplay of leaders and followers, and not solely by the characteristics and skills of a leader.

Commonly, in social experiments executed in laboratories with randomly selected participants as well as field studies with stakeholders, competition among players is implicit to the game (e.g. Vieira Pak and Castillo Brieva, 2010; Janssen et al., 2010) with only a few exceptions (e.g. García-Barrios et al., 2011). In the four pilot game sessions, we announced in advance that the game would have a single winner (no further consequences were mentioned). Through this announcement, we made the competitive aspect of the game explicit. We regarded this as necessary to ensure participants engaged in the game and to reflect the potential effects on collaboration and competition in rural communities of incentives schemes in current smallholder farming (Gómez-Baggethun et al., 2010). Future research with the RESORTES and other games could investigate the effects of explicit and implicit competition in games on the process and outcome.

None of the participant groups in the pilot sessions attempted to coordinate their field allocation in a way that could potentially lead to reaching maximum individual and / or group additional points. Several participants commented during and after the game, that their decisions were based on real-life preferences or field allocation. However, in order to make sure that the lack of coordination during field allocation was not due to poor understanding of the game at the beginning of the game, we could explore the effect of releasing the fixed field location rule.

In all sessions, the first author facilitated the game. We are conscious of the potential influence of the presence of a researcher during stakeholder interactions (e.g. Villamor and van Noordwijk, 2011). Therefore, throughout the stay in the community, researchers did not show a preference for specific groups within the community nor for a specific land-use type. This and previous research projects were carried out with all groups of the local population and were of a neutral and descriptive nature. The results from the game sessions show that players based their decisions mainly on real-life farming strategies (Table 3.1 and 3.3).

The social network among the group of players seemed to influence the willingness to participate and the level of actively participation in our pilot sessions. When the first pilot game sessions were planned and participants were personally invited, it became clear that there was resistance of some social actors to participate or to fully display their views and interests in front of their peers. In the first sessions, several invited participants who had confirmed their participation, failed to show up at the appropriate time. As a result, we were forced to reschedule several sessions. The first two sessions were played with four and five farmers instead of the desired six. We resolved the issue by relying more on the help of participants to invite other participants i.e. snow-balling method. This allowed the formation of groups with strong social network amongst them of which none of the confirmed participants remained absent during these last sessions. Dray et al. (2005), Barnaud et al. (2007), Becu et al. (2008) and Gourmelon et al. (2013) encountered similar problems in the planning of their role-playing experiments. Therefore, we recommend the use of the (i) snowballing method to decrease levels of absenteeism among invited participants and increase active participation during the game, or (ii) use an open informal invitation to all members of the community, as proposed by Gourmelon et al (2013). In both cases, participants who actually show up can be grouped randomly, by ages, by roles or any other reasonable scheme required by the hypothesis to be tested.

The hypotheses on the impact of communication, leadership and relatedness on the process of collective decision-making as formulated based on the pilot game sessions will be fully explored in RESORTES gaming workshops involving more players from this and similar rural localities. In addition, the RESORTES game could be further developed to a social experiment by integrating a specific experimental set up and having a multitude of sessions with a multitude of groups which differ in terms of real-life societal leadership, farming systems and relatedness among participants in a group. Also, the RESORTES game can be further developed into a pure participatory discussion tool by releasing some of the game rules and enlarging the solution space of the game. This and related games (e.g. García-Barrios et al., 2011) can shed light on farmer´s actual views on and responses to the land sharing vs. land sparing dilemmas currently in debate in academic and policy-making settings (see e.g. Vandermeer and Perfecto, 2005; Perfecto et al., 2009; García-Barrios et al., 2009). As shown in the pilot sessions, a clear land sparing scenario emerged among one group of players, whereas the other three groups developed diversified, mosaic landscapes.

5 Conclusions

Landscape planning is increasingly embracing the multi-functionality of landscapes and is moving towards more adaptive, participatory and context dependent planning. The RESORTES board game and its initial implementation in four pilot sessions as presented in this chapter are an example of a tool to stimulate participation in the landscape planning process. The board game and the corresponding monitoring and analysis scheme, were effective in actively involving smallholders in the design of more sustainable agricultural landscapes and institutions in our case study in Chiapas, Mexico. Thereby, the first step towards adoption of more sustainable agricultural landscapes and institutions was made. This simple and stylized game presented a more realistic coordination conflict in the context of smallholders in complex agricultural landscape where a variety of incentives schemes influence farmer's individual land-use decisions. Smallholders who participated in the pilot sessions enjoyed playing the game and the in-depth discussions on consideration of cleared-field and forest-based land-use types in the game as well as in real-life. RESORTES and other simple and stylized games (e.g. García -Barrios et al., 2011; Villamor and van Noordwijk, 2011) appear to be appropriate tools to stimulate active participation of farmers and other stakeholders in landscape planning process, especially those stakeholders that are usually not actively engaged in collective processes. The implementation of the RESORTES game in four pilot sessions allowed us to formulate the following hypotheses on the impact of communication, leadership and relatedness on the coordination in the land-use decision-making process: (i) communication smoothens communal decision-making, (ii) leadership stimulates the development of goals in the decision-making process, (iii) leadership of single players conduces to an imposed land-use pattern, whereas a process led by several people allows for more consensus building and a diversity of possible outcomes, (iv) strong social network and high relatedness among players facilitates communication during the communal decision-making process, (v) high relatedness positively affects communal decision-making, and (iv) relatedness increases the influence people have on each other's decisions. We will further explore these hypotheses in additional game sessions with the RESORTES board game in TyL and other communities with similar complex collective land-use decision-making.

Chapter 4

Learning through simulation: a simple simulation tool

Functional agrodiversity can be useful and even essential for i.e. the long-term sustainability of agriculture. However, still many aspects of this concept are not well understood. The interplay between species in diverse agro-ecosystems is based on processes as i.e. competition, facilitation, predator-prey relations. The net-effect of these processes on crop growth is not static and can change over time as the relative density of species change. The equilibrium state of an diverse agro-ecosystem might be far from optimum or even unproductive. This makes agrodiversity a concept which is not-easily grasped nor obtained or maintained. We believe that an agent-based model can facilitate learning on the topic of functional agrodiversity. In this chapter, we present the agent-based simulation model, Agrodiversity v.2, developed in Netlogo 3.1.5. The model simulates a virtual diverse agro-ecosystem with four ecological agents. The user is challenged to explore ecological parameters and design a productive sustainable system. The model's "simplest playing level" shows that a proper balance between the co-existing species is necessary so that their ecological interactions allow the multi-species system to become self-organized and persist over time. It demonstrates the transient nature of profitable functional agrodiversity. Our analysis on the effects of using Agrodiversity v.2 on actual learning show that learning took place. Students increased the quality of their answers to paper-based individual questions on the topic from 29% during passive/conceptual teaching to 86% after the simulation session. On average students stated to have learnt 55% of their current knowledge through the workshop of which 76% was learnt by using the simulation

Based on Speelman, E.N., García-Barrios, L.E., 2010. Agrodiversity v.2: An educational simulation tool to address some challenges for sustaining functional agrodiversity in agro-ecosystems. Ecological Modelling 221, 911-918.

1 Introduction

Agriculture and biodiversity are intuitively linked as agriculture has been built on the wide variety of species and genes. However, scientists know relatively little about the combined ecological and social functions of much of the world's agrodiversity, and ecological mechanisms underlying these functions (Jackson et al., 2007). Only since the Rio de Janeiro summit in 1992, biodiversity has been put on the agenda of agricultural research. Research is increasingly demonstrating that functional agrodiversity can be useful and even essential for the long-term sustainability of agriculture, natural resource use and biodiversity (Swift et al., 2004). In this chapter, agrodiversity refers to the many ways farmers use the natural biodiversity of the environment for production (Brookfield and Padoch, 1994). We use functional agrodiversity as the functional biodiversity in an agro-ecosystem. Diversified agricultural systems perform essential ecosystem services and can assist in in-situ conservation of (agricultural) diversity in creating a wildlife friendly agricultural matrix at the landscape level (Vandermeer and Perfecto, 2005; Perfecto et al., 2009; García-Barrios et al. 2009). Yet, agrodiversity is not always easy to establish nor functional, unless a complex suite of ecological, management and economic conditions are met. In our experience, such conditions are not easily grasped by stakeholders, researchers and students and there is a tendency to either dismiss functional agrodiversity or to be overly optimistic about it. Therefore, it is important to understand to what extent agent-based ecological modelling can contribute to increase awareness and understanding of the conditions that foster and maintain functional biodiversity at the plot level.

1.1 Ecological interactions, self-organized agrodiversity, and pest control at the plot level

Diversified agro-ecosystems harbor a mixture of planned (cultivated) and associated (wild) species (Swift et al. 2004). Some forms of functional agrodiversity stem from the synergies between species. Facilitation – a largely neglected interaction (Bruno et al., 2003) - is a key synergetic processes by which one species provides some sort of benefit for another species (Vandermeer, 1989). Especially at community level, facilitation seems to play an important role. Facilitation can be direct (A benefits B) or indirect (A is the enemy of the enemy of B) (García-Barrios, 2003). In many cases, however, A also competes with B, so that there is a trade-off between its positive and negative effects which pose a number of management issues.

Biocide-based monocrops have proven to be costly, unhealthy for people and their environment, and ultimately unsuccessful due to resistance developed by pests (Altieri, 1999). Agrodiversity has enormous potential as an alternative strategy for pest control.

Integrated pest management, habitat management and biological control are based largely on the interplay of positive and negative interactions between species (Landis et al., 2000; Bianchi and Van der Werf, 2004). In these methods, enhancing natural enemies and their host plants of agricultural pests in or around the fields is a fundamental asset (Letourneau, 1998). However, attracting and maintaining natural enemies of potential pests in an agricultural system is not an easy task. Natural enemies or their host plants, can have a variety of effects on crop production. Andow (1988) presented various of the possible relations among crops, weeds, pests and natural enemies in diverse agro-ecosystems. In some cases, weed can facilitate crop growth by hosting a natural enemy of the crop pest. However, weed not only facilitates crop growth; it also directly competes with the crop for space and resources (García-Barrios, 2003). These local effects of competition between weed and crop can diminish or even eliminate the beneficial effects of facilitation by the weed. The net-effect of competition and facilitation plays a critical role in maintaining a productive system (Vandermeer, 1989). Xia (1997), Trujillo-Arriaga and Altieri, (1990) and McGuinness (1987), have shown this empirically in wheat-cotton, corn-faba-bean and tomato-bean intercropping systems. The net-effect of competition and facilitation is not static; but changes over time as benefactor and target populations grow and their relative densities are modified. In general, when the relative density (or biomass) of the benefactor population is comparatively low, the net-effect on the target population is positive. Yet, beyond and optimum relative density its net effect can be negative (Figure 4.1).

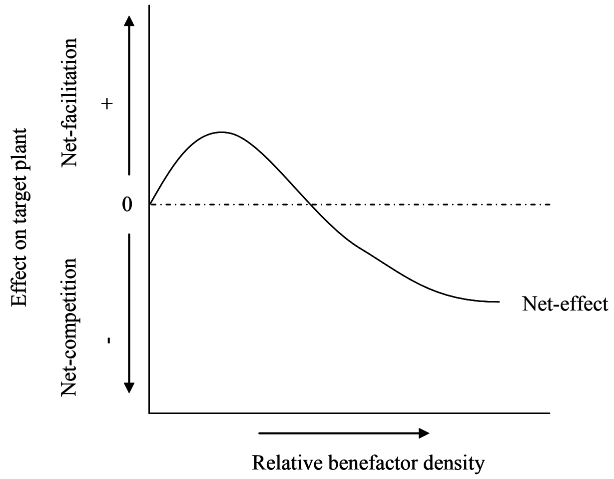

Figure 4.1: Net-effect of competition and facilitation as a function of relative benefactor density (Modified after: Vandermeer, 1989; García-Barrios, 2003).

Tonhasca (1993) measured the increase in natural enemies population and its effects in complex agro-ecosystems, demonstrating that time is required for proper population built-up. Some transition costs from conventional to organic farming are related to this required built-up of natural enemies and their host plants.

When weeds hosting natural enemies are tolerated or promoted in a field, functional agrodiversity self-organizes as natural enemies and their host grow in number or biomass. Yet, the system's attractor (e.g. a weed-infested crop) may be far from optimum and even unproductive. Weed control is commonly required to ensure the latter's positive role in insect pest management (Andow 1983; Schellhorn and Sork, 1997). In short, proper initial design and adaptive management schemes are needed for desired ecological interactions to self-organize and for functional agrodiversity to emerge and persist.

1.2 Education

Increasing stakeholder's awareness about the benefits, tradeoffs and requirements of agrodiversity can be a challenging task. Community processes such as self-organization and the dynamic interplay between positive and negative ecological interactions are not easily grasped. Agricultural sustainability and agrodiversity management need to be seen as complex long-term processes that can nevertheless be successfully navigated. Innovative tools and methods are required to facilitate learning on these complex issues.

We believe an agent-based ecological model can be particularly well-suited to represent, explore and teach why ecological interactions and their management define many of the conditions under which a community formed by a crop, a pest, a pest natural enemy, and a host for the pest natural enemy can self-organize and persist as a productive agro-ecosystem. This can be useful both for the sake of pest control and as an example for a broader understanding of agrodiversity issues.

Currently, an ongoing trend towards more active and experimentally based learning is seen in higher education (Lean et al., 2006). Simulation and games are commonly developed for interactive learning. Since the development of the field of simulation and gaming in the 1950s, it has been practiced by professionals from a variety of disciplines (Klabbers, 2001). Though, it has received both positive and negative responses. Critics have mainly focused on the validity of these tools, as only a few studies have actually attempted to study the effectiveness of the simulation tools on learning. Analyzing the effects of simulation and gaming on learning is made more difficult as clear methods are still lacking (Gosen and Washbush, 2004). However, in 90% of the computer based learning tools evaluated by Gosen and Washbush (2004), learning had taken place.

Agrodiversity v.2 (García-Barrios and Speelman, 2006) is an agent-based model that links the interplay among ecological interactions in an agro-ecosystem with some of its management, economic and social consequences. In its simplest "playing level", users are challenged to properly balance indirect facilitation, competition and predator-prey relationships to induce self-organized functional agrodiversity in a virtual four-species agro-ecosystem consisting of a perennial crop, a crop-foliage-eating insect, an insect-eating spider and a spider-hosting weed. As far as we know, there are no other agent-based models available in which students and other stakeholders can learn in an interactive manner about self-organization and ecological management of functional biodiversity in complex agro-ecosystems. In this chapter, we present some of the basic capabilities of Agrodiversity v.2 and experimentally evaluate their efficacy as a learning tool. In the methods and materials section, we describe these basic agrodiversity v.2 attributes in more detail. The learning experiment is described in the results section after presenting the model outputs used for this purpose.

2 Methods and materials

2.1 Model specification

Agrodiversity v.2 is a game simulation developed to facilitate learning on concepts and processes involved in agrodiversity. Users are challenged to explore ecological variables and processes and manage a virtual agrodiverse system. The simulation game was developed in Netlogo 3.1.5 (Wilensky, 1999), which provides a simple yet powerful programming language (Railsback et al., 2009). In addition, it allows building a very graphical and user-friendly interface. The user's interface we developed for Agrodiversity v.2 provides a wide range of buttons and sliders to modify the ecological and socio-economic parameters of the system, as well as performing management (Figure 4.2).

The virtual diverse agro-ecosystem has four ecological agents: (1) a perennial crop, that grows and produces fruit annually - in our story strawberries, (2) an insect population that eats crop foliage and consequently reduces crop yield, (3) a spider population that eats these insects, and (4) a perennial grass-like weed that grows much slower than the crop, competes with the latter for 2D space and is the host-plant for the spiders. The four species interact directly and indirectly through an ecological network involving predator-prey relations, commensalism, direct and indirect facilitation, inter-specific competition and intra-specific competition (Figure 4.3; intra-specific interaction are not shown). Thus, our perennial weed creates habitat for the natural enemy of the enemy of our crop, respectively the spider and the insect. The weed hereby facilitates strawberry growth. On the other hand, it also competes for space with the strawberry. Individual elements of each species population are spatially and explicitly modelled. The virtual field wraps around in a torus to avoid border effects. Agrodiversity v.2 calculates strawberry yield and labor and input costs. For simplicity, the costs/benefit ratio of strawberry production is assumed to remain constant over the years. Various socio-economic indicators such as gross-income, net-income, and return to labor are calculated on an annual basis. An economic threshold based on the 5-year moving average of net income is arbitrarily established to analyze the performance of the system. It sets the point at which the system is no longer economically viable and farmers abandon their strawberry fields forever.

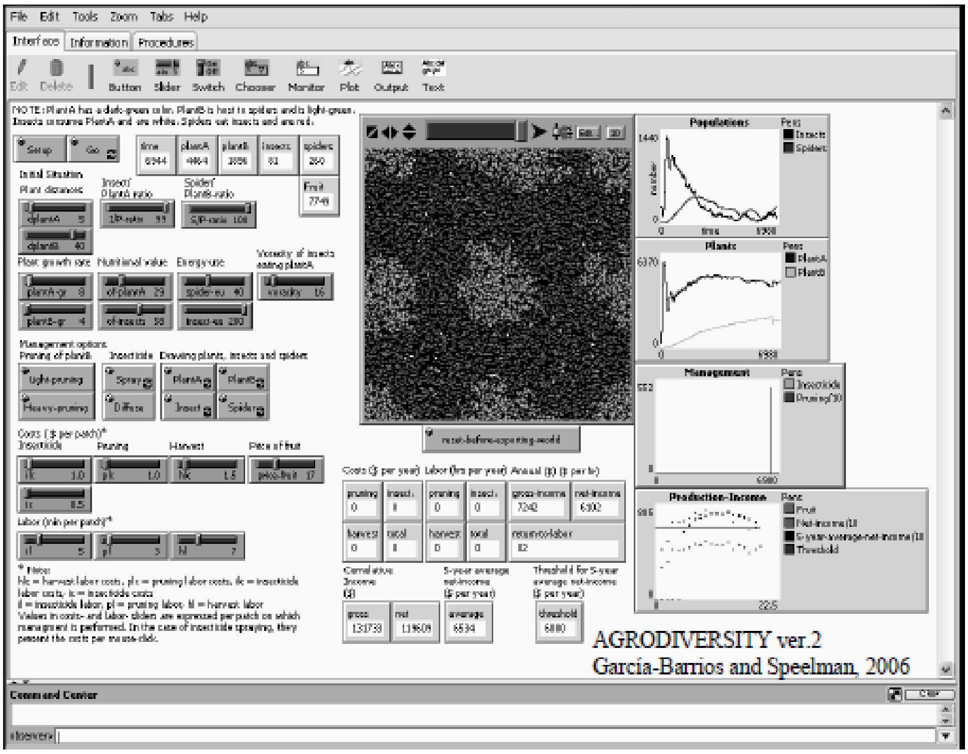

Figure 4.2: User's interface of Agrodiversity v.2. The virtual agrodiverse is situated in the middle of the interface. The four types of agents are shown in different colors and shapes (for feasibility some are shown unproportionally large).

All agents obey a set of probabilistic rules (Appendix 1). Plants grow new branch/leaf modules in available empty space; insects move around and eat the crop while spiders sit on weeds and wait for insects to come around. Users can define prey nutritional value and predator voracity and energy loss. The energy balance of each insect and spider is monitored. Above an energy threshold, they reproduce. Below a minimal energy threshold they die. Users set the initial density and spatial distribution of each species. At any given moment users can perform spatially explicit management. They can remove weeds that are in contact with strawberry plants or spray insecticide at any place in the field using the mouse. Both management options have money and/or labor cost. Weeding and spraying are not used in the simulations and exercises presented in this chapter. Following the proposal of Grimm et al. (2006) for a standard protocol to describe simulation models, in particular agent-based models, we have developed an full ODD-protocol (Grimm et al., 2006) for Agrodiversity v.2, which is available online.

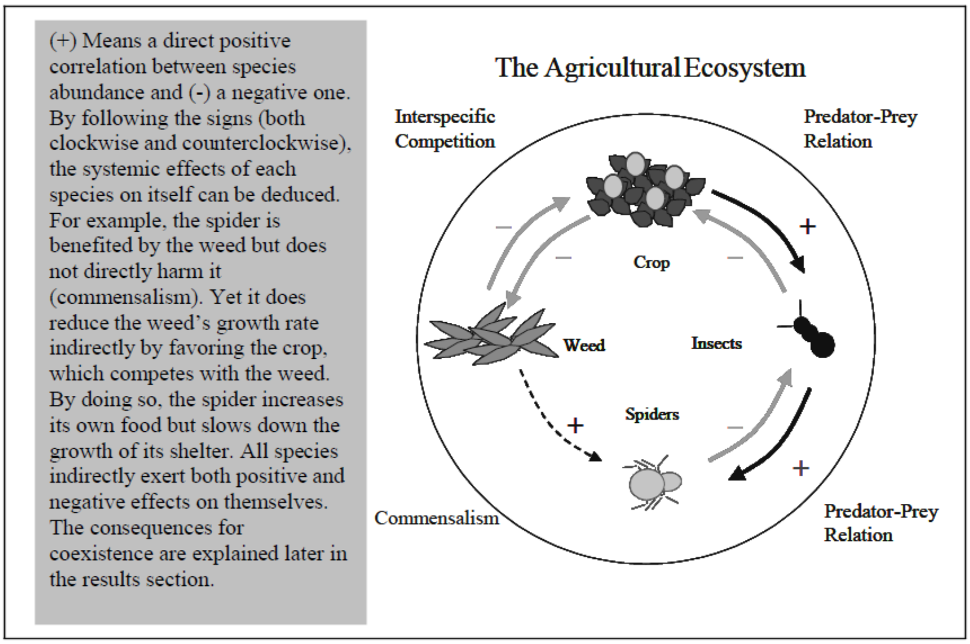

Figure 4.3: Ecological interaction network of the four species that form the biodiverse agroecosystem in Agrodiversity v.2.

3 Results and discussion

3.1 Model output

A proper balance between the co-existing species in the Agrodiversity v.2 environment is necessary so that their ecological interactions allow the multi-species system to become self-organized and persist over time. In a typical simulation, all four populations change over time as species affect each other. The predator-prey relations between crop and insects and between insects and spiders make all these three species oscillate (Figure 4.4). Strawberries occupy 2D space faster than weeds but every time foraging insects reduce crop modules, the weed has the opportunity to occupy more space. In the long run, this steadily reduces the crop population, and the fauna that depends on it. Network analysis and simulation results show that in the absence of external weed and insect control the equilibrium state of the diversified system is a mono-specific weed stand. The strawberry monocrop without weeds, insects and spiders is the other equilibrium condition of the dynamical system, but it is not considered here, given the purposes of this learning tool.

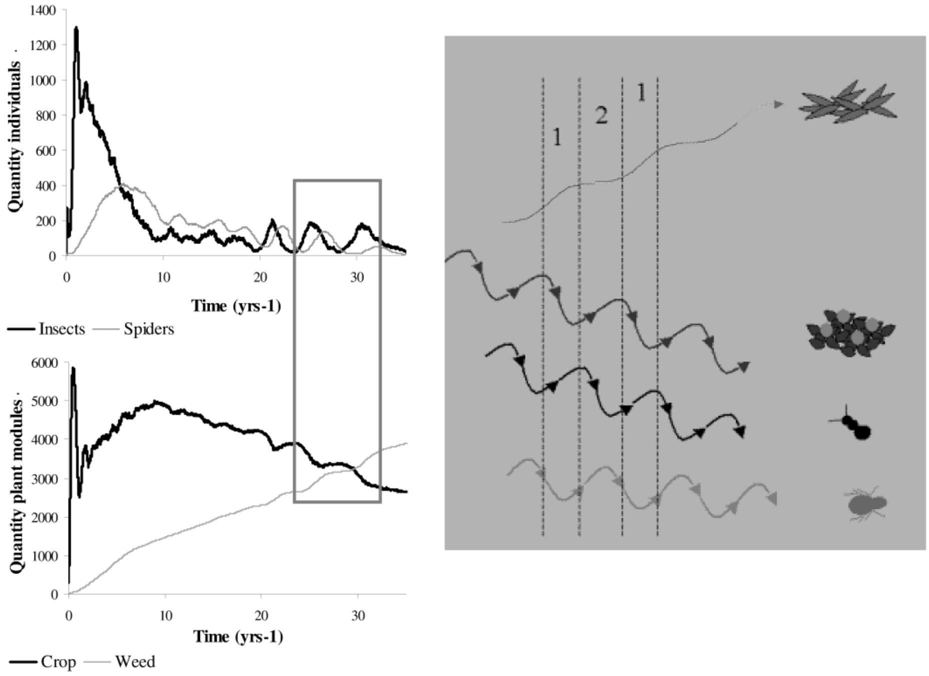

Figure 4.4: Model output showing oscillations in insect and spider populations (left-above), which makes the weed slowly encroach on the crop (left-below). A schematic view of these processes is presented on the right: (1) shows how a decrease in spider population, results in an increase in insect population, which in turn produces a decrease in crop population and an increase in weed (right-1), (2) shows the following phase in which the spider population increases, leading to a decrease in the insect population, which leads to an increase in crop population and a maintenance of the weed population.

Without management, three productive phases can be distinguished in this system when parameters that allow self-organization are chosen. In the first phase, the weed-spider populations are building up and there is insufficient pest control, which renders low strawberry yields and profits. In the second phase, the proper balance between species is reached such that net facilitation-effect and profits are maximized. In the third phase, the net-effect of ever-increasing weeds becomes negative on strawberry growth, and profits descend. These three phases render a hump-shaped profit curve that eventually drops below the economic threshold (Figure 4.5). Agrodiversity also exhibits graphically the trajectories of all species. These help users understand how the three phases emerge as a result of far-from-equilibrium coupling of all four populations.

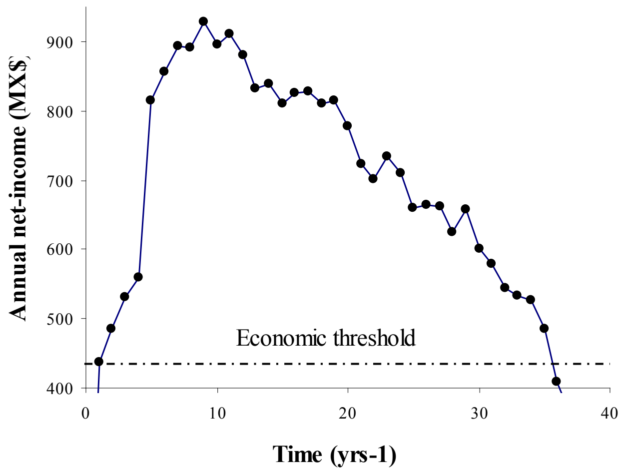

Figure 4.5: Annual net-income (5 year moving average) per strawberry field during 40 years in a system without management (average of 5 runs).

The hump-shaped curve is robust under a wide range of parameter values. The specific form of this curve and, consequently, the period of time during which profits stay above this threshold is determined by parameter values and initial population values selected by the user.

The software opens with system parameters which almost immediately induce collapse of insect and spider populations. User are not informed about the emergent properties of the agro-ecosystem; rather they are challenged to modify the initial abundances and intrinsic population growth rates until they find combinations that keep all four species alive and well, and the strawberry profit curve above the threshold as long as possible.

Careful observation of how populations are coupled help users understand how they respond to parameter changes. Predicting the attractor of the system is possible for some people trained in population dynamics theory. Yet, properly coupling one competition and two predator prey interactions is non-trivial, more so for those without such background and no previous simulation experience. Inexperienced users are expected to teach themselves how to navigate through the complex dynamics of this stylized agro-ecosystem, at first through trial and error, and later through increasing understanding of how interactions, community behavior and profit trajectories emerge and respond to their interventions.

3.2 Analyzing learning experience

Since we developed Agrodiversity v.2 in 2006, we have used it successfully with more than one hundred students in Agroecology Master courses in Mexico, Indonesia, Spain and the Netherlands. During simulation workshops, participants were very enthusiastic about the software. They have always been captured and surprised by the challenges of designing a sustainable agrodiverse system. All have enjoyed the trip and most have succeeded, although their capacity to formalize or verbalize their understanding of the underlying mechanisms has varied significantly. They have demonstrated an increased understanding of ecological processes such as competition, facilitation and of system dynamics concepts applied to sustainability analysis. Yet, until recently, we had not documented nor measured more rigorously the effects of using Agrodiversity v.2. simulations on actual learning, as compared to more passive, conceptual and static methods.

For such purpose, García-Barrios recently designed an evaluation tool that would serve as an "acid test" for the previously described features of this agent-based model. We organized a special workshop in which twenty-four agronomy bachelor students from a Mexican rural university (all of them sons and daughters of small farmers) were asked by their teacher (an agronomist with many years of experience in agricultural entomology) to participate in a four-hour non-stop highly structured workshop. The student's formal education background was unfortunately below national and international standards. They had never been exposed to computer simulations other than war games. Very few had previously attended a session on ecological interactions. All their answers to very specific questions were captured in written tests after each workshop stage, and no feedback was provided after each stage. Their teacher's answers were used as a control, to test for clarity of our tools (fortunately, all were correctly understood and correctly answered by him).

We defined very specific teaching and learning objectives for the workshop. The students would understand that: (a) biodiversity in an agro-ecosystem can but will not always lead to long-term profitability; (b) the outcome depends on the interactions among species and how they evolve in time; striking a proper balance among interactions can be non-trivial; (c) in a very simple crop-insect-weed-spider agro-ecosystem such as Agrodiversity v.2, functional agrodiversity can self-organize and profits can be attained as a transient condition but the attractor of the unmanaged system is an unproductive weed stand; (d) this occurs because no species decreases the weed population; rather, it slowly grows by encroaching on the fast-growing crop, taking advantage of the latter's insect-induced oscillations; (e) growth rates and initial densities of all four species can be combined to extend the transient condition so that profits can be made during a rather long period; (f) once a satisfactory agro-ecosystem with a relatively long transient has been "designed" it is unwise to significantly reduce initial insect and spider populations with "preventive" insecticide spraying as this can drastically modify the system's dynamics.

The workshop consisted of five stages designed to evaluate sequentially:

(1) students a priori opinions about the value of agrodiversity

(2) student's written predictions about the system's attractor (and insights about its mechanisms) after hearing definitions for competition, facilitation, and predation, watching and listening to an explanation of a diagram of the four species and their interactions (Figure 4.3), and seeing a classical one predator- one prey oscillation graph;

(3) students ability to (a) identify the attractor through interactive simulations, (b) to understand the attractor's drivers through tinkering with parameters and population time series, and (c) to keep the simulated system sufficiently far from the unproductive attractor during 20 "years" (7300 days/iterations) and (d) to foresee or later explain the negative consequences of significantly changing initial conditions of an already successful system;

(4) a self-report on what proportion of their understanding on the topics was acquired during the workshop and what percentage of this proportion was acquired during the simulation session.

(5) a self-report (short phrases) on three insights they acquired during the workshop.

In short, we analyzed the effects of stages 2 and 3 on learning by using "objective" measure of how much their answers and performance matched the abilities and messages we tried to convey "subjective" measures based on students self-report on learning. Gosen and Washburn (2004) reviewed the effectiveness of 20 computer-based simulation tools and found that both objective and subjective measures were frequently used and that low or no correlation between such measures was common.

We now describe the results from each stage:

1) A priori written opinions:

-Does biodiversity in an agro-ecosystem improve its performance and sustainability relative to the corresponding monocrop?

-Is it difficult, easy, inevitable to have all species coexist in the proportions that optimize the benefits of agrodiversity?

In most cases, students were biased towards positive mantras of agrodiversity. They frequently stated that a productive and sustainable system was inevitable as nature would create a perfect balance between species. Interestingly several students were not consistent with this answer when they answered after stage (2) – before using Agrodiversity- that they would prefer to eliminate some species from the system - mainly the crop-eating insect.

2) Predictions and explanations after passive/conceptual learning.

Ten out of twenty four students (44%) predicted that a weedy field was the attractor of the described system. Only 4 (15%) had the insight that strawberry-insect-spider oscillations favored weed encroachment over space previously occupied by the crop. On average students obtained 29% of the maximum score, attainable during this stage.

3) Performance during the simulation stage

Instructors gave a very brief explanation of the software's interface and did a DEMO with default parameters that would collapse insect and spider populations. The goal of this stage was carefully explained without providing hints. Students worked in couples on 12 computers. After 45 minutes, five couples (42%) had been able to make all species persist and to make above-threshold profits for at least 20 years. In previous workshops, around 75% of agro-ecology masters student had accomplished the task by this time. In this stage, the average grade for explaining the drivers of the weedy field attractor went up from 44% to 83% of the maximum attainable score. The average grade for explaining the effects of coupled predator-prey oscillations on weed encroachment rose from 15% to 52%. Overall, the average relative score increased from 29% in stage 2 to 68% in stage 3. Of the 24 students, 16 increased their average score between these two stages (Figure 4.6).

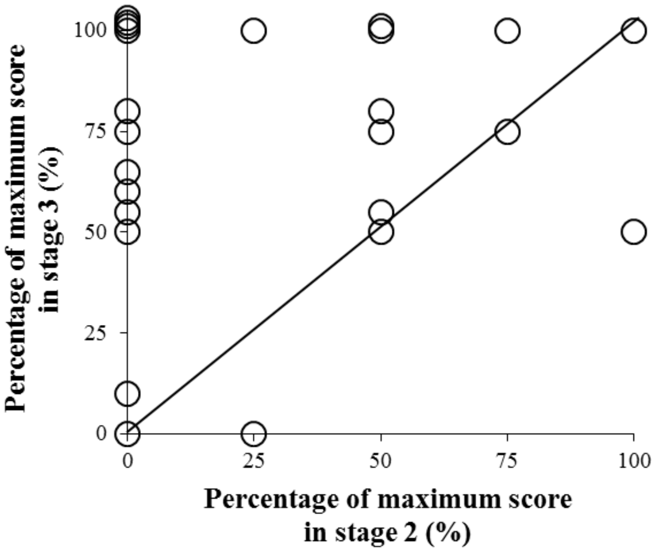

Figure 4.6: Relation between the student's score in stage 2- passive/conceptual teaching- and scores in stage 3-simulation.

Then, we showed the students a simulation with a set of parameter values with lead to a sustained production for a period of 20 years. We then asked them: given these parameters and these results would you do a preventive insecticide spraying that would kill 80% of all insects and all spiders to improve the productivity of the system? In other words, would you significantly reduce the initial insect and spider populations for this simulation to get an even better result? 21% of the students could foresee why spraying would not necessarily lead to a better performance and could even be counterproductive. We ran the simulation again with this change in initial condition. After seeing the very negative effects of such a preventive spray, 65% of the students were able to explain the consequences of significantly changing initial conditions of an already successful system.

(4) Self-report on learning experience

At the end of the workshop, we asked the students to self-report on their learning. On average, students responded that during the workshop they had obtained 55% of their current understanding of a four species agro-ecosystem. They stated that of what they had learnt during the workshop 76% was learnt during the simulation (Figure 4.7).

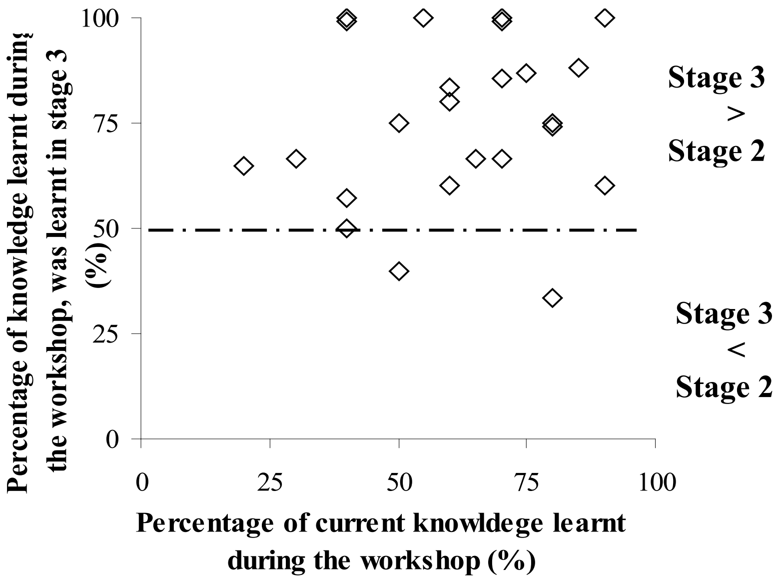

Figure 4.7: Relation between student's perception of how much of their current knowledge they learnt during the workshop ("subjective" measure) and their perception of how much was learnt during stage 3 - the simulation ("subjective" measure). A 50% line is placed in the graph to stress the number of students that felt they had learnt the majority of what they had learnt during the workshop during stage 3 - the simulation.

Interestingly, we found no significant correlation between our perception and student's self-perception of learning within stages 2 and 3 (Figure 4.8). This lack of correlation is in line with findings of Gentry et al. (1998) and Gosen and Washbush (2004). On one hand, figure 4.8a suggests that students might have understood "how much did you learn in this stage" as "how novel were these concepts to you", and that maximum scores during the passive/conceptual stage were lower as "novelty" increased. On the other hand, the lack of correlation speaks to the fact that learning is a complex individual and social experience and that some of its dimensions cannot be easily grasped through simple tests. Overall, our results on the effects of Agrodiversity v.2 on actual learning are very promising. Our ("objective") and student's ("subjective") measures and perceptions of learning were all significantly improved during the simulation stage.

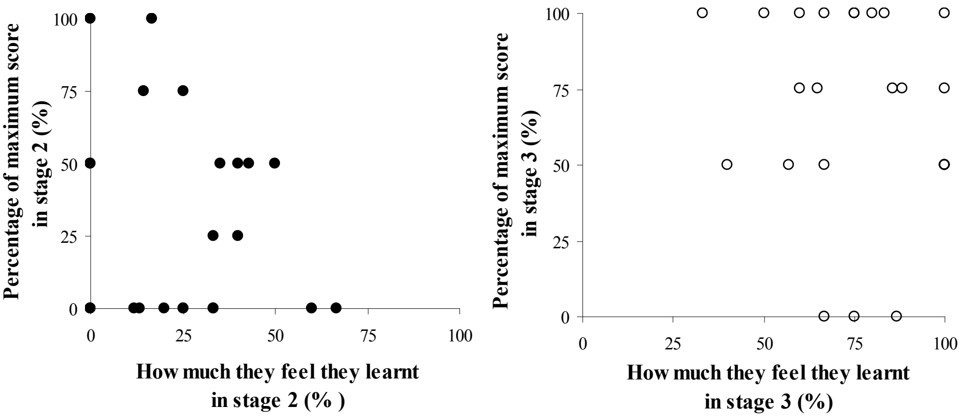

Figure 4.8: Relation between student's perception of how much they learnt in stage 2 –conventional teaching- (left) and stage 3 –simulation (right) ("subjective" measure) and the percentage of maximum score obtained by the students (objective measures") in stage 2 (left) and stage 3 (right).

(5) Self-report on three insights

We asked the students to state some three insights that they gained through the workshop.

Reponses differed in clarity and quality, but most students mentioned at least one of the following ideas: 1) the importance of each species in diverse agro-ecosystems, 2) the need to better understand the interactions between the species in an attempt to improve the performance of the system, 3) the highly dynamical nature of diverse agro-ecosystems, 4) the possible benefits of functional agrodiversity, 5) the principles of biological control, 6) the need to take into account the evolution of populations in an diverse agro-ecosystem in order to optimize it, and 7) a small initial change can have large consequences on the long run. These responses showed that the message we were trying to transmit, was grasped by a large part of the group of students.

It is worth noting that Agrodiversity v.2. has other higher-level features that allow users to compare the sustainability trade-offs that the system exhibits under contrasting management strategies (insecticide spraying vs. manual weeding). It also allows users to explore – again, in a stylized fashion - the unwanted effects and potential conflicts among "conventional" and "organic" farmers that emerge when neighboring fields with distinct levels of contiguity are managed differently. We are currently testing the usefulness of these features for learning through role-playing simulations

4 Conclusions

Research is increasingly demonstrating that functional agrodiversity can be an useful and even essential asset for the long-term agricultural sustainability. However, scientists still know relatively little about the combined ecological and social functions of much of the world's agrodiversity, and ecological mechanisms underlying these functions. Competition and facilitation between the various species in diverse agro-ecosystem can result either in net-beneficial effects for crop growth, neutral or net-negative effects. The outcome of the competition-facilitation interplay changes over time and is population density dependent. Therefore, in order to prosper from agrodiversity a proper initial design and adaptive management schemes are needed. Functional agrodiversity is not always an easily-grasped nor easily-reached concept. We believe that an agent-based educational model can facilitate learning and increase understanding on agrodiversity. In this chapter, we described the agent-based model Agrodiversity v.2. The model demonstrates in a stylized form that: (a) functional agrodiversity is not a given attribute of an agro-ecosystem but must self-organize; (b) attaining functional agrodiversity can be nontrivial; (c) functional agrodiversity has a transient nature- far from equilibrium- and therefore maintaining functional agrodiversity requires management. Agrodiversity v.2 allows users to see that functional agrodiversity emerges from ecological interaction networks and is sensitive to initial species abundances and species-specific biological parameters. In a number of Agrodiversity v.2 workshops, masters students have increased their understanding of these topics and of the issues involved in managing and benefiting from functional agrodiversity. Results of an acid test with bachelor students with hardly any formal ecological training and no previous exposure to ecological simulations, confirm that learning took place while using Agrodiversity v.2. Both the quality of answers ("objective" measure) as the students' perception of how much was learnt from the simulation ("subjective" measure) were strongly improved after using the simulation.

APPENDIX A: ODD for Agrodiversity v.2

Overview

Purpose:

The aim of developing the Agrodiversity v.2 model was to develop an educational tool that facilitates learning on functional agrodiversity and complex concepts involved such as facilitation, competition and predator-prey relations. Therefore, we created a digital agricultural field in which four organisms interact, namely a crop, a spider-hosting weed, a crop-eating insect, and an insect-eating spider who lives on the weed. The interplay of these four organisms shows how the system can go from non-productive to highly productive and back to non-productive, depending on the initial conditions. The insect and crop populations oscillate with each other, as well as the insect and spider populations (as long as there is enough weed for the spider to procreate). These two predator-prey relations result in advantage for the weed, which competes with the crop for space. The combination of these relations results that the weed both facilitates and hampers crop growth. When relative weed density is low, the weed facilitates crop production by harbouring the spider population, which is the natural enemy of the crop pest. However, when relative weed density increases, competition between crop and weed takes the overhand and the crop production is hindered.

State variables and scales

We used Netlogo 3.1.5 to build a spatially explicit agent-based model. The agricultural field created in Agrodiversity v.2 represents 0.5 ha. Each cell of the grid underlying the model equals 0.76 m^2. Each cell can contain one crop- or one weed-unit and an insect and/or a spider. The each time step equals 1 day. Fruit is grown once a year. Calculations concerning costs, and income are also calculated once a year. The spatial and temporal scale of the model were chooses according to agricultural setting in Chiapas, Mexico.

Process overview and scheduling

The order of processes occurring in each time step is as follows: 1) Crop actions; grow, produce fruit, 2) Weed actions; grow, 3) Insect actions; walking, eating, reproducing, death, and 4) Spider actions, eating, reproducing, death. Before eating a prey or growing a new plant unit in empty space a check is made to make sure that the prey or place is not already taken by another animal or plant-unit.

Design concepts

Interaction: Insects eat crop-unit. They in turn are eaten by spiders, when they walk into spider territory. The crop and weed compete for space. The populations of insects and spiders oscillate, as do the insect and crop populations.

Stochasticity Stochasticity is included in the model to develop unpredictable in the following procedures: - initial placing of insects near the crop according to the user's defined infestation rate, - initial placing of spiders on the weed according to the user's defined infestation rate, - reproduction of crop and weed according to user's defined growth rates, - growth direction of new crop and weed units, -growth of fruit, - determination of walking direction of insects (adjusted every 10 time steps), - eating of crop by insects, eating of insects by spiders.

Observation: The simulated populations of crop, weed, insects and spiders in our agricultural field are measured and shown in monitors and graphs.

Details

Initialization

In order to study the development and management of a diverse agro-ecosystem, the simulation is started with a bare agricultural field. Users are asked to "sow" plants and choose a infestation rate of both insects and spiders. Default setting for these variables are shown in table 1.

Ta ble 1: Default variable settings for Agrodiversity v.2.

Variable	Initial Value
Time	0
All cost variables	MX$ 0
Economic threshold	MX$ 6000
Insecticide costs per cell	MX$ 0.5
Insecticide labor costs per cell	MX$ 1.0
Weeding labor costs per cell	MX$ 1.0
Harvesting costs per cell	MX$ 01.5

** All economic variables have been based on inquiries with Mexican farmers.*

Input

Plant growth is only simulated as a function of randomness and growth, rates and available space. Nutrients, light, and water are assumed to be optimal.

Submodels:

Plant growth

Plant growth is simulated as optimum growth of both the crop and the weed, excluding limiting biophysical factors such as weather and soil characteristics. Plant growth is simulated as a function of growth rates, space availability and randomness. Growth is simulated as follows:

> If a random number under 100 < growth rates i.e. crop growth rate, weed growth rate, defined by user: grow new plant unit. New plant unit grows in available free space, if no free place is available, new plant unit dies.

Fruit growth

The crop in our model is a perennial crop that produces fruit once a year. The quantity of fruit grown is dependent on the number of crop-units and randomness. Each crop–unit has the possibility to grow a fruit. Fruit growth is simulated as follows:

> If a year has passed and a random number under 100 < 10: grow fruit.

Animal energy management

The life of simulated insects and spiders is dependent on their energy balance during the simulation. All insects and spiders start with 100 energy units. Every time step, the use energy to live and to looking for food.

> Insects: every time step decrease energy level with 2 energy units
> Spiders: every time step decrease energy level with 0.4 energy units

Insects and spiders can gain energy by eating crop-units and insects, respectively. When they encounter their prey, they eat it depending on a randomness. The amount of energy gained from eating is user-defined.

> If a random number under 100 < 16, eat prey
> When having eaten prey increase energy with nutritional value of prey (user-defined)

Reproduction and death are functions of the animals individual energy balance. When the animal has doubled its initial number of energy units; it will reproduce. Energy will be divided over "mother and child". If energy level drops below 0, the animal dies.

> If energy level > 200: reproduce
> If energy level < 0: die

Insect movement

The insects in our model walk around randomly. They change direction every ten time steps. Every time step, they walk a distance of the length of one cell.

> Every time step move distance 1 in direction

Every 10 time steps set direction to a random number under 360.

Box 1: Actions that are induced by pressing the “Set up”, “Go”, “Light weeding”, ”Spray insecticide” buttons are shortly described using Netlogo 3.1.5 logic. Actions induced by pressing the “Go” button are performed continuously, until the button is pressed again. All other buttons induce a one-time only action. “t_{+1}” refers to time now, whereas “t” refers to time in the previous run.

Set up

-Set all state variables to initial values (e.g income variables = 0, cost variables =0)
-Plant crop and weed according to initial plant spacing
-Infest crop and weed with insect and spiders, respectively according to initial infestation rates (each insect and/or spider owns 100 energy units)

Go

-Calculate time; set t+1 = t + 1 (each run equals 1 time unit, 1 time unit equals 1 day)
-Ask crop to:
- Grow; if a random number under 100 < crop growth rate: grow a new crop-unit.
  - Move new crop-unit to 1 of 8 neighbours. If there is no other crop or weed-unit here– let new crop-unit stay there; otherwise let new crop-unit die.
- Only once every 365 time units (if t+1 / 365 = integer), Grow fruit; if a random number under 100 < 10: grow fruit.

-Ask weed to:
- Grow; if a random number under 100 < crop growth rate: grow a crop-unit.

Move new crop-unit to 1 of 8 neighbours. If there is no other crop or weed-unit here– let new crop-unit stay there; otherwise let new weed-unit die.
-Ask insect to:

- Walk; only once every 10 time step (if t+1 / 10 = integer): set direction = random number under 360, move distance 1 (= length edge of cell) in direction
- Use energy; set energy level at t+1 = energy level at t – 2 energy units
- Eat crop unit; if a random number under 100 < 16 and there is crop unit which is not yet being eaten by another insect:
  - eat crop unit, ask crop-unit: die
  - set energy level at t+1 = energy level at t + nutritional value crop-unit
    - Reproduce: if energy level at t+1 > 200:
    - hatch new insect
    - set energy level of mother at t+1 = energy level at t+1 / 2
    - set energy level of new insect at t+1 = energy level of mother at t+1 / 2
    - Move new insect to 1 of 8 neighbours.
    - Die: if energy at t+1 < 0: die

Box 1 continued

-Ask spider to:

- Use energy: set energy level at t+1 = energy level at t – 0.4 energy units
- Eat insect: if a random number under 100 < 16 and there is insect which is not being eaten by another spider:
  - eat insect, ask insect: die
  - set energy level at t+1 = energy level at t + nutritional value insect
- Reproduce: if energy level at t+1 > 200:
  - hatch new spider
  - set energy level of mother at t+1 = energy level at t+1 / 2
  - set energy level of new spider at t+1 = energy level of mother at t+1 / 2
    - Move new spider to 1 of 8 neighbours. If there is a weed-unit and no other spider here – let new spider stay there; otherwise die.
- Die: if energy < 0, die

- Only once every 365 time units if t+1 / 365 = integer), Calculate annual net income:
  - Calculate annual costs (include both labour and material costs):
    - Set annual weeding costs = weeding cost per weed-unit removed * number of weed-units removed
    - Set annual spraying costs = spraying cost per area-unit sprayed * number of area-units sprayed
    - Set annual harvesting costs = harvest cost per fruit * number of fruit
    - Set total annual costs = annual weeding costs + annual spraying costs + annual harvesting costs
  - Calculate annual gross income:
    - Set annual gross income = number of fruit * price of fruit
  - Calculate annual net income:
    - Set annual net income = annual gross income – total annual costs
- Only once every 365 time units (start in year 5)(if t+1 / 365 = integer) Calculate average net income of last 5-years
- Update graphs

Box 1 continued

Light weeding

- Ask weed with crop-unit on 1 of 4 neighbours: die
- Ask spiders on weed with crop-unit on 1 of 4 neighbours:
    - if any weed on 1 of 8 neighbors without spider: move distance 1 in direction of this neighbor, otherwise; die

Heavy weeding

- Ask weed with crop-unit on 1 of 8 neighbours: die
- Ask spiders on weed with crop-unit on 1 of 8 neighbours:
    - if any weed on 1 of 8 neighbors without spider: move distance 1in direction of this neighbor, otherwise: die

Spray

- If mouse-down:
    - set insecticide level 10, diffuse insecticide 100 times
- Ask spiders: if insecticide level > 0.2: die
- Ask insect: if insecticide level >0.2: die

* <u>Underlined variables</u> are chosen by user

Chapter 5

Learning through simulation: a more complex simulation tool

Biotic communities subject to productive transformation – and social relations among stakeholders involved in their management – are complex, nonlinear, adaptive processes. The inner workings and potential behaviors of such processes are not always easily grasped. It is important to help people understand the dynamic nature of sustainability attributes and to better address the issues, tradeoffs and conflicts associated with sustainable management of natural resources. The program "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" was developed as an interactive workshop based on computer simulation explorations, role-play and negotiation sessions to enable learning on resilience thinking concepts such as stable and unstable equilibria, and non-linear responses. In three acts, participants take on the role of small-scale maize growers that face the need to intensify their production. Through computer simulations they explore the effects of nitrogen fertilizer application on their production, in the act 1. In act 2, participants take on the role of rural families that live of tourism of a lake downhill from the maize farmers. They are confronted with lake eutrophication due to nitrogen fertilizer application of the maize growers. The participants explore the eutrophication process and the dynamics of the bi-stable lake ecosystem. In act 3, the group of participants is split to play out a group of farmers and lakeside households. They negotiate possible solutions using simulation explorations. Results from 12 workshops with the program showed that participants improved their knowledge and understanding on the systems attributes: productivity, stability, resistance, resilience, reliability, adaptability and equity. In all workshops, participants managed to balance the biodiversity conservation and rural livelihood interests of all stakeholders involved through the development of creative solutions. Participants were challenged by concepts such as bi-stability, thresholds, risk, catastrophic shift, and hysteresis, but all stated that the program enabled them to learn about these concepts

Based on: García-Barrios, L.E., Speelman, E.N., Pimm M.S., 2008. An Educational Simulation tool for negotiating Sustainable Natural Resource Management Strategies among stakeholders with conflicting interests. Ecological Modelling 210: 115-126.

1 Introduction

A Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS, its acronym in Spanish) was developed in 1995 by a multi-institutional effort led by a Mexican NGO, GIRA A.C. This framework pioneered a multidisciplinary and fact-based evaluation of the sustainability of specific natural resource management systems (NRMS), most commonly by comparing a conventional vs. an alternative management strategy. It was the methodological core of the Natural Resource Management Network, financed by the Rockefeller Foundation, in which many Mexican organizations and institutes joined efforts on the research of peasant NRMS. MESMIS provides guidance in the process of operationalizing the concept of sustainability, evaluating current NRMS and developing and monitoring more sustainable alternatives.

MESMIS considers seven attributes relevant to sustainable NRMS, especially in the context of peasant NRMS, based on a systemic approach: productivity, stability, reliability, resilience, adaptability, equity and self-reliance. Critical socio-economic, technical and environmental indicators related to these attributes are used to characterize the strength and vulnerabilities of current and alternative systems. A multi-criteria analysis is then used to evaluate the systems under investigation as a whole. The multi-criteria analysis is visualized by means of an AMOEBA diagram (Ten Brink et al., 1991; Gomiero and Giampietro, 2005). This diagram shows in a snapshot to what extent a number of critical indicators of the reference and alternative systems approach optimum values. Since the framework's development it has received considerable attention resulting in 12 international courses, more than 40 case studies (of which 28 are reviewed in Speelman et al, 2007) and several articles and books (e.g. Masera et al., 1999, Masera and López-Ridaura, 2000; López-Ridaura et al., 2002; Astier and Hollands, 2005).

The improvement of the methodology is an ongoing process. Through its continued application it has become apparent that a methodology for evaluating the sustainability of NRMS needs to stress and further clarify: (1) the dynamical nature of sustainability attributes, (2) the complex/nonlinear response of resources to management strategies, (3) the interactive/adaptive nature of sustainable NRMS design (4) the tradeoffs involved when trying to optimize a set of critical indicators which are systemically and dynamically linked and (5) the need to deal with conflicts that arise between social actors who embark in a multi-criteria evaluation with different and sometimes opposite interests. In this chapter we present a simulation-supported role-playing game recently developed by García-Barrios and Pimm (2005a) that helps users become aware of these topics and/or understand them more clearly. In its current version, the tool is aimed at NGO members, government officers and academics; work is underway to expand it to rural actors and other stakeholders. In the rest of this introduction, we briefly review the background for developing this tool. In the following sections, we describe it and present the most relevant results produced by a dozen of workshops based on its use.

1.1 Understanding complex NRMS

So-called biotic resources are sets of strongly and weakly interacting species that self-organize into ensembles capable of persisting through short term regulation and long term adaptation to ever-changing bio-physical conditions (Capra, 2002). Although particular species might be substituted in the process, the ensemble as a whole persists as an ecosystem capable of accumulating, recycling and dissipating matter energy and information. This form of adaptive persistence requires stability, resistance reliability and resilience in the short and medium terms but also instability, alternative equilibriums and adaptability in the long term (García-Barrios et al., 2010). Human societies take advantage of these adaptive dynamical biophysical systems by transforming them into managed ecosystems. The level of transformation, extraction and other management decisions can either sustain the critical biophysical processes of the system (e.g. biomass accumulation, nutrient recycling, population regulation, soil and water conservation) or can make them collapse. One or the other outcome depends again on how the elements of the managed ecosystem interact to maintain its stability-related and adaptability-related attributes. Human actors directly and indirectly involved in such management also constitute networks that continuously reorganize through the workings of social cooperation and conflict (García-Barrios and García-Barrios, 2010). The dynamics of these networks has significant consequences both for human wellbeing and for the persistence of managed ecosystems. In short, NRMS are basically complex adaptive socio-environmental systems (Gunderson and Holling, 2002).

Complex systems are characterized by a few to many elements interacting in ways that lead to positive and negative feedbacks, nonlinear responses, irreversible thresholds, emergent properties, and unpredictable/unexpected/unwanted results (Sterman, 1988, 1994; Strohschneider and Güss, 1999; Spector et al., 2001). In general, human beings have problems dealing with complexity and tend to use short term, adaptive and ad hoc problem solving strategies that are successful only within certain limits (Dörner, 1996). The social process of NRM has become increasingly complex, interdependent and uncertain (Gunderson, 1999). In consequence, the apparently independent actions of different stakeholders involved can produce unwanted and uncontrollable consequences for all (Bouwen and Tailllieu, 2004) which contribute to conflict and separation between social actors. This is unfortunate, as understanding these complex domains requires more knowledge than any single social actor possesses because the knowledge relevant to a problem is usually distributed among learners (Spector and Anderson, 2000).

1.2 NRMS Issues and conflicts in peasant territories

The dispute over the way remaining terrestrial biotic resources are and should be managed in peasant territories has increased during the past decades. Many of these territories harbor a significant portion and diversity of remaining biotic communities as well as a number of local, national and international social actors that have different and contrasting interests over such resources. Their rural populations still depend on agriculture, and they use natural resources available in their local environment in sustainable and unsustainable ways to make a modest living (García-Barrios and García-Barrios, 1992). Companies and individuals with a resource-mining attitude exploit specific resources to their depletion. Development and Agriculture government agencies promote land-use intensification based on industrial inputs. New social actors (coming mainly from the urban-middle-classes) demand (through NGOs and government offices) that biotic communities are preserved for recreation, biodiversity conservation and ecosystem services. The decisions that each actor promotes or makes regarding NRM is subject to constraints and opportunities created by other actors and has a number of intended and unintended consequences on resources and on the interests of all actors.

With increased pressure on resources, relationships between stakeholders become more apparent and more intense. This often leads to conflicts (e.g. Senegal- D'Aquino et al., 2003; Mexico-Speelman et al., 2006; Bhutan- Gurung et al., 2006). They range from conflicts at a local level (e.g. upland vs. lowland groups managing a watershed) to conflicts between local and global interest such as disputes over the use of forestland for agriculture and preserving forests for carbon stocks and biodiversity reasons. Negotiating sustainable management options at the local/regional level that will be accepted and pursued by all legitimate stakeholders is high priority. It is, however, not an easy task. It involves a number of conflict transformation processes. One of them consists of developing in all stakeholders interested in the long term persistence of these resources: (1) a better understanding of how the relevant biotic communities respond in nonlinear/complex/unexpected ways to management practices and (2) a mind open to collectively designing strategies that take into account these responses and the interests of all legitimate stakeholders involved. It seems particularly important to involve in this latter process those NGO members, government officers and academics that (1) have a significant influence on policy-making and resource-assignment regarding NRM but (2) have a formal education that does not necessarily include the required complex dynamical system approach to NR sustainability.

1.3 Computer-based Decision and Negotiation support tools

Computer simulations can be an important support tools for scoping and consensus building. A model built to help people understand a complex system should simplify things as much as possible, but not to the point where the interesting characteristics of the phenomenon are lost (Gilbert, 2005). Complexity is not about details; it's about the variety of nonlinear behaviors a system can exhibit. Well-built simulation models can illuminate the mind confused by a complex system, by allowing it to acquire a comprehensive overview of the host of possible long-term behaviors and of the main drivers involved.

A wide variety of models directed to supporting negotiation in NRMS have been developed and many more are under construction (see e.g. van Noordwijk et al., 2001; Bousquet and Le Page, 2004). Dimensions by which models can be classified include phenomenological vs. mechanistic, big/detailed versus small/stylized, site-specific versus generic, real-case versus fiction (Gilbert, 2005) The size, level of detail and other model characteristics should be suitable and consistent with the model's goals (e.g. prediction, increased understanding, exploration, negotiation).

As mentioned earlier, complexity of peasant NRMS derives from both biophysical and sociological processes. In the past, agricultural and NRM models only simulated the biophysical side of the story (reviewed in García-Barrios et al., 2001). Yet, social actors have the lead in sustainable NRMS as they make decisions that eventually determine the system's sustainability. It is therefore essential to capture the social dimension of system management in negotiation support tools. Nowadays, it is recognized that modeling the management or co-management of NR requires considering and linking biophysical and social processes (e.g. Holling, 1978; Berkes, 1997).

Model-based support tools can aid social actors involved in negotiating the management of NR by: (i) providing simulated data on the status of relevant variables under different management strategies (ii) by intentionally displaying situations that compel participants to develop their communication and negotiation skills (iii) by doing both. The third option combines computer simulations with role-playing games. This third option is commonly developed by teams of researchers, modelers and programmers but important efforts are being made to involve stakeholders early on in the definition and construction of the models and the games (e.g. Barreteau et al., 2001; Becu et al., 2003; Etienne, 2003; Dray et al. 2006; Purnomo and Guizol, 2006).

Most simulators coupled to role-playing games are site specific and address a particular problem. They allow users to deal with complex NRMS and become aware of the model's behavior and the stakeholder reactions to it. More generic versions of these coupled tools e.g. "Sustainability and System Dynamics" by García-Barrios and Pimm (2005b) and the tool presented in this chapter, are oriented to education and use ad-hoc interactive stories that expose users step-by step to concepts and situations that are relevant for understanding the way nonlinear processes work in NRMS in a multi-stakeholder environment. They do not offer a "real fish" but focus more on providing users with "virtual fishing gear" that might be used in a number of different cases.

Using stylized stories inspired on plausible situations has obvious limitations but also benefits. One of Dörner's (1996) experiments described in his book "The logic of Failure" is based on inviting a group of people to manage Tanaland, a territory that only exists in a computer. Players of the Tanaland game became extremely involved when exposed to situations in which they had to make collective decisions which confront them with their contrasting interests, values, scopes of analysis and problem solving strategies. Similar results have been observed with the agent-based simulator "Agrodiversity ver.2" (García-Barrios and Speelman, 2006; Speelman and García-Barrios, 2006) which challenges users with contrasting strategies to sustain biodiversity and production in a strawberry field. Even very abstract agent-based models such as "Sugarscape" (Epstein and Axtell, 1996) are capable of increasing user's curiosity and interest in better understanding complex resource management behaviors.

Hands-on learning and problem-solving in collaboration with others produces a number of benefits (Milrad, 2002; Pahl-Wostl., 2002; Bouwen and Taillieu, 2004): (a) it catalyzes ideas as minds are triggered by the words and thoughts of others; (b) moments of discussion and reflection derived from exploring scenarios allow problems to be framed and reframed leading to a joint "reality"; (c) it creates a shared responsibility for the solution, resulting in a higher commitment and longer lasting learning experience.

By taking up a role in a generic story where conflict will arise, players are not personally tackled, they can detach more easily of their conventional views and emotions about an issue, and they can attempt to see the situation through the eyes of the person they represent (Dray et al., 2006). They also become aware of how implicit and explicit communication (including discourse, body language, and emotions) can promote or cloud discussions and negotiations. Conflictive situations, whether real or fictitious urge people to learn more and to quickly organize their points of view and fine-tune their arguments (Eshuis and Stuiver, 2005). Role-playing can have significant influence on the way the players will behave in the future (Gurung et al., 2006).

2 The tool and some relevant workshop results

The program "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" is a freeware that can be used on line at http://132.248.203.11:8080/mesmis-interactivo in both English and Spanish. It has a number of goals, a story, a user interface and a series of underlying simulation submodels named LINDISSIMA 1, 2, and 3. LINDISSIMA is the acronym in Spanish for "LIxiviación de Nitrógeno y DISeño de SIstemas MAiceros" (Nitrogen lixiviation/runoff and design of sustainable maize production systems). We will first describe the story, which is an interactive drama in three acts.

2.1 The Story

In act 1, users play the role of a group of slash-and-burn farmers compelled by the government to withdraw from a biodiversity-reserve zone and to intensify their maize production in a much smaller portion of their territory using partially subsidized nitrogen fertilizer. With the LINDISSIMA 1 submodel, users simulate production and income under different fertilization scenarios and decide if they can maintain or increase their current income in the long term under the government's proposal. In act 2, a group of rural families depends on ecotourism in a clear shallow lake downhill. They anticipate that their livelihood could be threatened by lake eutrophication caused by nitrogen runoff from the maize fields (Figure 5.1). As part of the negotiations with uphill farmers, they need to know how much N (in g m-2) can lixiviate from the fields without their lake becoming murky because of algal blooms. Users now take the role of managers who help the fictitious lakesiders answer this question. With the LINDISSIMA 2 submodel (adapted from Scheffer et al., 1993) they simulate a bi-stable lake system where algal bloom is dependent on previous lake conditions (hysteresis) and on stochastic climatic conditions. In act 3, users divide into three groups and dress up to represent the fictitious farmers, the lakesiders and the government officers. Through role-playing and dramatization they try to negotiate a proper N fertilization doses. (Users are now playing a dual role, as they bring together (a) the interests of a stakeholder in relation to this very specific technical part of the problem, and (b) the analytical abilities of a formally educated manager). Each proposition made by a manager/stakeholder is simulated with the LINDISSIMA 3 submodel, and its consequences are displayed with a number of graphical multi-criteria tools. The problem seems to be technically unsolvable and conflict escalates until a maize-leguminous shrub system is proposed. Yet this agroforestry system –when simulated- turns out to have its own tradeoffs, as it can increase N lixiviation and reduce maize yield if additional and costly management is not performed by the farmers. Users don't give up but thoroughly explore, fine tune and negotiate a suite of techniques, government subsidies and environmental services paid by the lakesiders to the farmers in order to meet the economic and environmental interests of all parties as equitably as possible. The program is built in a way that allows control of the situation and a happy ending, but restrictions can also be imposed so that social actors have to agree over suboptimal solutions with a degree of uncertainty, as occurs in “real life”.

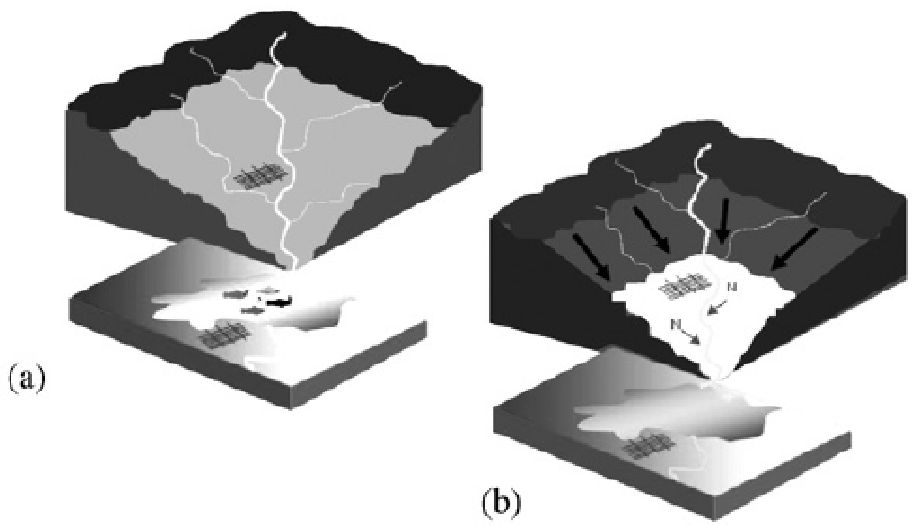

Figure 5.1: (a) Farmers in the upper part of a river catchment have been using 4 000 ha of land for slash-and-burn maize cultivation for decades. Downhill there is a beautiful clear lake where another group of rural families make a living by offering ecotourism services (b) The government is compelling the farmers to allow forest recover in the 3 000 ha that are part of a natural reserve zone. This would require using nitrogen fertilizer (urea) to intensify their agriculture in an area of 1 000 ha. As a consequence of N lixiviation, the lake could be eutrophicated and ecotourism would no longer be possible.

2.2 The goals of the program

The program is educational, as it is meant to further develop complex system thinking, basic eco-technical knowledge, social attitudes and negotiation skills required for sustainable NRM. Its current version was designed for users without any modeling background but reasonably familiar with numerical inputs and outputs displayed in tables and graphs. This includes undergraduate and graduate students, middle and high-level technicians, researchers, professional practitioners, middle and high-level government officers and formally or informally educated rural leaders. These goals and tools can still result quite challenging for many people so we were particularly careful to develop the program as a very visual and didactic step-by step process, slowly increasing in technical and social complexity. The story is a very simplified and generic version of reality as we normally conceive it (a stylized description or caricature). We had at least five reasons/limitations to keep the story this way: (a) the target users do not hold stakes linked to a single and local real-life case; (b) the underlying modeling and parameterization process should not overwhelm the modelers and users interested in model details; (c) the number of nonlinear interactions the user can analyze and explicitly deal with are limited; (d) a caricature can be a first and playful step in confronting the minds and hearts of a group of un-experienced decision-makers with the consequences of linear thinking and social myopia, and with the diversity of interests, scopes and problem-solving strategies involved in a simple NRM situation; (e) stylized situations can be good enough to become familiar with thresholds and tradeoffs and to grasp the dynamical nature of sustainability attributes such as productivity, stability, resilience, adaptability, and equality. They can also display very clearly important nonlinear dynamical features such as bi-stability, multiple equilibria, hysteresis and selforganization which are crucial for NRM.

Our simplification of socio-environmental dynamics and of stakeholder rationales, interests and options is justified given the purposes and limits of the program, but – of course – it comes at a cost. It can mislead those users who are not sufficiently aware of the degree to which slash-and-burn agriculture, lake eutrophication, agroforestry system development, and stakeholder negotiation are being simplified, both technically and socially. Those well aware of the complexities of these topics (e.g. the developers of the program and some of the more experienced users) need to deal with the frustration implied in simplification, and remember the quote by the industrial statistician George Box: “all models are wrong; some can be useful”. Instructors need to remind users that the story is stylized and that the “agroforestry solution” to the conflict would be partial in real situations and is only instrumental for the educational purposes of the program. During workshops – when time allows – we introduce and/or conclude each act with a broader and more realistic explanation/discussion of the major real-life topics involved. As explained below, the program has met its purposes for the targeted users. In order to expand its goals, our team is currently working on new programs based on the Companion Modeling approach (COMMOD; http://cormas.cirad.fr/ComMod/en/) which addresses real-life situations and involves real stakeholders from its inception.

2.3 A minimalistic modeling strategy

This chapter does not have the purpose of presenting in detail all the models used, adapted or developed for the three LINDISSIMA simulators (they are readily available upon request to the authors). We will only describe them in general terms. Yet, it is useful to exemplify the modeling strategy adopted. The following three equations model the sigmoid accumulation of maize aboveground dry matter along a 25-week growth period.

Accumulation depends on intrinsic maize parameters, maize plant density and nitrogen actually available to the maize plant. Other nutrients are assumed to be non-limiting. In this example, equations describing nitrogen partitioning with other plant species are not included.

$M_{(t)} = M_{(t-1)} + \text{DeltaM}$

Such that

$\text{DeltaM} = D(\, f(N)(r_a M_{(t-1)} - r_c A\, M_{(t-1)}{}^2)\,)$

and

$f(Nm) = 1 - (1 / (1 + B\, NmC\,)$

Where:
Mo = maize aboveground dry matter (ADM) at initial condition = 1 g m^{-2}
M(t) = maize aboveground dry matter (ADM) this week
M(t-1) = maize ADM the past week;
DeltaM = daily increase in maize ADM g m^{-2} day^{-1}
ra = maximum anabolic rate of maize ADM = 0.3 g $g^{-1}m^{-2}$; fixed
rc = maximum catabolic rate of maize ADM = 0.035 g $g^{-1}m^{-2}$; fixed
A = a parameter modulating catabolism = 0.018; fixed
D = maize density = 4 plants m^{-2}; fixed
Nm = N available to the maize plant after competition with any other plant species = 0 - 15g m^{-2}; user defined
f(Nm) = an ascending asymptotic (saturating) function of Nm, with values between 0-1
B = asymptotic function parameter = 1; fixed
C= asymptotic function parameter = 1; fixed

Grain yield (g m^{-2}) is estimated as 0.5*maize ADM. It is transformed to kg ha^{-1} and to net family income per ten hectares (after considering market price and production costs).

The models described are quite simple (i.e. a logistic growth function and a resource saturation function (Keen and Spain, 1992). They suffice to capture in a qualitative way the saturating effects of time, density and nitrogen on maize ADM accumulation during the growth period. Parameter values were selected arbitrarily and fixed or kept within ranges such that ADM could display credible responses, typical of rain-fed maize in the subhumid tropics. As an example, Figure 5.2 shows a simulation that reproduces the saturating effects of density and of nitrogen on final maize ADM.

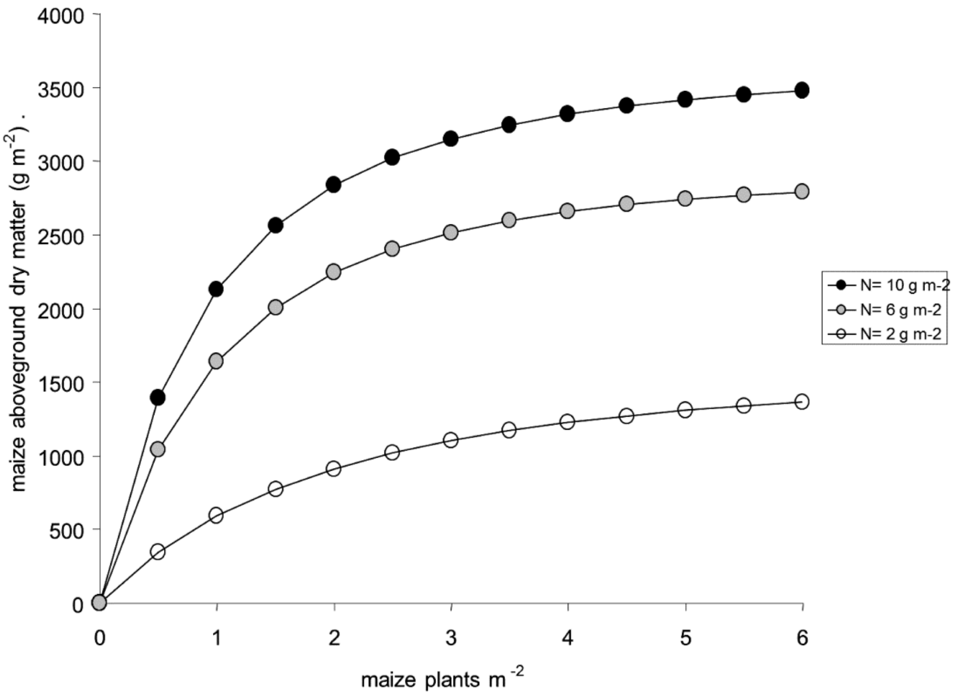

Figure 5.2: Simulated response of maize aboveground-dry-matter to crop density and nitrogen applied to the soil.

2.4 Some relevant model features

In Figure 5.3, we present a network of the major components of the three submodels and their interactions. All components are linked through nitrogen flows that ultimately define if farmer and lakesider incomes can be maintained above a threshold that makes their livelihood strategies and their resource managements sustainable.

Most of LINDISSIMA 1 has already been described above. N lixiviation and runoff during the (rainy) growth period is a linear function of N concentration in the soil, which depends on the pre-existing N stock in the soil and the balance between N fertilizer supply and N uptake by maize. Actual nitrogen uptake by maize plants depends on N demand and N available to their roots. Both depend on current maize ADM and the latter also on N concentration in the soil. Ecological thresholds are established for this latter variable: (1) a minimum N concentration value below which plant growth is arrested and irreversible erosion occurs due to lack of plant cover, and (2) a maximum value above which soil microbiota is severely affected.

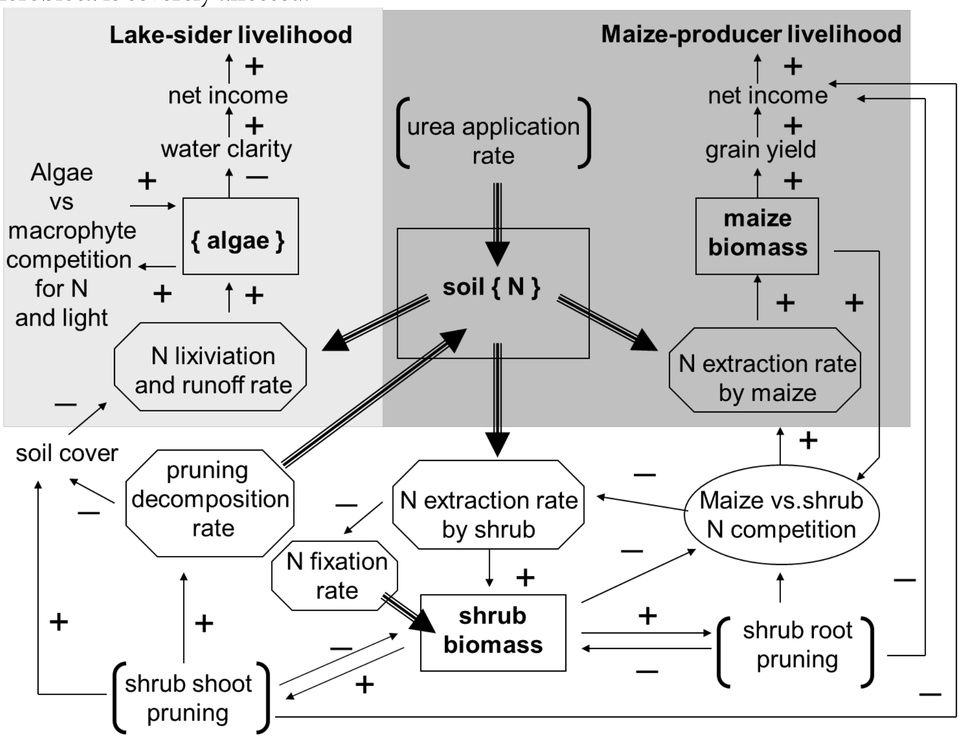

Figure 5.3: Diagrammatic representation of submodels LINDISSIMA 1 (dark gray), 2 (light gray) and 3 (all the figure). Thick arrows represent N flows. Thin arrows represent direct (+) and inverse (-) relations. Some state variables are highlighted in rectangular boxes and some rates in hexagonal boxes. The three most important N management decisions (aside from maize and shrub densities, not shown) are in brackets. Nitrogen flows in the model ultimately affect the possibility of sustaining the maize-based and the eco-tourism based livelihoods of two different rural groups.

LINDISSIMA 2 draws heavily from a validated eutrophication model developed by Scheffer et al. (1993), which captures the basic dynamical features that produce bistability of microscopic algal populations in shallow lakes. As previously mentioned, when algae populations explode, the lake in our story becomes murky, tourists flee from the place and lakesiders have no other way of making a living. LINDISSIMA 2 describes microscopic algeae concentration in the lake as the major cause of water murkiness and as a direct and strongly nonlinear function of nitrogen lixiviated from maize fields (NL hereafter). This "cusp catastrophe" function (Thom, 1989) arises from the following fact: macrophytic aquatic plants that live at the bottom of the lake compete strongly with algae for dissolved nitrogen. Under normal N concentrations, both populations coexist and low algeae populations are attracted to a clear-lake stable equilibrium. When algae concentration increases beyond a certain threshold, the lake becomes murky and the macrophytes are deprived of light and almost excluded, making most of the dissolved nitrogen available to the algae. As a consequence, the algal population at equilibrium becomes much higher for any given N lixiviation value as long as macrophytes are not reestablished; algea populations are now attracted to murky-lake stable equilibrium values. Macrophyte restoration is possible if algae concentration falls below the above-mentioned threshold but the latter will now occur at a much lower NL value. In short, if the algae population is currently attracted to equilibrium conditions producing a clear lake, then a threshold NL = X will cause the algae population to be attracted to a stable equilibrium condition producing a murky lake. To shift the population stable equilibrium back to the clear lake regime, NL has to be reduced to a value much lower than X. These two different thresholds define three NL intervals: (a) a low-value interval producing a stable clear lake irrespective of initial conditions; (b) an intermediate-value interval producing bi-stability such that the equilibrium state of the lake depends on initial conditions previous to lixiviation, and (c) a high value interval producing a stable murky lake irrespective of initial conditions. These behaviors are explained further in the program. A "cup and marble" (gradient analysis) representation of simulations is displayed in real time- coupled to a conventional time series graph of algae concentration- to help users understand how changes in NL move the system along these three stability regimes. This exercise stresses the fact that "the form of the cup is more important than the current position of the marble", a notion commonly overlooked in NRM (Figure 5.4) (Carpenter and Gunderson, 2001).

Lakesiders confront three complications for establishing the maximum NL level they can accept: (a) during very warm years (occurring any specific year with a 10% probability) algal blooms occur at normal N concentration value in the lake during the dry season even in the absence of NL, but they reverse spontaneously at the beginning of the rainy season if there is no excess N to sustain them; (b) if such a natural algal bloom occurs, the NL value they can accept is much lower than X; (c) farmers do not accept an adaptive strategy where the NL value could be decided every year depending on (a), because government bureaucracy is slow in delivering the subsidized fertilizer and it has to be requested and paid many months before anybody knows if a natural algal bloom will occur. The stochasticity of algal blooms and their consequences are captured in this submodel.

LINDISSIMA 3 introduces a small leguminous shrub into the maize fields as an additive intercrop (i.e. maize density is not reduced to make room for it). This submodel is again very simple and it is inspired in more elaborate and realistic ecological and ecophysiological tree-crop models (reviewed in García-Barrios and Ong, 2004). Shrubs in our story can be sown at densities between 0 and 2 plants m^{-2}. As in real situations, they can have positive and negative effects on both maize production and NL: On the one hand, (a) shrubs can absorb excess N in the field; (b) when N is insufficient, they can fix atmospheric nitrogen (investing energy on it) and reduce the need of N fertilizer and its cost; (c) their shoot prunings cover the ground and reduce N runoff. On the other hand, (d) as prunings decay, their nitrogen is incorporated into the soil (no attempt is made in LINDISSIMA 3 to model N mineralization; we simply assume that all N coming from prunings is available to plants within one year); (e) shrub roots invade maize root zones to a certain extent and compete for nitrogen. Partition of available N at any given time between maize and shrubs is a function of their dry matter ratio, their respective N demands and the extent to which shrub roots invade the maize root zone.

LINDISSIMA 3 allows for a user-defined number of shoot prunings per year, as well as a user-defined % of annual root pruning, both at a cost to the farmer.

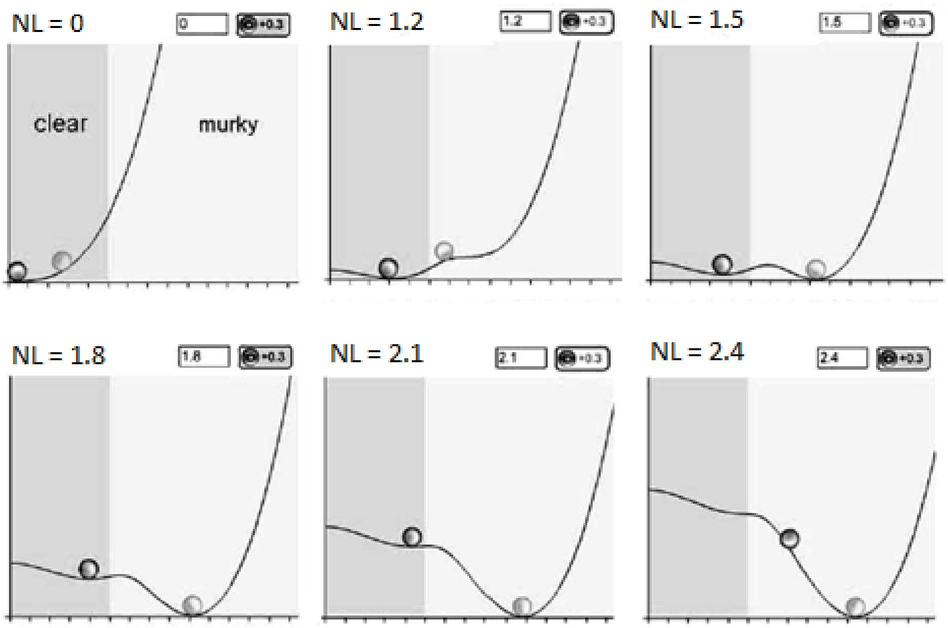

Figure 5.4: Cup and marble representation of the effect of NL on the stability regime of the lake. When NL= 0 and 1.2, there is a single clear-lake stable equilibrium state were the marble rests, irrespective of where the marble starts. When NL = 1.5, 1.8 and 2.1, there are two possible stable equilibriums (clear to the right and murky to the left), depending on the initial position of the marble. When NL = 2.4 there is a single murky-lake stable equilibrium state were the marble rests,

irrespective of where the marble starts. In the program, the movement for the cup and marbles is simulated for every NL value.

2.5 The user's interface

The program is built in FLASH ver.7 and has a total of 85 screens. As the story unfolds with text and illustrations, concepts are presented through examples and questions linked to animations and simulations (Figure 5.5).

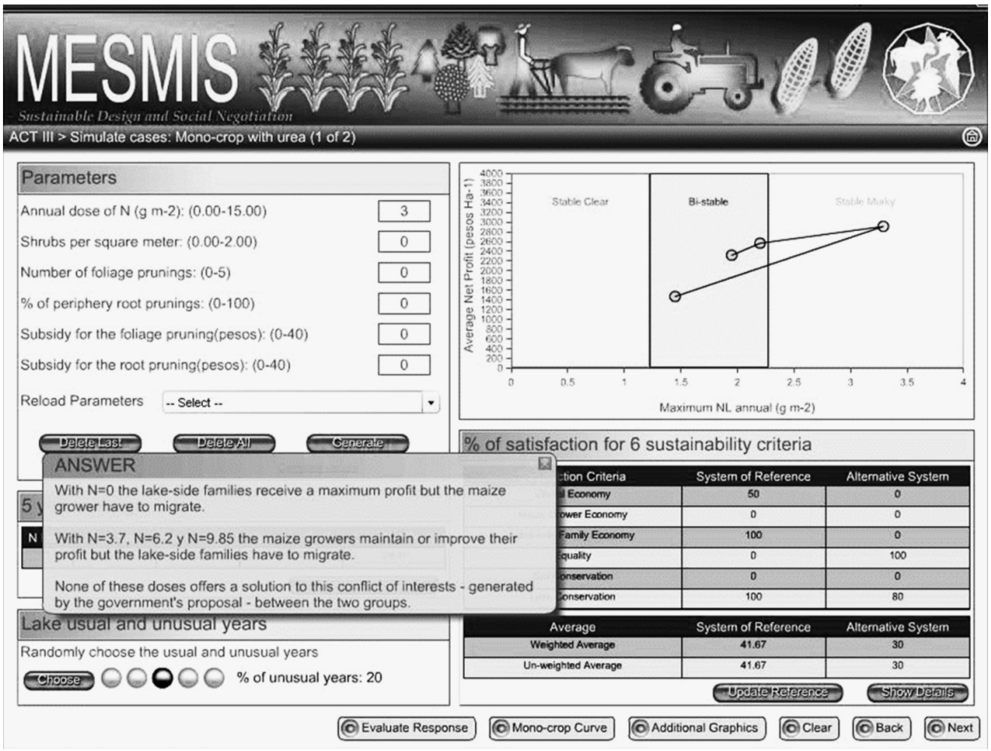

Figure 5.5: A typical interactive screen in act 3. Parameters are typed in by the user and results displayed in graphs, tables, text and pop-up windows.

The issues confronted by the social actors are presented as guided exercises, which the user must solve before moving ahead, by exploring scenarios with the simulators. Only the equations of the simple maize growth model are presented to users to give them a brief introduction to the underlying models. The use of the simulators is explained with detailed graphical tutorials. Many of the model's parameters are fixed and not shown; some can take on random values. User defined variables are displayed in interactive boxes. The most relevant output variables are shown directly as tables and multi-criteria graphs, and secondary-variable graphs appear in pop-up windows. In act 3, multi-criteria graphs and tables relate nitrogen management in the field with (a) NL, (b) maize yield, (c) 5-year average incomes of farmers and lakesiders (d) average income equality, and (e) lake and soil environmental status. Users can therefore readily analyze the tradeoffs and conflict involved when selecting a given scenario, until they come to an agreement.

2.6 Relevant experiences during workshops

Twelve local, national and international workshops (6-10 h long) have been performed directly by the authors with graduate students, NRM practitioners, researchers and high-level government officers. In all cases, participants (ranging from eight to twenty four people) have been highly motivated by the ludic nature of the program, by the interaction with other users playing different roles, and by the dramatization of the conflict (Figure 5.6). They have always been able to successfully meet the challenges posed by the exercises. In contrast, much more effort and discipline is required by those who attempt to use the program individually.

Figure 5.6: Workshop participants during exercise solving, conflict dramatization and negotiation phases.

In act 1, users learn to optimize the farmer's income within environmental sustainability constraints and thresholds. They also grasp the meaning of stable equilibrium by following the dynamics of yield and soil N along five years as a consequence of N incorporated and extracted from a field every year. In act 2 users identify context-dependant NL threshold values. In the process, they understand (and see in action) concepts such as unstable equilibrium, resistance and resilience, bi-stability, catastrophes, hysteresis and stochasticity. In act 3, users discover through the dramatization exercise that (given the rules of the game) there is no way of reconciling the minimum income needs of farmers and lakesiders with a fertilized maize-monocrop. During the dramatization, participants spontaneously and cheerfully adopt different interaction and problem solving attitudes: (e.g. the strongly involved vs. the unattached; the patient vs. the impatient; the optimist vs. the pessimist, the rule-follower vs. the rule-breaker, the detail-oriented vs. the big-picture-oriented, the negotiator vs. the conflict escalator, etc.). When negotiations come to a dead point, participants are invited to consider an agroforestry system that can still include the use of urea. If they agree, they split into farmer-lakesider couples and are urged to come up with negotiated proposals to be presented to all players.

The program offers them a thorough (but static) graphical explanation about the different effects the shrub and its management has on N pools. Not surprisingly, most users still expect that linear responses and conventional wisdom about "friendly technology" will operate (e.g. more leguminous shrubs = less urea fertilizer = less NL and more income for farmers). Figure 5.7 shows how the relation between farmer's average income and lake stability regime changes nonlinearly in response to shrub density (a) and to different combinations of shoot and root pruning (b). It also shows in (c) how the relative performance of the maize- shrub system vs the maize-monocrop system depends on the fertilizer doses. These nonlinear effects (perhaps a bit exaggerated in the program for didactic purposes) expose participants to dealing with tradeoffs, and challenges them to think more thoroughly about all interactions involved in the system when searching for appropriate scenarios.

In this last phase of the program, users get strongly involved in searching for solutions that require making technical and social decisions. Given the above-mentioned nonlinearities, it takes most of them a while, but through trial and error and increasing understanding of the system's behavior, they come up with highly satisfactory solutions. Figure 5.8 displays typical searching strategies and trajectories, which reflect the workings of the mind in the face of the system's nonlinear behavior. Figure 5.9 shows typical initial and final conditions of the searching process when no restrictions are imposed against a "happy ending". It is worth noting that, when the program is started, a shrub "variety" is randomly selected from a set of 10 "varieties" with slightly different N fixation capabilities. In consequence, there are different optimal solutions to the game, which will vary from one computer to another in a workshop.

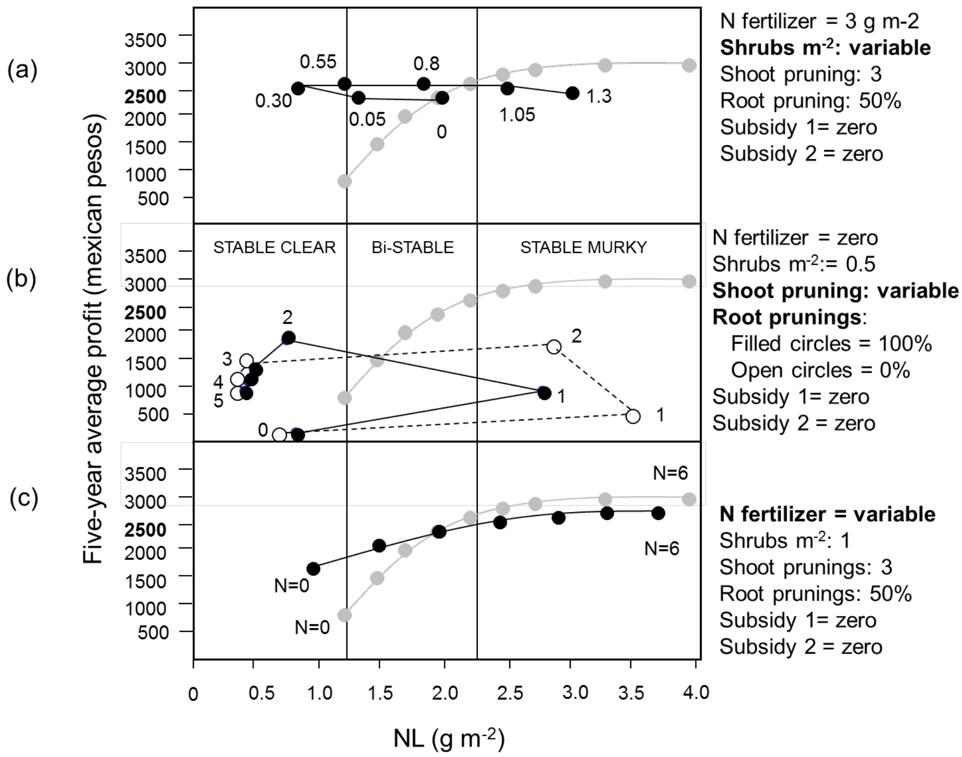

Figure 5.7: Examples of nonlinear responses in LINDISIMMA 3 observed when analyzing sensitivity to (a) shrub density, (b) shoot and root pruning and (c) N fertilizer doses. In all three graphs the gray curve corresponds to the maize monocrop situation, which is used as a reference point; it represents the effect of N doses ranging from zero to eight g m-2 on NL, lake regime and maize producer income per Ha. In (a), the lake regime improves by increasing shrub density but beyond an optimum it has the opposite effect, as N coming from shrubs increases NL. In (b), 100% root pruning and a single shoot pruning have a strong negative effect for lakesiders; two shoot prunings improve the situation for both stakeholders and more than two are unfavorable to the farmer. In this example the outcome is sensitive to root pruning only when shoot is pruned twice. In (c), the shrub-maize performs better than the maize monocrop for low fertilization levels but worse for high fertilization levels.

Along the game, participants become aware of the problems for the different stakeholders. During this third act, the maize-grower/lakesider couples are constantly monitoring the effects of their technical and economic agreements on a number of variables which affect their respective livelihoods. By becoming aware of tradeoffs and while striving for equity, they become familiar with more creative and open-minded attitudes when defending interests and making collective decisions in a multi-stakeholder environment.

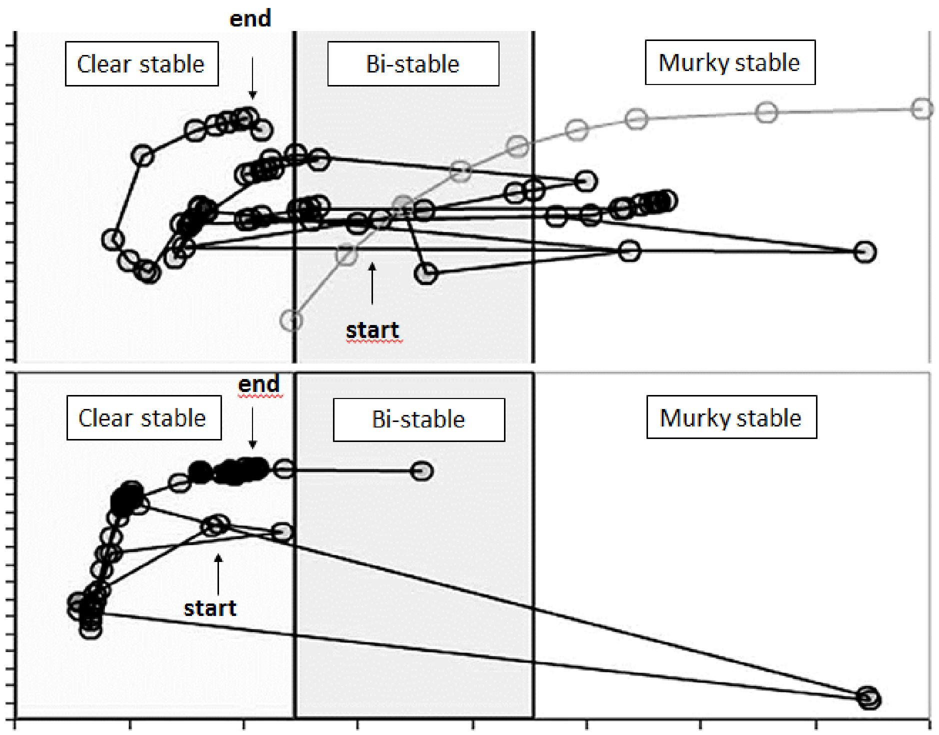

Figure 5.8: Two typical trajectories developed by workshop participants when searching for a negotiated solution. Optimum solutions for all stakeholders are to be found in the upper-left region of the graph. Because of nonlinearities, small parameter changes can strongly shift the outcome in unwanted directions. Note also how users alternate between fine-tuning an outcome in suboptimal regions of the graph and leaping into new, more promising regions.

Participants show great interest when all negotiated solutions are presented to the group (Figure 5.10). Competitive attitudes are discouraged when facilitators invite people to consider all solutions as interesting and valuable; this is easy to do, as most final scenarios are satisfactory. The process seems to combine difficulty and effort with fun and success in an appropriate way.

After every workshop, we have always asked participants to evaluate the program, and more recently we have done this with more clearly defined questions. All participants have answered that the story is reasonably to very consistent, very interesting and reasonably to very realistic (i.e. most do not seem to be frustrated with the fact that it is a stylized version of reality). They have found exercises to be from reasonably easy to not so easy to answer. They consider act II (the bistable lake) the most difficult to follow and requiring help by facilitators; participants seem to have a hard time with fully understanding isoclines in general, not to say the cusp isocline of a bi-stable system. Yet, even the most confused participants tend to be very pragmatic about it and can solve act III with the simple notion that “the bi-stable regime is not a good one to be in”. They all find the program to be fun, motivating and educational. They consider that between 10 and 30% of the content could be understood as well by simply reading papers on the subject, or by listening to a lecture. Most importantly, participants consider that even if they could read or listen about these topics, its the story, the dramatization, the simulations, the exercises and the personal involvement that makes the experience more meaningful to them and difficult to forget.

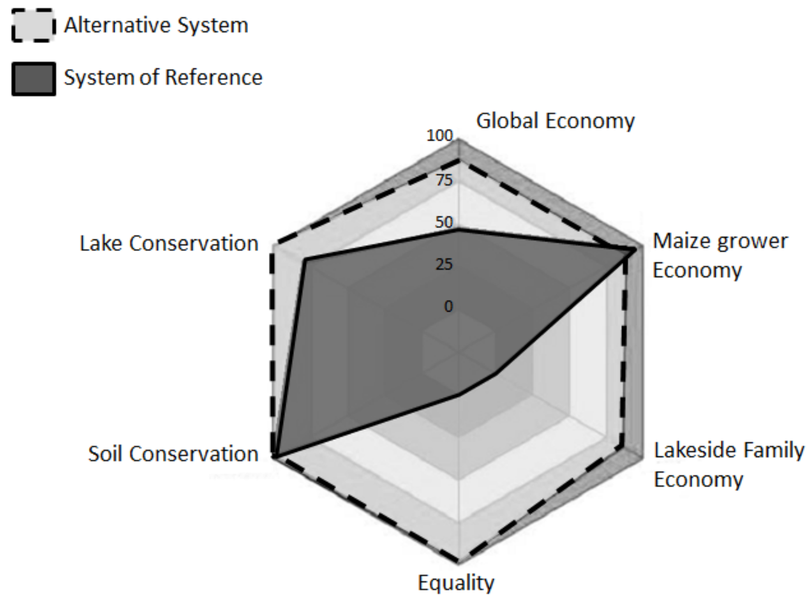

Figure 5.9: A typical radar graph representing the level of satisfaction (%) of six sustainability criteria. The smaller polygon within the larger hexagon represents the result at the first attempt to design the maize-shrub system. The almost hexagonal polygon (representing almost 100%

satisfaction of all six criteria) is the final scenario, which the "farmer" and the "lakesider" considered appropriate for ending the game.

Figure 5.10: A subgroup of participants discussing the results of one of the farmer-lakesider couples. International workshop held at ECOSUR in November 2006.

Like everything else, this program can be improved in many ways to meet the same goals and public, and we are working on it. By modifying the language and graphical representations it can also be extended to other stakeholders. This type of stylized story and program seems particularly amenable for helping people understand better the dynamical and nonlinear nature of NRM subject to natural and social constraints. Therefore, it can complement other modeling, role-playing and conflict transformation tools, which address local, real-life conditions and involve other stakeholders.

Chapter 6

Exploring social-ecological change: social simulation of land-use dynamics

Farmers increasingly experience the effects of globalization and international economic and institutional change. Governmental and non-governmental agencies have developed financial and legal instruments, to influence farmers' land-use decisions. In this complex social-ecological setting, research on land-use dynamics in agricultural landscapes require an innovative holistic approach with a key role for the final decision-makers, farmers. Here, we present an agent-based model entitled LUSES, for the simulation of land-use dynamics under global change scenarios using social psychology as a basis for agent decision-making. We present the first phase of model development, a qualitative validation and (further) model exploration. Preliminary simulation results showed qualitatively similar responses as identified in empirical data from the community Tierra y Libertad in Chiapas, Mexico. Although this first exercise points to a need of further model development, the results obtained so far support the implementation of social-psychological theory in modelling land-use dynamics in agricultural landscapes. Decision-making processes based on social-psychological theory appear to be more suitable for exploring responses to unknown future changes than rule-based methods derived from past decisions.

Based on: Speelman, E.N., Jager, W., Janssen, M.A., García-Barrios, L.E., Groot, J.C.J., Tittonell, P., in preparation. Implementing social-psychological theory to explore land-use dynamics in an agricultural landscape: a qualitative comparison between agent-based simulations and empirical data from a biosphere community in Chiapas, Mexico.

1 Introduction

In the last decades, land-use dynamics in agricultural landscapes have become increasingly affected by global economic and institutional change (Eakin and Lemos, 2010; Ribeiro-Palacios et al., 2013; Chapter 2). Effects of international market dynamics, and (inter)governmental economic policy changes, continuously challenge farmers to adjust their management and intensify their production (Fabricius et al., 2007). Simultaneously, local, national and international governmental and non-governmental organizations developed policies and incentive schemes to influence farmers' decision-making towards more sustainable land-use management in order to maintain ecosystem services provided by agricultural landscapes (Antle et al., 2003; Perfecto et al., 2005; García-Amado, et al., 2011). Farmers have responded to these changes by e.g. diversifying production, and developing collaborations to improve product quality and negotiate better prices for their products (Tittonell, 2013; Chapter 2). The impacts of globalization and international economic and institutional change are expected to increase (e.g. Eakin and Lemos, 2010). Improving current knowledge of how farmers respond to change and the mechanisms that allow agricultural landscapes to maintain their current functions is ever more relevant. The current trend of increasing competing claims on agricultural land requires an innovative and integrated approach for studying land-use dynamics in these social-ecological systems with a central role for farmer decision-making (Feola and Binder, 2010; Chapter 5).

Land-use dynamics in smallholder agricultural landscapes is primarily determined by the decisions of people who use the land, namely farmers and forest users (Rindfuss et al., 2004). Farmers pursue multiple goals from the land they use e.g. to generate income, to attain food security and to acquire social status, especially in smallholder agriculture (Speelman et al. 2006). Consequently, land-use dynamics have been studied from various perspectives. Social phenomena such as cooperation, collaboration and the development of institutions to manage natural resources have been extensively studied especially in the case of common-pool resources (e.g. Ostrom, 1990; 1999). Impacts of land-use/cover change on ecological processes and landscape functions and have been extensively researched at various spatial and temporal levels (e.g. Verburg et al., 2002, Willemen et al., 2010; Groot et al., 2010). The number of studies that actively coupled social and ecological systems in the analysis of land-use dynamics increased sharply, especially in the last two decades (e.g. Parker et al., 2003; An, 2012). Innovative computer supported modelling tools have been developed to facilitate the exploration of the behavior of these complex social-ecological systems. Good overviews on these methods are provided by e.g. Parker et al. (2003), Matthews et al. (2007), Schlűter et al.(2012) and An (2012). Agent-based modelling (ABM) has become a commonly-used approach to study land-use dynamics in social-ecological systems. ABM allows to explicitly simulate the interactions among (heterogeneous) agents and their environment (Grimm, 1999; An, 2012; Janssen en Jager, 2000). The autonomous decision-making of agents have been based on a variety of methods ranging from statistical to probabilistic, microeconomics, space theory, heuristic or empirical rules, institutions or stakeholder participation (An, 2012).

Decision-making can be described as a multi-dimensional optimization process in which one's needs and uncertainty are evaluated in the light of decisions, opinions and decisions of others (Jager, 2000). Within the behavioral sciences, particularly in the field of social psychology, models are being developed to understand and predict behavior of interacting individuals (Beedell and Rehman, 2000; Burton, 2004). The CONSUMAT framework (Jager, 2000) is a broad social-psychological approach developed to explore human behavior and decision-making processes. CONSUMAT agents engage in distinct cognitive processes for making decisions through imitation, repetition, optimization and inquiring. Agents sense the activities and expectations of other (similar) agents and incorporate this in their decision-making. The framework was developed and successfully implemented to explore consumer behavior (e.g. Jager et al., 2000; Vindigni et al., 2002; Jager and Mosler, 2007; Bravo et al., 2012). In a conceptual update of the CONSUMAT approach, agent abilities were expanded to include predictions of future product prices (Jager and Janssen, 2011). This feature would improve the suitability of the approach for the exploration of long-term decision-making processes. A broad social psychological theory as a base for decision-making processes in complex social-ecological system might be more appropriate for the exploration of responses to unknown change than methods based on historical statistics (Tschakert and Dietrich, 2010; Bert et al., 2014).

We aim to contribute to the growing literature on social-ecological systems modelling through the development of a ABM tool to analyze land-use dynamics in agricultural landscapes from a social-psychological theory perspective. We present the first development phase of the model LUSES (Land-Use in Social-Ecological Systems; Speelman et al., 2012). The LUSES model, once fully developed, will simulate an interacting population of heterogeneous agents that make land-use decisions based on the updated CONSUMAT approach. The land-use choices in the agent fields will affect ecological processes such as runoff and soil erosion and landscape function such as nature conservation and water level management. These effects might extend the boundaries of the field and impact neighboring fields. The decisions of agents can be directly and indirectly influenced by ecological impacts of land use on the agent's fields or elsewhere through changed behavior and decisions of other agents (Figure 6.1). The research question that guides the development of the LUSES model is whether social psychological theory can improve our current understanding of land-use dynamics in response to economic and institutional change and allow for exploration of future scenarios. We are in particularly interested in how instruments and mechanisms such as beneficial collaboration and/or subsidies affect the functions of the system under challenging economic and institutional scenarios. In this first phase of model development that is presented in this chapter, we explored (i) the ability of the updated CONSUMAT theory to reproduce farmer's land-use decisions in a real case, and (ii) the sensitivity of simulated land-use dynamics to basic model assumptions. The empirical data originated from the usufruct community, Tierra y Libertad (TyL) in the buffer-zone of a Man and Biosphere (MAB) Reserve in Chiapas, Mexico.

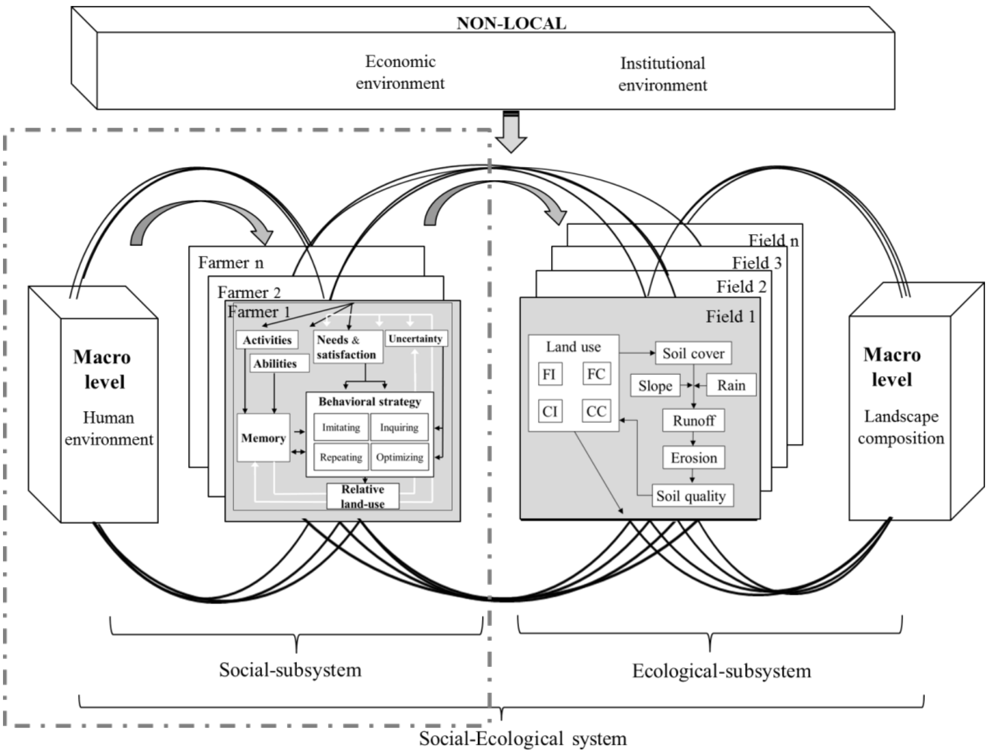

Figure 6.1: Graphical overview of the conceptual model of the LUSES model (Speelman et al., 2012) showing the links between the social and ecological system. An example of erosion and other associated ecological processes is presented in the ecological system. The initial development of the model described in this chapter focused on the decision-making processes, emphasized by the dotted rectangle.

2 Material and methods

2.1 Study area

The empirical data used to qualitatively validate the LUSES model was collected in the community Tierra y Libertad, Chiapas, Mexico. A comprehensive driver-response reconstruction of local land-use and social organizational change between 1960 and 2010 was developed and described in chapter 2. In the following section, the study area and the land-use dynamics are shortly recapitulated.

2.1.1 Description

The smallholder community Tierra y Libertad (TyL), Chiapas, Mexico, is situated near the ridge of the Sierra Madre de Chiapas mountain range in the upmost part of a watershed at an altitude between 900-1500 meters above sea level (Figure 1.4) (INE, 1999). The community has a young population of circa 750 persons (average age of 24 years SD = 18) (Chapter 2). The community is remote and poorly connected to the nearest urban center and market, but has basic facilities, e.g. a small health clinic and rural schools from kindergarten up to lower-secondary school. The territory of the community is hilly with average slopes of 20° and extremes of 60° and accounts for some 3200 ha (Toupet, 2010). In comparison to neighboring communities, TyL has a relative high forest cover. An estimated 80% of the territory is under forest cover including some forest-based production systems in the understory of existing forest i.e. coffee and palm plantations and livestock raising (Dahringer, 2004). Currently, farming is based on: 1) forest-based land-use types (organic palm and coffee cultivation), and 2) cleared-field land-use types (staple production and livestock herding).

2.1.2 Land-use dynamics

Our assessment of land-use change and associated social organization in the TyL territory between 1972 and 2010 showed that in the initial phase settlement (early 1960s to 1972), people developed livelihoods based on: 1) maize production, 2) the extraction of forest products. In the mid-1990s, coinciding economic and institutional drivers strongly limited the continuation of these local livelihoods based on maize production and the extraction of forest-products. The implementation of neoliberal policies and the ratification of NAFTA caused a sudden strong decline in farm-gate prices of maize (e.g. Nadal, 2002; Yunez-Naude, 2003; Appendini, 2008; Keleman et al., 2009). At the same time, Mexico signed the legally-binding convention on biological diversity, which initiated active national conservation policies and resulted in the establishment of a nature reserve in the area of the community. As of 1995, TyL and its entire territory became situated in the buffer-zone of the reserve in which land-use was strongly restricted e.g. deforesting and the extraction of timber and non-timber products became prohibited. In response to the effects of these coinciding drivers, a radical shift in land-use patterns was identified from 1990 to 2000 which was followed by the establishment of beneficial collaboration the among farmers between1995 and 2010 (Chapter 2).

2.2 Model description

This section provides an overview of the basic features of the model in its first development stage. A more detailed model description following ODD protocol (Grimm et al., 2006; 2010; Polhill, 2010) is provided in Appendix B. The model will be made freely available online via the Open ABM website.

2.2.1 Overview

The LUSES - Land-Use in a Social-Ecological System - agent-based model aims to explore land-use dynamics in agricultural landscapes through the implementation of the conceptual update of the social-psychological CONSUMAT model (Jager and Janssen, 2011). The LUSES model simulates an interacting heterogeneous population of agents who make land-use decisions for fields they own in an agricultural landscape (Figure 6.1). Interaction among agents is based on similarity. Agents may differ in their characteristics, abilities, and resources (Table 6.1).The time step of the model represents a cropping season for which the agents select land-use types for the fields they own. In the current version, every patch represents a field of 1 ha. An equal number of fields is assigned at random to every agent. Agents are located in one of their fields. The model simulates four land-use types which are generically described as: 1) individually-managed cleared-field cultivation (IMCF), 2) collaboratively-managed cleared-field cultivation (CMCF), 3) individually-managed forest-based cultivation (IMFB), and 4) collaboratively-managed forest-based cultivation (CMFB).

Every time step, agents receive income based on their land-use choices. Collaborative benefits are optional in the simulation runs. When included, collaborative benefits increase product prices of collaboratively-managed land-use types with 30% if the relative area with the specific land-use type is equal or larger than 30% of the total cultivated area. Every time step, agents select among the other agent five peers based on similarity for five agent characteristics (for more info see Appendix B). Agents use (part of) their income for household needs e.g. food, clothes. The difference between an agent's income and household need is subtracted or added to the agent's savings. All agents have an initial amount of savings. When agent's savings decrease to zero, they leave the agricultural landscape – the agent is removed from the simulation. Every time step, agents perform a series of processes to select land-use for their fields (Figure 6.2). The agent decision-making processes explained in more detail in the next section (see Section 2.2.2). The LUSES model was developed in Netlogo 4.1.3. (Wilensky, 1999).

Table 6.1: Overview of variables and variable range in the LUSES model. Values and ranges as used in the experiments.

Variable name	Variable range	Experiments
Ambition level	0-1	Random between 0-1
Uncertainty tolerance level	0-1	Random between 0-1
Cognitive effort	1-10	Random between 1-10
Relative need importance	0-1	(1) Equal need importance: Nex=Np,=Ns = 0.33 (2) High existence need importance: (0.8<Np<0.99), (3) High social need importance: Nex, Np, Ns = 0.33 (4) High personal need importance: Nex, Np, Ns = 0.33
Land holdings per agent	1-1676	16
Household size	2-9	5
Number of agents	5-1681	100

2.2.2 Behavioral model

Agent's decisions are driven by the satisfaction and uncertainty agents experience with their current land-use choice in relation to the agent's ambition and uncertainty tolerance level. These so-called relative satisfaction and uncertainty levels determine the behavioral strategy of the agent, 1) repetition, 2) imitation, 3) inquiring, or 4) optimizing. When an agent is satisfied and experiences low uncertainty, it simply repeats its current land-use choices without considering other activities thus engaging in habitual behavior (strategy: repetition). If an agent is satisfied but uncertain, the agent imitates the activity of a peer (strategy: imitation). If satisfaction is low and uncertainty is high, the agent will evaluate the activities performed by all other agents (strategy: inquiring). If both satisfaction and uncertainty are low, the agent will perform optimizing behavior by evaluating all available activities (strategy: optimizing) including activities currently not performed by any of the agents in the population. Agents that have an inquiring or optimizing strategy, evaluate the potential social, personal and existence need satisfaction levels of the different land-use types in relation to their own needs.

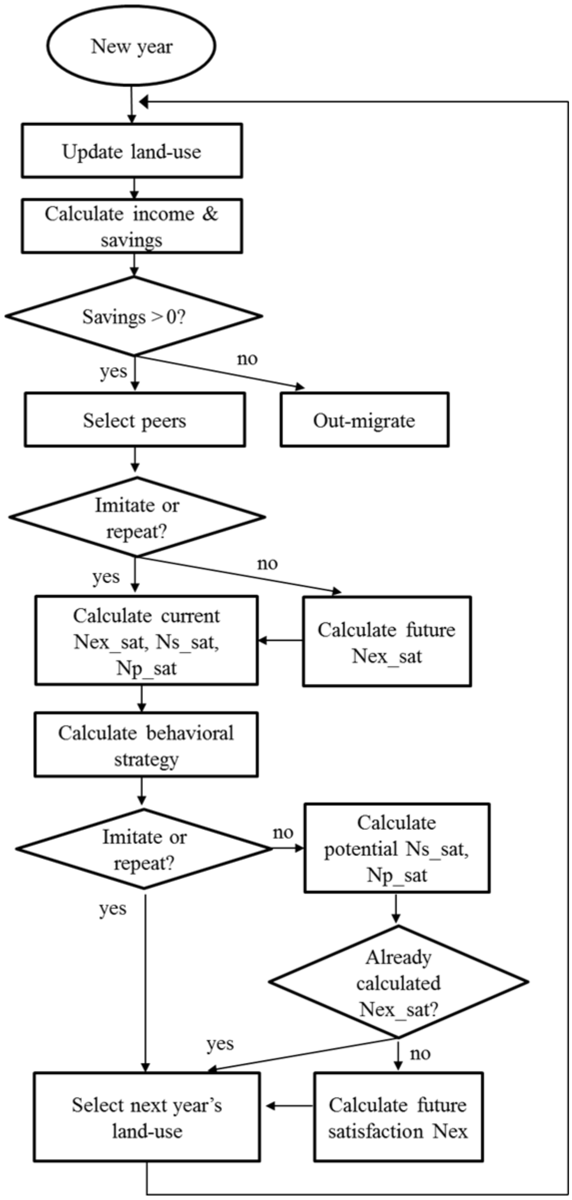

Figure 6.2: Flowchart of the main processes at agent level executed every time step.

For assessing the potential existence need, agents develop predictions of future product prices, which is explained in the next paragraphs. Key rules for determining the behavioral strategy of an agent are: 1) the lower the satisfaction of an agent, the more an agent is triggered to evaluate the performance of alternative land-use types for its own situation, and 2) the larger the uncertainty, the more an agent evaluates the land-use selection of other agents (see also Laland, 2004; Figure 6.3a).

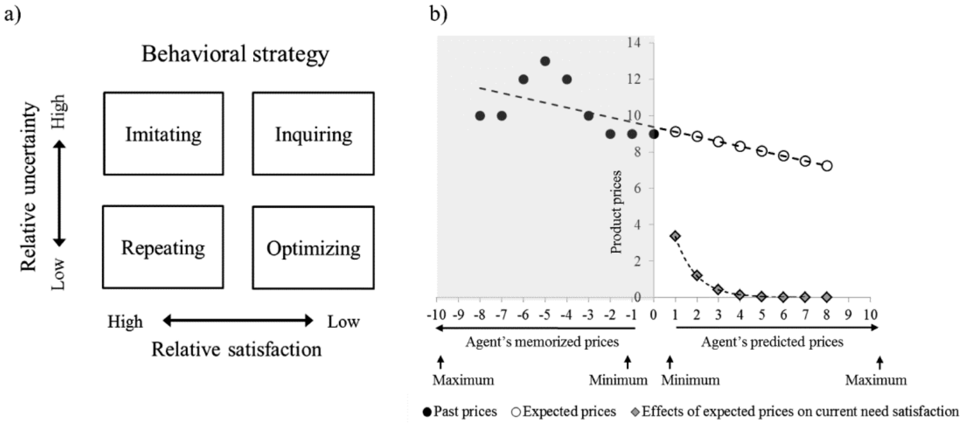

Figure 6.3: Graphical representation of: a the four behavioral strategies agents employ dependent on the relative uncertainty and relative satisfaction agents experience from current land-use choices. and b) agent's price predictions based on past prices stored in the agent's memory and effects of the predictions on current satisfaction.

Agents experience uncertainty as a result of comparing their own price predictions and land-use choices with those of peers. The uncertainty an agent experiences is based on 1) the deviation among the price expectations of the agent and those of its peers, and 2) the dissimilarity between the land-use decisions of the agent and those of its peers. The deviation among price expectations of the agent and its peers are calculated as the standard deviation of price predictions among the agent and its peers, divided by the average price predicted. Whereas, the dissimilarity between the land-use types of the agent and those of its peers is calculated as the average difference in relative land-use allocation between an agent and its peers. The larger the difference between the expected prices and land-use choices of the agent and those of its peers, the more uncertainty the agent will experience.

The satisfaction level agents experience is based on three needs: 1) existence, 2) social, and 3) personal needs (for more information on needs theory see: Maslow, 1954; Max-Neef, 1992; Lindenberg and Steg, 2007). The satisfaction dynamics of the three needs may be very distinct. For example, where the social need is susceptible to the (changing) behavior of peers, the personal need will be more stable as it is based on fixed preferences. The relative importance of the three needs are set at the agent level and fixed throughout the simulation, but they may differ among agents. The overall need satisfaction is calculated as a weighted average of the three needs. Agents and/or agent populations with a relatively high importance for social need are more influenced by the ideas and actions of others. In contrast, agents and/or agent populations with a relatively strong personal need will attempt to follow their own preferences.

The social need is linked to interactions with other agents in which similarity among agents is the driving force. The agents social need reflects the need to: 1) belong to a group, and 2) have social status (Festinger, 1954). Agents calculate their social need based on: 1) the similarity in land-use choice with peers, and 2) the difference in savings of the agents and its peers. Personal need relates to satisfying one's personal taste in activities i.e. land-use type. The personal need satisfaction is calculated as the similarity between land-use choice and agent land-use preference. The existence need relates to economic dimensions of existence. Agents gain income through the land-use they selected based and the associated product price per ha. Agents calculate their current existence need satisfaction level based on their household needs and their current income.

Agents which have an inquiring or optimizing behavioral strategy explore potential need satisfaction levels of land-use options. Potential social and personal need satisfaction are calculated for selected land-use types in the same manner as current social and personal need satisfactions. Potential existence need satisfaction for selected land-use types is calculated based on household needs and price predictions. These agents predict product prices by extrapolation of a linear regression of past product prices that are stored in the agent's memory (Figure 6.3b). The length of the agent's memory and the time horizon for which the agent makes predictions is set to the cognitive effort of the agent (Table 6.1). At the start of the simulations, the memory of the agents is set to include past price information for all four land-use types for the length of the agent's memory. Every time step, agents update their memory with current price data only of the land-use types they selected. Product prices of land-use types not currently selected by the agent are not updated. As a result, the price data stored in the memory of agents might differ among agents. Price data are updated every time step by taking consecutive numbers from pre-determined price data lists connected to each of the land-use types. These price trajectories consist of 50 product prices and represent 50 years of product prices. Price data can be based on historical data or scenario data. Agents update their memory by: (1) removing the product price that is stored longest in the agent's memory – the agent "forgets" this price information, and then (2) adding price data of the current time step to the agent's memory.

Agent with an inquiring or optimizing strategy incorporate price predictions of the land-use types they currently selected in the calculation of their current existence need satisfaction. This means that agents can experience more satisfaction from current choices if they expect prices to increase in the future. An effect of predicted prices on current existence need satisfaction levels, is calculated using a simple decay function. This means that the influence of expected returns diminishes strongly, making prediction of prices in the far future less important than those in the near future (Figure 6.3b). The sum of the effects of the calculated price predictions is then added to the existence need satisfaction resulting from currently selected land-use types. Depending on the price trend calculated by the agent, these effects can increase or decrease satisfaction of the selected land-use types. Existence need satisfaction is calculated by the following formula (1):

(1) $$S_X(t=0) = I_X(t=0) + \sum_{t=0}^{t=ce} I_x(t) * e^{-t}$$

Where:
S_X = existence need satisfaction of land-use x at time 0
I_X = income of Land-use Type *x*
t = time
ce = agent cognitive effort

2.2 Simulated experiments

We explored the ability of the updated CONSUMAT theory to reproduce farmer's land-use decisions using a series of *in silico* experiments and empirical data collected in the case study area. Subsequently, we further explored model output through a series of simulation experiments.

2.2.1 Qualitative validation

We developed simulation experiments using the following model setting were based on characteristics of TyL: 1) simulation time, 2) initial landscape composition, 3) external economic and institutional change, and 4) collaborative benefits. Every experiment was run for 40 time steps which corresponded to the time from the official establishment of the community until 2010 (the end of the driver-response reconstruction). The initial landscape at the start of the simulation consisted of equal area with: 1) individually-managed cleared-field, and 2) individually-managed forest-based land-use, which corresponded to the maize and forest-based livelihood strategies at time of official establishment of the *ejido*. External drives of change were simulated as 1) a 35% decline in price of the IMCF land-use type, and 2) a prohibition to reduce the area with forest-based land-use after 25 time steps. These drivers of change corresponded with coinciding effects of the ratification of NAFTA and establishment of the reserve since 1995 (Chapter 2). Simulations were performed with and without availability of collaborative benefits. We hypothesized that in systems in which decisions determine household income and where large price decreases put the income and the existence need under pressure, the relative importance of the existence need would become higher, than for consumers in previous model applications (Jager et al., 2000; Vindigni et al., 2002; Jager and Mosler, 2007). Therefore, we explored the effect of all of the above mentioned scenarios on two distinct agent populations: 1) agent population in which agents all have equal importance for existence, social and personal need (Nex.= Ns= Np= 033) and 2) agent population with a relatively higher importance for existence need. The relative existence need importance of agents was set randomly to a value between 0.8 and 0.99. The relative importance of social and personal need were both set to (1-Nex)/2. Consequently, values of relative social and personal need importance varied between 0.1 and 0.05.

2.2.2 Exploration

A series of experiments were developed to explore model output. All model exploration runs were ran for 50 time steps and were repeated 100 times to explore trends in average outcome and the variation in the outcomes (SD). Agent's cognitive effort, land-use preference and other characteristics were set randomly (Table 6.1). In addition, the effect of collaborative benefits on land-use dynamics was explored by performing two sets of simulations, one with and one without collaborative benefits.

Initial landscape composition

We explored the influence of the initial landscape composition at the start of the simulation on system dynamics, in particular on the equilibrium state of the system. We defined nine initial landscapes that differed heterogeneity and simulated these under stable 'no change' economic scenario. These landscapes were composed of: 1) all four land-uses, 2) only cleared-field based land-uses, 3) only forest-based land-uses, 4) only collaborative land-use, 5) only individual land-use, 6) only IMCF, 7) only CMCF, and 8) only IMFB land-use, and 9) only CMFB land-use types. In landscapes that consisted of more than one land-use type, the total area was equally divided among all simulated land-use types.

Economic and institutional drivers

We developed additional simulation experiments to (further) explore model behavior under distinct economic and institutional scenarios. The experiments included four economic scenarios and one institutional scenario. Four economic trajectories were developed to reflect: 1) no change, 2) gradual change, 3) shock (sudden change and recover), and 4) sudden permanent price change. Institutional change was analyzed through forest cover protection regulation. The 'no change' price trajectory was equal to the base price trajectory developed for the qualitative validation runs and consisted of random values within a small fixed range of 9 to 11. Averages of the four price trajectory lists connected to the land-use types were all 10. The gradual change trajectories were developed by increasing or decreasing the price values of the 'no change' trajectory step-by-step to a 50% price increase or decrease at the end of the simulation. Price shock trajectories were created in which prices experienced a sudden 50% increase or decrease during three consequent time steps. Subsequently, prices returned to normal values in the 'no change' price trajectory. A permanent change in price was simulated as a sudden 50% price increase or decrease after which prices remained at this level for the rest of the simulation time (Figure 6.4). In addition, we explored the effects of the magnitude of the shock or permanent change by performing a series of simulation experiments with price changes from -40%, -30%, -20%, -10%, +10%, +20%, +30%, +40%. Price changes were simulated separately for IMCF and CMCF land use types only. All economic and institutional changes were implemented after 15 time steps.

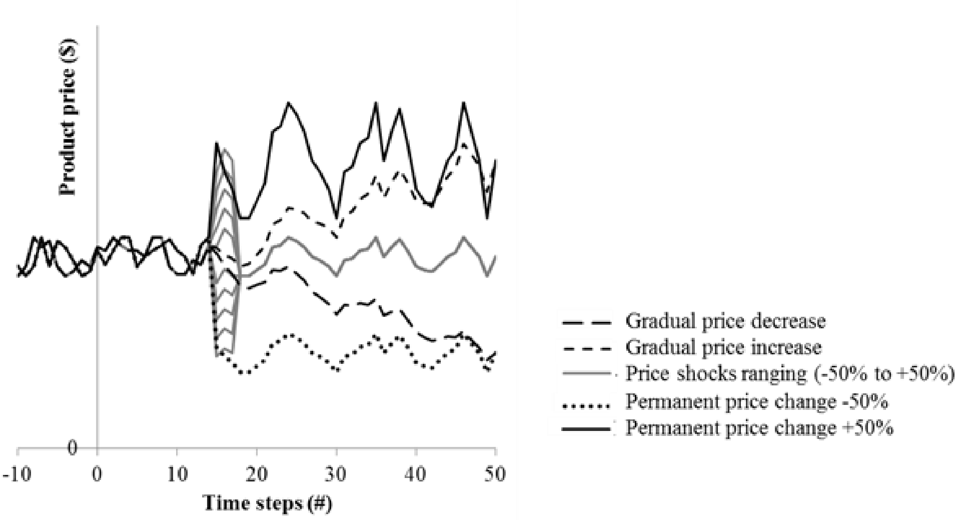

Figure 6.4:Price trajectories developed to simulate distinct economic scenarios, namely gradual price decrease, gradual price increase, price shocks from -50% to up to +50%, permanent change of -50%, and permanent change of +50%.

Agent population characteristics

To further explore the effect of the relative importance of existence, social and personal needs of agents and of agent populations, we performed all exploration experiments with four distinct agent populations that differed in relative need importance. The four agent populations reflected populations with: 1) equal need importance of all three needs, 2) relatively high existence need importance, 3) relatively high social need importance, and 4) relatively high personal need importance. The populations were initialized by randomly setting the relative need importance variables of the individual agents within a given range. The relative importance of existence, social and personal need of all agents in the population with equal need importance were set to 0.33. In order to create agent populations that had relative high importance for one of the three needs, the respective need was randomly set to a value between 0.8 and 0.99, the relative importance of the remaining two needs were both set to a value between 0.1 and 0.05.

2.2.1 Data analysis

Land-use dynamics, landscape functions, and social processes were assessed through four variables. Agricultural landscape functions were linked to the capacity of the landscape to produce economic output and allow the agents to remain farming in the area, the area forest cover and the establishment of social processes here collaboration among agents. The specific variables were assessed at landscape level as: 1) the relative area with forest-based land-use, 2) the relative area with collaborative land- use, 3) average agent savings and 4) the number of farmers. We assessed the average and standard deviations of 100 repetitions of the simulation experiments. Average trends at landscape level were calculated.

For qualitative validation experiments, we also assessed the relative area for all four land-use types during the simulation and diversity in responses at agent level. In the model exploration, we explored the effect of the magnitude of price shocks and permanent changes on the response.

Establishing peer networks was a key element in the agent's decision-making process. Therefore, we explored the developed peer networks and analyzed some basic network characteristics of the evolved networks in detail of one simulation experiment (Boccaletti et al., 2006). The simulation was run for 50 time steps, in which all 100 agents select 5 peers in each time step. This resulted in a total of 2500 connections. We assessed the stability in the peer networks by calculating the range, average, and standard deviation of the number of different peers an agent established relations with over the course of the simulation. We assessed the frequency of agents being selected as peers, to estimate the distribution of relative influence of each of the agents. A normal distribution would mean that all agents are equally influential. In contrast, a skewed distribution would hint to the presence of highly influential agents. Finally, we assessed the reciprocity in peer networks over 50 time steps by calculating the frequency of peer connections that were mutually established.

3 Results

3.1 Qualitative validation

Collaboratively managed land-use types increased immediately after the start of the simulation, in the simulations of the two agent populations (Figures 6.5a, 6.5b and 6.6a). The proportion of collaboratively managed land use was lower when agents valued the three needs equally (Figures 6.5a and 6.6a) than when agents had a stronger preference for existence needs (Figures 6.5b and 6.6a). The threshold for receiving collaborative benefits was not reached in either population before external changes affected the system in time step 25 and as a result collaborative benefits were not obtained during this period. In the empirical data, collaborative land use was only established after that the effects of coinciding economic and institutional changes affected the community in 1995 (Figure 6.5.c).

The simulated populations responded to the economic change that affected IMCF land-use and policy changes that limited land-use change by adjusting land-use. The population with high existence needs responded strongest by largely reducing the proportion of the IMCF land-use type that experienced the price decline (Figure 6.5b). Forest-based land-use types gradually increased for both populations (Figure 6.6b). The threshold for collaborative benefits was met and average agent savings increased strongly (Figure 6.6c). In contrast, the agent population with equal priorities for the three needs did not reach this threshold and savings slowly decreased after the price decline (Figure 6.6c). The simulated strong reduction in cleared-field land-use by the population with high existence needs after the imposed changes (Figure 6.5b) corresponded with the decline in cultivated maize area observed in TyL after the maize price decline and conservation policy implementation in 1995 (Figure 6.5c). A slow increase in simulated forest-based land use corresponded with a slow increase of the area cultivated with forest-based palm and coffee in TyL after economic and policy changes came into effect (Figure 6.5c). Moreover, the simulated data showed that the threshold for obtaining collaborative benefits was only reached after that economic and policy changes came into effect in time step 25. This corresponded with the fact that beneficial collaboration was only established after strong coinciding drivers affected the livelihoods in the community (Chapter 2). Once beneficial collaboration was established in both empirical and simulated data, the area with the associated collaboratively-managed land use increased slowly (Figure 6.5).

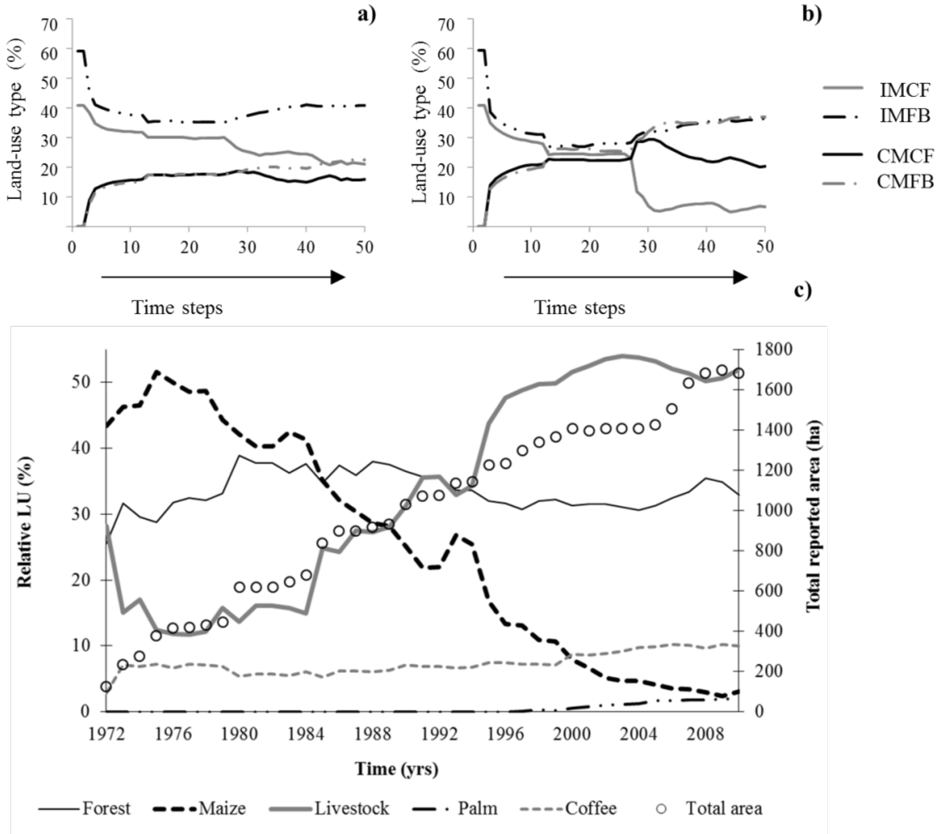

Figure 6.5: Simulated data runs (average of 100 runs) showing the relative area of the four land-use types for simulation of :a) agent population with equal need importance, and b) agent population with relatively high existence need importance., and empirical relative land-use change data from the study area Tierra y Libertad, Chiapas, Mexico.

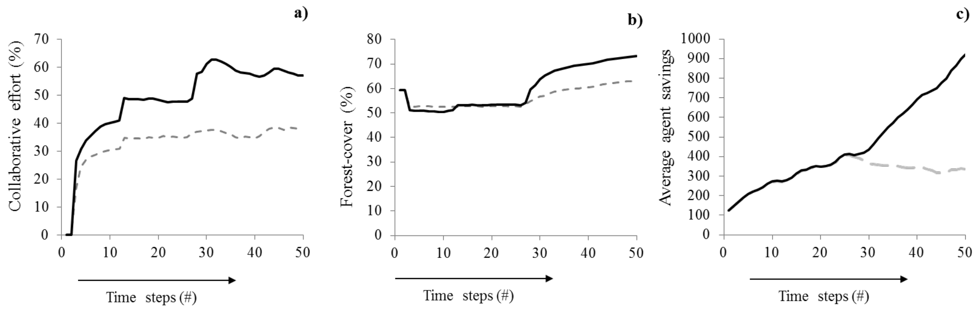

Figure 6.6: Simulated data from validation experiments (average of 100 runs) of an agent population with equal relative need importance and an agent population with relatively high existence need importance showing: a) relative collaborative effort, b) relative forest cover, and c) average agent savings.

3.2 Exploration

3.2.1 Initial land-use landscape

Results of simulation experiments with distinct initial landscapes, showed that all landscapes comprised of all four land-use types at the end of the simulation time (Table 6.2). The relative area occupied by each of the land-use types at the end of the simulation depended on the agent populations and on the land-use types present in the beginning of the simulation. The agent population with relatively high social needs developed a landscape in which the land-use types present at the start of the simulation occupied a relatively larger area. In contrast, the agent population with relatively high existence needs developed landscapes in which the four land-use types occupied similar areas. In general, the land use types present at the start of the simulation occupied a relatively larger area at the end of the simulation (Table 6.2).

3.2.2 Economic and institutional drivers

The base-line simulation experiment in which there are no price or policy changes simulated, showed that: 1) all agents remained farming throughout the simulation, 2) average agent saving gradually increased over time to around 650 at the end of the simulation, 3) forest cover was close to 50 throughout the simulation, and 4) collaboratively-managed land use was also around 50% throughout the run time of the simulation. Collaborative benefits were not obtained (data not shown). Simulation experiment with a prohibition to reduce the area with forest-based land-use, resulted in a slow increase in forest cover. Other variables were similar to the no change scenario (data not shown).

Table 6.2: Simulated data from experiments with different initial landscapes and agent populations, showing the relative land-use after 50 time steps.

			Forest cover at t=50 (%)								Collaboratively-managed land use at t=50 (%)							
			No collaborative benefits Agent populations[2]				Collaborative benefits Agent populations[2]				No collaborative benefits Agent populations[2]				Collaborative benefits Agent populations[2]			
Initial landscape composition	Land-use types[1]	#	**Eq**	**Ex**	**So**	**Pe**	**Eq**	**Ex**	**So**	**Pe**	**Eq**	**Ex**	**So**	**Pe**	**Eq**	**Ex**	**So**	**Pe**
	All	4	50	50	50	50	50	50	50	50	50	49	50	50	50	49	50	50
	Only F	2	64	53	72	64	67	58	73	64	50	49	51	50	51	52	51	51
	Only Cl	2	36	48	27	36	32	40	25	35	50	49	50	50	50	52	50	51
	Only Co	2	50	50	50	50	50	48	50	50	64	51	73	69	69	60	74	71
	Only I	2	50	50	50	51	50	50	50	50	35	46	27	31	35	46	27	31
	CMFB	1	62	52	71	64	72	72	74	66	63	51	70	71	73	72	74	73
	IMFB	1	63	53	71	64	63	52	72	64	36	46	29	30	36	46	28	30
	CMCB	1	37	46	29	36	27	28	28	36	63	53	71	70	73	71	71	70
	IMCB	1	37	48	29	36	37	48	30	36	36	47	28	30	36	46	29	30

[1]F-Forested; Cl-Cleared-field based; Co-Cooperatively managed; I-Individually managed; CMFB- Collaboratively managed forest based; IMFB- Individually managed forest based; CMCB- Cooperatively managed cleared-field based; IMCB- Individually managed cleared-field based.

[2] Eq-Equal need importance for existence (Nex=0.33), social (Ns=0.33) and personal (Np=0.33) need; Ex-high Existence need importance (0.8<Nex<0.99), and lower social (0.05<Ns<0.1), and personal need (0.05<Np<0.1); So- high Social need importance (0.8<Ns<0.99), and lower existence (0.05<Nex<0.1), and personal need (0.05<Np<0.1);Pe- high Personal need importance (0.8<Np<0.99), and lower existence (0.05<Nex<0.1), and social need (0.05<Ns<0.1);

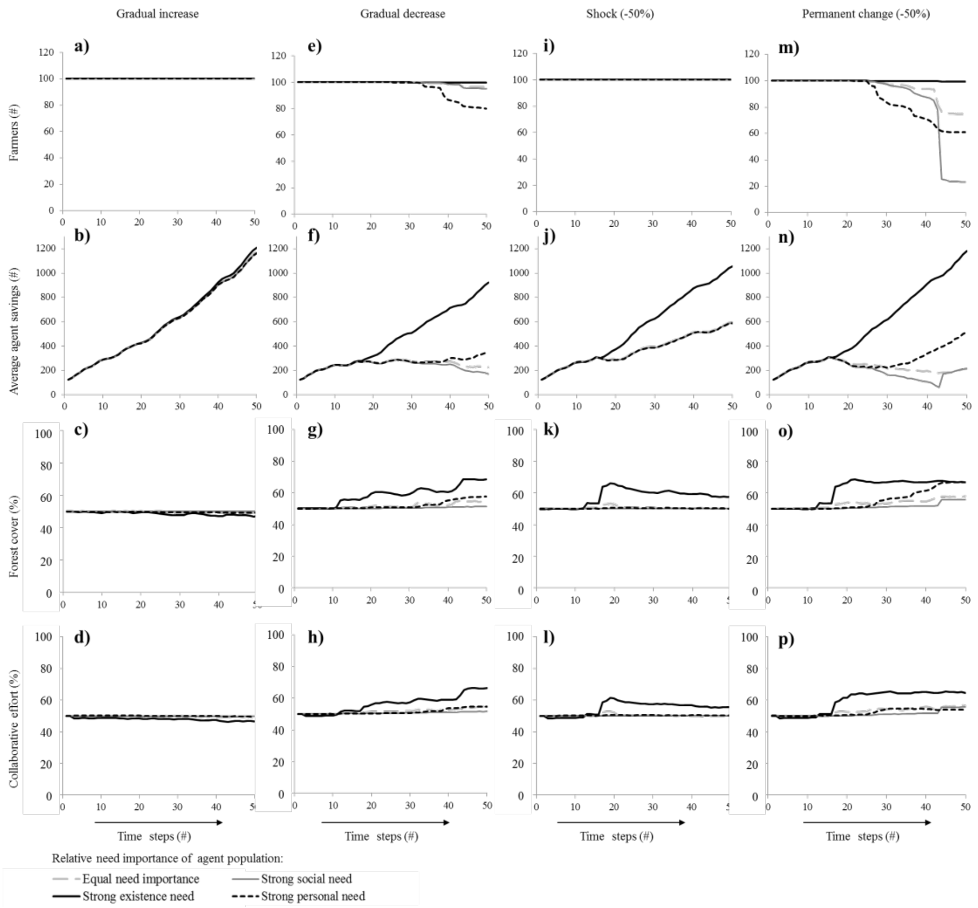

Figure 6.7: Simulated data from exploration runs (average of 100 runs) showing: -the number of farming agents,- average agent savings, -relative forest cover, and- relative collaborative effort for all four agent populations under the following economic and institutional scenarios: - gradual price increase, b-gradual price decrease, -shock, and -permanent change. Collaborative benefits were included in the simulation and change affected the IMCF land-use.

A gradual increase in product prices after 15 time steps resulted in a stronger increase in savings (Figure 6.7c), but had no effect on land-use allocation of the four populations with different needs (Figures 6.7c and 6.7d). However, agents with stronger existence needs increased the proportion of forest-based land-use when prices declined gradually (Figure 6.7g), managed to increase their savings (Figure 6.7f) and none of these farmers left (Figure 6.7e), whereas other farmer types only managed to stabilize savings and in some cases left farming, in particular in the population with strong personal needs.

Sudden changes in prices had stronger effects (Figures 6.7a-6.7h) than gradual changes (Figures 6.7i-6.7p). Land-use change in a response to a shock-event was temporary (Figures 6.7k and 6.7l), and savings continued to increase (Figure 6.7j). After a permanent price change, the population with strong existence needs increased forest-based and collaborative land-use types, and succeeded to accumulate savings, whereas farmers in other populations only stabilized total savings (Figure 6.7n) and many agents from the populations with strong social and personal needs left farming (Figure 6.7m).

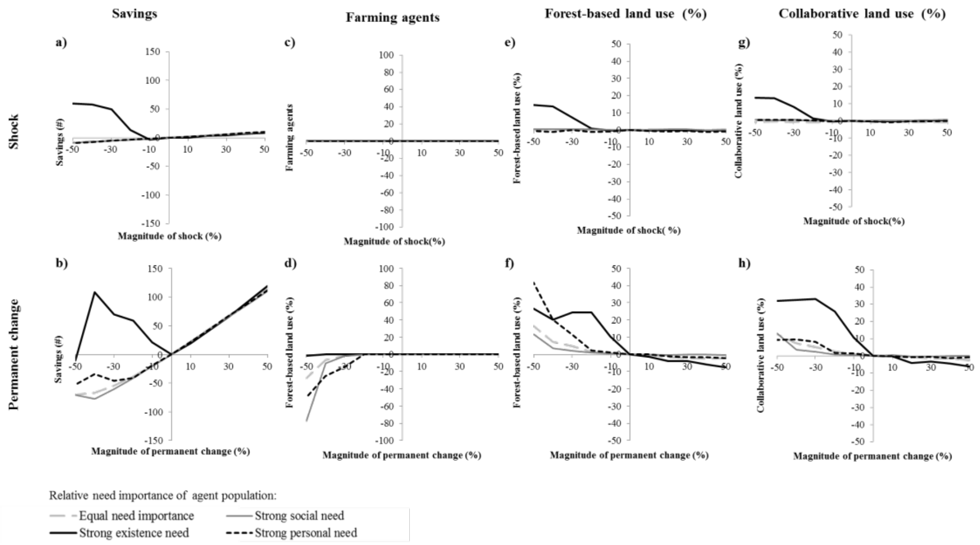

Figure 6.8: Effects of the magnitude of the simulated shock and permanent change on: 1) average agent savings, 2) number of farmers, 3) forest cover, and 4) collaborative effort. Collaborative benefits were included in the simulation and change affected the IMCF land-use.

The simulated dynamics in land-use and savings after sudden adjustment in prices differed between populations and were dependent on the magnitude of the change in particular in case of a permanent price change (Figures 6.8). Even at small declines of prices the agents with high existence needs shifted to forest-based and collaborative land-use, whereas for other agent types this adjustment in strategy occurred only at larger price declines and it was less pronounced (Figures 6.8 and 6.8h). As a consequence, agents with high existence needs were able to continue accumulating savings until a price decline of 40%, while other agent types lost savings (Figure 6.8b) and some of the agents with strong personal and social needs left farming when prices declined exceeded 25% (Figure 6.8d).

Model explorations showed that price increases had minor effects on land-use dynamics, whereas price decreases resulted in larger land-use adjustments (Figure 6.8f and 6.8h). Price declines triggered collaborative land use, which resulted in increased savings, especially in the case of the agent population with strong existence nee (Figure 6.8b and 6.8h).

3.2.3 Peer networks

Preliminary results of a detailed analysis of peer networks developed in one simulation experiment showed that there were no highly influential agents in the simulation and peer selection was normally distributed. Over the course of the simulation, agent established peer relations with a relatively small number of agents and all agents developed recurrent peer relations with at least one other agent that was selected in every time step of the simulation (Table 6.3). Reciprocity in peer selection was high with agents selecting each other as peers a similar number of times. For example, agent A selected agent B 45 times over the course of the simulation, whereas agent B selected agent A 46 times, or agent C selected agent D 5 times, whereas agent D selected agent C also 5 times. Peer networks were relatively stable throughout the simulation with strong peer connections that selected each other more than 45 times over the course of the simulation formed 45% of all connections. Less frequently developed peer connections in which the link was developed between 0 and 5 times over the course of 50 time steps represented only 12% of all established peer connections (Table 6.3).

Table 6.3: Peer network data from a single run with a 100 agents over 50 time steps, showing mean, SD, minimum and maximum values of peer network characteristics.

	Mean	SD	Min	Max
Number of times agent was a peer	248	86	53	429
Number of different peers	8.0	1.5	5	12
Number of "stable peers"	2.7	0.9	1	5
Difference in reciprocity in peer connections	10.0	13.1	0	48

4 Discussion

In this chapter, we proposed social-psychological theory as the basis for land-use decisions to guide the exploration of land-use dynamics under challenging global change scenarios. We presented the conceptual LUSES model (Speelman et al., 2012) and the first steps of its development - qualitative validation and model explorations. Results of validation experiments showed that the simulated agent population responded to economic and institutional drivers by adjusting land-use and establishing beneficial collaboration. These response mechanisms were also identified in empirical data (Chapter 2). However, simulated responses were most similar to empirical responses in simulations with agents with a relatively higher importance for existence need. Empirical and simulated data differed in the time period before economic and institutional changes impacted the system in simulations with both populations, but more in the population with high existence need. Simulated results suggest that when a system is under pressure the relative importance of needs changes and existence need become more important. In both the empirical and the simulated situation, collaborative benefits were only obtained after that the system experienced pressured through the impact of economic and institutional drivers.

Model explorations showed that in a stable scenario without economic or institutional changes, landscapes were developed that consisted of all four land-use types. In addition, economic changes in the form of price increases had minor effects on land-use dynamics, whereas price decreases resulted in larger land-use adjustments. Thresholds for obtaining collaborative benefits were only obtained in scenarios with strong price reductions or when collaboratively managed land-use types were present in the initial landscape. The agent population with relatively strong existence need responded fastest and strongest to the simulated economic and institutional changes and showed to be most resilient by maintaining or even increasing system variables under negative impacts.

Social-psychological theory showed to be successfully implemented in various (diffusion) research fields; environmental innovations (Schwarz and Ernst, 2009), fuel cell vehicles (Schwoon, 2006), waste management (Taylor and Todd, 1995). The CONSUMAT approach was successfully implemented in a various systems, flood management (Brouwers and Verhagen, 2003), diffusion of green products green products (Janssen and Jager, 2002), and vulnerability assessment of farming communities in the Philippines (Acosta-Michlik and Espaldon, 2008). The initial qualitative validation of the LUSES model that was presented here, showed that similar response mechanisms to economic and institutional change were identified in empirical and simulated data. This made us believe that the implementation of social-psychological theory in agricultural land-use decision-making through the updated CONSUMAT approach (Jager and Janssen, 2011) might improve current understanding of land-use dynamics. The conceptual CONSUMAT update as well as the LUSES model, presented here, comply to the three main inter-related factors necessarily included to explain farmer's decisions as identified by Beedell and

Rehman (2000), namely 1) policy structure facing farmers, 2) advisory system available to them, and 3) motives, feelings and goals of farmers.

Future development and research with the LUSES model will consist on three main research parts: 1) participatory model evaluation, 2) further model development, and 3) model adjustment to develop the LUSES model as a learning tool. Participatory model evaluation will focus on evaluating simulated behavior at agent and landscape level with stakeholders in the case study area i.e. farmers, farmers representatives, and local (agricultural) authorities, and local researchers. This will allow to identify and validate key assumptions about agent behavior (Macal and North, 2005; Ligtenberg et al., 2010). Further model development will consist of implementing the impact of the distinct land-use types on a set of ecological processes e.g. runoff, erosion and bush fire dynamics. In addition, additional explorations to test the hypothesis on changing relative need importance of agents under pressure are required. Also, the diversity of responses at landscape and agent level require to be analyzed in more detail and the developed peer networks, here only briefly examined, require more analysis to assess if different networks develop under different scenarios. Once, these analysis have been successfully performed model use can assessed future explorations of system's behavior under various global change scenarios. Model adjustments to develop the LUSES model into a learning tool will focus on the development of: 1) a user-friendly model interface in which users can "play" one of the agents and make land-use decisions, 2) a session structure in which stakeholders participation is guided through a) model exploration, b) interactive-discussion, and c) role-play similar to that developed in chapter 5, and 3) a highly structured monitoring and analysis scheme to assess learning similar to those proposed in chapter 3 and 4.

5 Conclusions

In this chapter, we presented the first steps of the development of the agent-based model LUSES (Speelman et al., 2012). for exploring land-use dynamics under different economic and institutional scenarios in which agent decision-making is based on the conceptual update of the CONSUMAT framework (Jager and Janssen, 2011). The research question that guided the development of the LUSES model is whether social psychological theory can improve our current understanding of land-use dynamics in response to economic and institutional change and allow for exploration of future scenarios. In this first phase of model development, we explored (i) the ability of the updated CONSUMAT theory to reproduce farmer's land-use decisions in a real case, and (ii) the sensitivity of simulated land-use dynamics to basic model assumptions. Preliminary results of a qualitative comparison of empirical data from a reserve community in Chiapas, Mexico and data from simulation experiments showed qualitative similar responses to economic and institutional change in simulated and empirical data. In addition, we found that the simulated land use dynamics after strong economic and institutional change of an agent population with a relative high importance for existence need, which relates to the economic dimensions of existence, was most similar to that identified in empirical data from the reserve community, Tierra y Libertad, Chiapas, Mexico. In contrast, empirical data before coinciding drivers affected land-use dynamics in TyL, was more similar to simulated data from the agent population with equal needs. These preliminary results seem to suggest that relative need importance of agents changes and existence need become more important when a system is under pressure. Price increases were shown to have minor effects on land-use dynamics, while price decreases did. Only price decreases were able to trigger the system towards achieving beneficial collaboration. We believe that these initial results support the implementation of social-psychological theory in modelling land-use dynamics in agricultural landscapes. Economic and institutional changes often generate unexpected responses in agricultural landscapes. Many of these response mechanism are only fully understood ex-post. Implementing decision-making theories such as the CONSUMAT approach in simulation studies tor the exploration of land-use dynamics under global change scenarios could result in the exploration of more realistic land-use dynamics

APPENDIX B: ODD of the LUSES model; following Grimm et al. (2006; 2010) and Polhill (2010)

Overview

Purpose

The aim of the LUSES (Land Use in a Social-Ecological System) agent-based model (Speelman et al., 2012) was to create a simple yet comprehensive simulation tool for the analysis of coupled socio-environmental systems in agricultural landscapes grounded in sound social behavioral theory and parameterized with empirical data. Through explorations with the LUSES model a variety of research questions can be addressed related to the effects of system's behavior e.g.: 1) social and environmental interactions, 2) exogenous drivers of change i.e. product price variations, 3) endogenous agent's characteristics. In addition, the circumstances under which regime shifts at one level trigger a shift at another level can be explored. As an example, the circumstances under which social behavior changes and leads to land use change at landscape level can be explored.

Entities, state variables and scales

We developed the LUSES model in Netlogo 4.3.1. (Wilensky, 1999). The LUSES agricultural landscape consists of a 1681 patches. Each patch represents an agricultural area of 1 ha (Table I). The number of patches that form the agricultural landscape can be adjusted by expanding or decreasing the size of the view in the user's interface of the model. Agents represent farmers that manage the agricultural landscape by selecting the patches' land use type. The number of agents can be selected through a slider in the model's interface and ranges from 6 up to the number of patches (Table I).

Table I: Overview of the variables and their range in the LUSES model.

Variable	Range
Ambition level	0-1
Uncertainty tolerance level	0-1
Cognitive effort	1-10
Land holdings per agent	1-1676
Household size	2-9
Number of agents	6-1681
Initial land use in landscape	Four land use types

At any time during the simulation, patches can hold one agent, and one land use type. The agents are located randomly on one of the patches that they manage. The model's time step represents one agricultural production year. The spatial and temporal scales were based on empirical data from a 50% systematic stratified sample of the smallholder community Tierra y Libertad in the buffer-zone of a Biosphere Reserve in Chiapas, Mexico (Chapter 2). Parameters i.e. agent, patch and global (not directly linked to agents or patches) parameters, are used to calculate and show the dynamics of the simulated social-ecological system.

Process overview and scheduling

The order of processes being executed by various entities in every time step is as follows: 1) <u>Globals, agents and patches</u>: lists are updated, 2) <u>Agents</u>: calculate income, 3) <u>Patches</u>: update land use to selected land use types, 3) <u>Agents</u>: select peers, peer calculations, need satisfaction calculations (in case of "inquiring "or "optimizing" – calculate expected prices for currently selected land use types and its effects for current need satisfaction levels), calculate next round's expected price, calculate uncertainty, calculate uncertainty ratio, select behavioral option, in case of "inquiring "or "optimizing" – calculate expected future need satisfaction levels including expected prices and its effects for selective or all land use types, select land use types percentages, allocate land use in space (Table II).

Design concepts

Basic principles

The LUSES model was based on social–ecological and complex system theory in which the social and ecological components of the system are intrinsically linked (see Gunderson and Holling, 2002; Berkes et al., 2003). Simulated social behavioral decision-making processes in the LUSES model were based on the conceptual update of the human behavioral CONSUMAT model (Jager and Janssen, 2011 - for more reading on the CONSUMAT approach see: Jager, 2000; Jager et al., 2000). The social behavior of agents is based on: 1) the satisfaction level of three basic needs in relation to the agent's ambition level, and 2) the level of uncertainty they experience with their current land use choices in relation to their uncertainty tolerance level (see also Laland, 2004). Three basic needs are included, namely 1) existence, 2) social, and 3) personal (for more information on needs theory see: Maslov, 1954; Festinger, 1954; Max-Neef, 1992; Lindenberg and Steg, 2007). The biophysical environment in the model reflects the consequences of land use decisions made by the agent population. Landscape characteristics are calculated using diversity index (Shannon, 1948) and a species richness index (Tuomisto, 2010a, b).

Table II: Overview of the procedures and sub-models of the LUSES model. The more complex sub-models have additional procedures and models embedded in them. These are indicated using superscript numbering and described in the lower section of the table.

Sub-model /Procedures	Description	Entities involved
Model initiation		
Procedures		
Set-up	Set all global parameters to initial values; randomly place agents in space; ask agents to set parameters to initial values; update view	Globals, Agents, Patches
Model running		
Procedures		
Update	Update global and agents lists and parameters; set land use type to land use type selected at the end of last year	Globals, Agents, Patches
Sub-models		
Income calculation	Calculate annual income of selected land use types	Agents
Peers selection	Select 5 peers based on relative similarity of: i) land use selection, ii) land use preference, iii) savings, iv) land holding, v) distance	Agents
Social need satisfaction	Calculate social need satisfaction based on similarity[1)] and superiority[2)] to peers	Agents
Personal need satisfaction	Calculate personal need satisfaction based on currently selected land use and the agent's preference towards land use type	Agents
Existence need satisfaction	Calculate existence need satisfaction based on agent's household need and returns of currently selected land use types. In the case of 'optimizing' or 'inquiring' agents, these returns include the effects of expected future income of currently selected land use types[3,4]	Agents
Overall need satisfaction	Calculate overall need satisfaction of currently selected land use types based on social, personal and existence need satisfaction and the relative importance of these three needs	Agents
Need satisfaction ratio	Calculate overall need satisfaction relative to the agent's aspiration level	Agents
Uncertainty	Calculate uncertainty of currently selected land use types based on expectations of future prices made by the agent's peers[5] and similarity in land use choices with agent's peers[1]	Agents
Uncertainty ratio	Calculate uncertainty relative to agent's uncertainty tolerance level	Agents
Behavioral option	Select one of four behavioral options (repeat, imitate, inquire, optimize) based on: i) need satisfaction ratio, and ii) uncertainty ratio	Agents

Continuation of Table II		
Repeat	Set next year's land use types to this year's land use types	Agents, Patches
Imitate	Set next year's relative land use types to currently selected relative land use types of one of agent's peers; allocate land[6]	Agents
Inquire	Evaluate the potential personal[7], social[1,2,8], existence[3,4,9,10] and overall[11] need satisfaction of land use types currently selected by any of the other agents; develop land use type -potential overall satisfaction level[12] list; select[13] and allocate[6] next year's land use types	Agents
Optimize	Evaluate the potential social[1,2,8], personal[7], existence[3,4,9,10], and overall[11] need satisfaction of all land use types; develop land use type -potential overall satisfaction level[12] list; select[13] and allocate[6] next year's land use types	Agents
Draw graphs	Update graphs that show the performance of the simulated social-ecological system	Globals, Agents, Patches
Processes embedded in sub-models		
1) Similarity to peers	Calculate similarity to peers based on currently selected relative land use types	Agents
2) Superiority to peers	Calculate superiority to peers based on agent's and peer's savings	Agents
3) Future income	Calculate expected future income based on memorized income per land use type of past years using a linear function. The number of years for which price data is memorized equals the agent's cognitive effort.	Agents
4) Effects future income	Calculate effects of calculated expected future income per land use type on current income using a discount function	Agents
5) Expected income uncertainty	Calculate uncertainty in next year's expected prices among peers and self for currently selected land use types based on the standard deviation of expected future income among peers and self, divided by the average expected future income of peers and self	Agents
6) Allocate land use	Set next year's selected land use type of randomly selected patches. The number of selected patches is calculated by the relative land use types for next year times the agent's land holding	Agents, Patches
7) Potential personal need satisfaction	Calculate potential personal need satisfaction based on agent's land use type preference and land use types	Agents
8) Potential social need satisfaction	Calculate social need satisfaction based on peers' land use selection and land use types	Agents

Continuation of Table II

9) Potential income	Calculate potential maximum income per land use type based on specialized farming, expected next year's income[3] and effects of future income on next round's income using discount function[4]	Agents
10) Potential existence need satisfaction	Calculate existence need satisfaction based on income from currently selected land use types and agent's household need	Agents
11) Potential overall need satisfaction	Calculate potential overall need satisfaction based on personal[7], social[8] and existence[10] need satisfaction and relative importance of the three needs	Agents
12) Develop list	Develop a list that combined land use type and its associated potential overall need satisfaction	Agents
13) Next year's selected relative land use types	Set next year's selection of land use types relative to its relative potential overall need satisfaction	Agents

Adaptation

The behavior of agents is based on need satisfaction and uncertainty experienced from currently selected land use types in relation to agent characteristics i.e. ambition level and uncertainty tolerance. Need satisfaction and uncertainty are determined by: 1) the behavior of the agent's peers, and 2) exogenous variables such as land use prices. Land use prices are pre-determined. Hard threshold determine the behavioral strategy an agent employs (Figure I).

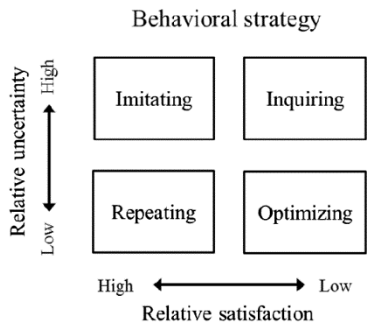

Figure I: Graphical overview of the four behavioral strategies that agents employ dependent on the uncertainty and satisfaction rates they experience from their current land use choices.

In short, an agent that experiences high is satisfaction and low uncertain will simple repeat current land use choices in the next time step (strategy: repeating). An agent that is unsatisfied and uncertain will engage in evaluating all possible options including those not presently selected with in the agent population (strategy: optimizing). An agent that is satisfied, but uncertain, will imitate relative land use types of a randomly selected peer (strategy: imitation). An unsatisfied, but certain agent, will evaluate the land use options currently performed by any of the agents in the population (strategy: inquiring) (Figure II).

Objectives

Only agents that employ 'optimizing' or 'inquiring' behavioral strategies, evaluate and rank the land use options available in that time step according to the option's weighted overall need satisfaction. The existence, personal and social need satisfaction is weighted using relative importance of the three needs into the overall weighted need satisfaction. The relative weighted overall need satisfaction per land use type is used to determine the relative land use for next year's selection.

Learning

Agents do not learn or adjust their decision-making rules.

Prediction

Agents that employ an optimizing or inquiring behavioral strategy make predictions for future prices as part of their: i) existence need satisfaction calculations, and ii) land use selection procedure. Whereas, agents that are in repeating or imitation behavioral strategy do not. The prediction for future prices is performed on an individual basis by the optimizing or inquiring agents.

For the existence need satisfaction calculations of optimizing or inquiring agents, agents predict prices of the currently selected land use activities, after which the effect of the predictions is calculated and added to current prices. First, the agent makes price predictions by extrapolation of memorized price data using a linear function (Figure II). The number of memorized prices equals the agent's cognitive effort. The cognitive effort an agent employs is fixed throughout the simulation and is set randomly for each agent at model initiation. The effect of predictions of future prices is then calculated using a discount function through which the importance of the predicted prices decreases with time. Price predictions closer in time have a stronger effect on current existence need satisfaction than predictions further away in time (Figure II). The sum of the effects of all predicted prices is then added to current price. As such, the price predictions affects current existence need satisfaction. If an agent expects income of current land use types to increase over time, the agent will feel more satisfied. Conversely, if the agent predicts a decrease of income over time, the agent will feel less satisfied with his current choice.

Existence need satisfaction was calculated using the following function (1):

S_X (t=0) = I_x (t=0) $+ \sum_{t=0}^{t=ce} I_x$ (t) $* \ e^{-t}$
(1)

Where:

S_X = existence need satisfaction of land-use x at time 0

I_x = income of Land-use Type *x*

t = time

ce = agent cognitive effort

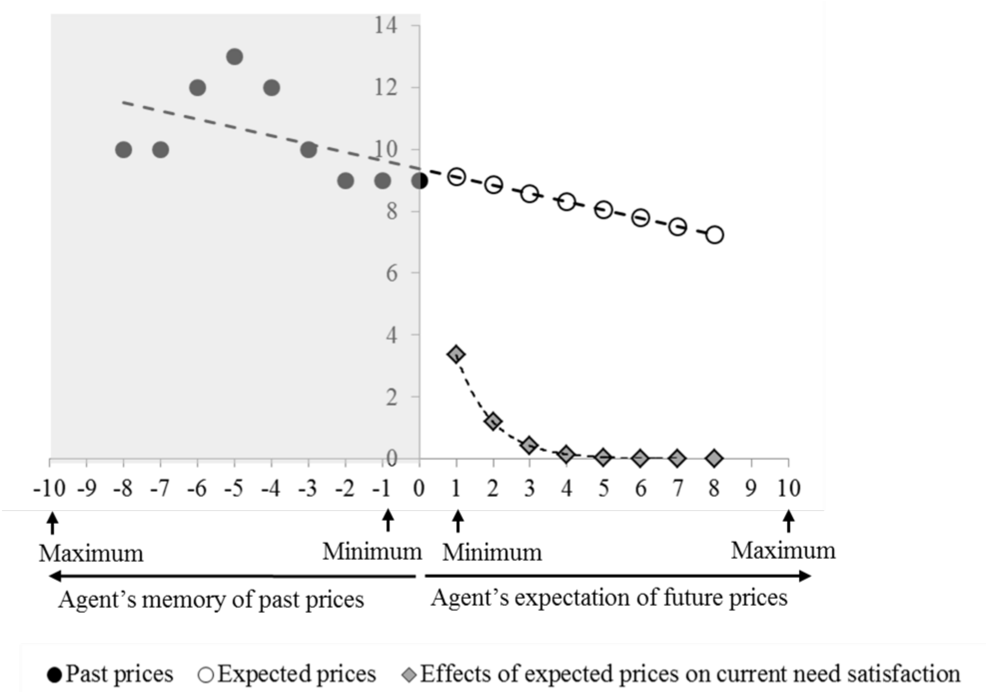

Figure 1: Graphical representation of agent's price predictions and effects on current existence need satisfaction. Expected prices are calculated using a linear function and based on memorized prices of anterior years. The effect of expected prices is calculated per year using a discount function and calculated as part of current existence need satisfaction (see function (1)).

In addition, agents in inquiring or optimizing mode make future income predictions as part of their land use selection procedure for the following year. While inquiring, agents calculate evaluate the land use activities that are currently performed by any of the agents in the entire agent population; while optimization mode includes all possible land use activities.

Sensing

Agents sense a range of variable values of other agents. All agents, sense the relative land use choices of their peers. Agents in inquiring or optimizing behavioral modes also sense: 1) price expectations of their peers, and 2) all land use types selected by any of the agents in the total population.

Interaction

Interaction among agents is implicit and mainly based on sensing the state of variables of peers and other agents. Agents do not compete for resources, however indirectly they can benefit from the choices from others. Social need satisfaction depends on similar land use choices are of the agents among its peers. In addition, existence need satisfaction might be affected by land use choices of others through meeting threshold values for higher product prices.

Stochasticity

At the start of the simulation, some agent characteristics are set to a randomly selected value within a specified range of values to create a heterogeneous population. These characteristics include: i) aspiration level: between 0 – 1, ii) uncertainty tolerance level: between 0-1, iii) cognitive effort: between 1-10, iv) household size: between 2 -9, v) initial saving: between 1-10, and vi) land use preference: one of the four land use types. In addition, the spatial allocation of agents and their fields is at random. This random spatial allocation is realized by first randomly allocating agents over space. The agents all have a distinct number which they assign to the field on which they are located. Unoccupied fields are assigned a random number smaller or equal to the number of agents. Agents manage all fields that have the same number assigned to it as the agent.

Collectives

No obvious collectives are present in the model. However, agents can implicitly form collectives by collectively meeting a threshold that renders them additional income based on benefits associated to collaborative production and sales of their produce.

Observation

In the user's interface of the LUSES model various graphs and parameters are presented that show the dynamics of the simulated social-ecological system. The graphs present systems land use, social and environmental change. Land use change is shown as relative change in: i) all four land use types, ii) forest-based land use types, and iii) cleared-field

land use types. Social change is presented as: i) relative change of social behavioral strategies of agents, ii) relative cooperative land use, and iii) farmer's richness of land use types at population level. Environmental change is represented by: i) landscape diversity, and ii) relative forest-cover.
In the simulation view, one can select to see: i) agents, ii) links between agents and their peers, iii) land use or land-ownership. A variety of monitors allow the state of many systems parameters.

Details

Initialization

In the user interface, the initial settings of the simulation can be selected. The size of the view can be adjusted to select the size of the simulated landscape. A variety of sliders and choosers allow the user to select: i) the number of agents, ii) the price trajectories, iii) presence of benefits for collaborative land use types, iv) relative need importance of the overall population, and v) land division.

Input data

The current version of the model does not use data from external sources.

Sub-models

Main sub-models and procedures in the LUSES model are described in Table I. Some of the more complex sub-models have other sub-models embedded in them.

Chapter 7

General discussion

1 Introduction

Collective governance systems through which human societies organize themselves are of central importance to the capacity to adapt to change in social-ecological systems (Robinson and Berkes, 2011). Even communities in relatively isolated rural areas in the world are currently challenged to respond to the effects of globalization and international economic and institutional change (e.g. García-Barrios et al., 2009; Schwarz et al., 2011; Butler et al., 2013; Ribeiro-Palacios et al., 2013). Growing global interests in nature and biodiversity conservation resulted in often conflicting policies and incentive schemes for these previously neglected areas (e.g. Giller et al., 2008; Sayer et al., 2013). The increased connectivity between biophysical and governance scales and levels is expected to further increase as the globalization process continues. The capacity of rural communities to adapt to this fast-changing environment is key in securing the continuation of livelihoods in rural parts of the world.

Resilience thinking (Holling, 1973; Walker et al., 2004) and complex adaptive systems theory (Levin, 1998) provide new perspectives for analyzing processes of change in social-ecological systems such as smallholder agricultural landscapes. Lately, the term resilience has become somewhat of a buzzword. The increased popularity of resilience and related concepts have resulted in ambiguity of the interpretation of the concepts and has not (yet) led to more solution-orientated approaches for the application of the concept (e.g. Rist and Moen, 2013; Tittonell, 2013). Currently, resilience theory thinking primarily allows an innovative conceptual understanding of how systems deal with change, but still requires operationalization in many fields of research including contested agricultural landscapes, as studied in this thesis (e.g. Walker et al., 2010; van Apeldoorn et al., 2011; Tittonell, 2013). Against this background, the overall objective for this thesis was to explore and apply concepts of resilience theory to contested agricultural landscapes in particular the concept of adaptive capacity, by means of innovative gaming and simulation methodologies to facilitate (social) learning related to these concepts. Four specific objectives were formulated:

1. To identify how and under which circumstances smallholder communities adapt to social-ecological change (Chapter 2).
2. To develop a gaming methodology to facilitate the active involvement of stakeholders and to assess factors and patterns of communal decision-making (Chapter 3).
3. To develop computer simulation tools to enable (social) learning on complex concepts related to sustainable management of social-ecological systems in agricultural landscapes (Chapter 4 and 5).

4. To improve the current understanding of land-use dynamics in agricultural landscapes in response to economic and institutional change through applying social psychology theory to the analysis of farmer decision-making processes (Chapter 6).

In the previous chapters, innovative methodologies to explore systems resilience in the context of smallholder communities in contested agricultural landscapes were developed and implemented. In this chapter, the main findings are discussed in a broader context of learning tools for resilience of contested agricultural landscapes focusing on the conceptual, methodological and empirical findings of this thesis.

2 Gaming and simulation

Games and social simulation tools are said to allow social learning and facilitate cognitive learning through the experience (e.g. Barreteau et al., 2003). In this thesis, four gaming and simulation tools were developed to explore the concept of resilience in social-ecological systems in contested agricultural landscapes and to facilitate social and cognitive learning of participants on these concepts (Chapter 3, 4, 5 and 6). Participants interacted and learnt through gaming and simulation tools in groups (Chapter 3 and 6), in couples (Chapter 4 and 5) or on an individual basis (Chapter 4). The tools focused on different types of learning. In chapter 3 the main focus was on social learning, in chapter 4 on cognitive learning and in chapter 5 both learning methods were combined. In all three chapters, participants experienced the concepts by managing simulated systems (Kolb, 1984) (Chapter 3, 4 and 5). In particular in chapter 5, role-play, negotiation and knowledge acquisition allowed forward-looking or anticipatory learning on complex systems behavior. Learning and in particular anticipatory learning can prepare stakeholders for dealing with complex systems behavior e.g. uncertainty, sudden shocks and changes, and to the non-linear behavior of systems (Tschakert and Dietrich, 2010).

Assessing the effects of (social) learning remains difficult and objective measures on the process and effects of (social) learning through participatory methods, gaming and simulation are still scare (e.g. Gosen and Washbush, 2004; Scholz et al., 2013). In the majority of the studies analyzed by Gosen and Washburn (2004) little attention was given to assessing learning effects. The additional investment of time and resources required to assess the effects of gaming and simulation tools on learning seems to be substantial (e.g. Kok et al., 2007; Van Paassen et al., 2007) and is often outside the scope of projects. The most commonly used assessment on learning process was self-reported learning, a highly subjective measure (Gosen and Washbush, 2004). In addition to self-reported learning, group discussion, written evaluations and interviews ex-post were implemented in this thesis. An objective assessment on the acquiring of knowledge through the interaction with a computer simulation model was developed (Chapter 3). The analysis of this detailed evaluation on learning confirmed self-reported accounts of learning in previous workshops with the model. Participants gained in-depth knowledge and understanding on the concepts introduced and explored and shared ideas on land-use decision-making and reflected on their own and each other's decisions.

Since the first development of games as tools to facilitate learning in business education (Duke, 1974), games have been developed and used in a variety of settings for distinct goals. In the last years, an ongoing trend towards more active and experiential learning is seen in higher education (Lean et al., 2006). Participatory methods that allow social learning in problem solving processes or explorations of future have been successfully used especially in the western world through e.g. cognitive mapping and scenario building (Kok, 2009; van Vliet et al., 2010). In the context of natural resource management and/or agricultural landscapes problem settings, the companion modelling approach (COMMOD) has been widely applied to address a variety of issues e.g. water management (Dray et al., 2005; Gurung et al., 2006; Ferrand et al., 2009; Barreteau et al., 2012), soil erosion (Souchère et al., 2010), and collective awareness (Mathevet et al., 2007).

The majority of current methods does not particularly focus on anticipatory learning, but are part of a specific problem solving project. As a consequence the tools developed in these projects are highly site-specific and require major adjustments to be used in other situations. This one-problem-one-game approach is potentially more costly than the development of more generic tools that create a general understanding of processes of change and prepare for unknown change. The tools developed in this thesis aimed to be more generically applicable while yet still remaining useful in the context of resilience in contested agricultural landscapes (Chapter 3, 4, and 5).

Future research should focus on developing relevant anticipatory learning tools for smallholders and other local stakeholders in contested agricultural landscapes. These tools should be as simple as possible to facilitate the participation of stakeholders that are illiterate or functional illiterate while at the same time complex enough to create realistic system's behavior to allow understanding and experience with processes of change.

Social-ecological systems behave like complex adaptive systems when a long time perspective is taken into account. Humans, as the managers of social-ecological systems, then become an integral part of the system and including human decision-making in model explorations will allow a more comprehensive understanding of system's behavior (Walker et al., 2004). Innovative computer-supported modelling tools in which human decision-making was simulated based on e.g. probabilistic, microeconomics, and statistical empirical rules, have been developed to facilitate the exploration of the behavior of complex social-ecological systems (An., 2012).

A simulation tool for the exploration of land-use dynamics in complex social-ecological systems in which decision-making is based on social-psychology, currently under development, was presented in chapter 6. This model aimed to increase understanding on how farmers respond to change and which instruments and mechanisms e.g. collaboration benefits and/or subsidies, might be best suited to maintain system functions under economic and/or institutional change scenarios. Broad social-psychological theory was selected for the decision-making processes in the model to be able to generate plausible output under unknown change. Preliminary simulation results show responses to change that were qualitatively similar to those identified in chapter 2. In addition, the results suggest that decision-making processes change when systems are under pressure and the subsistence needs (i.e. provision of income and food) become more important. Positive economic changes had a minor effect on land-use decisions. In contrast, negative changes resulted in larger adjustment in landscape composition. Beneficial collaboration was only reached when the system was affected by a large negative change.

This type of holistic modeling of social-ecological systems allows analyzing processes of change at different levels and from distinct angles. Figure 7.1 illustrates a stylized example of the dynamics of a social-ecological system in response to an external driving variable such as price fluctuations or policy changes. The illustration was based on driver-response data collected from the case study area and presented in chapter 2. Four aspects of an agriculture-based social-ecological system are shown in response to changes in the driving variable. This tool shows the diversity of potentially slow and immediate response mechanisms at the various scales and levels. An important addition could be the inclusion of the simulation of satisfaction of local resource managers or farmers. Similar social facets were previously modelled by e.g. Bregt and Ligtenberg (2013).There are often sentiments of dissatisfaction that remain unnoticed. Through human interactions these sentiments can spread fast and result in surprising social uprising (Gladwell, 2000). Agricultural related uprisings resulting from price vitality were e.g. Zapatista movement in Chiapas, Mexico triggered by the ratification of NAFTA in 1994; farmer protests against lower prices in response to European trade and agricultural policies were intermittent since the late 1980s; worldwide food riots during 2007-2008 and 2011-2012 as a consequence of reduced and failed harvest in various part of the world. The latter has been predicted by computer simulations.

Future research should focus on the further development of similar tools by explicitly simulating the impacts of social processes on ecological processes and vice versa. In addition, Social mechanisms that could improve system resilience such as beneficial collaboration in view of economic and institutional change should be explored further.

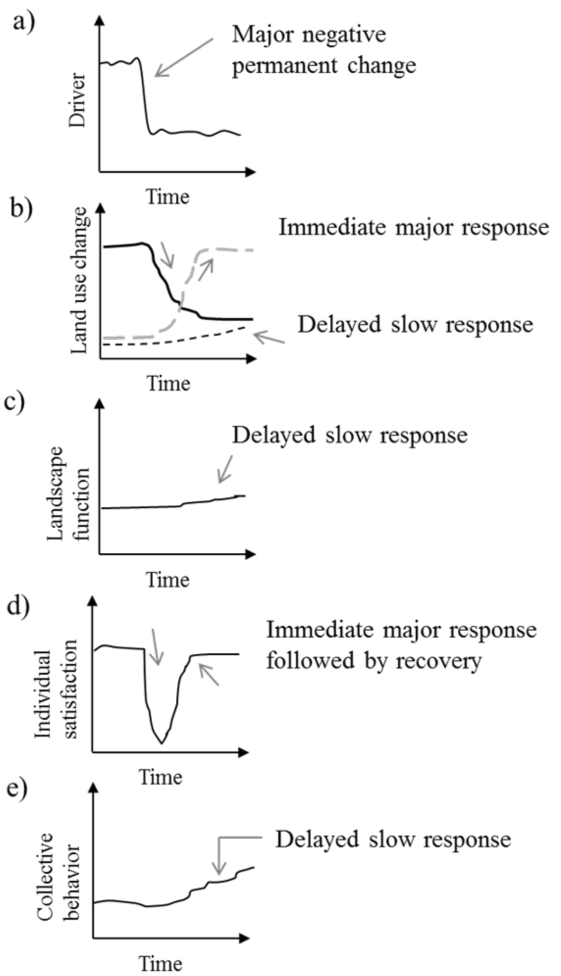

Figure 7.1: An example of simulated output from the LUSES model on land-use dynamics in social-ecological systems based on social-psychological theory. An overview is presented of a permanent change in a driving variable (a), and subsequent effects on (b) relative land use changes, (c) the state of a landscape function, (d) individual satisfaction of farmers, and (e) collective behavior.

3 Resilience thinking in contested agricultural landscapes

Resilience and adaptive capacity were two central concepts explored in this thesis. Walker et al. (2004) defined a third main system attribute that determine how systems deal with change, transformability, as the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable (Walker et al., 2004;Walker and Westley, 2011). The distinction between a system that adapts to absorb disturbances and one that transforms itself into a new system, is a rather subjective matter and depends amongst others on the temporal and spatial levels at which one analyzes the system. For example, a change in farming practices from maize to livestock production - as seen in chapter 2 - can be identified as a transformation during the time span of a farmer's life. The investments made to establish such a change and the ecological consequences of this change are likely to hamper a smooth change back to a maize-producing farm. For a smallholder farmer, this represents a radical transformation. Such transitions may be felt as all the more irreversible for smallholders as the hysteresis between both transition pathways is wide (cf. Tittonell, 2013). However, from a larger-temporal perspective or from a higher spatial or organizational level, these changes in land use and farming activities may be seen as an adaptation of the system, based on the argument that the system retained its farming function. In this thesis, adaptability and adaptive capacity was interpreted broader than the definition provided by Walker et al. (2004) and encompassed also their definition of transformability (Walker and Westley, 2011). Here, the specific definitions of adaptive capacity and resilience encompass desirable system features that not only allow the system to deal with current change, but also prepare it for future changes.

In order to apply resilience theory beyond conceptualization of processes of change, stakeholders need to reach agreements on the precise definitions of concepts used in the assessment e.g. resilience, the system, its states and the specific system function for which resilience is explored need to be agreed upon (e.g. Carpenter and Gunderson, 2001, Folke et al., 2010; Walker and Westley, 2011). This requires the participation of a variety of multi-level stakeholders to identify the diversity of views on the associated concepts and to potentially agree on joint definitions (Walker and Salt, 2012; Sayer et al., 2013, Walker et al., 2002). Commonly, non-local stakeholders define system resilience in terms of landscape functions (Figure 7.2-a,b) particularly of those that are seen as services to the local or global society (e.g., watershed regulation, soil carbon sequestration, biodiversity conservation, etc.). In contrast, farmers generally focus on production aspects of their farm to satisfy household existence, social and personal needs (Chapter 2 and 6) (Figure 7.2-e).

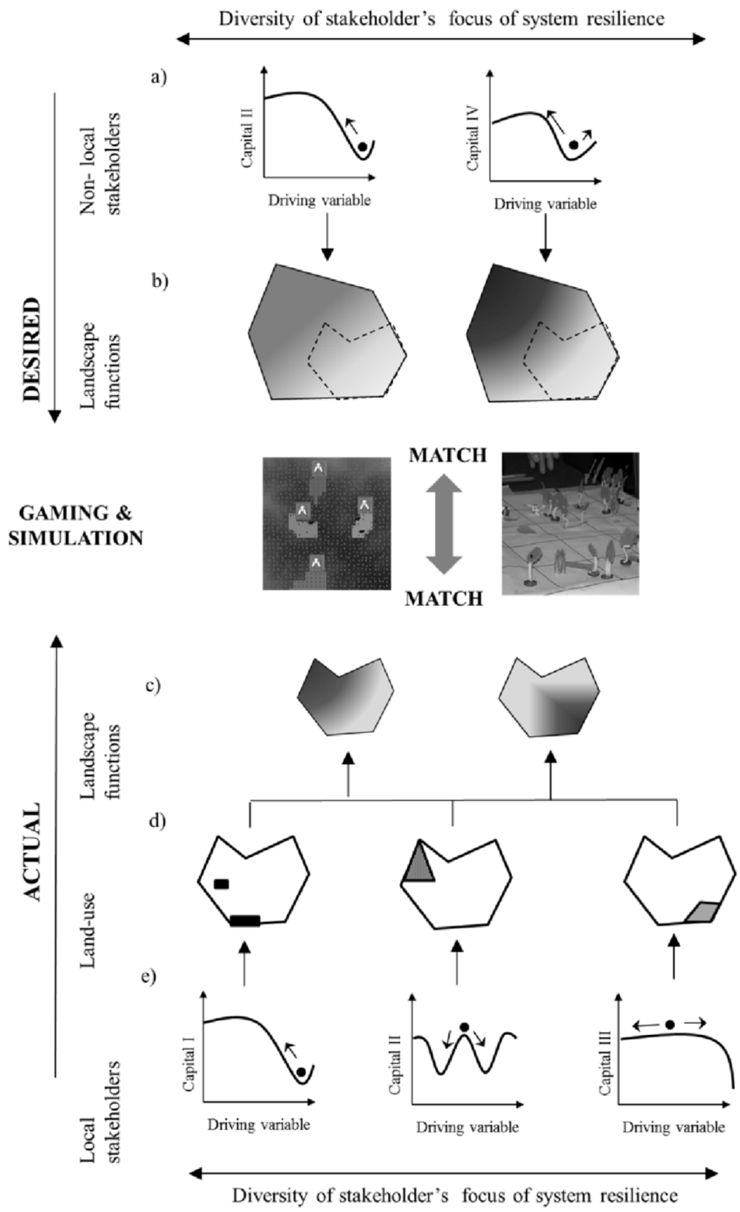

Figure 7.2: Schematic overview of the potential role of gaming and simulation tools in social learning processes between local and non-local stakeholders to match the desired and actual landscape functions resulting from the diversity of their views on resilience of social-ecological systems.

The land-use decisions made by farmers according to their view on system resilience and needs determine the actual state of landscape functions (Figure 7.2-d,e). The actual state of the landscape functions and those desired by non-local stakeholders often do not match and require interventions, informed negotiation and consensus. This thesis proposes the use of gaming and simulation to jointly explore solutions and build consensus on the system feature for which resilience is required. As an example, in the case study area, non-local stakeholders strongly focused on forest protecting to preserve local biodiversity and rules and regulations were put in place for this purpose. Effective forest protection was assessed only through forest cover measurements through satellite images. Farmers and local communities focused more on the production facets of their farms and forest plots and made land-use decisions accordingly. Farmers selected and manipulated the trees in their coffee and palm plots to optimize the amount of shade. As a result, forest cover was maintained, while no local biodiversity was necessarily protected. Also, farmers differed in their views on the value they gave to the forest and to sustainable management of their territory (Chapter 2 and 3).

Further research should explore the development and implementation of games and simulations for building joint views on resilience in social-ecological systems.

4 Case study

4.1 Case study selection

The empirical analysis of social-ecological change, presented in chapter 2, was based on a detailed study in one community, which was specifically selected for its history, location and pre-identified signs of adaptation to be the case study for chapter 2, 3 and 6 of this thesis. Consequently, data and processes described were highly site-specific, but allowed for some generalizable observations. The main drivers of land use change were all originated from global trends that affect many (smallholder) farming communities all over the globe, namely liberalization of economies and increasing claims for nature conservation (Kiers et al., 2008). Land-use change as a result of individual household responses to drivers was immediate (Figure 2.4). In contrast, social processes such as the development of social cohesion, social organization structures were slow (cf. Scheffer et al., 2003). The relatively short history of the selected community offered a unique opportunity to analyze the process of establishing a local society and its agricultural landscape from the start of the settlement, as a significant number of community members had vivid memories of the early phase of settlement.

4.2 Driver-response reconstruction

The development of a historical driver-response reconstruction allowed identifying the local perceptions of change and its drivers. The combination of first qualitative semi-structured interviews on change and its drivers, followed by surveys to collect detailed land-use change data allowed an open start of the interviews and allowed the interviewee to guide the interview on social organizational and land use change as viewed by the participant. For some participants, the broad questions on 'change' were difficult to grasp. Several of these farmer explained general changes in the community while recording their land-use decisions at plot level. Interviewing key non-local stakeholders and cross-checking field data with literature were important: (i) to confirm driver-response identified by local stakeholders, and (ii) to identify differences in perception on change and its drivers. Farmers' livelihoods were heavily affected by the impacts of globalization and international economic and institutional change (see Figure 2.1 and 2.3). However, they did not identify these changes as originating from global or international processes. Their view did generally not go beyond the level of the national government.

4.3 Communal decision-making

The formation of social organizational structures such as community management structures and producer groups (Chapter 2) was initially a prerequisite for the establishment of the *ejido* and the application of subsidy schemes. Many farmer were part of these groups. Network structure of these official groups was not linked to effective organization, collaboration or knowledge exchange (Chapter 2). The development of effective local organization was a slow process that started only when the livelihood strategies in the community were under severe pressure resulting from coinciding economic and institutional drivers (Chapter 2) (Scheffer et al., 2003). The development of effective community management was greatly facilitated by the support of a local NGO (Chapter 2). Preliminary results from agent-based simulation explorations, also showed that beneficial collaboration was only established when the system was under strong economic pressure (Chapter 6).

The functioning of these groups differed strongly. Results of a network analysis exercise on advice networks of livestock farmers which was not presented in this thesis, showed that farmers made use of very distinct advice networks to address problems related to e.g. grass production, stomach problems of livestock, problems related to the birth calves, etc. This study showed that the identification of formal and informal networks did not provide information on the functioning of these networks. Additional qualitative information was needed to assess the functioning of these networks.

Decentralization of power and responsibilities slowly improved communal decision-making processes since 2004 (Chapter 2). Nonetheless, a small pool of heads of households were responsible for decision-making roles in the community. These were all *ejidatarios* with average to larger landholdings. The growing group of non-*ejidatarios* and in particular landless were excluded from active participation in communal decision-making. Through intensive interactions with a large number of households, some worries and frustrations were heard from both non-*ejidatatios* as well as *ejidatarios*. In general, decentralization of communal decision-making and sustainable management of natural resources were strongly felt in the households with smaller landholdings and those who focused more on forest-based production systems.

During the game sessions presented in chapter 3, communal decision-making was analyzed in detail to identify influential factors and patterns. This exercise, led to the formulation of hypotheses on the positive influence of communication, trust and leadership on effective communal decision-making (**Figure 3.6**). It appeared extremely challenging to provide hard generalizable evidence on factors influencing communal decision-making due to the complex relationships between the participants, their status within the community and incidents that were hidden for the researchers. For example, in one of the sessions, some participants that were related through marriage seemed to ignore each other. Only after the workshop, the researchers heard that the couple had had marital problems and that the man had left his wife for another woman. In addition, non-verbal communication and processes such as imitation seemed to be an important feature, but very difficult to assess.

Future research could focus on exploring the link between formal and informal network structure and functioning and on testing the hypothesis on the effects of communication, trust and leadership on communal decision-making processes (as formulated in Chapter 3).

4.4 Stakeholder participation

The research presented in chapters 2 and 3 was based on data collected through surveys, interviews and participant observations during gaming workshops. Data were much strengthened by the approaches used from the field of cultural anthropology. I stayed in the community for prolonged periods of time between 2008 and 2011. During these stays, I actively participated in community life. I lived with one of the local households and visited all other households. Throughout my stays in the community, I was conscious of the potential influence of the presence of a researcher during stakeholder interactions (e.g. Villamor and van Noordwijk, 2011). I did not show any preference for specific groups within the community nor for a specific land-use type. All research activities were carried out with all groups of the local population and were of a neutral and descriptive nature. The research approach I used was essential to take away initial skepticism towards 'visitors'. The approach required substantial time investment and personal sacrifices, but it gave me the opportunity to build trust and confidence in the community and to better understand local life. This understanding greatly assisted me in assessing, analyzing and interpreting the data collected through interviews, surveys and gaming. To assess social processes and in particular social cohesion, it was important to talk to a variety of people in the community and not only to those involved in community management and producer groups. This research approach was essential for understanding the complexity of smallholder farmers in a contested agricultural landscape.

Despite the trust build with the community, problems were encountered during the initial phase of planning and performing of game sessions. Invited participants that previously confirmed their presence, failed to show up. It became clear that there was resistance of some social actors to participate or to fully display their views and interests in front of their peers. Dray et al. (2005), Barnaud et al. (2007), Becu et al. (2008) and Gourmelon et al. (2013) encountered similar problems in the planning of their role-playing experiments.

5 Conclusions

Concepts of resilience theory and in particular the concept of adaptive capacity were explored throughout this thesis and applied to contested agricultural landscapes, by means of innovative gaming and simulation methodologies to facilitate (social) learning related to these concepts. The complexity of multi-scale intersecting processes of economic, institutional, social and agricultural change resulting from globalization requires comprehensive integrated studies of these processes. The study was largely based on: 1) a comprehensive research in one community, which was specifically selected for its history, location and pre-identified signs of adaptation, and 2) a series of workshops in which distinct gaming and simulation tools were explored with a variety of stakeholders and students. The following conclusions can be drawn from this thesis:

- Current drivers of land-use change originate largely from (coinciding) global trends e.g. international market dynamics, nature conservation agenda, but have strong local implications.

- Strong local social organizations and institutions are key in improving adaptive capacity in complex social-ecological systems.

- Simple games can actively involve smallholders and other stakeholders in communal landscape planning processes.

- Innovative gaming and simulation methodologies facilitate (social) learning among stakeholders about ambiguous and not easily grasped concepts.

- Stakeholder's learning on concepts and processes that underlie the resilience of a system is essential in improving stakeholder's adaptive capacity to change.

- Both cognitive and social learning processes are needed to make improvements towards resilience of contested agricultural landscapes.

- Incorporating social-psychology in simulated land-use decision-making processes provides new insights on individual and collective behavior in social-ecological systems under pressure and allows for more realistic forward-looking explorations.

This thesis contributes to the emerging literature on the exploration and application of resilience thinking to contested agricultural landscapes by presenting empirical evidence on the development of adaptive capacity in a reserve community. In addition, methodological and empirical insights on the development and exploration of gaming and simulation tools to actively involve stakeholders in social learning processes on landscape planning are provided. The thesis proposed future lines of research to identify the diversity of views of stakeholders on system resilience and to address conflicting views of local and non-local stakeholders through gaming and simulation.

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Summaries

Summary

Over the past decades, smallholder farming communities have become increasingly affected by the (unexpected) impacts of globalization and economic and institutional change. Resilience thinking and complex adaptive systems theory provided new perspectives for analyzing processes of change in social-ecological systems such as smallholder agricultural landscapes. The capacity of agricultural communities to develop resilient systems and adapt to social-ecological change is key in securing the continuation of livelihoods in rural parts of the world. Improving the adaptive capacity of rural communities has been proposed as the largest challenge of the century, especially in contested areas were the interests of non-local stakeholders often strongly conflict with those of local communities. Against this background the objective of this thesis was to explore and apply concepts of resilience theory to contested agricultural landscapes in particular the concept of adaptive capacity, by means of innovative gaming and simulation methodologies to facilitate (social) learning related to these concepts. This thesis was based on 1) a comprehensive research in the usufruct community Tierra y Libertad (TyL) in the buffer zone of a Biosphere Reserve in Chiapas, Mexico. This community was specifically selected as a case study for this research for its history in the context of contested agricultural landscapes and pre-identified signs of adaptation, and 2) a series of workshops in which distinct gaming and simulation tools were explored with a variety of stakeholders and students. In this thesis, four gaming and/or simulation tools were developed and implemented to explore resilience and related concepts in contested agricultural landscapes and to assess their capacity as (social) learning tools towards more resilient agricultural landscapes.

In chapter 2, a comprehensive reconstruction of local land-use and social organizational change in TyL was developed. This detailed reconstruction identified that the main drivers of change originated from global change processes. These were: (1) Strong decrease in maize price due to the implementation of neoliberal policies and the ratification of North America Free Trade Agreement, and (2) Land-use limitations resulting from the establishment of the La Sepultura MAB reserve connected to the initiation of active nature conservation policies at the National level. Initial responses were identified as short-term coping mechanisms characterized by large-scale land conversions and temporary out-migration (between 1990 and 2000). Gradually coping mechanisms were replace by more sophisticated adaptation strategies based on e.g. improved social organization and land use diversification (1995-2010). The circumstances that allowed for the development of adaptation were the long-term support of a neutral agency that bridged the gap between

interests of the community and of non-local actors together with ample forest resources and a highly motivated community.

In chapter 3, a stylized yet complex land-use board game rich in ecological and social outcomes was developed to (i) actively involve farmers in the process of agroecosystem design, and (ii) to identify factors and patterns of communal decision-making through an in-depth analysis of game strategies deployed by participants. Results of four pilot sessions with the RESORTES board game in TyL showed that the game sessions actively involved participants in discussions on landscape planning in the game and in real-life. Participants especially appreciated that the game sessions facilitated the engagement of stakeholders that were new to active involvement in communal decision-making. It allowed participants to openly discuss and share their ideas. Results of an ex-ante/ex-post analysis identified communication, leadership and relatedness among participants as influential factors that smoothened the collective decision-making process in the four pilot sessions.

In chapter 4 and 5, two computer simulation tools were developed to facilitate (social) learning on concepts related to sustainable management for resilient multi-actor agricultural landscapes. The Agrodiversity v.2 model was developed to enable learning on the concept of functional agrodiversity (chapter 4). Users are challenged to explore ecological parameters of a small agroecosystem in a field with a perennial crop and design a productive sustainable system and experience that a proper balance between the co-existing species is necessary so that their ecological interactions allow the multi-species system to become self-organized and persist over time. More than a hundred university students in Mexico, Indonesia and the Netherlands, self-reported that they gained in-depth knowledge through exploring the model. An in-depth analysis on the effects of using Agrodiversity v.2 on actual learning was performed by comparing between the knowledge of students after a normal lecture and after an additional interactive session with the Agrodiversity v.2 model in a workshop with 24 students. Results showed that students increased the quality of their answers to paper-based individual questions on the topic from 29% to 86% after the simulation session. On average students stated to have learnt 55% of their current knowledge through the workshop of which 76% was learnt by using the simulation.

The program "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" was developed to enable learning on resilience thinking concepts such as stable and unstable equilibria, and non-linear responses (chapter 5). The program was developed as an interactive workshop for groups of participants in which participants learn through computer simulation explorations, role-play and negotiation sessions. In three acts, the participants take on different roles. participants take on the role of small-scale maize growers that face the need to intensify their production. Through computer simulations they explore the effects of nitrogen fertilizer application on their production, in act 1. In act 2, participants take on the role of rural families that live of tourism of a lake downhill from the maize farmers. They are confronted with lake eutrophication due to nitrogen fertilizer application of the maize growers. The participants explore the eutrophication process and the dynamics of the bi-stable lake ecosystem. In act 3, the group of participants is split to play out a group of farmers and lakeside households. They negotiate possible solutions using simulation explorations. Results from 12 workshops with the program were analysed and showed that participants improved their knowledge and understanding on the systems attributes: productivity, stability, resistance, resilience, reliability, adaptability and equity. In all workshops, participants managed to balance the biodiversity conservation and rural livelihood interests of all stakeholders involved through the development of creative solutions. Participants were challenged by concepts such as bi-stability, thresholds, risk, catastrophic shift, and hysteresis, but all stated that the program enabled them to learn about these concepts.

In chapter 6 the LUSES model and its first steps of development were presented. The LUSES model aimed to contribute to the growing literature on social-ecological systems modelling through the development of a ABM tool to analyze land-use dynamics in agricultural landscapes based on social-psychological theory on individual decision-making. A qualitative validation exercise between simulated and empirical data from the study area, the smallholder farming community Tierra y Libertad, in Chiapas, Mexico, showed that real-life farmers and farming agents responded in a qualitative similar manner to economic and institutional change. The simulated data suggested that agents increased the importance of satisfying the existence need, which relate to economic dimensions of existence, when systems were under economic pressure. Simulated price increases resulted in minor land use changes, whereas price decreases corresponded with larger land us change. Although this first exercise points to a need of further model development, the results obtained so far support the implementation of social-psychological theory in modelling land-use dynamics in agricultural landscapes. Decision-making processes based on social-psychological theory appear to be (more) suitable for exploring responses to unknown future changes than rule-based methods derived from past decisions.

Finally in chapter 7, the main findings of the thesis were discussed in a broader context of resilience of contested agriculture and tools to explore resilience and facilitate learning on resilience related concepts. This thesis contributed to the emerging literature on the exploration and application of resilience thinking to contested agricultural landscapes by presenting empirical evidence on the development of adaptive capacity in a reserve community. In addition, methodological and empirical insights on the development and exploration of gaming and simulation tools to actively involve stakeholders in social

learning processes on landscape planning are provided. This thesis proposed future lines of research to identify the diversity of views of stakeholders on system resilience and to address conflicting views of local and non-local stakeholders through gaming and simulation.

Samenvatting

In de laatste decennia, kleinschalige agrarische gemeenschappen zijn meer en meer beïnvloed door (onverwachte) effecten van globalisering en economische en institutionele veranderingen. Resilience thinking theory ("theorieën over veerkracht") en theorie over complexe adaptieve systemen geven nieuwe perspectieven voor het analyseren van veranderingsprocessen in sociaal-ecologische systemen zoals kleinschalige agrarische landschappen. De capaciteit van agrarische gemeenschappen om veerkrachtige systemen te ontwikkelen en om zich aan te passen aan sociaal-ecologische veranderingen is van essentieel belang voor het zekerstellen van de continuïteit van het leven in rurale gebieden overal in de wereld. Het verbeteren van het adaptieve vermogen van rurale gemeenschappen is genoemd als de grootste uitdaging van de eeuw, in het bijzonder in conflictgebieden waar de belangen van niet-lokale actoren vaak sterk conflicteren met die van lokale gemeenschappen. Tegen deze achtergrond is het doel van dit proefschrift geformuleerd als: het toepassen en onderzoeken van de concepten uit resilience theory in de context van agrarische conflictgebieden met in het bijzonder het concept van adaptief vermogen door middel van innovatieve spel en simulatie methoden om (sociaal) leren over deze concepten te stimuleren. Dit proefschrift is gebaseerd op 1) een uitgebreid onderzoek in de vruchtgebruik gemeenschap Tierra y Libertad (TyL) in de buffer-zone van een biosfeerreservaat in Chiapas, Mexico. Deze gemeenschap is speciaal geselecteerd as casus voor dit onderzoek voor zijn geschiedenis in de context van betwiste agrarische landschappen en vooraf geïdentificeerde tekenen van adaptatie en 2) een serie van workshops waarin verschillende spel en simulatie hulpmiddelen werden toegepast en onderzocht met verschillende actoren en studenten. In dit proefschrift, zijn vier spel en/of simulatie middelen ontwikkelend en geïmplementeerd om resilience en gerelateerde concepten in betwiste agrarische landschappen te onderzoeken en om de capaciteit van deze middelen voor het faciliteren van (sociaal) leren vast te stellen.

In hoofdstuk 2, is een uitgebreide reconstructie van de lokale veranderingen in landgebruik en sociale organisatorische in TyL ontwikkeld. Deze gedetailleerde reconstructie stelde vast dat de belangrijkste drijfveren voor verandering afkomstig waren uit mondiale veranderingsprocessen. Deze waren: (1) Sterke afname in maïsprijs als gevolg van de invoering van het neoliberale beleid en de ratificatie van Noord-Amerika Vrijhandelsovereenkomst en (2) Landgebruiksbeperkingen door de oprichting van de La Sepultura MAB reservaat dat voortvloeide uit de start van een actief beleid natuurbehoud op nationaal niveau. Eerste reacties op deze externe drijfveren werden geïdentificeerd als korte-termijn coping-mechanismen gekenmerkt door grootschalige land-conversies en tijdelijke emigratie (tussen 1990 en 2000). Geleidelijk werden deze coping-mechanismen vervangen door meer geavanceerde adaptatiestrategieën op basis van bijvoorbeeld verbeterde sociale organisatie en landgebruiksdiversificatie (1995-2010). De omstandigheden die de ontwikkeling van adaptatiestrategieën toestonden waren de langdurige ondersteuning van een neutrale organisatie die de kloof tussen de belangen van de gemeenschap en die van niet-lokale actoren overbrugde in combinatie met natuurlijke hulpbronnen met name bos en een strek gemotiveerde gemeenschap.

In hoofdstuk 3, is een gestileerd maar complex landgebruiksbordspel rijk aan ecologische en sociale uitkomsten ontwikkeld om (i) boeren actief te betrekken bij het ontwerpproces voor landbouwecosystemen, en (ii) factoren en patronen van gemeenschappelijke besluitvorming te identificeren door middel van een diepgaande analyse van spelstrategieën van de deelnemers. Resultaten van vier pilot-sessies met het Resortes bordspel in TyL toonden aan dat de spelsessies deelnemers actief betrok aan discussies over landschapsplanning in het spel en in het echte leven. De deelnemers waardeerden in het bijzonder dat de spelsessies de deelname van actoren nieuw in actieve participatie in gemeenschappelijke besluitvorming vergemakkelijkte. De spelsessies creëerden een sfeer waarin de deelnemers openlijk hun ideeën konden bespreken en delen. Resultaten van ex-ante/ex-post analyse hebben de factoren communicatie, leiderschap en verwantschap tussen deelnemers, geïdentificeerd als invloedrijke factoren die de collectieve besluitvorming bespoedigden in de vier pilot-sessies.

In hoofdstuk 4 en 5 zijn twee computersimulatie methoden ontwikkeld voor het stimuleren van (sociaal) leren over concepten gerelateerd aan duurzaam beheer van veerkrachtige multi-actor agrarische landschappen. Het Agrodiversity v.2 model is ontwikkeld om het leren over het concept functionele agrodiversiteit (hoofdstuk 4) te faciliteren. Gebruikers worden uitgedaagd om ecologische parameters van een klein landbouwecosysteem met een meerjarig gewas te verkennen en om een duurzaam en productief systeem te ontwerpen en te ervaren dat een goede balans tussen de samenlevende soorten nodig is zodat de hun ecologische interacties het multi-species systeem zichzelf laat organiseren. Meer dan honderd studenten in Mexico, Indonesië en Nederland, hebben gerapporteerd dat zij diepgaande kennis hebben opgedaan door middel van het verkennen van het model. Een uitvoerige analyse van de effecten van het gebruik van Agrodiversiteit v.2 op het werkelijke leren, is uitgevoerd door het vergelijken van de kennis van de studenten na een normale lezing en na een extra interactieve sessie met het Agrodiversiteit v.2 model in een workshop met 24 studenten. Resultaten toonden aan dat de studenten de kwaliteit van hun antwoorden op papier gebaseerde individuele vragen op het onderwerp verbeterden van 29% voor tot 86 % na de simulatie sessie. Gemiddeld verklaarden studenten 55% van hun huidige kennis te hebben geleerd door de workshop waarvan 76 % werd geleerd met behulp van de simulatie.

Het programma "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" is ontwikkeld om het leren over concepten gerelateerd aan resilience theory zoals stabiele en instabiele evenwichten en niet-lineaire reacties te faciliteren (hoofdstuk 5). Het programma is ontwikkeld als een interactieve workshop voor groepen die door middel van computersimulaties, rollenspel en onderhandelingssessies leren. In drie bedrijven nemen de workshopparticipanten verschillende rollen aan. In het eerste bedrijf nemen de participanten de rol van kleinschalige maïstelers aan die worden geconfronteerd met de noodzaak om hun productie te intensiveren. Via computersimulaties verkennen ze de effecten van stikstofbemesting op hun productie. In het tweede bedrijf nemen de deelnemers de rol van gezinnen die leven van het toerisme van een meer bergafwaarts vanaf de maïsboeren aan. Ze worden geconfronteerd met eutrofiëring van het meer als gevolg van stikstofkunstmest door de maïsboeren. De deelnemers verkennen de eutrofiëring van het meer en de dynamiek van het bi-stabiele ecosysteem van het meer. In het derde bedrijf wordt de groep deelnemers gesplitst om de rol van maïsboeren en gezinnen die leven van het toerisme uit te spelen. Samen onderhandelen ze over mogelijke oplossingen met behulp van simulatie verkenningen. Resultaten van 12 workshops met het programma werden geanalyseerd en toonden aan dat de deelnemers hun kennis en inzicht op de systemen attributen: productiviteit, stabiliteit, weerstand, veerkracht, betrouwbaarheid, flexibiliteit en gelijkheid verbeterden. In alle workshops slaagden de deelnemers erin om een balans te vinden tussen het behoud van biodiversiteit en de belangen van alle stakeholders te bereiken door middel van het ontwikkelen van creatieve oplossingen. Deelnemers werden uitgedaagd door concepten zoals bi-stabiliteit, drempelwaardes, risico, katastrofische veranderingen, en hysteresis; allen verklaarden dat het programma hen in staat stelde om te leren over deze concepten .

In hoofdstuk 6 is het LUSES model en de eerste stappen van de ontwikkeling van dit model gepresenteerd. Het LUSES model poogt bij te dragen aan de groeiende literatuur over het modelleren van sociaal-ecologische systemen door de ontwikkeling van een ABM instrument om de dynamiek van landgebruik in agrarische landschappen op basis van sociaal-psychologische theorie over individuele besluitvorming te analyseren. Een kwalitatieve validatie tussen de gesimuleerde en empirische gegevens van het studiegebied, de kleinschalige agrarische gemeenschap Tierra y Libertad, in Chiapas, Mexico, toonde aan dat echte boeren en gesimuleerde agenten op een kwalitatieve vergelijkbare wijze op economische en institutionele veranderingen reageerden. De gesimuleerde data suggereerden dat agenten het belang van het voldoen aan de bestaansbehoefte die gerelateerd is aan de economische dimensies van bestaan, verhoogden wanneer systemen onder economische druk stonden. Gesimuleerde prijsstijgingen resulteerden in kleine landgebruiksveranderingen, terwijl prijsdalingen overeenkwamen met grotere landgebruiksveranderingen. Hoewel deze eerste oefening wijst op een behoefte aan verdere ontwikkeling van het model, ondersteunen de tot nu toe behaalde resultaten de toepassing van sociaal-psychologische theorie in het modelleren van landgebruiksdynamiek in agrarische landschappen. Besluitvormingsprocessen op basis van sociaal-psychologische theorie lijken geschikt(er) voor het verkennen van reacties op onbekende toekomstige veranderingen dan op regels gebaseerde methoden afgeleid van beslissingen uit het verleden te zijn.

Tenslotte in hoofdstuk 7 worden de belangrijkste bevindingen van dit proefschrift besproken in een bredere context van resilience in betwistte agrarische gebieden en middelen die het leren van resilience gerelateerde concepten faciliteren. Dit proefschrift draagt bij aan de opkomende literatuur over de verkenning en de toepassing van resilience thinking in betwiste agrarische landschappen door de presentatie van empirische gegevens over de ontwikkeling van adaptief vermogen bij een reservaatgemeenschap. Bovendien geeft dit proefschrift methodologische en empirische inzichten voor de ontwikkeling van spel en simulatie instrumenten om stakeholders actief te betrekken in sociale leerprocessen voor landschapsplanning. Dit proefschrift doet voorstellen voor toekomstige onderzoekslijnen om de diversiteit van standpunten van stakeholders over de resilience van system te identificeren en om tegenstrijdige standpunten van lokale en niet-lokale actoren via spel en simulatie te bespreken.

Resumen

Durante las últimas décadas, las comunidades de pequeños productores rurales han sido muy afectadas por los (inesperados) impactos de la globalización así como por cambios económicos e institucionales. El concepto de resiliencia y la teoría de sistemas adaptativos complejos brindan nuevas perspectivas para el análisis de procesos de cambio en sistemas socio-ecológicos como son los territorios de pequeños productores rurales. La capacidad de las comunidades agrícolas de desarrollar sistemas resilientes y adaptarse a cambios socio-ecológicos es un elemento clave para asegurar la continuidad de los productores de subsistencia en varias partes del mundo. La mejora en la capacidad de adaptación de comunidades rurales ha sido propuesta como el mayor desafío del siglo, especialmente en regiones donde existe disputa entre los intereses de los actores externos y las comunidades locales generándose conflictos muy fuertes. Considerando estos antecedentes, el objetivo de esta tesis fue explorar y aplicar conceptos de la teoría de resiliencia en territorios rurales donde hay disputas sobre el uso de la tierra, en particular el concepto de capacidad adaptativa, mediante la aplicación de juegos innovadores y metodologías de simulación para facilitar el aprendizaje (social) relacionado a estos conceptos. Esta tesis se basó en 1) un estudio exhaustivo en la comunidad en usufructo Tierra y Libertad (TyL) en la zona buffer de una Reserva de Biosfera en Chiapas, México. Esta comunidad fue específicamente seleccionada como estudio de caso para este trabajo, por sus antecedentes en el contexto de situaciones de disputa de tierra, y por una pre-identificación de adaptación a los mismos, y 2) una serie de talleres en los cuales diferentes herramientas de juego y simulación fueron exploradas con diversos tomadores de decisiones y estudiantes. En esta tesis, cuatro herramientas de juego y/o simulación fueron desarrolladas e implementadas para explorar la resiliencia y conceptos relacionados a la misma, en territorios rurales donde existe disputa por los recursos, y evaluar su capacidad como herramientas de aprendizaje (social) para mejorar la resiliencia en territorios rurales. En el capítulo 2, se desarrolló una reconstrucción exhaustiva del uso de la tierra a nivel local y cambios organizacionales en TyL. Esta reconstrucción detallada permitió identificar los principales factores de cambio originados por procesos de cambios globales. Los mismos fueron: (1) Una gran disminución de los precios de maíz debido a la implementación de políticas neo-liberales y la ratificación del Tratado de Libre Comercio de América del Norte, y (2) Limitaciones en el uso de la tierra por el establecimiento de la reserva La Sepultura MAB conectada con la iniciación activa de políticas de conservación del medio ambiente establecidas a nivel Nacional. La conversión de tierra a gran escala y la migración temporal (entre 1990 y 2000) fueron identificadas como respuestas iniciales para hacer frente a esta situación. En forma

gradual, los mecanismos para intentar superar esa realidad, fueron reemplazados por estrategias de adaptación más sofisticadas basadas en una mejora en la organización social y en la diversificación del uso de la tierra (1995-2010).

Los factores que permitieron el desarrollo de la adaptación fueron el apoyo a largo plazo de una agencia neutral, que disminuía las diferencias existentes entre la comunidad y los actores no locales, junto con amplios recursos forestales y una comunidad altamente motivada. En el capítulo 3, se desarrollo un juego práctico y complejo sobre uso de la tierra, con diversos resultados que consideraron aspectos ecológicos y sociales para (i) involucrar activamente a los productores en el proceso de diseño de agro-ecosistemas, y (ii) identificar factores y patrones de toma de decisiones mediante un análisis en profundidad de las estrategias de juego desarrolladas por los participantes. Los resultados de las cuatro sesiones piloto utilizando el juego RESORTES en TyL mostraron que la aplicación del mismo logró involucrar a los participantes en la discusión de la planificación del territorio en el juego y en la vida real.

Los participantes apreciaron especialmente, que la sesión de juegos facilitaba el compromiso de los actores nuevos a un activo involucramiento en la toma de decisiones de la comunidad. Esto permitió a los participantes una discusión abierta y un intercambio de ideas. El resultado de un análisis ex-ante/ex-post identifico a la comunicación, el liderazgo y la vinculación entre los participantes como factores que influenciaron y permitieron mejorar el proceso de toma de decisiones colectivo en las cuatro sesiones piloto. En el capítulo 4 y 5, dos herramientas de simulación fueron desarrolladas para facilitar el aprendizaje (social) en conceptos relacionados con manejo sustentable de territorios rurales resilientes, en los cuales varios actores con diferentes intereses están involucrados. El modelo Agrodiversity v.2 fue desarrollado para permitir el aprendizaje del concepto de agro-diversidad funcional (capítulo 4). Los usuarios son desafiados a explorar parámetros ecológicos en agroecosistemas pequeños con un cultivo perenne, y a diseñar un sistema de producción sostenible, de manera de poder experimentar que un balance adecuado entre las especies co-existentes es necesario, y que sus interacciones ecológicas deben permitir a un sistema multi-especie, transformarse en un sistema auto organizado, pasible de persistir en el tiempo. Más de 100 estudiantes universitarios de México, Indonesia y Holanda, auto-reportaron que mejoraron su conocimiento en profundidad explorando el modelo. En un taller con 24 estudiantes fue realizado un análisis en profundidad sobre los efectos del uso de Agrodiversity v.2 en el conocimiento actual, comparando el conocimiento de los estudiantes después de una clase normal y después de una sesión interactiva adicional con el modelo Agrodiversity v.2. Los resultados de un cuestionario individual escrito mostraron que los estudiantes aumentaron la calidad de sus respuestas en el tema de 29% a 86% después de la sesión de simulación. Los estudiantes manifestaron haber aprendido, en promedio, 55% de su conocimiento inicial debido al taller, en el cual el 76% fue aprendido por el uso de la simulación. El programa "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" fue desarrollado para permitir un aprendizaje sobre el concepto de resiliencia así como de equilibrio estable e inestable y respuestas no lineales (capítulo 5). El programa fue desarrollado para que grupos de participantes realizaran exploraciones de simulación con computadoras, juego de roles y sesiones de negociación en un taller interactivo. En tres actos, los participantes tomaron el rol de productores pequeños de maíz que tenían la necesidad de intensificar su producción. En el acto 1 , mediante el uso de simulaciones de computación, exploraron los efectos de la aplicación de fertilizante nitrogenado en su producción. En el acto 2, los participantes tomaron el rol de familias rurales que viven del turismo, y están ubicadas en un lago abajo de las montañas donde los productores plantan maíz. Estas familias presentaban problemas de eutrofización del lago debido a la aplicación de fertilizante nitrogenado por parte de los productores de maíz. Los participantes exploraron el proceso de eutrofización y las dinámicas de ecosistemas estables del lago. En el acto 3, el grupo de participantes fue dividido para representar grupos de productores y grupos de familias dueñas del lago. Ellos negociaron posibles soluciones mediante el uso de las exploraciones de la simulación. Los resultados de los 12 talleres con el programa fueron analizados, mostrando que los participantes mejoraron su conocimiento y entendimiento sobre los atributos de los sistemas: productividad, estabilidad, resistencia, resiliencia, confiabilidad, adaptabilidad y equidad. En todos los talleres, los participantes manejaron el balance entre la conservación de la biodiversidad y los intereses de sustento rural de todos los actores involucrados, mediante el desarrollo de soluciones creativas. Los participantes fueron desafiados por conceptos como el de bi-estabilidad, umbrales, riesgo, cambio catastrófico e histéresis, mencionando todos que el programa les permito aprender sobre esos conceptos. En el capítulo 6, fue presentado el modelo LUSES y su primer paso de desarrollo. El modelo LUSES tiene como objetivo contribuir con la literatura emergente en sistemas socio-ecológicos, mediante el desarrollo de un sistema multi-agente, que permite analizar dinámicas en el uso de la tierra en territorios agrícolas basado en la teoría socio-psicológica de toma de decisiones individual. Un ejercicio de validación cualitativo entre datos simulados y empíricos del área de estudio, la comunidad rural Tierra y Libertad, en Chiapas, México, mostro que los productores y los agentes externos tienen una respuesta similar en términos cualitativos a los cambios económicos e institucionales. Los datos simulados sugirieron que los agentes aumentaron la importancia de satisfacer las necesidades existentes, las cuales se relacionan con la dimensión económica, cuando los sistema están bajo presión económica. El aumento del precio simulado resultó en menores cambios en el uso de la tierra, mientras que la disminución del mismo produjo mayores cambios en el uso de la tierra. A pesar de que este primer ejercicio arrojo la necesidad de un desarrollo más exhaustivo del modelo, los resultados obtenidos demostraron que es necesario implementar la teoría socio-psicológica cuando se modelan las dinámicas de uso de la tierra en territorios rurales. Los procesos de toma de decisión basados en la teoría socio-psicológica resultarían (más) adecuadas para explorar respuestas en cambios futuros desconocidos que aquellos basados en reglas derivadas de decisiones pasadas. Finalmente, en el capítulo 7, se presentan y se discuten los principales resultados de la tesis, considerando un concepto amplio de resiliencia en el contexto de disputa de territorios agrícolas, y herramientas para explorar resiliencia y facilitar el aprendizaje de conceptos relacionados con la misma. Esta tesis contribuyo con la literatura emergente en la exploración y aplicación del concepto de resiliencia, pensado en un contexto de disputa de territorios rurales, presentando evidencia empírica en el desarrollo de la capacidad adaptativa en una comunidad reservada. Asimismo, provee de conocimiento metodológico y empírico en el desarrollo y exploración de juegos y herramientas de simulación para el activo involucramiento de actores en los procesos de aprendizaje social en planificación de territorios. Esta tesis propuso líneas futuras de investigación para identificar los diferentes puntos de vista de distintos actores en la resiliencia de un sistema y abordar visiones conflictivas en actores locales y externos mediante juego y simulación.

Riepilogo

Durante le ultime decadi, le piccole comunità agricole sono state soggette sempre più (inaspettatamente) agli impatti della globalizzazione e ai cambiamenti istituzionali e economici. Resilience thinking e complex adaptive systems theory hanno fornito nuove prospettive per analizzare i processi di cambiamento nei sistemi socio-ecologici come, ad esempio, nei paesaggi delle piccole comunità agricole. La capacità delle comunità agricole di sviluppare sistemi resilienti e adattarsi ai cambiamenti ecologici è la chiave nell'assicurare la sussistenza nelle parti rurali del mondo. Il miglioramento delle capacità adattative delle comunità rurali è stato proposto come la più grande sfida del secolo, specialmente all'interno delle area contese dove spesso gli interessi delle diverse parti (non locali) interessate entrano in conflitto con quelli delle comunità locali.

L'obiettivo di questa tesi è stato quello di esplorare e applicare i concetti di resilienza a paesaggi agricoli contesi e più in particolare il concetto di capacità adattativa tramite l'utilizzo di giochi innovativi e metodologie simulate, per facilitare l'apprendimento (sociale) di tali concetti. Questa tesi si è basata su 1) una esaustiva ricerca della comunità usufruttuaria di Tierra y Libertad (TyL) all'interno della zona di transizione di un Riserva in Chiapas, Mexico. Questa comunità è stata specificamente selezionata come area di studio per questa ricerca per la sua storia nel contesto di paesaggi agricoli contestati e per i primi segni di adattamento, e 2) una serie di attività in cui specifici giochi e /o strumenti simulativi sono stati sviluppati e implementati per esplorare il concetto di resilienza all'interno di paesaggi agricoli contestati e per attestare le loro potenzialità come strumenti di apprendimento (sociale) verso un paesaggio agricolo più resilente.

Nel capitolo 2 vengono descritti i cambiamenti socio-organizzativi e di uso differente del suolo in TyL. Queta dettagliata ricostruzione ha identificato che i principali fattori di cambiamento furono originati da processi globalli. Questi furono: (1) Forte decremento nel prezzo del mais legato all`instaurarsi di politiche neoliberali e dalla ratificazione del North America Free Trade Agreement, e (2) limitazioni nell`uso del suolo legate alla creazione della riserva La Sepultura MAB connessa all`instaurarsi di politiche di conservazione a livello Nazionale. Le risposte iniziali sono state identificate come meccanismi adattativi a breve termine caratterizzati da cambiamenti del suolo a larga scala e temporanea migrazione (tra il 1990 e 2000). Gradualmente i meccanismi adattativi furono rimpiazzati da più sofisticate strategie di adattamento come, ad esempio, migliore organizzazione sociale e diversificazione nell`uso del suolo (1995-2010). Le circostanze che permisero lo sviluppo di tali strategie furono permesse grazie al supporto a lungo termine di agenzie neutrali che colmarono il vuoto tra interessi della comunita e attori non locali assieme con le ampie risorse ferestali disponibili e ad una communità molto motivata.

Nel capitolo 3, e` stato sviluppato uno stilizzato ma, allo stesso tempo, complesso gioco da tavola socio-ecologico con l`intenzione di (i) coinvolgere attivamente i contadini nel processo di delineare un sistema agroecologico, e (ii) identificare i fattori delle scelte della comunità attraverso una dettagliata analisi delle strategia di gioco utilizzata dai parteciapanti. I risultati delle quattro sessioni pilota tramite il gioco da tavola RESORTES in TyL hanno mostrato che le sessioni di gioco hanno attivamente incentivato i partecipanti a discutere la pianificazione del paesaggio sia nel gioco e sia nella vita reale. I partecipanti hanno apprezzato specialmente che le sessioni di gioco hanno facilitato il coinvolgimento dei nuovi stakeholders nel processo di decisioni. Il gioco ha permesso ai partecipanti di discutere apertamente e condividere le propire idee. I risultati di una pre- e post-analisi hanno identificato la communicazione, leadership e i legami parentali come i fattori più influenti nel processo di gestione dei processi decisionali collettivi.

Nel capitolo 4 e 5, due simulazioni (computer based) sono state sviluppate allo scopo di facilitare l`apprendimento (sociale) di concetti legati alla gestione sostenibile all`interno di paesaggi agricoli. Il modello Agrodiversity v.2 e` stato sviluppato per permettere l`apprendimento di concetti come quello di agrodiversitá multifunzionale (capitolo 4). I giocatori sono stati invitati ad esplorare i parametri ecologici di un piccolo agrosistema in un campo coltivato con raccolto perenne e disegnare un sistema produttivo sostenibile sperimentando che solamente tramite un corretto bilanciamento tra le specie esistenti è possibile che le interazioni ecologiche permettano al sistema di auto-organizzarsi e persistere nel tempo. Piu di un centinaio di studenti in Messico, Indonesia e Olanda hanno commentato di aver appreso conoscenze dettagliate tramite l`utilizzo del modello. Una analisi approfondita degli effetti dell`uso di Agrodiversity v.2 sull`attuale apprendimento e` stata fatta paragonando la conoscenza di 24 studenti a seguito di una normale lezione e di una interattiva. I risultati hanno mostrato che gli studenti hanno aumentato la qualità delle proprie risposte su un questionario dal 29% al 86% dopo la siulazione. In media gli studenti hanno ammesso di aver appreso il 55% delle proprie conoscenze tramite il workshop di cui il 76% tramite l`uso della simulazione.

Il programma "Negotiated Design of Sustainable Production Systems among Social Agents with Conflicting Interests" fu sviluppato per permettere l`apprendimento dei concetti di resilience thinking in condizioni stabili e non-stabili (capitolo 5). Il programma fu sviluppato come workshop interattivo utilizzando strumenti come similazioni (computer based), giochi di ruolo e sessioni di negoziazione. Inizialmente, i partecipanti prendono il ruolo di piccolo agricoltori di mais che affrontano il bisogno di intensificare la loro produzione (fase 1). Attreverso la simulzione i partecipanti esplorarno gli effetti nell`applicare nitrogeno come fertilizzante sui loro prodotti. Nella fase 2, I partecipanti impersonificano il ruolo di famiglie rurali che vivono di turismo alla prossimita di un lago alle pendici di coltivatori di mais. I partecipanti si confrontano con i processi di eutrofizzazione legati agli effetti dell`uso di fertilizzanti da parte dei coltivatori di mais. I partecipanti esplorano i processi di eutrofizzazione e delle dinamiche di un sistema stabile a due componenti. Nella fase 3, il gruppo di partecipanti è diviso in due gruppi ad impersonificare un gruppo di abitanti nelle prossimita di un lago e di un secondo di coltivatori. Assieme negoziano possibili soluzioni usando il programma di simulazione. I risultati dei 12 workshop sono stati analizzati e hanno mostrato che i partecipanti hanno migliorato la loro conoscenza sugli attributi di un sistema come: produttività, stabilita`, resistenza, resilienza, affidabilità, adattabilità e equità. In ogni workshop, i partecipanti sono riusciti a bilanciare la conservazione della biodiversità e gli interessi delle popolazione rurali attraverso lo sviluppo di soluzioni creative. I partecipanti si sono confrontati con concetti come stabilità bidimensionale, limite, rischio, cambiamento catastrofico, e isterisi, ma tutti hanno dichiarato che il programma ha permesso di apprendere tali concetti.

Nel capitolo 6 e` presentato il modello LUSES e i suoi primi sviluppi. Il modello LUSES intende contribuire alla crescente letteratura sui sistema socio-ecologici tramite l`utilizzo di ABM per analizzare le dinamiche di sviluippoo del suolo in paesaggi agricoli basato su teorie socio-psicologiche. Una conferma qualitativa tra i dati simulati ed empirici raccolti all`interno dell`area di studio, la piccola comunità terriera di Tierra y Libertad, in Chiaps, Mexico, ha mostrato che i contandini e gli agenti del modello hanno risposto qualitativamente in maniera simile ai cambiamenti economici e istituzionali. I dati ottenuti dalla simulazione suggeriscono che gli agenti hanno soddisfatto maggiormente i bisogni esistenziali quando i sistemi erano sotto una pressione economica. Un incremento dei prezzi ha risultato in un minimo cambiamento nell`uso del suolo, dove invece un decremento dei prezzi ha generato vasti cambiamenti. Sebbene il modello debba essere ancora sviluppato nel futuro, i isultati ottenuti fino a questo punto supportano l`implementazione delle teorie socio-psicologiche nella gestione dell`uso del suolo all`interno di paesaggi agricoli. I processi di decisione basati su processi socio-psicologici sembrano maggiormente adatti per esplorare le risposte a futuri cambiamenti ignoti rispetto a metodi basati comoparando decisioni precedenti.

All`interno dell`utltimo capitolo (7), i principali risultati di questa tesi sono stati discussi in un contesto più ampio di resilienza in aree agricole contestate e di strumenti per facilitare l`apprendimento sui concetti di resilienza. Questa tesi contribuisce all`emergente letteratura sull`applicazione e esplorazione dei concetti di resilienza presentando evidenze empiriche sullo sviluppo di capacita adattative all`interno di una communità locata all`interno di una riserva. In aggiunta, sono fornite metodologie empiriche per lo sviluppo di strumenti di gioco e di simulazionme allo scopo di coinvolgere attivamente gli stakeholders nel processo di apprendimento sociale sulla pianificazione paesaggistica. Questa tesi propone future linee di ricerca per sottolineare le diversità dei punti di vista dei diversi stakeholders su sistemi di resilienza e tramite l`uso di giochi e simulazione.

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Early 2006, I developed the first ideas for a PhD research of which many made it into this thesis. I would like to use the last words of this thesis to thank and acknowledge the many people that helped, motivated, assisted and supported me to do the work.

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About the author

Erika Speelman was born on the 13th of September, 1979 in Wedde, in the northeast of Groningen, the Netherlands. She grew up on the arable farm of her parents together with two big sisters. Erika received secondary education at the Dollard College in Winschoten. In 1997, she worked and travelled for a little over a year in Spain, Australia, New-Zealand, and South-East Asia.

Inspired by the agricultural and natural systems encountered during her travels she enrolled at the University of Groningen to study Biology, in 1998. In 1999, her interest in agricultural systems led her to Wageningen, where she enrolled in the BSc/MSc program Tropical Land Use at Wageningen University. During her studies, Erika's interests in agricultural systems grew increasingly more interdisciplinary. In 2001-2002, she was an intern at the Chinese Academy of Sciences in Beijing for 8 months where she explored maize growth in the North China Plain through the WOFOST model. Her major MSc thesis (2004) focused on multi-level sustainability evaluation with a case study in the Purhepecha Region, Mexico in collaboration with the local NGO GIRA A.C. Erika performed a minor MSc thesis on the innovation behavior of farmers in Central and Southern Ethiopia for the International Center for Tropical Agriculture (CIAT) in 2005. Erika graduated from Wageningen University with a specialization in Plant Production Systems in 2005.

After graduation, she was offered a to return to Mexico to join the MESMIS team as a junior researcher at GIRA A.C. in Pátzcuaro, Michoacán, and later at el Colegio de la Frontera Sur (ECOSUR) in San Cristóbal de las Casas, Chiapas. Here, she worked on sustainability evaluation of small-scale farming systems, and the development and implementation of educational simulation tools to improve these systems. In 2006-2007, Erika worked as an Associate Expert at UNESCAP-CAPSA, Bogor, Indonesia, where, she was part of several research projects on the development of secondary crops and the dissemination of agricultural information to partner organizations in the region. She continued to collaborate within several MESMIS projects. In early 2008, she returned to Mexico for further develop interactive simulation games.

In September 2008, Erika started her PhD project at the Farming Systems Ecology group (formerly Biological Farming Systems) at Wageningen University of which this thesis is the result.

Since February 2014, Erika has been employed as a postdoctoral researcher at the same group. Erika shares her life with Valerio Minorenti and their daughter Chiara.

List of publications

Journal articles

Speelman, E.N., Groot, J.C.J., García-Barrios, L.E., Kok, K., van Keulen, H., Tittonell, P., under review. From coping to adaptation to economic and 1 institutional change – Trajectories of change in land-use management and social organization in a Biosphere Reserve community, Mexico. Land Use Policy

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Speelman, E.N., W. Jager, J.C.J. Groot, L.E. García-Barrios, P. Tittonell, 2012. Multi-level simulation of farmers decision-making on land use and social organization; an agent-based approach. In: Koch, A., Mandl, P. (Eds.) Modeling social phenomena in spatial context, 8th Conference of the European Social Simulation Association (ESSA 2012), 10-14 September 2012, Salzburg, Austria, 63-69.

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PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)
- Modelling of social-ecological systems: a review

Writing of project proposal (4.5 ECTS)
- Flows of matter, energy and information in social-ecological networks – the role of multi-scale governance in dairy agro-ecosystems

Post-graduate courses (5 ECTS)
- Scaling and governance; WU (2009)
- ISAGA Summer school; ISAGA (2009)
- Sampling in space and time for survey and monitoring of natural resources; WU (2013)

Invited review of (unpublished) journal manuscript (2 ECTS)
- Ecology and Society: resilience of organically managed cocoa farming systems in Bolivia (2013)
- Agricultural systems: transition from conventional to organically managed vineyards (2013)

Competence strengthening / skills courses (3.3 ECTS)
- Interpersonal communication for PhD students; WGS-WU (2008)
- Scientific publishing; WGS-WU (2008)
- PhD Competence assessment; WGS-WU (2008)
- The art of writing; CENTA-WU (2009)
- Information literacy, including introduction endnote; Library-WU (2010)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.8 ECTS)
- PE&RC Weekend (2008)
- PE&RC Day (2008, 2011 and 2012)

Discussion groups / local seminars / other scientific meetings (4.2 ECTS)

- Discussion group: Stakeholder Participation in Scientific research (2008-2010)
- Seminar: SAGA-Net "Meten is weten" (2010)
- Workshop: ESSA@ work (2012)
- Seminar: Contested Agronomy (2013)
- Seminar: Validation of Agent-based Land use models (2013)
- Discussion group: Sustainable Intensification of Agricultural Systems (2013)

International symposia, workshops and conferences (8.9 ECTS)

- Integrated Assessment of Agriculture and Sustainable Development: Setting the Agenda for Science and Policy; Egmond aan Zee, the Netherlands (2010)
- Scaling and Governance Conference; Wageningen, the Netherlands (2010)
- The 8th Conference of the European Social Simulation Association; Salzburg, Austria (2012)
- The 9th Conference of the European Social Simulation Association; Warsaw, Poland (2013)

Lecturing / supervision of practical's / tutorials (3 ECTS)

- Systems analysis, simulation and systems management (2011, 2012 and 2013)

Supervision of MSc students (3 ECTS)

- Toupet, A.L., 2009. Mapping social-ecological systems to identify key areas and stakeholders in processes of change in natural resource management. A case study on soil erosion and cattle grazing in the ejido "Tierra y Libertad", Chiapas, Mexico.
- Kawai, A., 2011. Farmers' entrepreneurial orientation, sensitivity to subjective norm, and land use change: The case in a small scale farming community "Tierra y Libertad," Chiapas, Mexico

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