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Présentée par **Arthur Perrotton**

Conduite du bétail et coexistence entre les aires protégées et leurs périphéries :

Une approche participative

Cattle Herding and coexistence between protected areas and their peripheries:

A participatory approach

Soutenue le 17 Décembre 2015 devant le jury composé de

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A mon grand-père,

“Tu vois ce pré ?”

Avant-Propos / Foreword

Cette thèse a été effectuée dans le cadre du projet SAVARID[1] financé par l'Agence Nationale de la Recherche (ANR) et la plateforme de recherche "Produire et Conserver en Partenariat " (RP-PCP) qui associe au Zimbabwe le CIRAD, le CNRS, l'Université du Zimbabwe (UZ, Harare) et l'Université Nationale des Sciences et Technologies (NUST, Bulawayo). Durant les deux années de travail de terrain, nous avons eu l'honneur d'être affilié au Centre de Science Sociales Appliquées de l'Université du Zimbabwe (CASS). La conduite de ce travail a également été rendue possible par le projet HERD (Hwange Environmental Research Development) et des chercheurs du CIRAD, du CNRS et de différentes universités européennes qui ont étudié les dynamiques écologiques dans et autour du Parc National de Hwange depuis plus de dix ans. Afin de faciliter la restitution aux partenaires locaux, ce manuscrit a été rédigé en anglais.

This PhD was conducted under the SAVARID project[2] funded by the French National Research Agency (ANR), and the research platform "Produce and Conserve in Partnership" (RP-PCP) that involved the CIRAD, the CNRS, the University of Zimbabwe (UZ, Harare) and the National University of Science and Technology (NUST, Bulawayo). During the two years spent in Zimbabwe for fieldwork, we had the honor of being affiliated to the Center for Applied Social Sciences of the University of Harare (CASS). We also beneficiated from the support of the HERD project (Hwange Environmental Research Development) and of the researchers from CNRS, CIRAD and several European universities that have been working for more than a decade with the objective of better understanding ecological dynamics in and around Hwange National Park. In order to ease the restitution of this work to Zimbabwean partners, this PhD thesis is written in English.

[1] http://www.agence-nationale-recherche.fr/suivi-bilan/editions-2013-et-anterieures/environnement-et-ressources-biologiques/societes-et-changements-environnementaux/fiche-projet-cep-s/?tx_lwmsuivibilan_pi2[CODE]=ANR-11-CEPL-0003

[2] http://www.agence-nationale-recherche.fr/?Project=ANR-11-CEPL-0003

Preamble

"En route, le mieux c'est de se perdre. Lorsqu'on s'égare, les projets font place aux surprises et c'est alors, mais alors seulement, que le voyage commence."

Nicolas Bouvier

This PhD is the result of more than a three years long contract. Like most of my colleagues, I've always been interested by the nature surrounding me. The obsession about Africa came late and my first step on this continent, in 2010, changed my vision of human-nature relationships. Doing an "environment, farming and development" Master degree, I went for a 6 months long attachment with CIRAD, and conducted an impact assessment of a development project aiming at providing legal bush meat to rural communities living on the edge of a private conservancy in eastern Zimbabwe. Over the course of my fieldwork I spent several weeks pitching my tent in schools' yards and interviewed villagers. The young adult that I was saw for the first time what was "behind" conservation. I realized how rural communities were absent of public conservation discourses in western country. Back in France, I knew two things. First I knew that I wanted to continue this academic cursus and do a PhD. I also knew that the interactions between conservation areas and their peripheries was the field I wanted to investigate. I applied for a second master degree, this time in anthropology at the French National Museum of Natural History because I felt I needed social sciences skills to achieve my objectives. I went back to Zimbabwe for an attachment, and obtained the trust of researchers who proposed me to do this PhD. The quote given on top of this preamble summarizes the past years of my existence: I started, got lost and wandered quite a lot. I was lucky enough to be supervised by the good people, thanks to whom this journey was possible.

Remerciements

I spent most of the last five years of my life either in Zimbabwe or in France…writing about Zimbabwe. Five years of work, including three for this PhD, but also five years of the purest form of happiness. Many are those to be thanked for it, and I will do my best not to forget anyone. This PhD thesis is written in English, but the acknowledgements will include a bit more diversity and adopt the language of people I needed to thank for having allowed me to go through this fantastic adventure.

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Du fond du cœur je tiens à remercier **Michel de Garine-Wichatitsky**, **Christophe Le Page** et **Doyle McKey**. Merci de m'avoir fait confiance, merci de m'avoir encadré scientifiquement et encouragé à pousser toujours plus loin ma réflexion. Merci de m'avoir initié à la modélisation d'accompagnement, une approche qui restera au cœur de mes travaux futurs. Merci aussi de m'avoir mis la pression quand j'en avais besoin et recentré quand je m'égarais…ce qui est arrivé souvent. Votre soutient est allé au-delà de l'encadrement scientifique et je vous remercie donc aussi d'avoir été là pour moi quand j'avais besoin d'aide, qu'elle soit logistique, économique parfois, ou émotionnelle. Cela a été un grand plaisir de découvrir le monde de la recherche à vos côtés, et j'espère que nous continuerons à travailler ensemble.

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Au membres dujury…

Merci à **Serge Bahuchet** et **Juliette Rouchier** d'avoir accepté d'évaluer ce travail, et à **William McConnell** et **Raphael Mathevet** d'avoir accepté de se joindre au jury de soutenance. Ces remerciements ont été écris après la soutenance, et je tiens donc à tous vous remercier pour ce moment de partage dont je garde un très bon souvenir.

To the academic and local partners…

I want to thank the academic and institutional partners without whom this work could not have been done. I want to thank all the researchers from the research platform "produce and conserve in partnership" (RP-PCP) in Zimbabwe. I particularly want to thank the **Center for Applied Social Sciences** and particularly **Dr Billy Mukamuri** for his support, his knowledge about rural communities and advice. This PhD took me in and out of **Hwange National park** and **Sikumi Forest**, I express my gratitude these institutions and to their **local representatives**. I am deeply grateful to **Tendai Selima** (Sikumi Forest Manager), **Mr Jura** (Main Camp Area Manager), **Edwin Makuwe** and **Lovelater Sebele** (Main Camp ecologists), and all the other members of the Main Camp team, **Simeon**, **Juliet, Bloomer**, **Philani**, **Owen Mangwana** and those I forget!

A mes collègues…

Un immense merci à tous les collègues du CIRAD et du CNRS et leurs familles, compagnons de route au Zimbabwe avec qui j'ai travaillé, discuté et collaboré. La liste est longue et ne répond à aucun ordre particulier. Merci à **Alex** et **Carole Caron**, **Sophie de Garine**, **Laure Guérini** et **Constant**, **Daniel Cornelis**, **Mathieu Bourgarel** et **Marion StGéry**. Partager ce moment de vie au Zimbabwe a été fantastique. Merci pour l'aide scientifique et les coups de main du quotidien. Merci de m'avoir aussi ouvert les portes de vos foyers quand je daignais sortir de ma « brousse » pour aller retrouver la capitale. Merci d'avoir sorti la tête du « chti pèpère » de l'eau quand il se noyait. Un immense merci à **Hervé Fritz**, incarnation de la joie de vivre qui sait partager avec les autres son amour de Hwange et des autres. Merci à **Chloé Guerbois** et **Eve Miguel** de m'avoir ouvert les portes des communautés rurales, et d'avoir partagé leurs expériences avec moi. Merci à **Simon Chamaillé** et **Marion Valeix**, **Florence Hulot** et à l'in-cro-yable **Patrick Ducan** et à **Alisson Ducan** pour leur sagesse, leur bienveillance et les « lovely moments » passés ensemble à regarder le monde fascinant de Hwange.

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This work was made possible by the support of Honorable **chief Nelukoba**, and **Headman Victor Bitu**. I sincerely thank them from the bottom of My heart. To **Headman Bitu and his familly**, thanks for allowing me to share your life for all these weeks. **Bary, Frazer**, thank you for all these days walking in the villages and introducing my to local cultures…Taboka !!

A huge thank you to all the Kulayinjana team: **Victor, Cephus, Ambu, Fumbane, Ferdinand, Raphael, MaNdlovu, Zenzo, Patrick and Killion.** Thank you all for spending all this time with us, sharing our knowledge, our ideas and visions of the world. There are no words to express my gratitude. Working with you was a real pleasure. I slowly realize how this experience changed me. Thanks to you I know how I want to make science. I think we can be proud of ourselves my friends! I don't know how, or when, but our roads will meet again.

A ceux que j'aime…

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Abbreviations

A: Actor (SES Framework)

ABM: Agent-Based Model

AM: Adaptive Management

ANR: Agence Nationale de la Recherche (French National Research Agency)

BSAC: British South African Company

CAMPFIRE: Community Area Management Program For Indigenous Resources

CBRNM: Community Based Natural Resources Management

CIRAD: French International Cooperation Center for Agronomic Research and Development

ComMod: Companion Modeling

CORMAS: Common-pool Resources and Multi-Agent Systems

DMP: Decision Making Process

ENSO: El Niño Southern Oscillation

FAO: Food and Agriculture Organization

GL-TFCA: Great Limpopo Transfrontier Conservation Area

GS: Governance System (SES Framework)

HNP: Hwange National Park

I: Interactions (SES Framework)

IUCN: International Union for the Conservation of Nature

IDOZM: Indian Ocean Dipole/Zonal Mode

KAZA-TFCA: Kavango Zambezi Transfrontier Conservation Area

LKS: Local Knowledge System

MAB: Man and Biosphere

MAS: Multi-Agent System

Nb: Nambya

Nd: Ndebele

NPWLMA: National Parks and Wildlife Management Authority

O: Outcomes (SES Framework)

ODD: Overview, Design, Details (Standardized framework to describe Agent-Based Models)

PA: Protected Area

PAC: Problem Animal Control

PNS: Post-Normal Science

RDC: Rural District Council

RPG: Role-Playing Game

RS: Resource System (SES Framework)

RU: Resource Unit (SES Framework)

SF: Sikumi Forest

SES: Social-Ecological System

TFCA: Transfrontier Conservation Area

UNEP: United Nations Environment Program

UNESCO: United Nations Educational, Scientific and cultural Organization

UNDP: United Nations Development Program

V0: Launch Version

V1: Version 1

V2: Version 2

VF: Final Version

WINDFALL: Wildlife Industries New Development For All

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CHAPTER 1. General Introduction

Social-ecological systems, an alternative vision of societies and their environment

Directly linked with the social-ecological perspective (Emery and Trist 1965), several analytical frameworks aiming at studying the interaction between social and ecological systems emerged during the last decades (Binder *et al.* 2013). The Social-Ecological System (SES) framework originally emerged from ecological research at the end of the 1990s (Berkes *et al.* 1998). The argument from which the notion of SESs was developed is that of an historical and misleading separation of the two components (social vs. ecological) of what is in reality a single interconnected system (Bruckmeier, 2011). A brief overview of the literature provides various definitions of SESs and approaches to the concept. For Glaeser *et al.* (2007 p. 190) "*A SES consists of a bio-geo-physical unit and its associated social actors and institutions … SESs are complex, adaptive and delimited by spatial and functional boundaries surrounding particular ecosystems"*. For Ostrom (2009), "*SESs are composed of multiple subsystems … such as resource system, resource units, users, and governance systems*, [which are] *relatively separable but interact to produce outcomes at the SES level"*. For Collins *et al.* (Collins *et al.* 2011 p. 351), "*the conceptual scope of ecology must expand to embrace not only other scientific disciplines, but also the pervasive human dimension of environmental structure and change … Every ecosystem on earth is influenced by human actions … the environment is best understood and studied as a socio-ecological system*". Relatively close to the SES framework is the Coupled Human and Natural System (CHANS) approach (Alberti *et al.* 2011, McConnell *et al.* 2011) that acknowledges that "*human and natural systems are coupled via reciprocal interactions, understood as flows (e.g., of material, energy, and information). Of particular interest in studying these interactions is the understanding of feedbacks, surprises, nonlinearities, thresholds, time lags, legacy effects, path dependence and emergence) across multiple spatial, temporal and organizational scales*" (McConnell *et al.* 2011 p. 219).

Beyond the variations in the definitions, the adoption of the SES framework undeniably contributed to a shift of paradigm in environmental science by urging researchers to consider human beings and their environment as entwined parts of a complex and dynamic system (Ostrom 2007, 2009, Epstein *et al.* 2013, McGinnis and Ostrom 2014).

According to the latest work on the theme (McGinnis and Ostrom 2014), a SES (Fig. 1) can be seen as one or more resource systems ('RS', *e.g.* a forest) composed of resource units ('RU', *e.g.* trees) that are used and produced by actors ('A', *e.g.* park rangers, farmers, tourists) whose actions are framed by governance systems ('GS', *e.g.* laws, institutions, traditional authorities). These elements, called first-tier variables (Ostrom 2009, McGinnis and Ostrom 2014), are the highest-level components of the SESs, that is the fundamental bricks of the system. They "*relatively separable but interacting to produce outcomes at the SES level*". Indeed, beyond these logical linkages, the SES framework assumes a set of feedback loops between the first-tier variables, either directly or through the interactions ('I') and outcomes ('O').

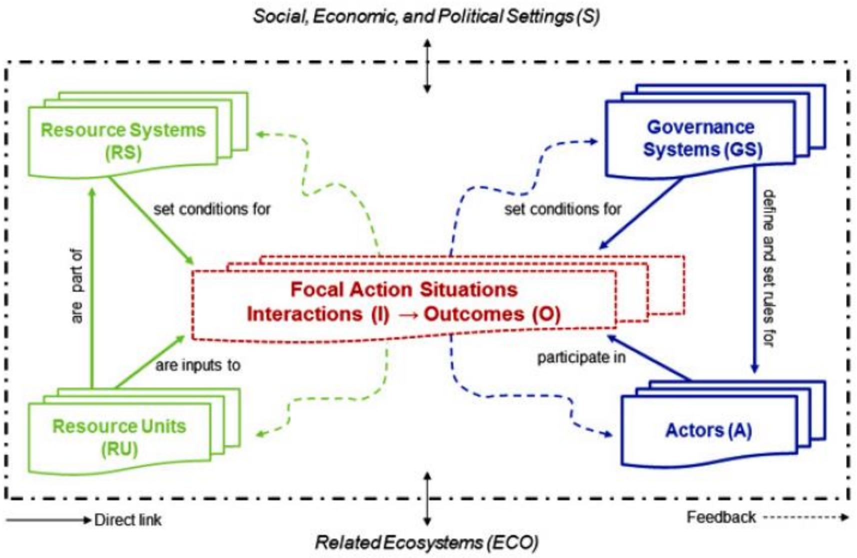

Figure 1.4. The Revised social-ecological system (SES) framework (extracted from McGinnis and Ostrom 2014).

Interactions take place in focal action situations, and among them are conflicts, harvesting, information sharing, lobbying activities, monitoring activities or investment. The outcomes resulting from interactions between the first-tier variables highlighted by Ostrom and McGinnis (2014) fall under three categories: social performances, ecological performance and externalities to other SESs. Indeed, joining Gunderson and Holling's concept of *panarchy* (Gunderson and Holling 2002), a fundamental property of a SES is that its boundaries only exist for analytical reasons, whereas in fact, social-ecological dynamics are influenced by and have influence on "external" social-ecological systems.

An overview of social-ecological issues within SESs

When opening the "Actors" box (Fig. 1) of a given SES, one will come to consider a potentially high diversity of local actors/groups of actors, sometimes also called stakeholders in this thesis. Taking the simple example of a river, Webber (1998) explains how the fisherman's, the engineer's, the geographer's and the ecologist's river are different, although they are based on the same environmental feature. Power games between actors (Barnaud and Van Paassen 2013), interactions between land uses (Chitakira *et al.* 2015), co-operation or its opposite (tensions and conflicts) will impact the functioning of the SES (Tompkins and Adger 2004, Wehrmann 2008).

This plurality of stakeholders interacting around common resources therefore brings with it the question of coexistence, for which the Collins dictionary[3] provides us with two definitions: (i) the situation of existing together at the same place and at the same time, or (ii) to exist together in peace. Coexistence is more than the sum of interactions and outcomes, and is a key driver of SESs (Guerbois *et al.* 2013). In cases where the coexistence of different land use results in reciprocal benefits, we can expect local actors to collaborate to maintain these benefits. But when one or more actors dominate and achieve their own objectives at the expense of others, we can expect the emergence of conflicts, along with an increase in individualism and rule avoiding mechanisms that can *in fine* threaten the system as a whole.

A conflict is a "difference within a person or between two or more people (or groups of people) that touches them in a significant way" (LeBaron and Pillay 2006; p. 12). A conflict is characterized by five phases: initiation, escalation, controlled maintenance, de-scalation and some kind of termination (Cheldelin *et al.* 2003). Conflicts can take many forms, and produce more or less violent outcomes. Tensions and conflicts can happen at different scales, from local employee/employer conflicts within companies[4], to larger societal conflicts where part of the population disagrees with political decisions, such as the opposition of a part of the French population to the reintroduction of Eurasian brown bears (*Ursus arctos arctos*) in the Pyrenees mountains by the French government between 1990 and 2006 (Chetrit 2012), or the worldwide

[3] www.collinsdictionary.com

[4] A recent example is given by the Air France social conflict: http://www.lemonde.fr/economie/article/2015/10/06/air-france-un-an-de-conflit-en-trois-dates_4783704_3234.html

growing opposition to the use of nuclear power (Hartmann *et al.* 2013). Social conflicts are part of societal dynamics and are usually solved before reaching overtly violent manifestations. At the end of the Cold War, ethno-political conflicts excontinued a trend that began in the decolonization processes of the1960s (Harff and Gurr 2004) and often reached the most violent forms of conflict: genocide and war.

As shown in the previous examples, the natural environment often plays a major role in conflicts (Libiszewski 1992). Natural resources have always been the object of contention and sometimes violent conflict between different social groups and between states (Westing 1986). On a large scale with the previous example of the opposition to nuclear power, or the recent media frenzy about Cecil the lion, who was shot by a trophy hunter in the periphery of Hwange National Park in Zimbabwe[5], environmental conflict can transcend SESs and take place around conflictive values and ideologies about human/nature relationships and occur between people who do not directly interact with each other. On a local scale, coexistence issues often rely on the interactions between groups of actors and their respective use of the land. A land use is defined by the United Nations Food and Agriculture Organization (FAO) and the United Nations Environment Program (UNEP) as the "arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it". Using LeBaron and Pillay's (1996) definition of a conflict, a land use conflict is a situation where the land uses and related practices of two or more people (or groups of people) produce outcomes that touch them (negatively) in a significant way. SESs are complex systems with strong feedback loops, and land use conflicts have extensive negative effects on economic, social and ecological development of SESs as whole entities (Wehrmann 2008).

[5] http://www.bbc.com/news/world-us-canada-34188768

Protected areas and their peripheries: examples of land-use conflicts

According to the International Union for the Conservation of Nature (IUCN) Red list published in 2012, 22% of the earth's vertebrate species, 41% of invertebrates and 70% of plants were threatened at that time. Thus, more than one species in five on the globe was threatened by extinction, and the list is only getting longer (Hoffman et al. 2010). The extent to which human activities have impacted the environment has taken the Earth to what some authors consider to be the sixth mass extinction crisis (Barnosky 2011). Protecting and conserving the environment is crucial to the survival of humanity (e.g. Sukhdev et al. 2010). Nevertheless, conservation activities are not undertaken without raising questions about the human/nature relationship promoted, and about international power games at stake and their local consequences. As our work is focused on tensions and conflictive relationships between actors at the edge of a Protected Area (PA), a short analysis of conservation, its, ideological roots and social effects is necessary at this point. The last part of this section will give examples of social-ecological issues affecting spaces in and around protected areas, with a particular focus on eastern and southern Africa.

PAs are the most widely known strategy for conserving biodiversity in the face of ecosystem degradation (Palomo *et al.* 2014). The IUCN defines a PA as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2013). This definition is refined by six categories depending on the management objectives and conditions: from exclusives nature reserves (Ia) and wilderness areas (Ib), where human visitation is prohibited or controlled and limited to ensure protection of conservation values and to maintain "natural" conditions, to PAs allowing sustainable use of natural resources[6] (VI), which conserve ecosystems while maintaining the exploitation of the resources that they contain. Different GS (McGinnis and Ostrom 2014) apply to PAs: governmental governance, shared governance, private governance or local community-based management (Dudley 2013). The UNEP World Database on Protected Areas (WDBPA)[7] records PAs existing in the world and shows how the geographical extent of PAs has increased

[6] The Sikumi Forest, at the end of which our study took place, can be considered as a type VI protected area.
[7] http://sea.unep-wcmc.org/wdbpa/

by at least 50% since 1996[8] (West et al. 2006). Although this increase is partly due to an improved recording of already existing PAs, the fact remains that since the 19th century and the creation of the iconic Yosemite National Park in the USA, the total surface of PAs increased to reach a total of 209,429 PAs recorded in 2014, a total area of 32.10^6 km², an area larger than the continent of Africa. Excluding Antarctica, 15.4% of the world's terrestrial area is in some kind of protected status (Fig. 1.2).

In a globalized world, PAs have become the means by which people see, understand, experience and use parts of the world that are often called "nature" and "environment" (West et al. 2006). They are cultural artifacts, a virtualizing vision (Carrier and Miller 1998, West and Carrier 2004) imposing the European nature/culture dichotomy[9] on places and people where this distinction did not previously exist. PAs imposed themselves as an imperialist cosmology of nature, defined what is just, moral and right in terms of environmental management and as such, can be seen as the material and discursive means by which conservation and development discourses, practices and institutions remake the world (Brosius 1999). There is more to PAs than just the IUCN's definition. They are physical projections of the western division between nature and culture, and through their implementation and the process of their classification, they participate in a generification of the external world (West and Carrier 2004). As expressed in the Durban Action Plan produced after the fifth World Park Congress (2003), there are connections between dispossession and poverty, culture change and social subsistence losses on the part of people living around protected areas (MacKay and Carison 2004). Although the philosophy of conservation is slowly changing (Dudley *et al.* 2014), and the social-ecological framework is partly adopted in PA management (Palomo *et al.* 2014) with the integration of concepts such as complementarity of landscapes (e.g. Chitakira *et al.* 2015), the historical implementations of PAs and their consequences are still apparent (Neumann 2001). The meeting and interactions of wildlife conservation on one side and farming and cattle herding on the other on make the edges of African PAs often conflictive. Taking the example of the Maasai Mara National Reserve in southwestern Kenya, Butt (2012, 2014) showed how the Maasai herders were marginalized despite the fundamental role of their practices in the production and maintenance of landscapes in which wildlife thrives.

[8] Other protection designations exist, such as RAMSAR sites (RAMSAR Convention), the United Nations Education and Science Organization (UNESCO) World Heritage Sites or Man and Biosphere program (MAB) sites. These do not always fit in the categories previously cited (Dudley 2013).

[9] About the different ontologies, *i.e.* relationships between human societies and other forms of life, see Philippe Descola's « Par-delà nature et culture » (Descola 2005).

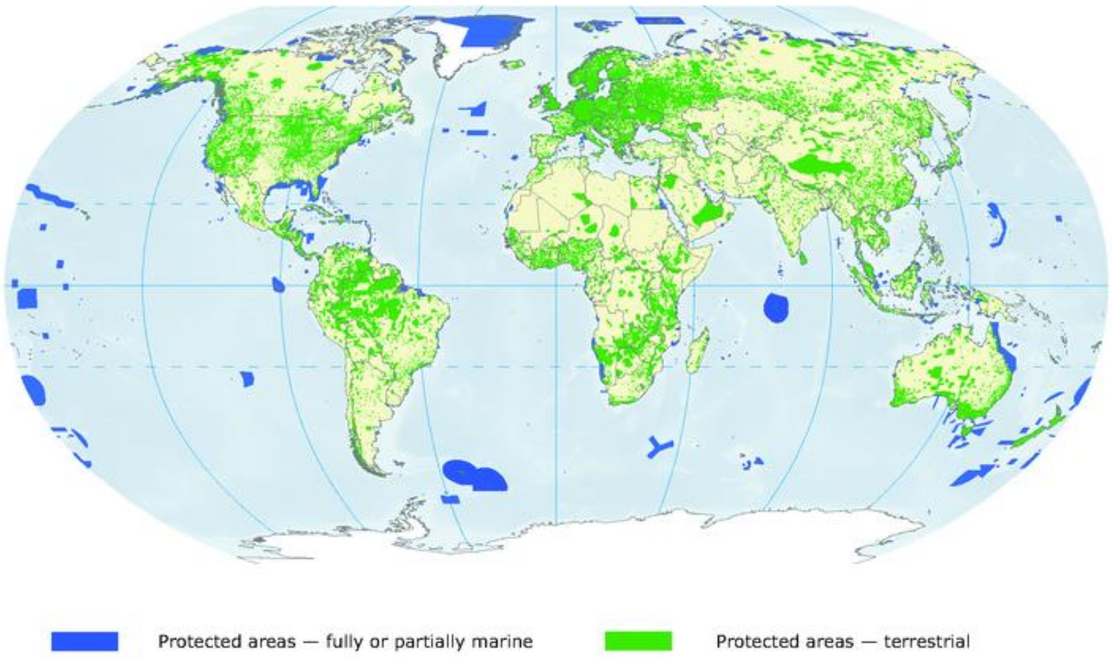

Figure 1.5. Overview of the protected areas as included in the World Database on Protected Areas (http://www.unep-wcmc.org/resources-and-data)

The three transformational moments identified by the author as leading to regular conflicts between pastoralists and PA managers are (i) the creation of safaris as a distinct commodity through which one can observe a wildlife-rich environment devoid of humans, (ii) the strategic spatial and temporal placement of National Parks officials to protect the safari experience within which tourists interact with local communities only during community-tours and therefore cannot really appreciate their practices, and (iii) the identity (re)creation where tourists and rangers regard herders as a threat to pristine wilderness, tourists see rangers as protectors, rangers identify herders as a threat to their identity of protectors and Maasai herders see rangers (who are Maasai too) as cattle raiders (Butt 2012). Conflictive interactions between PAs and surrounding populations are found in other places in eastern and southern Africa. Human-wildlife conflicts are omnipresent and mainly involve livestock, humans and carnivores (Lyamuya *et al.* 2014, Dickman *et al.* 2014, Matema and Andersson 2015, Constant *et al.* 2015), or elephants (*Loxodonta africana*) (Dublin and Hoare 2004, Guerbois *et al.* 2012a, Hoare 2015). The risk of transmission of infectious diseases between livestock and cattle is also a major concern (Miguel *et al.* 2013, de Garine-Wichatitsky *et al.* 2013), as is forage competition between livestock and wild ungulates (Butt and Turner 2012).

Transfrontier Conservation Areas (TFCAs, Fig. 1.3) are defined in the Southern African Development Community (SADC) protocol on wildlife conservation and law enforcement as

> "*components of a large ecological region that straddles the boundary of two or more countries, encompassing one or more protected areas as well as multiple resource use areas* [e.g. communal farming land, mines, etc.] (…) *founded with the aim of collaboratively managing shared natural and cultural resources across international boundaries for improved biodiversity conservation and economic development*"[10].

With the rise of TFCAs in southern Africa, many people who were often displaced in the formation of protected areas decades earlier now find themselves residing conservation area of this type (Andersson et al. 2013a). There are currently 13 TFCAs in southern Africa (Fig. 1.3), although not all are at the same point of development. Five of them include Zimbabwean protected areas, among which are the two largest ones: the Great Limpopo TFCA (GL-TFCA), and the *Kavango-Zambezi* TFCA in which we conducted our work.

Emblematic of TFCAs, the Kavango-Zambezi (KAZA-TFCA) was officially inaugurated in 2012. It sprawls over five countries (Fig. 1.4) and covers a total of 444 000 km², an area equivalent to Italy. Centered around the Okavango and Zambezi river basins, it encompasses 36 PAs, among which are more than a dozen National Parks (NPs), notably Hwange National Park (HNP) and the Sikumi Forest, at the edges of which our study area is located (Chapter 2).

[10] http://www.sadc.int/themes/natural-resources/transfrontier-conservation-areas/

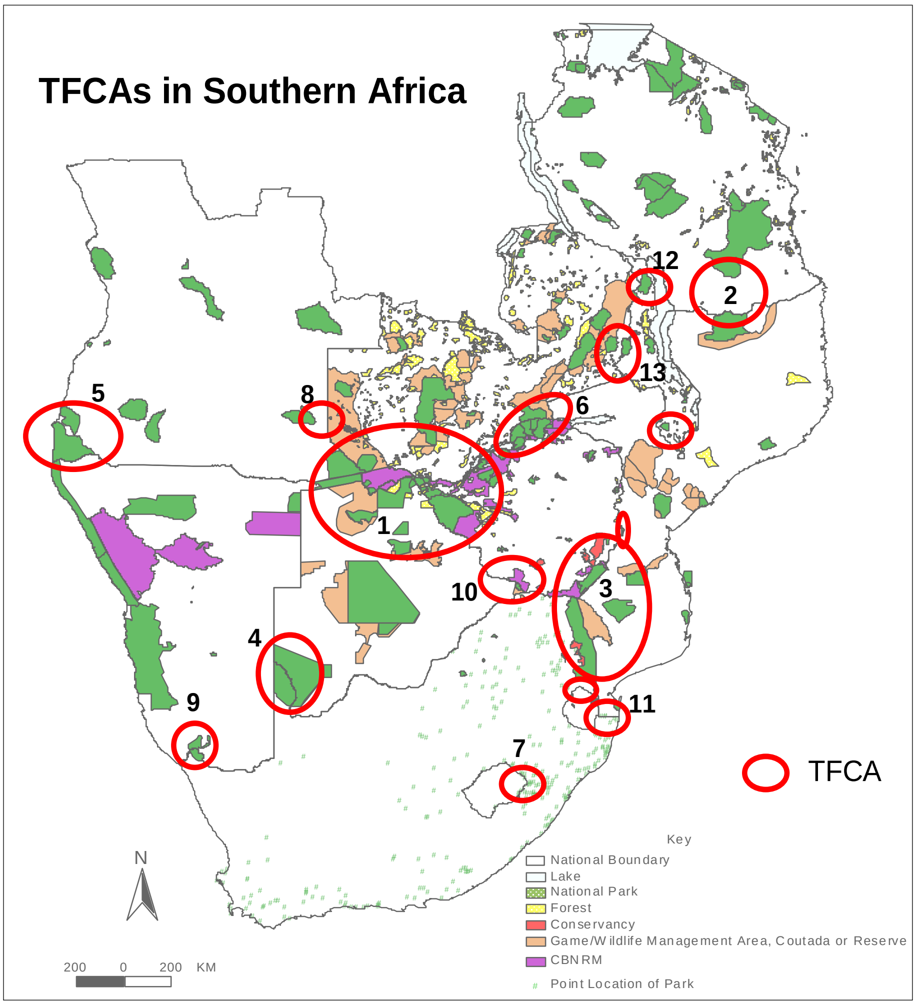

Figure 1.6. TFCAs in southern Africa (reproduced after Andersson et al 2013, chapter 2). *The figure shows the thirteen southern African TFCA: (1) Kavango-Zambezi (KAZA), (2) Niassa-Sealous, (3) Great Limpopo, (4) Kgalagadi, (5) Iona-Skeleton Coast, (6) Mana Pool-Lower Zambezi, (7) Drakensberg-Maloti, (8) Liuwa Plain, (9) Ai-Ais/Richtersveld, (10) Greater Mapungubwe, (11) Lebombo, (12) Nyika-Vwaza Marsh, (13) Kasungu-Lukusuzi. Not all these TFCAs are at the same point of development*

.

By including protected and communal areas within gigantic international conservation-oriented areas, TFCAs offer particularly relevant contexts to study the coexistence of diverse actors within them, and especially land use conflicts. Although TFCAs are built on enchanting promises and potentially provide conversation and development benefits, they also impose additional constraints for people living within their boundaries, such as risks of increased physical aggression by wildlife, crop raiding, predation on livestock and disease transmission (Murphree 2013).

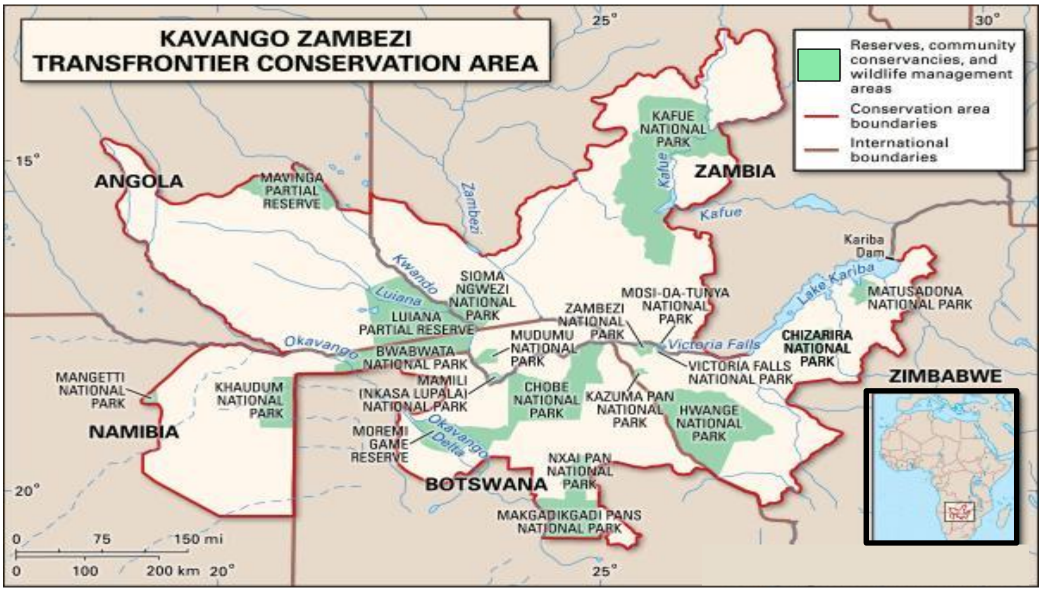

Figure 1.4. Map showing the five southern African countries covered by the Kavango-Zambezi TFCA: Botswana, Namibia, Angola, Zambia and Zimbabwe (www.britannica.com).

Our research project: questions, objectives and organization of the manuscript

The previous paragraphs set the general context of our work. We described how the interactions between societies and their environment could be formalized to produce the SES framework. We do not argue that this framework is the only one to approach the matter, but we chose to adopt it as it allows the integration of several disciplines and therefore enhances dialogue between researchers and practitioners originating from different academic fields. We briefly gave a definition of what a conflict is and how conflicts emerge in SESs. We proposed our vision of protected areas and provided examples of actors and land-use conflicts shaping these.

Social-ecological problems are complex and in some cases *wicked problems*, that defy simple solutions (Balint 2011). Incomplete scientific knowledge, uncertainty, competing cultural values and the gap between the real matter as it appears to local stakeholders and the matter as it exists for exogenous researchers, make studying such problems quite challenging. Local stakeholders' participation is one of the possible strategies allowing us to cope with this challenge. Conducted at the edge of a Zimbabwean PA, this PhD study focuses on a coexistence issue grounded in the interactions between farming and cattle herding activities on the one hand, wildlife conservation and timber production on the other hand. We focused our attention on cattle herding practices, which are at the heart of the interactions between the two land uses and the actors who conduct them. These rely on complex decision making processes, and we decided to put efforts in the co-design of a research tool that would allow us to elicit these strategies. This research tool took the form of a Role Playing Game (RPG) and was created by a team involving researchers and 10 members of the local communities. The RPG was later implemented with 4 sets of villagers leaving in the area. The manuscript is structured as follows: Chapter 2 will describe our study site and the interdisciplinary approach (ComMod) implemented during the past three years; chapter 3 will provide an ethnographical description of the production system of local communities, with a particular focus on local meteorological knowledge on which farmers rely in this semi-arid environment; Chapter 4 will describe the core of our activities, i.e. the co-design of a role-playing game aimed at eliciting and modeling cattle herding strategies; A general discussion and conclusion will be given in Chapter 5.

1

CHAPTER 2. Context and Theoretical frameworks

WHAT IS THIS CHAPTER ABOUT?

This chapter introduces the reader to the context in which we conducted our research, and present the theoretical frameworks and methodological approach we adopted to achieve our objectives.

The chapter is organized as follows:

- The first section gives a detailed description of our study area. This includes of course the geographic location and the general agro-ecological characteristics. Keeping the political-ecological approach developed in the first chapter, we put a particular emphasize on the description of the social and political history of the area. This covers the precolonial period, and explains the history of current ethno-linguistic groups living in our study site. The Rhodesian era (1889-1980) and the post-colonial period (since 1980) are described mostly in relation with the land-related policies that shaped the coexistence between rural communities and protected areas.
- The second section of the chapter describes the theoretical frameworks used during our work. As the detailed methods are given in their related chapters, we propose the reader the theories behind the methods. We describe how social ecological problems are *wicked* problems, and how addressing them needs to transcend the classical frames of science. We describe the notion of post-normal science and the role of participation and interdisciplinarity. The last part of this second sections how the former mentioned frameworks were put into practice, that is through companion modeling process and the use of role-playing games and agent-based models.

Study site

This work was conducted within Ward 15 of the Hwange District, western Zimbabwe (Fig 2.1), at the interface between the villages of Magoli, Siyalwindi, Chezhou, Dingani and Jwape and two unfenced protected areas, namely Hwange National Park (HNP, 14651km²), a wildlife conservation area located a few kilometers to the southwest and the contiguous Sikumi Forest (SF, 11000 km²), a wildlife conservation and timber production area separated from the villages only by a tarred road. The study area can be qualified as semi-arid. Three seasons can be distinguished, a cold and dry season ranging broadly from May to August followed by a hot and dry season from September to October, and a rainy season from October to April, although the start of the rainy season varies greatly among years (Fig. 2.2). Annual rainfall ranges between 450 and 650 mm per year and is spatially highly heterogeneous (Chamaillé-Jammes *et al.* 2007). Severe droughts occur, as well as recurrent 'dry spells' during the rainy season (Fig. 2.2, Matarira and Jury 1992).

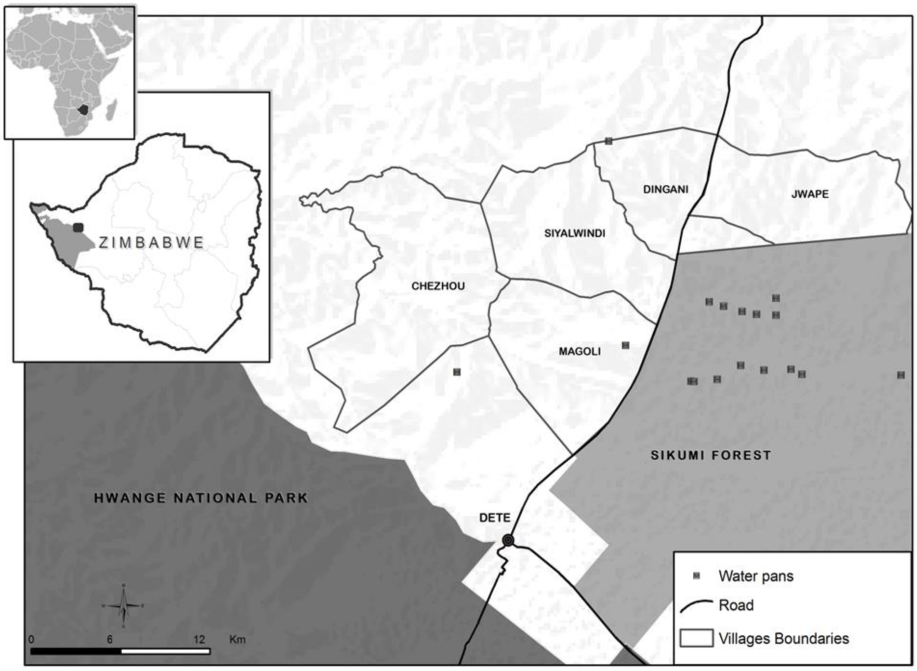

Figure 2.1. Map of the study area showing the interface between villages studied and the two adjacent PAs: Hwange National Park and Sikumi Forest, Zimbabwe. *Village boundaries are often contested and it is difficult to gain access to official records. The boundaries displayed on the figure were collected by Guerbois et al (2013).*

Villages are restricted to the CA, that is an area dedicated to human settlements with lands allocated by traditional leaders (Guerbois *et al.* 2013), while HNP and SF are managed by their respective governmental authorities, the National Parks and Wildlife Management Authority (NPWLMA) and the Forestry Commission. As demonstrated in Chapter 1, coexistence issues between protected areas and neighboring communities are omnipresent throughout the African continent, among which are poaching (Rowcliffe *et al.* 2004), cattle incursions in protected areas (Butt 2014) and the lack of benefits derived for rural communities (Emerton 2001).

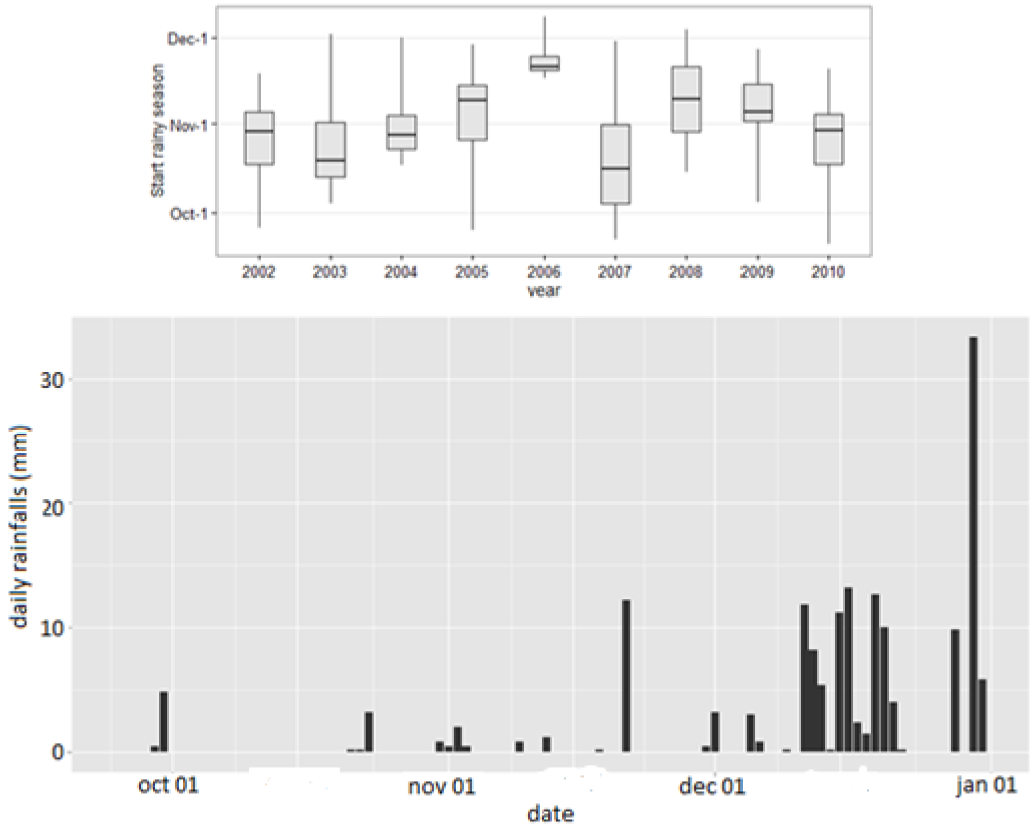

Figure 2.2. Rainfall patterns in the study area. *The upper panel summarizes the range of variation in the starting date of the rainy season between 2002 and 2010. Based on rain gauges deployed in the communal land at the edge of the Sikumi Forest, the lower panel shows the temporal heterogeneity of rainfall during the onset of the 2013-2014 rainy season (form Oct 1st to Jan 1st).*

The interface between HNP, SF and rural populations is no exception and tensions exist between local stakeholders: human-wildlife conflicts (Metcalfe and Kepe 2008), poaching (Muboko *et al.* 2014), illegal wood harvesting, livestock predation by wild carnivores and crop raiding (*e.g*. Guerbois *et al.* 2012), along with disease transmission between domestic livestock and wildlife (de Garine-Wichatitsky *et al.* 2013). An important point is that although local demography is partly explained by the presence of protected areas, which attract people hoping to find a land of plenty (Guerbois *et al.* 2013), the positions of the studied villages themselves are mainly due to historical political violence; interactions between protected and communal areas were shaped by colonial and post-independence policies (Compagnon 2003, Ncube 2004, Mlambo and Raftopoulos 2009). To enable full understanding of the context of coexistence in the area, the description of the study site will follow three steps. Firstly, we will describe the pre-colonial history of human settlements in the area. With a focus on conservation, the second part will describe the colonial and modern history and its implications in terms of conservation policies and integration of communities in wildlife management and benefit sharing. The final part of the description of the study site focuses on the current interactions between rural communities of Ward 15 of Hwange District and will justify the consideration of cattle herding in our study.

A brief pre-colonial history of human populations in the area

Historical and anthropological literature on southern Africa is relatively scarce. The history of pre-colonial human settlements in our study area, although poorly described in published literature, is composed of several waves of migrations. The *San* people, hunter-gatherers and original inhabitants of southern Africa, left traces of their presence in Matabeleland north, the Zimbabwean province where our study was conducted (Cooke and Reese 1972) and are still living in the area (Mukamuri et al. 2013), although they are a minority. The first Bantu settlements in western Zimbabwe were located in the region of Victoria Falls (200 km from our study site) and belonged to the *Kangila* tradition, dating from between the 4th and the 5th century. The *Tonga* people descend from these early inhabitants and are still present in the Hwange District, although they are found more along the Zambezi River, both on the Zimbabwean and the Zambian sides. The name *Tonga* was probably given to them by other ethnolinguistic groups and means "chiefless", people who do not recognize a paramount leader (Nyathi 2005). Other Bantu peoples migrated into the area and local traditional leaders we met during our work confirmed that within Matabeleland, the Hwange district is the "*Nambya* area" (Ncube 2004, Mlambo and Raftopoulos 2009). The *Nambya* people (plural *baNambya*), settled in the area in the beginning of the 18th century after breaking away from the *Rozvi* empire. The name Hwange itself is derived from *Wange*, the dynastic title of Nambya rulers. The town of Hwange and Hwange National Park also took their names from it. There is still a chief Hwange ruling Hwange town and its surroundings nowadays. Several Nambya sacred places can be found in the district, such as *Chigehari* (about 30 km north of our study area) and the *Mtoa* and the *Bumbusi* ruins (both inside Hwange National Park), where Nambya ancestors' bodies are buried. Livelihoods of the *Nambya* historically relied primarily on livestock husbandry, agriculture, and wild food harvesting (Ncube 2004, Nyathi 2005). The group most represented in the area today are the *AmaTabele* (sing. *Ndebele*). The *Ndebele* presence in the area started a few years when Mzilikazi Khumalo and about 500 of his men split apart from the Zulu Kingdom (in the northern part of South Africa) in 1821 during the *mfecane* period during which King *Shaka* created the militaristic *Zulu* kingdom (Laband 2011).

Picture 2.1. A rural homestead at dawn, Magoli. *local homesteads are structured as sets of small houses, each one serving a purpose (bedroom, food storage, kitchen,etc.) (12/04/2012, A. Perrotton)*

During their migration from Zululand, Mzilikazi and his people assimilated individuals of other Bantu groups such as *maShona*, *maKalanga*, and Sotho people, among others, creating a complex society (Lindgren 2004). The Ndebele kingdom no longer exists, but Bulawayo, its former capital, is now Zimbabwe's second largest city, and two of the country's provinces, namely Matabeleland North and Matabeleland South, are named after this kingdom.

The colonial era: evictions, resettlements and wildlife conservation

The colonial history of Zimbabwe, known at that time as Rhodesia, is characterized by two major trends, land appropriation by white settlers and the resulting resettlement of original populations, and the creation of large protected areas. Land appropriation by white settlers started in 1889 when the Rudd Concession was signed by the *Ndebele* King Lobengula and the *British South African Company* (BSAC) of Cecil Rhodes (Parson 1993, Mazarire 2003, Ncube 2004, Nyathi 2005). White settlements started in 1890 and Rhodesia was officially established in 1895. Throughout the history of Rhodesia, racial discrimination had a considerable impact on access to land for black farmers by giving the best arable land to white Rhodesians (e.g. Mlambo and Raftopoulos 2009)[11]. In our study area, local rural communities were chased or relocated several times since the end of the 19th century, the first time in 1895 when Albert Giese took over 1036 km² around *Bumbusi* to exploit coal. Thirty years later, the Hwange district was shared between mining concessions (45%), inalienable land (50%), and a Nambya reserve (3%). In 1928 the Wankie (Hwange) Game Reserve and the Sikumi Forest were created on the previously inalienable land, and local communities were evicted from land in which they were either settled, driving their cattle or gathering natural resources such as fruits or firewood (Ncube 2004). To ensure the non-return of rural communities, some of the villages were burnt by the first Wankie warden, Ted Davison (DNPWLM 1999).

National Parks and tourism represent a substantial part (±15%) of the Zimbabwean economy (Peter Sai *et al.* 2015). HNP was created and managed to maintain wildlife in an area that was only used by wild animals and only during the rainy season. The main management tool was the development of a network of artificial water pans, which began in 1935 (DNPWLM 1999). Consequently, wildlife populations increased both within and outside the boundaries of the park. They actually increased so dramatically that the park's managers were concerned by vegetation degradation and initiated culling programs in 1963 to control populations of wild herbivores, of which impalas (*Aepyceros melampus*), buffalos (*Syncerus caffer*) and elephants

[11] This unfair allocation of arable land was partially addressed by the first land reform conducted under the *Lancaster House Agreement* (Compagnon 2003) by President Robert Mugabe in the early 1980s, and continued during the second land reform in the 2000s (Hanlon *et al.* 2012).

(*Loxodonta africana*) were the main targets (DNPWLM 1999). The elephant population in the HNP-SF ecological continuum and their periphery went from approximately 2000 individuals in 1928 to about 10 000 in 1963, when culling activities began. Due to underestimates of the elephant population, culling had little impact on population growth (Cumming 1981) and the population was estimated at around 21 668 in 1983. It was reduced to 13 000 in 1986 (De Garine-Wichatitsky *et al.* 2013). For economic reasons, and under international pressure, culling was stopped in 1987 and the elephant population has regularly increased (Fig. 2.3), with an average annual increase of 17% until 1992 and a population of about 35 000 individuals (Chamaillé-Jammes *et al.* 2008). The elephant population in and around HNP partly increased due to immigration from neighboring countries, justifying the concept of TFCAs.

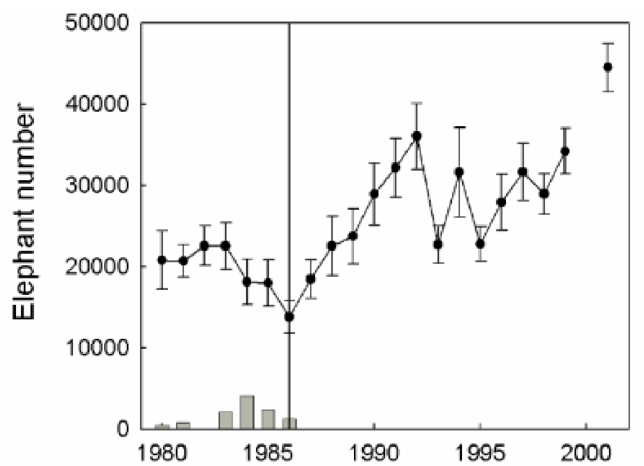

Figure 2.3. Estimated number of elephants (± SE) in HNP between 1980 and 2001. *Bars at the bottom of the graph represent the number of elephants culled (extracted from Chamaillé-Jammes et al. 2008).*

The last elephant census initiative[12] estimated that 54 000 individuals were living in the Hwange area, accounting for 18% of the world population of African elephants.

From a conservation perspective, the increase of wildlife populations was undoubtedly a success. Nevertheless, this was not achieved without generating conflicts with local populations. Indeed, except for private conservancies and hunting areas, PAs in Zimbabwe are mostly unfenced and wild animals can move freely in and out of HNP and SF. Conscious of the

[12] http://www.greatelephantcensus.com/elephant-info/

potential benefits of wildlife for rural development, and of the necessity to propose mechanisms compensating rural communities for the losses due to the presence of wildlife, Zimbabwe was among the first countries adopting integrated Community-Based Natural Resources Management (CBNRM) (Jones and Murphree 2001). In the early 1960s, the country's wildlife policy radically shifted from a protectionist philosophy to one of conservation through sustainable use (Duffy 2000, Brosius 2006). This instrumentalist approach to wildlife issues (Brosius 2006) could be summarized by the statement, "proprietorship and the ability to earn direct benefits from wildlife provides more effective incentives for wildlife conservation". The Park and Wildlife Act of 1975 transferred wildlife management to land owners, and three years later the *Wildlife Industry New Development for All* (WINDFALL) pushed this principle further, trying to entrust to rural communities the management of wildlife and to create local benefits taking the form of meat and of financial revenues derived from trophy hunting. Although the WINDFALL program failed, its conceptual roots remained and gave birth to the *Community Areas Management Program for Indigenous Resources* (CAMPFIRE) in 1989, which was implemented in our study area in 1992.

Picture 2.2. Elephants (*Loxodonta africana*) and a giraffe (*Giraffa camelopardalis*) drinking in a pumped water pan (*Guvalala*) inside Hwange National Park during the dry season. *(05/05/2012. A. Perrotton).*

CAMPFIRE works as a decentralized institution, managed by Rural District Councils (RDC). The program relies on two main pillars, a sharing of trophy hunting revenues with local communities, and the distribution of meat collected when wildlife causing damage in communal land ("problem animal control", PAC; mainly elephants) is shot. Praised by some, criticized by others, more than 30 years after its beginning, the CAMPFIRE program has mixed and heterogeneous results across the country. In the Hwange district, the economic crisis of the 2000s (Compagnon 2001) and the consequential collapse of the tourism economy virtually put an end to the program. Villagers living on the edge of HNP and SF still suffer from crop raiding by elephants and livestock predation by wild carnivores, but do not really get any benefits anymore, except occasional meat from PACs. CAMPFIRE is fortunately not the only mechanism through which communities derive benefits from PAs. Indeed, protected areas provide natural resources such as non-timber products, but also poles and firewood and grazing for livestock. These natural resources are sometimes acquired through legal agreements between local actors, and often taken illegally.

Picture 2.3. A road sign warning about the risk of elephants encounters. (26/11/2014. Arthur. Perrotton)

Cattle herding at the heart of coexistence between rural communities and the Sikumi Forest

Nowadays, local communities have no right of access for any use/extraction of natural resources from HNP except for occasional grass harvesting for thatching, under close supervision of rangers. Unlike HNP, the management of SF includes a direct use of natural resources (IUCN, cat.VI). The SF is made of several blocks, some dedicated to timber production, others leased to lodges for photographic safaris or trophy hunting. Neighboring communities have a controlled access to the forest and its natural resources. Women for instance, are allowed to collect firewood one day per week, only dead wood. Managers of the SF and traditional leaders collaborate in the management of pole harvesting. A villager who needs poles will write an official demand specifying the exact number of poles needed and have it stamped by the local traditional leader. This letter will be advised by a SF officer in Dete (Fig. 2.1) who will deliver an official authorization. As part of their veld fire prevention plan, the SF managers also involve local villagers in the harvesting of thatching grass (*Hyparrhenia spp.*). Although part of the grass collected is delivered to the Forestry commission, villagers get benefits as they can use and locally sell it. Furthermore, the severe droughts of the early 1990's (Maphosa 1994) led the Forestry Commission and traditional leaders to negotiate a complementary right of access for neighboring communities. Herders obtained the right to graze their cattle within the SF (Guerbois *et al.* 2013), although the official authorized distance of incursion remains unclear and, depending on the informant, ranges from 2 km according to a Forestry manager to 3 km (Guerbois *et al.* 2013), and up to7 km according to local herders.

Previous studies conducted in the area confirmed the extensive use of the SF by local herders. The work conducted by Miguel *et al.* (2013) provides significant information. Figure 2.3 represents a simulation of cattle movements in the study area between December 2010 and August 2011 obtained by the deployment of 10 GPS collars. The reader will recognize the study area (Fig. 2.1), although two additional land uses are displayed, a residual inalienable state land between HNP and the communal area and a Marist Brothers' concession (that is a land entrusted to a marist congregation by the local traditional authorities). These will not be mentioned in the rest of this thesis because we specifically focused on the SF/communal land interface. Even with this small sample (N = 10), the simulation shows the intense use of the forest by cattle owners living on the edge of the SF, and the central role of seasonal water pans, which, unlike those in HNP, are natural and do not benefit from (or depend upon) any pumping system.

Thirteen years after the agreement on this right of access, the forest's land has become essential for livestock owners. Beyond the obvious benefits in terms of high-quality forage and water for their livestock, both resources being scarce in communal land, the use of the SF also represents a form of land claiming on a territory that was formerly used by the villagers a few decades ago. The right of access is a 'bone of contention' between traditional leaders and the forestry commission. On the one hand, villagers ask for an extended authorized distance of incursion into the forest, and on the other hand, forestry managers are concerned by the possible consequences of such an agreement: overgrazing to the detriment of wildlife, and an increase in opportunistic activities such as illegal wood harvesting or poaching.

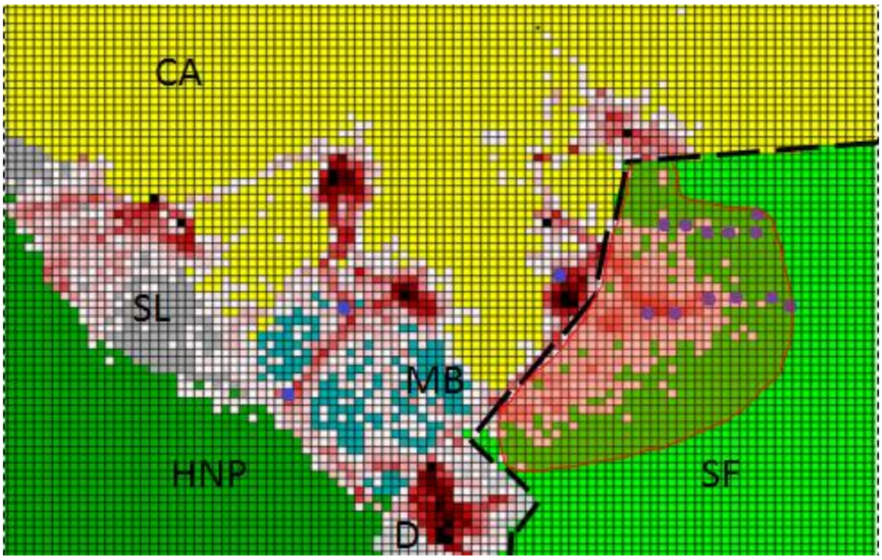

Figure 2.4. Simulated cattle movements in and out of the Sikumi Forest. *This simulation was obtained using the CORMAS simulation platform (cf. chapter 3). Data used were obtained from GPS collars deployed on 10 individuals from 10 different homesteads (Miguel et al. 2013). The communal are (CA) is represented in yellow, the Sikumi Forest (SF) in light green, Hwange National Park (HNP) in dark green, a Marist Brothers' concession (MB) in blue, the state land buffer(SL) between the Park and communal land in grey and the town of Dete (D) in white. The blue dots represent natural water pans. The red gradient (From white to dark red) represents the use of the landscape by collared cattle between (2010 and 2011) The darker red a cell is, the more extensively cattle used this portion of the landscape. The orange shape shows the surface of the SF used by cattle herders.*

This area offers the opportunity to understand how these different types of actors and land use can coexist. It provides a good study site for different reasons. First, its environmental parameters are characteristic of biodiversity-dependent semi-arid dystrophic savanna ecosystems, with low rainfall, recurrent droughts and dry spells and poor soils. The potential outcomes of our work could therefore be used in many other African SES characterized by coexistence issues between PAs and neighboring communities. Both land uses considered rely strongly on the environment, and influence the environment in return.

Picture 2.4. The cattle and the forest. *Top: Cattle entering the Sikumi Forest (2013. Hugo Valls-Fox), Down: Cattle drinking in a water pan (17/04/2012. A. Perrotton)*

Finally, as the literature cited shows, and as explained in further chapters, researchers have been present in the area for over a decade and have worked both with PA officers and rural communities, facilitating our integration into the local social network. The interactions between the SF and the local communities are diverse, some legally framed, some not. Although at first we considered studying coexistence as a whole, the knowledge gathered on the SES (social-ecological system) prior to our study, added to our own observations (cf. chapters 3 and 4), highlighted a particular activity, a "keystone" practice of interactions between the Sikumi Forest that merited focusing on: cattle herding. As the next section of this chapter will show, we focused our attention on eliciting cattle herding strategies by co-designing our own research tool with members of the local communities.

Theoretical framework and methodological approach

In the general introduction of this thesis (chapter 1), we described the SES framework that we have adopted. The second part of this chapter will not describe the specific methods used during our work, which will be detailed in their relative chapters, but rather the methodological approach adopted and the theoretical concepts we relied on. Land-use conflicts, like other social-ecological issues, can be seen as *wicked* problems, that are social problem in which the various stakeholders can barely agree on what the definition of the problem should be, let alone on what the solution is. To address the land-use conflict studied, we decided to transcend the classic frame of traditional science, and to adopt a *post-normal* posture (Funtowicz and Ravetz 1993), which was fundamentally *interdisciplinary* and *participatory* in a *companion modeling process* (*ComMod*) ((Etienne 2014). The main outcome of our work is a Role Playing Game (RPG) that was co-designed to elicit cattle herding strategies. This was done in several steps: (i) ethnographical fieldwork (cf. chapter 3), (ii) the iterative design of the research RPG (cf. Chapter 4), and its implementation with local villagers (cf. Chapters 4 and 5).

Theoretical approach

Wicked problems, a major challenge in social-ecological research and management

Originally coined by Churchman (1967) and developed by Rittel and Webber (1973) in the context of governance and policy planning, the term *wicked problem* is defined in opposition to what the authors saw as *tamed* or *benign* problems. According to these authors, classic scientific problems, such as identifying the molecular structure of an organic compound, or solving equations, or sending rockets into space, can be complex. Nevertheless, in all these cases, the problem(s) can be clearly defined, plans can be drawn, many factors must be considered but in the end, a team of researchers and engineers can do it. In turn, one can "easily" say at the end if the problem has been solved or not. In contrast, problems involving social dynamics are *wicked*, because they have none of these clarifying traits. Several examples are given, such as deciding the location of a freeway, adjusting a tax rate, or modifying a school curriculum. To better understand the difference between "simple", "complex" and "wicked" problems, we adapted the comparison proposed by Roberts (2000 pp. 1–2):

1. "simple problem": A group of machinists agree that a machine has broken down, and they agree to fix it. The problem could be clearly defined, and problem solving is straightforward, engendering little if any conflicts, and within a short period the problem is solved.
2. "complex problem": School administrators agree that students are not learning in school, as judged by their results. Stakeholders become embroiled in debates about the best way to solve the problem, some arguing for an increase in school funding, some for a different teaching team, or for an improvement of students' home environments. Despite the agreement on the problem definition, conflicts related to potential solutions make the problem solving more complex.
3. "*wicked problem*": A rural community faces water shortages and an influx of wealthy people who are buying up all available houses for second homes in the area, which creates a niche for developers who build golf courses, and some of the original members of the community complain that they have to drive longer distances to find affordable housing and jobs. What is the problem? Is it the lack of affordable housing? The lack of water? The lack of jobs? Too much growth? A particular kind of growth? The lack of public transport? Is the problem local or dependent on a higher scale dynamic? Identifying the problem is almost impossible and often depends on the problem solver's agenda. Furthermore, stakeholders will block or encourage the initiative depending on their interests, leading to a potentially high level of conflicts between actors. Nothing bounds the problem solving process, as the problem is ambiguous, fluid, complex, environmental, political…in short, it is *wicked*.

The ten properties distinguishing *wicked problems* are summarized in Box 2.1. At the time when Rittel and Webber (1973) wrote their paper, the SES framework had not yet clearly emerged. In terms of its theoretical approach, by arguing for the simultaneous consideration of social and ecological dynamics and insisting on their fundamental intertwining, the SES brought *wicked problems* into the field of environmental sciences. As expressed by Balint (2011), environmental *wicked problems* defy simple solutions and are characterized by uncertainty, incomplete scientific knowledge, competing cultural values and interconnections with other problems (Balint 2011). Turnpenny *et al.* (2009) demonstrated how energy and climate change-related environmental policies, or food health, were *wicked* environmental problems. Bruggerman *et al.* (2012) described how in a coral reef context, policy actions to reduce fishing might lead to a compensatory development of agriculture and tourism, which can lead to an increased use of fertilizers that cause eutrophication in coastal areas, or more physical degradation of coral reefs by visitors.

The introductory chapter of this thesis described the multiple conflictive interactions between PAs and their peripheries. The first section of this second chapter described the coexistence issue between the SF and rural communities. Although both types of actors get benefits from the current agreement, none are fully satisfied and concerns are expressed on both sides. Is the problem the number of cattle? The modalities of the right of access? The particular areas used for grazing? The lack of grazing land in communal areas? Rural demography? Unemployment? Climate change? The historical boundaries of the land uses? The failure of CAMPFIRE to provide benefits to rural communities? The list could be long... Uncertainties about the studied SES are high, among which are, on a local scale, the robustness of the local agreement allowing herders to enter the SF or the unpredictable resource availability due to climatic variability, and on a large scale, climate change (cf. chapter 3).

Scientific knowledge related to the SF/cattle grazing problem is incomplete, the main gaps concern the rationale behind cattle herding strategies, the characteristics of the vegetation inside the SF (composition, biomass, dynamics) and the actual impact of cattle grazing on forage resources in the area. A certain level of ambiguity is maintained by local actors concerning the actual right of access that herders have. This coexistence issue relies on competing cultural (*sensu lato*) values and objectives, timber production, tourism and conservation of a valuable environment on the one hand, and the achievement of food security and historical land claiming on the other. Finally, the issue of coexistence is interconnected to other problems, such as unemployment (that lead people to focus more on subsistence agriculture), soil erosion (that threatens an already poor communal grazing area), or environmental justice (Schlosberg 2007a). The classical positivist approach, or 'normal science', consisting in defining the problem, gathering information, analyzing information and working out a solution, does not work with wicked problems (Rittel and Webber 1973). During our work, we opted for an alternative way of "doing science".

(i)	Wicked problems have no definitive formulation.
(ii)	It's hard, maybe impossible, to measure or claim success with wicked problems because they blend into one another, unlike the boundaries of traditional design problems that can be articulated or defined.
(iii)	Solutions to wicked problems can be only good or bad, not true or false.
(iv)	There is no idealized end state to arrive at, and so approaches to wicked problems should be tractable ways to improve a situation rather than solve it.
(v)	There is no template to follow when tackling a wicked problem, although history may provide a guide. Teams that approach wicked problems must literally make things up as they go along. There is always more than one explanation for a wicked problem, with the appropriateness of the explanation depending greatly on the individual perspective of the designer.
(vi)	Every wicked problem is a symptom of another problem.
(vii)	No mitigation strategy for a wicked problem has a definitive scientific test because humans invented wicked problems and science exists to understand natural phenomena.
(viii)	Offering a "solution" to a wicked problem frequently is a "one shot" design effort because a significant intervention changes the design space enough to minimize the ability for trial and error
(ix)	Every wicked problem is unique.
(x)	Designers attempting to address a wicked problem must be fully responsible for their actions

Box 2.1. The ten properties of *wicked* problems (adapted from Rittel and Webber 1973).

"Post-normal science", addressing wicked problems through interdisciplinary and participatory approaches

As stated by Voinov and Bousquet (2010), a debate exists between two opposing paradigms of science. On the one hand, the positivist paradigm leads researchers to discover an objective truth, although they realize that single truths and single solutions do not exist. On the other hand, the constructivist approach (*e.g.* Fosnot 2013) assumes that reality is socially constructed, and studying and addressing *wicked* problems therefore requires insights on local stakeholders' perspectives. This second paradigm forces us to consider social-ecological issues as fundamentally context-dependent, and any research action or policy decision as necessarily collective. Echoing the constructivist approach, the concept of post-normal science (PNS; Funtowicz and Ravetz 1991, 1993, 2003) emerged as an alternative to the Kuhnian ‘normal science’ (Popper 1970), and distinguishes a given issue according to two dimensions (Fig. 2.4): system uncertainties (i.e. complexity, lack of knowledge), and decisions at stake (i.e. potential outcomes to concerned parties) (Turnpenny *et al.* 2010). It is built around aspects usually neglected in traditional scientific practice: uncertainty, value loading and plurality of legitimate perspectives. As such, it constitutes one attempt to meet the demands of a world permeated by *wicked* issues (Funtowicz and Ravetz 2003). PNS links science and governance and is designed to study and address social-ecological problems. The PNS approach is relevant in cases where stakes are high and decisions urgent, but facts are uncertain and values are disputed (Fig. 2.4). PNS advocates for interdisciplinary initiatives, and a recursive relationship between ‘experts’, policy-makers and others likely to have a stake in the research/policy formulation, or its consequences. The understanding of the word ‘science’ in PNS is wider than conventional understanding of the word, such as experimental results, or predictive models. It refers to an activity mixing different forms of evidence, knowledge and data. In practice, PNS involves the participation of all relevant stakeholders who are concerned by the problem under study to form an ‘‘extended peer community’’ (Funtowicz and Ravetz, 1994). As expressed by Roberts (2000), participation is a way to address *wicked* problems. Creating this extended peer community helps filling the gap between the matter as it appears to local stakeholders, and the way it exists for exogenous actors such as researchers or policy makers (d’Aquino et al. 2003). Indeed, the extended peer community provides important knowledge of local conditions that scientific experts may not have.

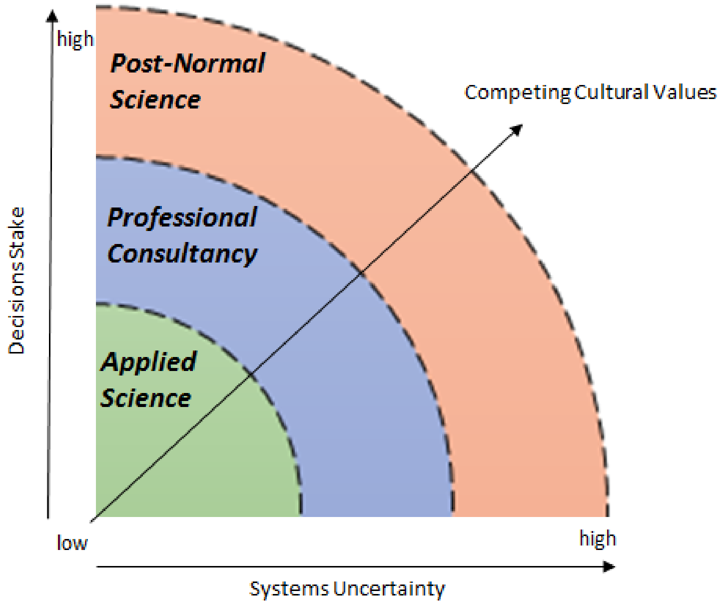

Figure 2.5. Post-Normal Science diagram (adapted from Funtowicz and Ravetz 2003).

In a research project like ours, the question of the legitimacy of external agents (researchers) to conduct participatory processes (Barnaud and Van Paassen 2013), was considered and resulted in strategical choices when we decided to involve local actors in the co-design of our research tool. The dilemma of participation is related to the consideration, or not, of power asymmetries existing within a SES. When facilitators of a participatory process (e.g. researchers) claim a neutral posture, ignoring these power asymmetries, they are accused of being manipulated by the most powerful stakeholders, therefore reinforcing asymmetries. On the other hand, what is their legitimacy when adopting a non-neutral posture empowering particular stakeholders? Such a dilemma is not solved by using a particular method, but by being reflexive about our posture (Daré *et al.* 2010, Barnaud and Van Paassen 2013). In our study area for instance, local communities and protected area managers are all equally concerned by coexistence issues and one choice could have been to involve them equally. Other research activities are conducted by our team with HNP and SF authorities, and while this cooperation legitimizes us in their eyes it also leads rural communities to see researchers (us) as conservation agents. With the objective of initiating a fair collaboration between researchers and local actors (*i.e.* creating an extended peer community) in the study area, we chose to start by involving rural communities only. First, rural communities are the owners of cattle and their participation made perfect sense (and in fact is crucial). Furthermore, this choice is coherent with our vision of conservation presented earlier. Rural communities have little or no say in conservation policies and their implementation, except for traditional leaders, but these were not directly involved in the process. We assume this posture, although we are conscious of its limits (cf. chapters 4 and 6).

Our vision of interdisciplinarity

As a transition between the previous theoretical arguments and the two paragraphs to come, we propose to give the reader a short definition of our vision of interdisciplinarity. The SES framework and the PNS approach both advocate interdisciplinary approaches. In an interview given to the blog of the journal *Nature*, "A view from the bridge"[13], Harvey Graff defined interdisciplinarity as "what emerges from the effort to develop new answers to questions or new approaches to problems when elements from different disciplines, subdisciplines or fields are required". For him there are two major myths around interdisciplinarity: (i) it is based on the integration of disciplines and requires "mastery" of these and (ii) there is one path toward interdisciplinarity, a large group and expensive science. An interdisciplinary PhD like this one is a demonstration of the validity of Graff's first point: a PhD student does not master all disciplines (yet). In the context of participatory research, we assume that communication among the extended peer community is crucial, and that a large group of researchers could bring two disadvantages. First, it could unbalance the expert/ 'profane' ratio and skew the power relationships, causing us to miss out on some of the benefits of participation. Secondly, having a large team of scientific experts could lead to disagreements about directions to take (*c.f.* Robertson's example about the school administrators given earlier), and a large scale interdisciplinarity used as a coping strategy to a *wicked* problem would take us back to the original problem.

To our way of thinking, interdisciplinarity must be context-based; there are no optimal discipline associations. Just as "part of the art of dealing with *wicked* problems is the art of not knowing too early which type of solution to apply" (Rittel and Webber 1973 p. 141), we argue that part of the art of creating interdisciplinarity is the art of not knowing too early which disciplines to integrate. Moreover, the PNS approach and the creation of an extended peer community will lead to the emergence of unexpected perspectives, new questions and

[13] http://blogs.nature.com/aviewfromthebridge/2015/09/16/the-undisciplinarian/

expectations. In the three years of this PhD, we operated with a small core team and successively or simultaneously resorted to different disciplines and fields, among them political ecology (cf. chapter 1), ethnoecology (cf. chapters 3 and 4), cognitive sciences (cf. chapter 4) and modeling (cf. chapters 4 and 5), in which we were assisted by various people belonging to these various disciplines. In our opinion, interdisciplinarity is a process rather than a framework. It must be fluid, dynamic and perpetually collectively revised.

From theories to practice

Companion Modeling

Our work was conducted according to the Companion Modeling (ComMod) approach (Etienne 2014). Developed in the 1990s by researchers from CIRAD (Bousquet *et al.* 1999), it aims at identifying the various viewpoints and knowledge that local actors implicitly refer to and use in their relationship with their environment, working out – together with local stakeholders - a common vision of a given SES in order to (i) understand its functioning or (ii) facilitate decision-making processes of stakeholders using a common resource. It is clearly positioned within PNS, with a constructivist approach through which knowledge is constructed, contingent to human perception and social experience, and not necessarily reflecting any external "transcendent" realities (Le Page *et al.* 2013 p. 529). ComMod processes have been conducted in various contexts in the past decades, such as facilitating land-use management in Senegal (d'Aquino et al. 2003, d'Aquino and Bah 2014), studying and solving conflicts over water management in Thailand (Barnaud *et al.* 2006, 2008) and Bhutan (Gurung *et al.* 2006), improving collective awareness of sustainable reedbed use (Mathevet *et al.* 2007), initiating collective management of erosive runoff risks in France (Souchère *et al.* 2010), or exploring hunting practices in African tropical forests (Le Page *et al.* 2015). All of these ComMod processes shared common characteristics. There are six types of human protagonists in a ComMod approach (Etienne 2014). The first four are endogenous actors: (i) "profane actors" drawing their knowledge from their empirical experience of the world, (ii) "researchers" drawing their knowledge from their academic background, (iii) "technicians", who are generally exterior to the system but who will be occasionally consulted on precise matters and (iv) "institutionals", who are for example policy makers and have their own vision and knowledge of their system. Two types of exogenous human protagonists are found in ComMod processes: (i) “ComModians”, researchers who have mastered the approach and its ethical implications and rules, and (ii) “students” (for instance PhD students), who are learner ComModians and who will, through the implementation of a ComMod approach, test their scientific knowledge and build their own vision of the ComMod approach, and master it in turn. In our case, the co-design team was composed of 2 “researchers” and 1 PhD “student” (they were the ComModians), and 10 “profane actors” (villagers from our study area). During the process, we got advice from other ComModians, who played the role of “experts”. Among the fundamentals of ComMod are the loop between the models and reality. These loops constitute an iterative process during which the model is designed, tested and redesigned with local actors. Figure 2.5 shows these iterations in our work (cf. chapter 4). ComMod processes are long processes. In our case, two years passed between the beginning of the ethnographic work and the implementation of the RPG. During three workshops, four successive versions of the RPG were built during this period. The process was undeniably long, partly due to our choice of spending time to understand the local context and meet local actors through ethnographic work. This first step of our work is not mandatory in a ComMod process (Mathevet *et al.* 2011), some considering that some sort of context description is crucial because it will influence the modalities of participation (e.g. choice of actors, social dynamics considered), some arguing that the results of such endeavor will be incomplete and highly subjective, the ComMod process being the process through which participants will propose the key contextual elements needed. Several reasons led us to start with ethnographical fieldwork. Beyond individual academic backgrounds, it was seen as a way to discover the study area, explore potential re-framings of our work (which happened), start collecting data and introduce ourselves to start building social relationship and trust with local actors. It also reflects our will of integrating discplines, ethno-ecology in that case. By doing so, we distinguished ourselves from the way social scientists were usually involved in ComMod processes, which is during the process and led to misunderstanding and sometimes “conflictive” situations (Charles *et al.* 2008)

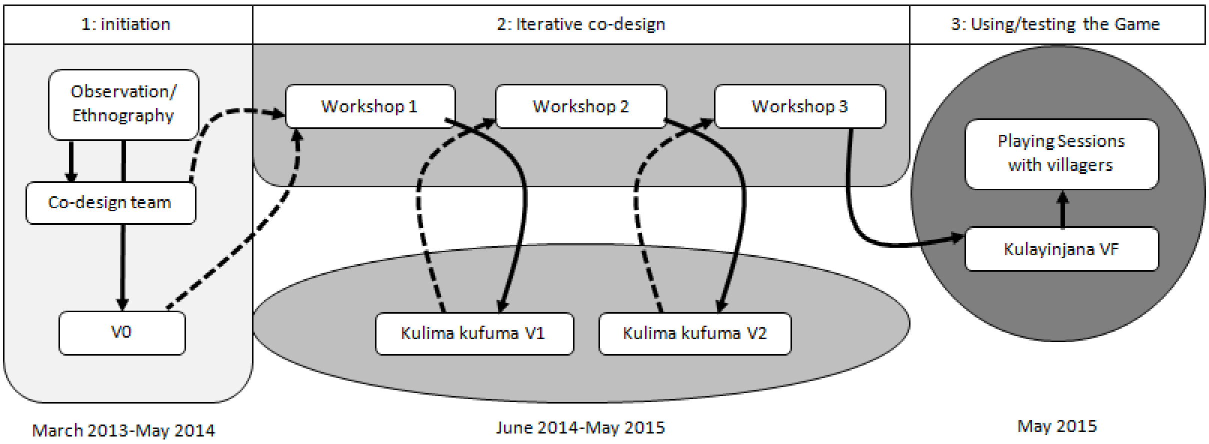

Figure 2.6. The Role Playing Game co-design process. *Plain arrows represent creation or (re)design phases, dashed arrows represent testing phases.*

Agent-Based Models, Role Playing Games and situated knowledge

Agent-Based Models (ABMs), or Multi-Agent Systems (MASs) are one of the recurrent tools for studying natural resource management and socio-environmental dynamics (Schlüter *et al.* 2012), and the literature provides various examples of applications (Bonnefoy *et al.* 2001, Bousquet and Le Page 2004, Janssen and Ostrom 2006, Acosta *et al.* 2014, Carter *et al.* 2015). An ABM is a computer program composed of a set of smaller autonomous programs called "agents": systems that are situated in some environment and that are capable of autonomous actions in this environment in order to meet the design objectives of the ABM. Multi-Agent Systems originally emerged from the field of distributed artificial intelligence. Agents are virtual *alter egos* of living organisms that can evolve, communicate and interact in a shared environment. Agents behave according to internal decision-making processes (DMPs) that are coded within the model. DMPs can be simply characterized by the value of a key parameter to which the agent will react, or integrate complex mechanisms through which agents will perceive and monitor their surrounding natural and social environment, choose among a range of possible actions and readjust their strategies to fulfill their objectives (Le Page *et al*. 2013). The challenge is therefore to elicit local actors' DMPs and formalize them in a computer language that codes agents' behavior. The theory of *situatedness* (Clancey 1997) states that knowledge can only be represented once a person has actually put his or her knowledge into use. In other words, understanding is achieved through observing the actions. If our objective is to model practices, we therefore need a way to observe actors putting their knowledge into use in a controlled environment in order to link the variety of possible actions to the context in which they take place, and their repercussions on the environment. One could easily imagine the difficulty of conducting real life experiments like that. The use of a Role-Playing Game (RPG) allows us to bring local actors to re-enact their practices in a controlled environment, record their strategies and their consequences. By co-designing the game, we aimed at proposing a virtual environment as close as local representations as possible. The direct reactions of the environment also allowed us to cope with the time issues. Indeed, observing annual variations of herding practices would take a year, while with a RPG, it can take a few hours, depending on the time step adopted for the game. Furthermore, if individuals are key elements of a system, behaviors are influenced by collective dynamics. A knowledge elicitation exercise must therefore include these two dimensions, which is exactly what the game does by having several participants simultaneously playing the game. ABMs and RPGs (computer-based or not) have the same formal architecture (Barreteau and Abrami 2007) with autonomous agents/players dynamically interacting among themselves, within but also with a (virtual) environment. Results from the use of a RPG can therefore directly nurture an autonomous ABM and lead to simulations of the studied system.

CHAPTER 3. Ethnographical fieldwork: Exploring rural livelihoods and local knowledge

WHAT IS THIS CHAPTER ABOUT?

This chapter presents the ethnographical fieldwork conducted prior to the co-design of the role-playing game. As we briefly explained in the previous chapter, there is a gap between the way a researcher will consider his object of research (in our case cattle herding at the edge of the Sikumi Forest) and the way this object appears for local actors. The immersion in rural communities' reality was a way for us to start filling this gap. In other words, with the objective of initiating a participatory process with local actors, this particular moment allowed us to gather necessary knowledge about the system to legitimize ourselves as leaders of a participatory process dealing with reality, and we could meet and know key people in the area and, most importantly, be known by them, and thus start building mutual trust.

During this ethnographical fieldwork, we were hosted by a family and shared their life, observing and participating in their daily activities. Several months of life shared with rural communities allowed us to acquire a good knowledge of local livelihood and production systems. We focused on gathering local knowledge related to agriculture and cattle herding. In this semi-arid social-ecological system, we hypothesized a central role of climate in agricultural practices.

This chapter comprises two sections:

- The first part presents our main findings concerning the local seasonal and agricultural calendars. We will provide the reader with a general overview of rural communities' knowledge and practices and how these are articulated with the climate.
- The second section is adapted from a paper submitted to the *Journal of Southern African Studies*. We propose an in-depth study of local ethno-meteorological knowledge, that is, local knowledge related to weather forecasting methods. Indeed, rural communities in the area rely mostly on subsistence farming. Food production relies on rain-fed agriculture and being able to anticipate the rainy season and rainfalls during the season is crucial for villagers. As explained in the previous chapter, our study area is multi-cultural and we explored the knowledge system of the two dominant groups.

Introduction: exploring local knowledge and practices

There are many ways to initiate a ComMod process. One can start by an initial diagnosis based on secondary data (Barnaud *et al.* 2008), or begin straightaway by the creation of a co-design team and proceed to the construction of the ABM or the RPG. Drawing lessons from Becu *et al.* (2005), we decided to first take time to discover the reality of local actors, with several months of ethnographical fieldwork. As suggested by d'Aquino et al (2003), there is a gap between the real matter as it appears to local actors, and the matter as it exists for researchers who remain fundamentally exogenous. As this was our first experience in this part of the country, this gap was even wider. The will to dedicate time to immersion in the everyday life of local actors was our answer to two personal interrogations "how can we find legitimacy in a participatory process if we don't know the life of local actors?" and "How can we expect people to engage themselves in a long participatory process if they do not know us?". Indeed, the question of the legitimacy of the researchers is salient in the field of participatory research (Barnaud and Van Paassen 2013). Although issues around cattle concern diverse local actors, the choice was made to focus on rural communities. This position was assumed for several reasons. Rural communities are the owners of cattle, and the ones making decisions about herding strategies, whereas the SF managers are rather institutional actors.

Rural populations living in Ward 15 of Hwange District rely on rain-fed agriculture (Rockström *et al.* 2004, Cooper *et al.* 2008, Mutekwa 2009, Schrimpf and Feil 2012). In a semi-arid environment, climate is at the heart of food security and is logically the central thread of this chapter. Our first objective was therefore to explore agricultural practices as a whole, without restricting the analysis to cattle herding, and the articulation of these practices with climate. By doing so, we expected to gather a "minimum" knowledge about local farming practices to bring into the co-design process. As facilitators of a participatory process, we could not be naïve and needed to have our own understanding of the system. Simultaneously, by sharing rural communities' everyday life we wanted to become, to a certain extent, local actors of the SES. In other words, building our own understanding of the system beyond what is described in the literature, and knowing and being known by local actors, was our first step towards legitimacy as facilitators of a participatory process.

Methods: an ethno-ecological approach

The ComMod approach is intrinsically interdisciplinary. In this first part of fieldwork, we adopted an "ethno-ecological" approach. Ethno-ecology is a subdiscipline of anthropology that can be described as "the study of bidirectional relationships between a human society and its environment, based on the one hand on the perceptions that individuals have of themselves about the environment and the consequences of their actions on it (emic), and on the other hand on an external analysis of the environment and human actions (etic). It involves the observations and descriptions of practices linking humans and their environment and allows highlighting of ecological constraints and livelihoods of human groups in a given environment" (adapted from Bahuchet 1986). The notion of Local Knowledge Systems (LKS) is linked to the ethno-ecological approach. LKSs are complex sets of knowledge and know-how, practices and rules that guide societies in the everyday lives of people. Developed and sustained through generations of informal 'trial-and-error experimentations' and based on an intimate understanding of the biophysical and social world, LKSs are anchored within the cultures of those who hold them (Anderson et al. 2012).

Conducting research on local knowledge does not necessarily imply respect and consideration for local cultures (Shackeroff and Campbell 2007). In an interdisciplinary project like ours, the risk is to lose sight of local actors' rationales (Dounias 2011) in a practical separation between knowledge and culture. In other words, a quantitative approach would have been directly usable in the initiation of the design of the role-playing game, but the risk would have been to produce an erroneous and incomplete typology or classification of local knowledge and practices (Agrawal 2002, Shackeroff and Campbell 2007). Furthermore, as stressed by Dowling (2000), knowledge is power and the translation, analysis and publication of local knowledge can affect its holders. This warning is particularly important in participatory processes where local actors are not only consulted, but also involved as part of a process that will necessarily impact the local SES (cf. Chapter 2, box 2.1 point (x)).

In order to minimize the potential deformation of local villagers' knowledge and practices, we focused our efforts on a qualitative approach. In order to study the LKS and the related practices concerning agriculture and cattle herding, we chose a classic methodology in social sciences: direct and participatory observations combined with open and semi-structured interviews. During this first phase of our work, we were hosted by a rural homestead living in Magoli (cf. Chapter 2, Fig. 2.1), and shared their everyday life for several months, although our presence was not continuous, as we alternated two or three weeks in the communal area and a week out. We employed a local villager as our translator, and trained him for a few days. Most of our interviews were conducted in local languages. Several local names will be used in this chapter and the language concerned will be specified between brackets: 'Nb' for ChiNambya, 'Nd' for SiNdebele.

Secondary data were used. We had access to census books kept by traditional leaders, which record not only population but also livestock censuses. We were not the first researchers to have worked with rural populations of Ward 15. Previous studies conducted by Guerbois (2012, 2013) and Miguel (Miguel *et al.* 2013), among others, brought particular insights, and the historical presence of these researchers in the area facilitated our integration into the local social network, as we were identified as their colleagues.

The fields, the cows and the forest: a holistic approach to rural livelihoods at the edge of a protected area

Food production: farming in a semi-arid area

We have already explained how rural populations of this region rely on subsistence farming. Agricultural production is centered on three cereals: maize (*Zea mays*), sorghum (*Sorghum bicolor),* and millet (*Pennisetum glaucum*). Ground into flour and mixed in boiling water, they give the local staple food: *sadza*[14]. A typical meal is composed of *sadza*, most of the time eaten with legumes (peas, beans), vegetables (onions, tomatoes), and occasionally meat (Fig. 3.1). Although villagers we met usually declared they favored millet *sadza*, it appears that most of the *sadza* consumed is made of maize. One of the explanations for this fact is that unlike millet, which necessitates several processing steps, maize needs only to be dried and ground before being cooked. As explained by a Nambya villager (Magoli),

> "Sadza *is better with millet, it feeds you more, but with maize we've got better harvests if rain is there, and it dries up faster…you see millet needs two months before we can prepare it, and it's long, but with maize it is faster*."

Finally, maize *sadza* is regarded as a modern food, the one eaten in towns. Maize flour, often known as "milly meal", is sold in shops and delivered by food aid non-governmental organizations, and this also tends to homogenize peoples' tastes. Small grains such as sorghum and millet are also brewed to produce traditional beer called *busukwa* (Nb), *utshwala* (Nd) or "seven days", as it takes seven days to brew. This beer is produced for self-consumption, but also to be used as payment when one needs help from neighbors, for instance to plow or build. Other plants are grown in fields, such as groundnuts (*Arachis hypogaea*), Bambara groundnuts (*Vigna subterranea*) and cowpeas (*Vigna unguiculata*), but also a wide variety of cucurbits (*Cucurbita* spp.).

[14] *Sadza* is the standardized word used across the country.

En	Nb	Nd	Sci	Cons	Harvest	Consumption
Maize	*chimanga*	*umumbu*	*Z .mays*	grains	March/Apr	Fresh cobs boiled or roasted
					Apr/June	*Sadza*
Millet	*inzembwe*	*inyawhuti*	*P. glaucum*	grains	Apr/June	*Sadza*
Sorghum	*mafhunde*	*amabele*	*S. bicolor*	grains	Apr/June	*Sadza*
	impwe	*infe*	*S. bicolor*	stem	Apr/June	Chewed as "sugar cane"
Groundnuts	*mandongo*	*izambane*	*A.hypogaea*	fruit	Feb/June	Raw, ground, roasted
Bambara groundnuts	*inyimo*	*indlubu*	*V. subterranea*	fruit	Feb/May	Boiled
Cowpeas	*inyemba*	*indumba*	*V. unguiculata*	fruit	March/may	Boiled
Rape	-	*chomolia*	*Brassica sp.*	leaves	Apr/May	Sliced and boiled
Gombo	*okra*	*okra*	*Ibiscus esculentus*	Leaves/ fruits	All year	Boiled
Tomatoes	-	-	*Solanum lycopersicum*	fruit	All year	Sauce
Watermelon	ibisi	-	*Citrullus lunatus*	Fruit	Jan/May	Raw

Table 3.1. A sample of Food crops in the study area. *En: English name; Nb: ChiNamnya name; Nd: SiNdebele name; Sci: Scientific name; Cons: part consumed; Harvest: usual harvesting period; Consumption. A "-" means the English name is used. The cucurbits do not appear in the table. We couldn't identify the species, but at least 4 different types of cucurbits are named. They are harvested between January and May, and both fruits (boiled) and leaves (boiled or fried) are consumed.*

We defined the three climatic seasons in the introduction: a rainy season from broadly October to April, a cold and dry season from May to August and a hot and dry season from September ro October. This is the average pattern, and the onset, intensity and end of each season, particularly the rainy season, fluctuate greatly. When villagers were asked to define their own seasonal calendars, these fluctuations were even more salient and manifested themselves through the heterogeneity of sesonal calendars described by our informants (Tab. 3.2). Only three variations of the local seasonal calendar are shown, but during our interviews, we could identify up to nine variations.

The agricultural calendar is obviously linked to the rainy season. Local weather forecasting knowledge plays a crucial role in local communities' subsistence. Indeed, the rains are heterogeneous, both in space and time.

Figure 3.1. A few typical dishes. *The left column shows three different non-meat side dishes, top to bottom: okra (Abelmoschus esculentus), beans (bought) and potatoes. The right column shows three different types of protein-rich animal foods, from top to bottom: beef, chicken and "mopane worms" (caterpillars of Gonimbrasia belina [Lepidoptera: Saturniidae]).*

Official weather forecasts are often irrelevant and not always available, and agricultural decisions (preparing seeds, plowing, harvesting) rely on the ability of villagers to anticipate the weather (cf. second part of the chapter). Two types of agricultural calendars were noted and depend on the plowing strategy. Farmers following the first strategy wait for the first or the second rain of the season to start plowing their fields, usually at the end of November or early in December. Those following the second strategy practice dry planting and plow their fields at the beginning of October. Although one can find farmers practicing only dry planting, or only wet planting, most farmers rely on combining the two strategies and adapt their practices according to the situation. To optimise their yields, local farmers mix long- and short-season crops. The long-season crops are usually local breeds, rustic varieties that are used for dry planting or when rains are abundant. Short-season crops are used for late planting.

Nov	Dec	Jan	Feb	Mar	Aprl	May	Jun	Jul	Aug	Sep	Oct

Table 3.2. Examples of three seasonal calendars described by local informants living in the study area. *The rainy season is represented in blue, the cold and dry season in yellow and the hot and dry season in orange.*

The reason why we present agricultural practices in a thesis focused on cattle herding strategies in a PA (protected area) is that these two activities are fundamentally dependent on each other. Indeed, throughout the months spent in the communal area we realized that although cattle were driven inside the SF (Sikumi Forest) to find forage and water, this practice was also a way to prevent cattle from going into farmers' fields.

Agriculture, wealth and social networks, insights into the multiple dimensions of cattle in the study area

Based on local records, only 32% of homesteads living in the study area have cattle. In average, these families each own 5.46 cattle (sd = 4.19). Livestock is nevertheless central to agricultural production and draft animals, if not owned, are often borrowed or sometimes rented, enforcing social cohesion in the area. Livestock is the main form of capitalization for rural populations. Beyond their agricultural value, cattle also have a social dimension. A large herd is a sign of wealth, and cattle traditionally participate in the payment of the bride price, locally called *lobola*. Although foraging resources are a crucial driver, the cattle-herding calendar is largely determined by agricultural practices (Valls-Fox *et al.* In prep) and we can broadly distinguish three phases of cattle grazing. Once crops are planted, cattle are actively herded in order to minimize incursions into fields. Not every owner sends his cows into the SF, and some favor the communal grazing areas, which present lower risks of predation. Cattle herded out of the communal area feed approximately from 11h00 to 16h00 in the forest, and natural water pans shape the herd's movements. The routes followed by cattle inside the SF change throughout the season, as Figure 3.2 shows. These shifts depend on water availability, but also on affinities between herders, who avoid or join each other during the day.

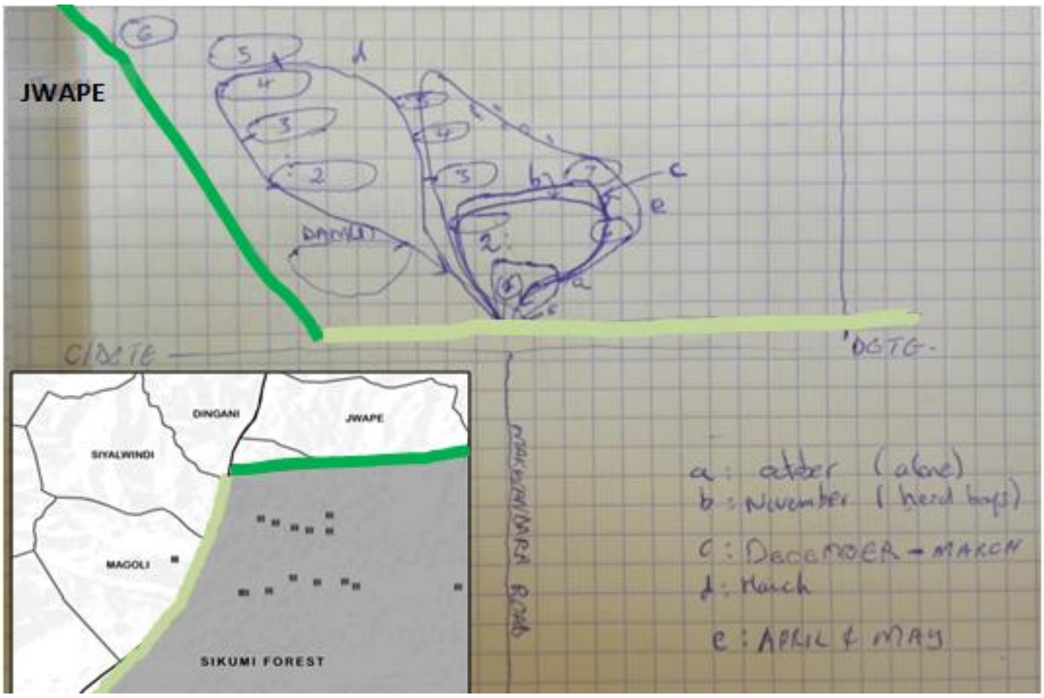

Figure 3.2. Map of cattle-herding roads in the Sikumi Forest drawn by a local herder. *To facilitate the understanding of this hand-drawn map, we extracted a part of the map of the study area (Fig. 2.1) and added the location of one village (Jwape) and of the two boundaries between the SF and the communal area. The two lines of water pans clearly appear. The herder drew five different routes followed by cattle (a, b, c, d, and e), and the indicated the months during which each route is used, as well as whether cattle are left alone (October) or not (from November).*

The date from which livestock can begin to roam freely in the communal area is annually defined by local traditional leaders, and is called *xotshela*, meaning "release" in *SinNdebele*. The traditional leader in charge of the Ward, called the *headman*, evaluates the state of fields and decides of the *xotshela* date, usually at the end of May or beginning of June. Once it is chosen, farmers have to make sure all their fields are harvested in time. From *xotshela*, all cows are released in the villages and roam free, feeding on grass and crop residues left in the fields, and drinking either in communal reservoir, if they are not dry, or at boreholes. Crop residues are often partly stored within the homestead (usually on a wooden platform or up a tree), where they are used to feed cows around the kraal and prevent them from wandering too far from the homestead. Towards the end of August, cattle start going unguarded into the forest. During this time, they usually go deeper into the forest and herders are often forced to go and collect them, sometimes more than 7 km inside the SF. This general pattern is shown by the majority of cattle herds, but on an individual scale, cattle-herding strategies are complex mechanisms that depend on personal histories of owners and herd-boys, a perpetual consideration of dynamic environmental parameters, the proximity of homesteads to the forest, and the herding strategies employed by neighbors.

After reading this first part of the chapter, the reader will know the fundamentals of food production in the study area and will have a global understanding of the seasonal, agricultural and herding calendars. The second part will give an in-depth study of local ethno-meteorological knowledge. We would like to think that this second part, although appearing as a "stand-alone" publication in our work, is actually entirely part of our approach, as it helped us understand local perceptions of climate and weather, which play a central role in the role-playing game. Nevertheless, the reader is free to proceed directly to Chapter 4 and discover how we co-designed the game, returning to finish Chapter 3 later.

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(The style of the title and figures numbers were adapted to adopt the style chosen for the manuscript, the journal's referencing system was kept)

Reading the environment: dynamics of the ethno-meteorological knowledge system of a multicultural community farming in a semi-arid area of Zimbabwe

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Abstract : We describe local ethno-meteorological knowledge systems of a multicultural community of western Zimbabwe. The two ethno-linguistic groups considered are the amaTabele and the baNambya, two Bantu groups. We analyzed the way subsistence farmers classify rains, produce local meteorological forecasts, and the internal dynamics of this knowledge in the multicultural context. We show that these two groups present very similar weather forecasting knowledge. Farmers are good observers of their natural environment, from which they draw sets of ethno-meteorological indicators. Observations by individuals of such indicators are shared and discussed among social networks that mix ethno-linguistic groups within the community. This sharing is essential as it is part of agricultural cooperation. Simultaneously it creates intra- and inter-group dynamics through which baNambya and amaTabele share and re-create a common knowledge. This knowledge allows farmers to cope with the inherent climatic heterogeneity. Southern Africa will experience significant changes in annual temperature and rainfall patterns during the forthcoming decades as consequences of the climatic changes generated by human activities. There is an urgent need to understand how global changes, including climate change, will impact LKSs, for example through environmental shifts due to aridification. By gathering data on this theme, we will improve our understanding of the impacts that global changes will have on rural communities and thereby contribute to enhance the capacities of small-scale farmers to cope with these changes.

Introduction

Local Knowledge systems (LKSs) are complex sets of knowledge and know-how, practices and rules that guide societies in the everyday lives of people. Developed and sustained through generations of informal 'trial-and-error experimentations' and based on an intimate understanding of the biophysical and social world, LKSs are anchored within the cultures of those who hold them[15]. Although culture is classically considered as a whole, one can consider LKSs as a sum of different compartments that can be studied individually[16]. When looked at in relation to agriculture, local knowledge is particularly important because of the role it plays in the subsistence of farming households, which account for 60% of the population of sub-Saharan Africa[17].

Despite the general recognition of the role of anthropology in research on adaptation to climate change[18], most studies of LKSs to date have focused on plant and animal species and related knowledge and practices, and only few have considered knowledge of natural physical phenomena[19,20] such as the weather[21]. This knowledge is nevertheless essential to the resilience of rural communities [22]. In southern Africa for instance, they allow communities to cope with

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[15] For a detailed and comprehensive treatment of the field, see (Anderson et al. 2012)
[16] (Olivier de Sardan 1995)
[17] L. Séhouéto, 'Savoirs Agricoles Localisés et Production Vivrière en Afrique Subsaharienne', *Revue internationale des sciences sociales*, 187 (2006), pp.127-134.
[18] C. Roncoli, T. Crane, and B. Orlove, 'Fielding Climate Change in Cultural Anthropology' in S. Crate and M. Nutall (eds), *Anthropology and Climate Change: From Encounters to Actions* (San Francisco, Left Coast Press, 2009), pp. 87–115.
[19] N. Chalmers and C. Fabricius, 'Expert and Generalist Local Knowledge About Land-Cover Change on South Africa's Wild Coast: Can Local Ecological Knowledge Add Value to Science', *Ecology and Society* 12, 1 (2007).
[20] S. Strauss and B.S. Orlove, 'Up in the Air: The Anthropology of Weather and Climate', in S. Strauss, and B. Orlove (eds), *Weather, Climate, Culture* (New York, Berg, 2003), pp. 3-14.
[21] For a few case studies see for example N. Anandajara, M. Ramasubramanian, P. Saravanan and N. Suganthi, 'Indigenous Weather Forecast Practices of Coimbatore District Farmers', *Indian Journal of Traditional Knowledge*, 7 (2008), pp. 630-633; T. Huber and P. Pedersen, 'Meteorological Knowledge and Environmental Ideas in Traditional and Modern Societies: The Case of Tibet' *Journal of the Royal Anthropological Institute*, 3 (1997), pp. 577-98; C. Ifejika Speranza, B. Kiteme, P. Ambenje, U. Wiesman and S. Makali., 'Indigenous Knowledge Related to Climate Variability and Change: Insights from Droughts in Semi-Arid Areas of Former Makueni District, Kenya', *Climatic Change* 100, 2 (May 2010), pp. 295-315; B. Orlove, C. Roncolil, M. Kabugo and A. Majugu, 'Indigenous Climate Knowledge in Southern Uganda: The Multiple Components of a Dynamic Regional System', *Climatic Change*, 100,2 (May 2010), pp. 243-65; Carla Roncoli, Keith Ingram, and Paul Kirshen, 'Reading the Rains: Local Knowledge and Rainfall Forecasting in Burkina Faso', *Society & Natural Resources*, 15, 5 (May 2002), pp. 409-427.
[22] F. Berkes, C. Folke, and G. Madhav, 'Traditional Ecological Knowledge, Biodiversity, Resilience and Sustainability', *Ecology, Economy & Environment*, 4 (1994), pp. 269-287.

inherent climate variability, and possibly to adapt to climate change, which is among the major current threats to rural populations' livelihoods[23].

Southern Africa is characterised by high intra- and inter-annual climatic variability. For a given location, annual rainfall can vary between 200 and 1000 mm, which corresponds to the average regional amplitude[24]. This variability leads farmers to cope with unpredictable rainfalls. In addition, climatic trends assumed to be due to global warming are of major concern for the region. According to climate change scenarios, annual rainfall in the region should decrease by about 10%[25] by 2100[26], halving rain-fed agriculture production by 2020[27], with dramatic impacts on food security in the region[28]. Consequences of climate change are already observed. The tropical belt has widened by 2 to 4 degrees[29]. Analysing climatic data from 1961 to 2000, New *et al.*[30] showed evidences of an ongoing aridification in southern Africa, with a significant increase in the numbers of hot days and nights, a decrease in the number of cold days and nights[31], and a general decline of annual rainfall going along with an increased frequency of extreme events, *i.e.* floods and droughts.

The work presented here focused on rain-related knowledge of a multilinguistic rural community living in a drought-prone area of Zimbabwe[32]. In the past century, the country experienced several severe droughts, for instance in 1992[33]. Although the inherent climate variability makes the detection of climate change effects difficult[34], Chamaillé *et al.*[35] showed

[23] S. Bharwani, M., Bithel, T.E. Downing, M. New, R. Washington and G. Ziergovel, 'Multi-Agent Modelling of Climate Outlooks and Food Security on a Community Garden Scheme in Limpopo, South Africa', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360, 1463 (November, 2005), pp. 2183-2194.
[24] M. New, B. Hewitson, D. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C. Coelho, D. Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M. Mdoka, R. Lajoie, 'Evidence of Trends in Daily Climate Extremes over Southern and West Africa', *Journal of Geophysical Research*, 111, (2006); R Schulze, 'Modeling Hydrological Response to Land Use and Climate Change: A Southern African Perspective', *Ambio*, 29 (2000), pp. 12-22.
[25] Compared to the average annual rainfall recorded during the 20th century.
[26] (Giannini *et al.* 2008)
[27] Oxfam, *Adapting to Climate Change: What's Needed in Poor Countries, and Who Should Pay*, Oxfam briefing paper (Oxfam International, 2007).
[28] V. Mutekwa, 'Climate Change Impacts and Adaptation in the Agricultural Sector: The Case of Smallholder Farmers in Zimbabwe', *Journal of Sustainable Development in Africa*, 11, 2 (2009), pp. 237-56.
[29] (Siedel *et al.* 2008)
[30] *ibid*
[31] Were considered as "hot" every days and nights when the temperature is superior to 90% of the average temperature on the same period, and "cold" every days and night when the temperature was inferior to 10% of the average temperature on the same period.
[32] (Vincent and Thomas 1961)
[33] (Maphosa 1994)
[34] (New *et al.* 2006)
[35] (Chamaillé-Jammes *et al.* 2007)

how droughts have worsened in western Zimbabwe in the past thirty years. Subsistence farmers are already facing a constraining environment with poor soils and unpredictable rainfalls, and such a trend is of major concern for food security. Villages we worked in are not remote and official weather forecasts are, to a certain extent, available. Some people have a radio but these necessitate buying batteries, or having solar panels. Newspapers are available in Dete or in Cross-Dete, respectively about 6 and 7 kilometers away, which represents a 3 hours walk round-trip. Money is an obvious factor limiting the access to official weather forecasts. Furthermore, official forecasts are often irrelevant for farmers. Due to their probabilistic nature, and to the fact that they provide information on a regional scale, and for a full season, seasonal forecasts are hardly appropriated by farmers[36]. On a local scale, rains are most of the time very localized and a ward-wide forecast available in newspapers, for instance, is not accurate enough in an area characterized by extreme climatic heterogeneity. The ability to produce local weather forecasts is essential for rural communities. Local knowledge plays a major role in coping strategies and is therefore at the heart of local communities' resilience to climate change. Understanding this knowledge and the way it evolves is crucial and could lead to aid in building adaptive capacity.

Our first objective was to provide a detailed ethnography of rain-related local knowledge. We focused on how rains are classified and on traditional rain-forecasting methods. We also investigated the connections between perception of the environment and agricultural calendars and practices. The second objective of our work was to understand the local dynamics of knowledge. The villages studied are inhabited by different ethno-linguistic groups; hence this multicultural context was an opportunity to investigate the dynamics of local knowledge, and especially the processes of both diffusion and sharing of climate-related knowledge. In other words, we focused on whether or not different ethno-linguistic groups living together have similar rain classifications, similar ways to anticipate rains and ways to anticipate extreme events like droughts or floods.

Methods

The community studied lives in Ward 15 of Hwange district (Figure 3.3), Matabeleland North, in western Zimbabwe. The respondents with whom we interacted are spread in five

[36] On a brilliant attempt to overcome this issue, see A. Patt and C. Gwata, 'Effective Seasonal Climate Forecast Applications: Examining Constraints for Subsistence Farmers in Zimbabwe', *Global Environmental Change* 12, 3 (2002), pp. 185–95.

contiguous villages, namely Magoli (now named “Bitu”), Siyalwindi, Dingani, Chezhou and Mambanje. These villages are wedged between two Protected Areas: Hwange National Park and the Sikumi Forest. During our stay we were based in Magoli and accommodated by a Nambya family. A first round of 22 semi-structured interviews (14 men; 8 women) was conducted during the 2012 dry season (March to May). A second round of 22 interviews (7 men; 15 women) was carried out in October 2013, a few weeks before the onset of the rainy season. Homesteads were chosen randomly and for each one we interviewed either the household head or the oldest available person.

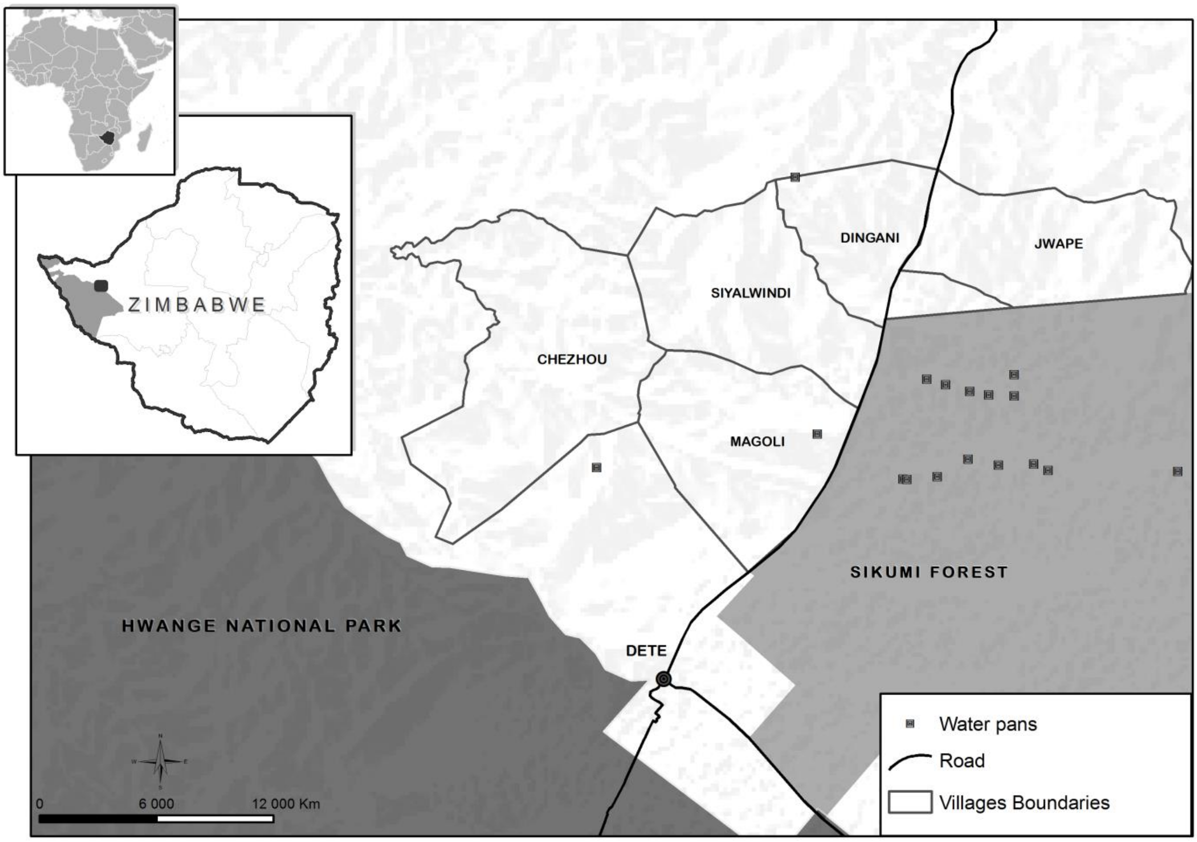

Figure 3.3. Study area.

We conducted semi-structured interviews covering several topics. The first part was focused on rain classifications, with the objective of leading the respondent to name (in his/her mother language) and give descriptions of the different types of rain occurring in the area. The name given to the rainy season was collected during this first part of the interview, along with the usual rainfall pattern. The second part of the interview aimed at collecting all the indicators and practices the respondent could use/do to predict the arrival of the rainy season, and rainy events during the season. Interviewees were also asked to explain the origins of their knowledge. Finally, during the third part of the interview we asked the respondents to explain their agricultural decision-making processes in relation to their weather-related observations. The objective was to understand how the rain-related knowledge was used to observe the environment and how this could, individually or collectively, lead the interviewee to take practical decisions concerning his agricultural calendar. We completed these interviews with group discussions and free discussion with our hosting family. Direct observation constituted a major source of information. All interviews and discussions were conducted in English and in either of the two local languages, ChiNambya and SiNdebele, respectively the language of baNambya (sing. Nambya) and amaTabele (sing. Ndebele) people[37].

Context of research

A multicultural and plurilinguistic community

The coexistence and mixing of different ethno-linguistic groups is intrinsically part of the history of Matabeleland[38]. Pre-colonial invasions[39,40,41], wars and alliances between groups, and the colonial and modern era marked by large resettlement programs, created complex ethnic assemblages countrywide [42,43,44]. Local traditional leaders we met during our work confirmed that within Matabeleland, the Hwange district is located in the "Nambya area"[45]. The name

[37] Translations from vernacular to English were done by two local translators fluent in these two local languages and in English. Some of the words or expressions given in the paper were translated using dictionaries: an English-ChiNambya dictionary locally published by the Nambya Cultural Association (Hwange), and a SiNdebele-English dictionary (J.N. Pelling, *A Practical Ndebele Dictionary, Second Edition* (Harare, Longman, 1971)). Informants' quotations used in this paper are written in English. A "*"indicates that the quote was translated to English.

[38] Zimbabwe is divided into eight provinces according to ethno-linguistic parameters: Matabeleland North and Matabeleland South dominated by SiNdebele speaking people; Midlands, Mashonaland West, Mashonaland Central, Mashonaland East, Midlands, Manicaland, and Masvingo, dominated by ChiShona speaking people .

[39] B.Lindgren, 'The Internal Dynamics of Ethnicity: Clan Names, Origins and Castes in Southern Zimbabwe', *Africa*, 74, 02 (May 2004), pp. 173-93.

[40] G. Mazarire, 'Who Are the Kalanga and the Ndebele ? Report of the Project 'Ethnicity in Zimbabwe'' (Konrad Adeneur Foundation, 2003).

[41] A. Mlambo and B. Raftopoulos, *Becoming Zimbabwe, a History from the Precolonial Period to 2008* (Harare, Weaver Press, 2009).

[42] D. Compagnon, 'La Prétendue 'Réforme Agraire' Au Zimbabwe', *Études*, 3 (2003), pp. 297-307

[43] G.T. Ncube, *A History of Northwestern Zimbabwe, 1850-1960* (Bulawayo, Mond Books, 2004).

[44] P. Nyathi, *Zimbabwe's Cultural Heritage* (Bulawayo, 'amaBooks, 2005).

[45] P. Hubbard and G. Haynes, 'Mtoa Ruins, Hwange National Park, Zimbabwe', *Zimbabwean Prehistory*, 30 (2012), pp. 25-33.

Hwange itself (applied to the district, its principal town and the national park within it) is derived from *Wange*, the dynastic title of Nambya rulers. There is still a Chief Hwange, whose jurisdiction includes Hwange town and its surroundings. Several Nambya sacred places can be found in the district, such as *Chigehari* (about 30 km north of our study area), a hill believed to be inhabited by the Nambya ancestors' spirits. Ruins of Nambya cities dated from the 19th century, such as the *Mtoa* and the *Bumbusi* ruins, both located inside Hwange National Park, are key spiritual loci for baNambya people. The bodies of historical Nambya rulers are buried under the ruins, and *Mtoa* is assumed to have been an important rain-calling site for the area, at least until the arrival of the SiNdebele-speaking tribe in or around 1865[46].

Interactions between baNambya and amaTabele people began when Mzilikazi Khumalo and about 500 of his men split apart from the Zulu Kingdom (in the northern part of South Africa) in 1821. During their migration from Zululand, Mzilikazi and his people assimilated individuals of other Bantu groups such as maShona, maKalanga, and Sotho people, among others, creating a complex society[47]. The Ndebele kingdom no longer exists, but Bulawayo, its former capital, is now Zimbabwe's second largest city.

Although ChiNambya and SiNdebele belong to different clades of Bantu languages[48], they both belong to the S zone of Bantu language[49] and therefore are partly mutually intelligible, as they present a certain number of cognate terms. This proximity of languages is the first factor explaining plurilingualism in our study area, *i.e.* the fact people from different ethno-linguistic groups living together can speak each other's language. During our fieldwork we came to meet many families in which one of the parents was Ndebele and the other one was Nambya. In such a situation, children will learn their mother's language first. In all situations, they would learn SiNdebele and English at primary school, as they are the official teaching languages in the school system of Matabeleland. In the past twenty years, efforts have been made by the Nambya Cultural Association to maintain and promote the Nambya culture and language, for instance at school, encouraging amaTabele to learn and adopt ChiNambya. The local headman, traditional leader in charge of the ward, also explained how during community meetings the

[46] *Ibid*.
[47] B. Lindgren, 'The Internal Dynamics of Ethnicity: Clan Names, Origins and Castes in Southern Zimbabwe'.
[48] The S zone corresponds to the southern Bantu languages and covers a part of South Africa, Botswana, Zimbabwe and Mozambique. ChiNambya belongs to the Shona languages coded S.10 in Guthrie's classification (1948). SinNdebele is a Nguni language that falls under the clade S40.
[49] M. Guthrie, *The Classification of the Bantu Languages* (London, Oxford University Press for the African Institute, 1948).

villagers, including SiNdebele speakers, were supposed to use only ChiNambya. Modern traditional power[50] goes beyond ethnicity: local headmen and village heads belong to the two groups, facilitating the communications and exchanges between groups.

BaNambya and amaTabele also share several cultural attributes, such as the totems, sometimes referred to as clan names[51]. People are known and called by their totems, often in preference to their official family name. Totems are usually animals, or animal body parts. Someone named Victor Chuma whose totem is *Ndlovu* (elephant, *Loxodonta africana*) could be equally referred to as "Chuma" or "*Ndlovu"*. A child will take his father's totem and it comes with two principal rules: the totem should not be eaten by the person who bears the name, and two persons bearing the same totem should not marry.

This sharing of totem names creates networks that go beyond ethnic differences, as people having the same totem will consider themselves as relatives, even without proven family links, even if they belong to different ethno-linguistic groups.

Communal land in Hwange district: farming in unproductive drought-prone areas

Ethno-meteorological knowledge is crucial because it provides subsistence despite poor agro-ecological conditions in the area. Climatic dynamics in Zimbabwe are linked to ENSO (El Niño Southern Oscillation) and IODZM (Indian Ocean Dipole Zonal Mode) oscillations[52]. A climatic year comprises three seasons: a rainy season, ranging broadly from November to April; a cool and dry season, from May to July; and a hot and dry season, from August to November. Nevertheless, climate in Zimbabwe is characterized by great inter-annual variability in rainfall[53]. The country is divided into five agro-ecological regions[54], known as Natural Regions, according to rainfall regime, vegetation and soil quality among other factors. Natural Region

[50] H. Kyed and L. Buur, *Recognition and Democratisation. 'New Roles' for Traditional Leaders in Sub-Saharan Africa* (Copenhagen, Danish Institute for International Studies, 2006).

[51] Among the most common totems found in the area we could cite *Shoko* (vervet monkey), *Ndlovu* (elephant), *Dube* (zebra), *Sibanda* (lion), *Nkomo* (cow), *Ngwenya* (crocodile), *Nyoni* (swallow), *Nyathi* (buffalo) and *Moyo* (heart).

[52] A. Patt, 'Understanding Uncertainty: Forecasting Seasonal Climate for Farmers in Zimbabwe', *Risk Decision and Policy*, 6, 2 (2001), pp. 105-19.

[53] About climate in Southern Africa and Zimbabwe see D. Manatsa and G. Mukwada, 'Rainfall Mechanisms for the Dominant Rainfall Mode over Zimbabwe Relative to ENSO And/or IODZM', *The Scientific World Journal* 2012 (2012), pp. 1-15; A. Patt and C. Gwata, 'Effective Seasonal Climate Forecast Applications: Examining Constraints for Subsistence Farmers in Zimbabwe'.

[54] (Vincent and Thomas 1961)

IV, within which our study area is situated, usually receives between 450 and 650 mm of rain per year and is characterised by the presence of ‘dry spells’ and droughts[55]. The soil is mainly Kalahari sand. That added to limited rainfalls make this area poorly suited for agriculture.

The presence of farming communities in drought-prone areas of Zimbabwe is largely explained by land appropriation by white settlers during the Rhodesian era (1895-1980). Throughout the history of Rhodesia, the best arable land was given to white Rhodesians[56], leaving African farmers to farm on low productive soil, such as our study area. The creation of wildlife conservation areas by the colonial power also contributed to spoil local communities from their land. In ward 15 of Hwange district, local rural communities have been forced to flee or relocate several times since the end of the 18th century, for instance during the creation of the two neighbouring protected areas. Indeed, Hwange National Park (1928) and the Sikumi Forest (1968) were created by evicting local communities from land in which were located spiritual shrines, or land in which they were settled or which they used for grazing their cattle or for gathering natural resources such as fruits or firewood[57]. In the case of Hwange National Park, after communities were chased from their villages, the premises were burnt by the first warden[58].

Rural households living in our study area rely on subsistence agriculture, with maize, millet and sorghum being the main food crops, sometimes complemented by wild food, and animal husbandry[59]. The poor agro-ecological conditions of the area and the consequences of environmental injustice[60] are major challenges, and for the inhabitants being able to read their environment and anticipate the rain is crucial to achieving food security.

[55] C.H Matarira and M.R Jury, 'Contrasting Meteorological Structure of Intra-Seasonal Wet and Dry Spells in Zimbabwe', *International Journal of Climatology*, 12, 2 (1992), pp. 165-76.
[56] e.g. A. Mlambo and B. Raftopoulos, *Becoming Zimbabwe, a History from the Precolonial Period to 2008*.
[57] See for example G.T. Ncube, *A History of Northwestern Zimbabwe, 1850-1960*.

[58] DNPWLM, *Hwange Management Plan 1999-2003*, UNDP Technical Report (Harare, UNDP, 1999).
[59] About food production and diet in Zimbabwean rural areas, see M. I. Gomez, *A Resource Inventory of Indigenous and Traditional Foods in Zimbabwe* (Harare, University of Zimbabwe, 1988); S Shava, R. O'Donoghue, M.E. Krazny and C. Zazu, 'Traditional Food Crops as a Source of Community Resilience in Zimbabwe', *International Journal of African Renaissance Studies* 4, 1 (2009), pp. 31-48.
[60] Environmental injustice is to be understood as a situation where different actors have different access rights to their environment, and thus to ecosystem services, based on a racial or social discrimination. For an exhaustive description of the concept, see D. Schlosberg, *Defining Environmental Injustice: Theories, Movements, and Nature* (Oxford, Oxford University Press, 2007).

Nambya and Ndebele meteorological knowledge

Local rain classifications

BaNambya and amaTabele people have similar rain classifications (Table 2). In ChiNambya as in SiNdebele there is a generic word for rain, respectively *ivula* and *izulu*. The rainy season is called *izhizha* in ChiNambya and *intwasa* in SiNdebele. The three types of rain which have names in both ChiNambya and in SiNdebele are related to agriculture.

ChiNambya	SiNdebele	Description	Occurrence
Imboja machanga	*Imbolisamahlanga*	*"rain that makes the remains easy to break"*	September
Champembe	*Insewula*	*"First rain of the season"*	End of November
Umvumbi	*Imvimbi*	*"light rain that lasts for days"*	January - February
Chivulamabwe	*Isichoto*	*"rain with ice drops"*	Anytime during the rainy season
-	*Umfefezo*	*light rain*	Second half of the rainy season

Table 3.3. Local rain classifications expressed by Nambya and Ndebele villagers. *Descriptions are terms given by informants (N = 44).*

First is *imboja mashanga* in ChiNambya or *imbolisa mahlanga* in SiNdebele, two cognate terms. *Imboja* or *imbolisa* means "to decompose", or "to rot", and m*achanga/amahlanga* are the names given to crop residues left in the field after cereal grains have been harvested. This rain occurs during the second half of the dry season, usually towards the end of August or the beginning of September and it facilitates the integration of crop residues into the soil, an effect that is perceived as "improving the fertility". This rain is not considered to be part of the rainy season.The rain opening the rainy season comes by the end of November and is called *champembwe* in ChiNambya and *insewula* in SiNdebele. This rain is named *a posteriori*. Indeed, *imboja mashanga*/*imbolisa mahlanga* can be followed by rainy events in October or November. Nevertheless, these can be isolated events[61] that can be followed by several weeks without any rain. Villagers will date the first rain retrospectively once the rainy season has started.

Described by all the informants, *imvumbi/imvimbi* is a

> "light rain that can last for a long time, two hours and it stops, then comes back for two hours […] and that can be like this during two days or more"* (a Nambya women, Chezhou).

Thirty-six (85%) of our informants said that this was the most important rain because it enhances the ripening of crops. As stated by one of our Ndebele informants:

> "A good rainy season must start early, but it needs to bring *imvimbi*, if not we won't have good harvests"*(a Ndebele man, Siyalwindi)

Hailstorms are rare but happen and are named *Chivulamabwe* in ChiNambya, meaning "water-stone"and *isichoto* in SinNdebele[62]. It can come at any time of the year. Ndebele villagers mentioned *umfefezo*, the light rain that falls in the middle or at the end of the rainy season. No ChiNambya name was given to light rains, baNambya people use the Ndebele name.

Ethno-meteorological indicators and forecasts: From individual observation to collective forecasts and knowledge sharing

We define an ethno-meteorological indicator as *any kind of environmental phenomenon observed by people and used to produce weather forecasts*. The sky, plants and animals provide precious information to those who know what to look for. Tables 3.4 and Table 3.5 describe the ethno-meteorological indicators used by Nambya and Ndebele villagers interviewed during this study. Two types of indicators can be considered, seasonal indicators announcing the beginning of the rainy season (Tab. 3.4), and daily indicators announcing imminent rain during the rainy season (Tab 3.5). We arbitrarily distinguished the natural objects holding the information (e.g.

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[61] C.H Matarira and M.R Jury, 'Contrasting Meteorological Structure of Intra-Seasonal Wet and Dry Spells in Zimbabwe'.
[62] Spelled *isiqhoto* in the English-Ndebele Dictionary we used.

a particular tree species) and the indicators themselves (e.g. the moment when the new leaves are produced). Rather than presenting an exhaustive description of all the indicators, this section will emphasize the forecasting process, which is how indicators are used to anticipate the rains.

From the beginning of October, farmers start observing their environment and close attention is paid to natural objects or phenomena announcing the arrival of the rainy season. As Table 2 shows, most of the indicators are used by both ethno-linguistic groups.

Dark clouds, thunder, lightning strikes and westerly winds are the first seasonal indicators to be observed, along with the return of whirlwinds. These are usually observed in October and appear three to four weeks before the first rains. Seeing particular animal species again also indicates the arrival of the rainy season. Birds are particularly important and observing migratory birds like Jacobin cuckoos (*C. jacobinus*) and swallows, or observing the non-migratory Ground hornbills (*B. leadbeateri*) in the villages indicates the return of the rainy season. An unidentified frog named *kakololombe* in Nambya is used by Nambya and Ndebele people as an indicator. According to them, this frog is more commonly seen a few weeks before the onset of the rainy season. Plants are widely used to predict the arrival of the rainy season. The flushing of young leaves of trees, particularly of *Afzelia quanzensis*, *Brachystegia boehmii*, *Kirkia acuminata* and *Lannea discolor*, are used as indicators of the arrival of the rainy season. Other tree species were also cited, although less frequently. Tree species given in Table 2 are used in two different ways, as “generic” or “individualized” indicators. The flushing of a tree belonging to a species known to provide information, for instance *A.quanzensis*, indicates the arrival of the rainy season and is in this case a “generic” indicator. Rather than monitoring a species, some villagers would rather monitor individual trees with which they have an “intimate” relationship. In that case the species identity does not matter. These trees usually grow in their homestead or in the family field, and farmers state that their parents also monitored them.

Due to the heterogeneity of rainfall patterns, time frames for ploughing are short, and many villagers need to plough their fields at the same time. Being able to anticipate the beginning of the rainy season early enough is crucial, as it gives the farmer time to prepare the field and gather seeds and tools. Not every family owns draft animals, or a plough, or enough seeds to produce sufficient food for the coming year.

- **One indicator:**

"For me I only wait for clouds. If I can see the big clouds of rain, we call them *amayezi ezulu*, it means the rain will come in a week or 10 days. You will hear people talking about it and we will prepare for plowing". (A Ndebele man, Chezhou)

- **Two indicators, a bird and an "individualized tree":**

"Myself I trust birds. I use the same bird my parents were using, we call it *kiwa*, it's black and white and it comes back before the rains to warn people so that we can prepare our fields. I also have that tree [he points at a tree in his field], if it makes flowers I have to be ready to plough". (A Ndebele woman, Magoli)

- **Three indicators relying on trees, two "generic" and one "individualised":**

"When we see trees like *umkhomo* shooting new leaves, or *umkamba* we know that in maybe a week or two the first rains will come. But myself I also look at one tree in my yard […] it's one we call *isigangacha*, and I know that this tree never lies"*. (A Ndebele man, Siyalwindi)

- **Four indicators produced by four different types of environmental objects:**

"First I wait for the *kamphungwe*. When I see them I make sure I have at least 20 kilograms of seeds. When I see baobab trees shooting new leaves it means I have two weeks to prepare my fields. You can also see *makole ivula* coming. They don't stop but they warn. I start removing bushes and I make sure I finish before the swallows are back because once they are there, it [the rainy season] can start anytime". (A nambya women, Magoli)

- **Two shared indicator:**

"I heard they had *kamphungwe* in cross-Dete [a small town about 7 kms north-west of our study area] yesterday, this l morning I went to see *makhumalo* [his neighbour, who is Ndebele] to organize with her for our fields. She told me she saw swallows. We will share my oxen to plough". (A Nambya man, Magoli)

Box 3.1. Sets of seasonal indicators and their link with agricultural calendars**.** *Each farmer has his/her own set of indicators and they evolve throughout their lives. These are a few examples captured during interviews.*

Seasonal indicators are used as time markers in the agricultural and social calendar. As shown in Box 3.1, people use sets of indicators, each person having his/her own set used to produce an individual forecast.These trigger social dynamics through which people will borrow, rent and lend agricultural assets, or ask for seeds. They usually address such requests to family members but also to neighbours or friends. As part of the requesting process, individual observations are shared and compared. By doing so, people share knowledge within social networks that transcend ethnic identity, creating a dynamic multicultural knowledge system. These dynamics shape agricultural practices at the community scale.

Objects	Indicator	ChiNambya	SiNdebele	Month of occurrence	People using the indicator (N=44)
Atmospheric objects				October	
-Rain clouds ("clouds of rain")	Can be seen again	*makole evula*	*amayezi ezulu*		45,5%
-Thunders ("thunders of rain")	Can be herd	*kutimba kwevula*	*ukuduma kwezulu*		18,2%
-Lightnings ("lightnings")	Can be seen again	*kampalanganda*	*umbane*		13,6%
-Wind ("wind")	Stabilizes from the west	*imepho*	*umoya*		13,6%
-Whirlwinds ("whirlwind")	Can be seen again	*kamphungwe*	-		9,1%
Trees				November	
-*Afzelia quanzensis* Welw. (Fabaceae)	Flushes young leaves	*mukamba*	*umkamba*		27,3%
-*Brachystegia boehmii* Taub. (Fabaceae)	Flushes young leaves	**	*umfuthi*		13,6%
-*Kirkia acuminata* Oliv. (Simaroubaceae)	Flushes young leaves	*umvumila*	*ivumila*		13,6%
-*Lannea discolor* Sond. (Anacardiaceae)	Flushes young leaves	*chigangacha*	*isigangacha*		13,6%
-*Brachystegia spiciformis* Benth. (Fabaceae)	Flushes young leaves	*unshungu*	*igonde*		9,1%
-*Pterolobium exosum* Gmel (Fabaceae)	Flushes young leaves	*unkotonga*	-		4,5%
-*Adansonia digitata* L. (Bombacaceae)	Flushes young leaves	*umbuyu*	*umkhomo*		4,5%
-*Colophospermum mopane* (Fabaceae)	Flushes young leaves	-	*mopane*		4,5%
Animals				October to November	
- Jacobin cuckoos (*Clamator jacobinus, Cuculidae*)	Can be seen or heard again in the villages	*kiwa*	*amangabuzani*		40,9%
-Swallows (*Hirundo* spp.)	Can be seen or heard again in the villages	*inkonjayni*	*inkonjayni*		18,2%
-Ground hornbills (*Bucorvus leadbeateri, Bucorvidae*)	Can be seen or heard again in the villages	*mandandobe*	*insingisi*		9,1%
-A frog (unidentified species)	Can be seen again with increasing frequency	*kakololombe*	**		9,1%

***Table* 3.4**. Ethno-meteorological indicators of the arrival of the rainy season**.** *For atmospheric objects, all the names given in English in parentheses are direct translation of local names. Concerning plants and animals, scientific names are given when the species could be identified. A "**" signifies indicators that are used, but for which names were only known in the other language. The percentages given correspond to the proportion of people using the indicator (N = 44).*

The presence of heavy winds and lighting strikes are also considered as indicators of rain, but to a lesser extent. Several weeks may pass between two episodes of rains, with important consequences for the optimal timing of agricultural activities. In particular, the timing of seed planting is crucial, and farmers develop their personal strategies to maximize the chances that the seeds are not washed away by very heavy rains, while ensuring that the seedlings receive sufficient water to achieve growth to maturity stage. Once the rainy season has started, the sky is therefore actively scrutinized by farmers, and some of the natural objects used to anticipate the onset of the season can also give indications about daily rains during the rainy season (Table 3.5). When *clouds of rain* are seen in the morning they announce an imminent rainy event for the afternoon. When they are observed in the evening people expect rain in the next morning. A sudden increase in temperature or hearing thunder getting closer, even with a cloudless sky, are also signs of coming rain.

The same animals which announced the beginning of the rainy season by “re-appearing” are also used to predict daily rains through their behavior. The Jacobin cuckoo is the main bird used by villagers of both ethno-linguistic groups. For Nambya people, hearing this bird singing announces imminent rain as its song sounds like « come rain » in ChiNambya. This indicator is considered to be the most reliable by our informants, and is for example particularly used by herders while driving their cows in the Sikumi Forest:

> “ When we are in the forest and we hear *amangabuzani*, it’s a sign that warns us that we must go back home quickly (…) we have to be careful with the rain, especially in the afternoon when it’s time to go home because if you get caught by rain you can get lost, or lose your cattle”. (A Ndebele herd boy, speaking of cattle herding in the forest)

For Nambya and Ndebele villagers, swallows fly “*close to the ground and in every direction”* before the rain. Hearing ground hornbills in the fields indicates the end of a dry spell. Twelve Nambya villagers also reported that the unidentified frog mentioned previously changes its colour to become completely white a few hours before a rainfall.

Object	Indicator	ChiNambya	SiNdebele	People using the indicator (N=44)
Atmospheric object/phenomena				
Rain clouds (clouds of Rain)	can be seen	X	X	27.3%
Thunder	can be heard getting closer	X	X	18.2%
Temperature	increases	X	X	18.2%
Heavy winds	Can be felt	**	X	9.1%
Lightning strikes	can be seen	X	X	4.5%
Animal indicator				
Jacobin cuckoos	sing	X	X	45.5%
swallows	fly low	X	X	31.8%
Ground Hornbills	sing in fields	X	X	27.3%
Frogs (unidentified species)	turns from grey to white	X	**	13.6%

Table 3.5. Daily indicators used to predict imminent rains during the rainy season**.** *For names in vernacular languages, see Table 3.4. Concerning plants and animals, scientific names are given when the species could be identified. An "X" stands for when the informant described the indicator in his/her own language A "**" signifies indicators that are used, but for which names were only known in the other language. The percentages given correspond to the proportion of people using the indicator (N = 44).*

As indicated earlier, informants could usually speak ChiNambya and SiNdebele. Most of the climatic indicators mentioned have a name in each language; when this is not the case, and even when there is a name in the informant's language, people name the indicator using the word in the alternate language. For instance, some of the Nambya people we met used the Ndebele word *umoya* to name the wind instead of *imepho*, and Ndebele people used the Nambya word *kakololombe* to name the frogs announcing the rain.

"You know sometimes it's hard to see if the rain is coming. That's why we look at different things like the clouds, or birds […] but you also have to listen to other people or ask them if they know something. If you do that you will be good"*. (A Ndebele woman, Chezhou)

"I don't know, maybe I will go to my fields, Dumisani [the other herder of the group that day] told me he saw clouds of rain over Mabale [a village on the other side of the Sikumi forest], if they are there now, it will come tonight and the soil will be good for ploughing tomorrow"*. (A Ndebele teenager herding cattle, Magoli)

"[talking to us] So who will you see now? If you pass by my brother's homestead tell him there was some heavy wind coming from Cross-Dete this morning"* (A Nambya woman, Magoli)

Box 3.2. Examples of individual observations shared to anticipate the rains during the rainy season.

Most the indicators described in Tables 3.4 and 3.5 are known by everyone, but not all are trusted and used. The average number of indicator known by our informants was six. Although older people gave us a wider range of indicators[63], no one from the community was identified as an "expert" on climate[64], whether self-declared or indicated as such by peers.

Individual observations are shared and forecasts are collectively produced (Box 3.2). Each individual will observe the surroundings and use his own set of indicators. Observations are reported and discussed with relatives and friends. As we were staying in the villages and walking from one homestead to another, many villagers spontaneously asked if we had noticed such or such sign of the rain coming, and regularly asked us to spread information to other households (Box 3.2). When questioned about the origin of their knowledge, all our informants acknowledged that they had been taught by their elders, but also developed their own knowledge through experience:

> "It is my parents who told me to observe the dew in the morning, or to feel where the wind is coming from. When I was working as a ranger in the Park I checked it and they were right"*. (A former Park ranger, Siyalwindi)

[63] Such trend is not surprising as Local Knowledge is built through a life long process of trial-error and observation process, see for instance E.N. Anderson et al, *Ethnobiology*. This makes LKSs particularly relevant for natural resources management, as explained in F. Berkes, J. Colding and C. Folke, 'Rediscovery of Traditional Ecological Knowledge as Adaptive Management', Ecological Applications 10, 5 (2000), pp. 1251-62.
[64] (Chalmers and Fabricius 2007)

> "At school we learn things, but our elders know things too, so I listen to them. I look, if it works. I follow their advice and I try to improve. An old thing, if it's still working you can make it modern". (A Nambya villager, Magoli)

Following what previous generations were doing is important for baNambya and amaTabele because it contributes to maintaining their knowledge and traditions. BaNambya people are a minority and maintaining their traditions and knowledge is particularly important for them. Using the same ethno-meteorological indicators as the elders is also a way to show respect for the ancestors. The permanent sharing of observation between family members, friends and neighbours represents occasions to learn, create and re-create folk knowledge. A person will therefore inherit his knowledge from his parents, but throughout his life he will learn from others, Nambya and Ndebele.

Conclusion: creating knowledge

In this paper we explored the ethno-meteorological knowledge system of a multicultural community. We showed several noteworthy characteristics. Classifications of different kinds of rains are similar in the two ethno-linguistic groups, especially concerning rains which have a direct effect on agricultural production. Although they speak different languages and have different origins, ChiNambya and SiNdebele live in a common environment, have the same agricultural practices and face the same climatic constraints. It is therefore not surprising that they distinguish the same types of rain.

Ethno-meteorological indicators rely on several types of natural phenomena, which can deliver different kinds of information depending on their aspect and temporality. The use of a wide range of natural objects to produce local weather forecasts, such as birds' behaviours, leaf flushing and flowering of tree species, or atmospheric phenomena, has been observed in other societies[65]. Each farmer uses his own set of indicators, some being generic, while others are individual. Such a diversity of indicators allows cross-validation of weather forecasts by the observers. Furthermore, although individuals make their own observations, they are systematically confronted with others' observations, and weather forecasting is a collective

[65] See footnote 7.

process. We suggest that this may be explained by two facts. First, climate variability being high, people gather information from other sources and cross-check their observations in order to increase the quality of the prediction of the upcoming weather events. Secondly, weather forecasts trigger agricultural practices that can be achieved only through the sharing of the means of production. We assume that through these collective processes, villagers perpetually share knowledge and recreate a common LKS where ethno-linguistic identity is blurred by the necessary cooperation between individuals in a highly constraining agro-ecological context.

Climatic scenarios for southern Africa predict not only the general decrease of rainfall, but also a modification of rainfall patterns involving a higher frequency of extreme events such as floods and droughts, which will have important consequences for small-scale farmers in the region[66]. In this perspective, our results highlight several important features of weather-related indigenous knowledge. Like other LKSs, they are fundamentally dynamic. Weather forecasts by rural communities in south-western Zimbabwe are the result of dynamic processes occurring within social networks transcending family, village and language boundaries. As we described, weather forecasting, along with the resulting agricultural practices, are collective processes. Within the community, they rely on, and maintain, social networks. Such networks and the social cohesion that they generate have been shown to be positive factors of resilience to natural disasters such as droughts or floods[67], two kinds of extreme events for which climatic scenarios predict increased rates for the coming century. During our fieldwork we observed how the sharing of information and assets allowed farmers to cope with a constraining environment. Although weather related LKSs are recognized to be adaptive and to allow local communities to cope with environmental change, they will be greatly challenged by the current climatic trends, which will have major consequences on the environment [68] on which LKSs mainly rely[69]. Alongside with climate change, other threats to LKSs were identified by Berkes et al[70], among which are "*commercialisation, change of technology, pressure due to demography, breakdown of traditional land tenure, and the change of world view*". Our work only focused on a portion of a knowledge system. LKSs cover more than climatic knowledge and contribute to rural communities' resilience. There is an urgent need to understand how global changes, including

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[66] (Neil Adger *et al.* 2005)
[67] On community resilience, see (Cutter *et al.* 2008)
[68] On climate change scenarios and their consequences for environment and livelihoods, see (Simmons *et al.* 2004, Araujo 2006, IPCC 2014)
[69] See for instance E.N. (Berkes et al. 2000, Anderson et al. 2012)
[70] (Berkes *et al.* 1994) p. 272.

climate change, will impact LKSs, for example through environmental shifts due to aridification. By providing insights on LKSs, we will improve our understanding of the impacts that global changes will have on rural communities and contribute to enhance the capacities of small-scale farmers to cope with these changes.

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CHAPTER 4. The Co-design of the Role Playing Game

WHAT IS THIS CHAPTER ABOUT?

This chapter takes the reader to the next step of our companion modeling process. After a period of participative observation and interviews, we had a good general knowledge of rural livelihoods and production systems. We therefore proceeded to the co-design step. During our ethnographical fieldwork, we realized the centrality of cattle herding and its articulation with the agricultural calendar. We therefore decided to include both of these practices in the game.

The co-design was done in several steps:

- First was the translation of our newly acquired knowledge in a launch version of the role playing game. As we will explain in this chapter, the choice of initiating the participatory process with a launch version, in opposition to starting "from scratch", was strategical.
- Then came the creation of the co-design team. As explained in the second chapter, there are different types of human protagonists in a ComMod approach (Etienne 2014). The exogenous protagonists were: The PhD student (learner ComModian), and two senior researchers, a confirmed ComModian, and an expert on Zimbabwean rural areas and livestock management. Ten local villagers were proposed to join the co-design team. They corresponded to the profane category of the endogenous type of protagonists (Etienne 2014) .
- The co-design *sensu stricto* was achieved through iterative workshops during which the latest version of the game was tested and improved until a consensual situation was reached.
- A year after the first co-design workshop, the game was implemented with 28 villagers living in the study area. Pushing participation further, these playing sessions were facilitated in local languages by volunteering local members of the team, our role was only to record player's actions.

This chapter is adapted from a paper submitted to peer-reviewed journal, *Ecology and Society*. In order to maintain a visual homogeneity throughout this manuscript, we simply modified the titles' format, and re-indexed the figures and tables. The literature cited in the paper is compiled in the references at the end of the manuscript.

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(The format of the paper was adapted for the visual homogeneity of the PhD thesis. The journal's referencing system was kept, along with the legends'format)

"Teaching each other"': A Co-designed research tool to elicit cattle herding strategies at the interface between a protected area and rural communities in Zimbabwe

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Abstract: With the plurality of stakeholders coexisting within a social-ecological system (SES) comes the plurality of legitimate knowledge and perspectives about the functioning, issues and needs of the system. Managing, studying or simulating social-ecological systems implies dealing with wicked problems characterized by uncertainty, incomplete knowledge, competing cultural values and interconnections with other problems. Bringing together local actors and experts in a joint dynamic is a way to tackle wicked problems. This can take the form of the co-design of simulation models to explore the complexity of SES. Within a project aiming at simulating the coexistence between stakeholders at the interface between protected areas and farming communities in Zimbabwe, we co-designed a role playing game with members of a rural community. Following the companion modeling method, we engaged local stakeholders not only in the co-production of results but in the co-design of the research tool itself and in the co-facilitation of workshops supported by this tool, extending the traditional scope of participation. Eighteen months of ethnographical fieldwork led us to focus our activities on the coupled farming-cattle herding practices that constitute the main interaction between rural and protected areas. Three co-designing workshops iterations were necessary to reach consensus and obtain a game that was played with naïve villagers, i.e. villagers that were not involved in the creation of the game. The game brings local farmers to reproduce their farming-cattle herding strategies in a virtual environment mimicking their reality. We highlight an ongoing appropriation process by local members of the co-design team and its consequence on the nature, and the actual and potential uses of the game. We conclude by drawing lesson from our experience, contributing to the formalization of empirically-based modeling of SES. We assume that such approach can be implemented to address other wicked environmental issues in a wide range of social-ecological contexts.

Key Words: Environment; cattle herding; *wicked problems; Role Playing Game; Participatory modeling; coexistence; Zimbabwe*

Introduction

The emergence of the social-ecological perspective (Emery and Trist 1965), and the formalization of the Social-Ecological System (SES) framework at the beginning of the 2000s (Berkes *et al.* 2002) participated to a shift of paradigm in environmental science by urging researchers to consider human beings and their environment as entwined parts of a complex and dynamic system (Ostrom 2007, 2009, Epstein *et al.* 2013). The framework is still at the heart of active improvements and evolutions (McGinnis and Ostrom 2014). With the plurality of stakeholders coexisting within a SES also comes the plurality of legitimate knowledge and perspectives about the functioning, issues and needs of the system (Curtin 2014). Managing, studying or simulating social-ecological issues therefore implies dealing with *wicked problems* (Balint 2011). Originally coined by Rittel and Webber (1973) in the context of governance and policy planning, the term *wicked problem* applies when a problem is characterized by uncertainty, incomplete knowledge, competing cultural values and interconnections with other problems. Wicked problems defy simple solutions (Balint 2011). Considering the plurality of legitimate perspectives concerning such problems necessarily leads to acknowledge the gap between the real matter as it appears to local actors, and the matter as it exists for researchers that remain fundamentally exogenous (d'Aquino et al. 2003).

Participation was pointed as a way to tackle this gap and address *wicked problems* (Roberts 2000, Davies *et al.* 2015) by bringing together local actors and experts in a joint dynamic, turning the first from passive objects to partners of research, natural resources management or development (Eversole 2003). The potential benefits of participation were summarized by Stringer et al (2006). Participation uses perspectives from a range of sources and can produce more robust factual bases, therefore reducing uncertainty. Profane actors provide local social, ethical and political insights that cannot be achieved through scientific approaches. Finally, involving local stakeholders can promote democratic ideals in natural resources management, empowers the "marginalized", and facilitates long term collaboration between local stakeholders. The objects used for and produced through participation (e.g. sketches, tables, or maps) are *boundary objects* linking different actors belonging to different social worlds but involved in a common dynamic (Daré 2005, Vinck 2009, Daré *et al.* 2010). In the past decades, the theory and practice of participation have considerably evolved (Chambers 2006, Reed 2008). Engaging local stakeholders became *quasi* inescapable, and new analytical frameworks have been drawn (Barreteau *et al.* 2010).

Among the various tools available, simulations and models are recurrent in participatory approaches. SES models are now flourishing in the literature (Schlüter *et al.* 2012). In the editorial of a special feature of *Ecology and Society,* Marco A. Jansen and Elinor Ostrom (2006) explained how agent-based models (ABMs) in particular could offer relevant tools to study SESs. Recent works described uses of ABMs in fields such as social-ecological system management (Miller and Morisette 2014), climate change adaptation (Tschakert and Dietrich 2010), land-use/cover changes dynamics (Acosta *et al.* 2014), water management (Souchère *et al.* 2009), wildlife dynamics (Carter *et al.* 2015), bushmeat hunting (Le Page *et al.* 2015) agriculture (Naivinit *et al.* 2010) or epidemiology (Amouroux *et al.* 2010).

As stated by D'Aquino et al (2003) "the more endogenous the design is, the more appropriate the tool is". The authors insist on the necessity to bring local actors to self-design the model. From this principle they highlight the challenge of conceiving a methodological framework that provides local actors all relevant knowledge and information so that they themselves design their own tool and ultimately manage their issues. The Companion Modeling (ComMod) approach developed in the 1990s by researchers from CIRAD (Bousquet *et al.* 2002, Etienne 2014) aims at identifying the various points of views and knowledge that local actors implicitly refer to and use in their relationship with their environment, working out – together with local stakeholders - a common vision of a given SES in order to (i) understand its functioning or (ii) facilitate decision making processes of stakeholders using a common resource. These objectives are achieved through the co-construction and the use of ABMs and role playing games (RPGs) with the local actors of a SES to reflect the expectations and constraints of the actors involved, to enhance discussion and co-operation among them, and between them and researchers.

RPGs are often used in participatory processes to induce discussions among local stakeholders, although there are examples of research-oriented uses of participatory ABMs and RPGs (Washington-Ottombre *et al.* 2010, Vieira Pak and Castillo Brieva 2010). Our main objective was to co-design a research-oriented RPG to better understand the practices associated with cattle herding at the interface between a protected forest and a communal land in Zimbabwe. Furthermore, whereas most participatory models and RPGs are built and used by the same individuals, we decided to co-design, with a group selected of individuals, a game that could be used with any members of the same rural community. As sharing the control over the research process is part of the approach (Barreteau *et al.* 2010, Daré *et al.* 2010), the main challenge was to develop a methodology which would fulfill the expectations of the researchers and those of the local actors involved, leading to the design of a research tool –the RPG- that could be understood and used by naïve individuals. More broadly, we address the question: how and to what extent can participation foster the inclusion of endogenous perceptions and knowledge and meet answering local actors' expectations while maintaining scientific relevance? Context-based empirical models still raise several questions among which is the generalization of findings and the lack of standardized methods to develop empirically-based ABMs (Janssen and Ostrom 2006). With this work, we contribute to address these concerns by drawing theoretical lessons from our experience.

In this paper we first outline our methodology. We describe the study area, its agroecological characteristics, and give an overview of the history of land use in the area. Although they are briefly described in the study area description, the human practices of interest are detailed in the ethnography, which is one of the methodological steps we followed from our arrival in the area to the co-design of the RPG and its final implementation through playing sessions with villagers. We then present the results, including the characteristics of the game and the analysis of questionnaires conducted with the co-design team, and with players. We finally discuss these results and draw lessons participating in the improvement of participatory modeling frameworks.

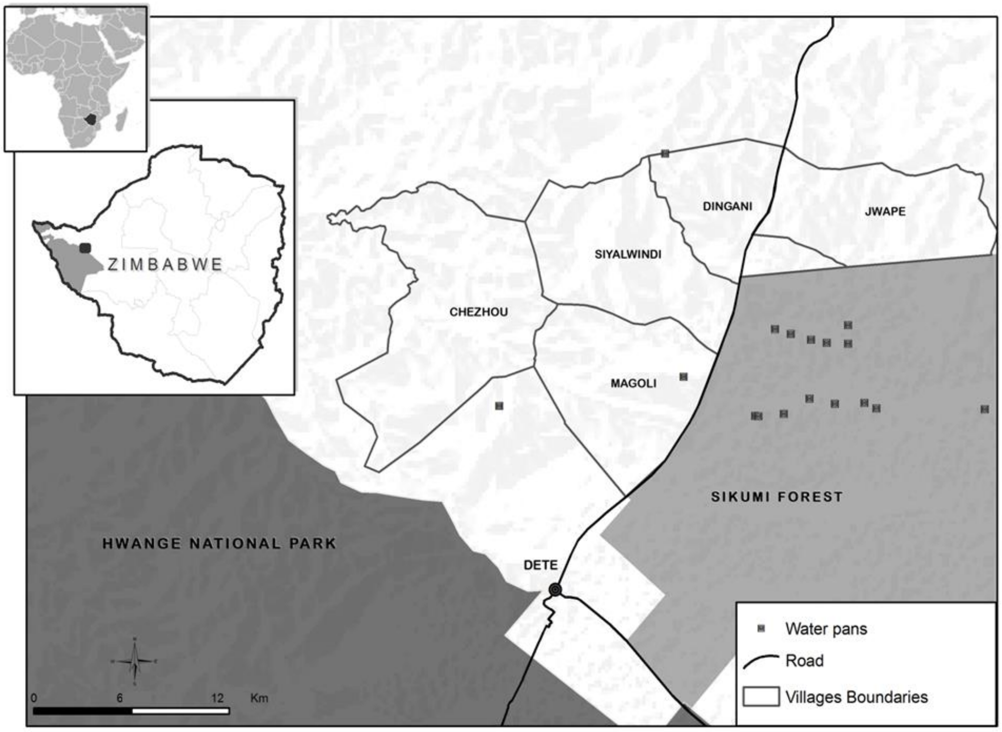
Methods

Study Area

This work was conducted in the villages of Magoli, Siyalwindi, Chezhou, Dingani and Jwape within the ward 15 of the Hwange District, western Zimbabwe (see Fig 4.1). The study area receives between 450 and 650 mm of rain per year and is characterised by the presence of 'dry spells' and droughts, which added to poor soils make this area poorly suited for agriculture (Matarira and Jury 1992). Several types of land use coexist in the area. Villages are restricted to the communal area, that is an area dedicated to human settlements with lands allocated by traditional authorities (Guerbois *et al.* 2013a). Rural populations rely mainly on subsistence agriculture with maize, millet and sorghum being the main food crops, and livestock keeping (Perrotton *et al.* in Rev, de Garine-Wichatitsky *et al.* 2013). Neighboring the villages are two unfenced protected areas, namely Hwange National Park (HNP, 14651km^2), a wildlife conservation area located a few kilometers to the southwest and the contiguous Sikumi Forest

(SF, 11000 km²), a wildlife conservation and timber production area separated from the villages only by a tarred road.

Figure 4.1. Study Area, villages adjacent to Hwange National Park and Sikumi Forest, Zimbawe.



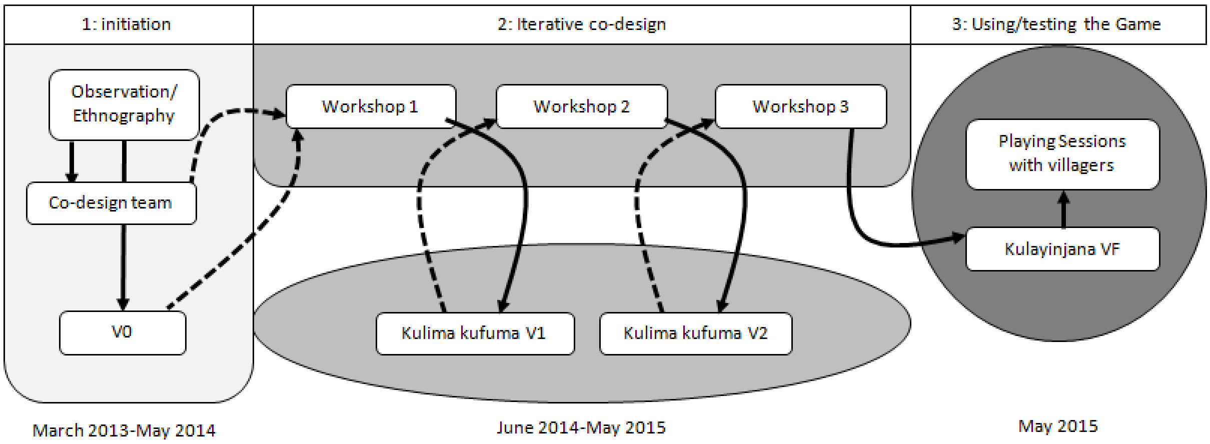
Coexistence issues between protected areas and neighboring communities are omnipresent throughout the world, among which are poaching (Rowcliffe *et al.* 2004), cattle incursions in protected areas (Butt 2014) and the lack of benefits derived for rural communities (Emerton 2001). The interface between HNP, SF and rural populations is no exception and tensions exist between local stakeholders: human-wildlife conflicts (Metcalfe and Kepe 2008), poaching (Muboko *et al.* 2014), cattle incursions in restricted protected areas, illegal wood harvesting, livestock predation by wild carnivores and crops raiding (e.g. Guerbois *et al.* 2012) along with disease transmission between domestic livestock and wildlife (de Garine-Wichatitsky *et al.* 2013). Interactions between protected and communal areas were shaped by colonial and post-independence history. In the process of the creation of HNP (1928) and of the SF (1968), local communities have been evicted from land in which they were either settled, driving their cattle or gathering natural resources such as fruits or firewood (Ncube 2004). If local communities have no right of access for any natural resources use/extraction from HNP except for occasional thatching grass harvesting under close supervision of rangers, the severe droughts of the early 1990's (Maphosa 1994) led the forestry commission and traditional leaders to negotiate a right of access for neighboring communities. Herders obtained the right to graze their cattle within the SF (Guerbois *et al.* 2013) although the official authorized distance remains unclear and, depending on the informant, ranges from 2 Km according to a Forestry manager to 3 Km (Guerbois *et al.* 2013), and up to7 Km according to local herders. The right of access to the forestry's land is essential for livestock owners and simultaneously constitutes a form of land claiming on a territory that used to be used by the villagers. On the other hand, forestry managers are concerned by the possible consequences of such agreement: overgrazing to the detriment of wildlife and opportunistic activities, such as illegal wood harvesting or poaching. The right of access is a bone of contention between traditional leaders and the forestry commission.

Tensions around cattle driving at the interface between the SF and neighboring rural community show characteristics of wicked problems: uncertainty (climate, resources availability), incomplete scientific knowledge (*e.g.* how do herders drive cattle? what is the vegetation structure in the forest? How do cattle impact vegetation in the forest?), ambiguity maintained by local actors (What is the legal right of access) competing cultural values (rural livelihood versus wildlife conservation and timber production) and interconnections with other problems (unemployment, droughts). Such a context justified the implementation of a ComMod/self-Design approach that allows the acquisition of data through the enhancement of communication between local actors and researchers.

Implementing a ComMod approach to understand cattle herding strategies

Although issues around cattle diverse local actors, the choice was made to focus on rural communities. This position was assumed for several reasons. Rural communities are the owners of cattle, and the ones making decisions about herding strategies, whereas the SF managers are rather institutional actors. Furthermore, decision making processes concerning the SF management are centralized and taken either in Bulawayo (regional office), or Harare (national office), rarely in the local office. We are conscious that forestry actors will have to be involved, but with the idea of initiating a long-term collaboration with local stakeholders, creating an arena for rural communities to express themselves freely was the necessary first step to a fair potentially long-term ComMod approach. This section describes the co-design process (Fig. 4.2), from the initial ethnography to the implementation of the RPG with villagers.

Figure 4.2. The Role Playing Game co-design process. *Plain arrows represent creation or (re)design phases, dash arrows represent testing phases.*



Ethnographical fieldwork: A first understanding of the system

This first phase was critical in the implementation of our ComMod approach. Ethnographic fieldwork was conducted to understand how cattle driving was structuring coexistence in the study area and gather information to design a "launch version" (V0) of the RPG, *i.e.* a simplified representation of the system designed to initiate the co-design with local actors. Semi-directed interviews and open discussions were carried out with livestock owners and herders. These were completed with direct observations (*e.g.* herding cattle with them inside the SF). We also had access to livestock census books kept by traditional leaders. This section presents the main findings of our observations, and shows how cattle herding is at the core of interactions between the different land uses, therefore justifying the decision of design a RPG around cattle-related practices.

Based on local records, only 32% of homesteads living in the study area have cattle. In average, these families owe 5.46 cattle (sd=4.19). Livestock is nevertheless central to agricultural production and draft animals are often borrowed or sometimes rented if not owned, enforcing social cohesion in the area. Livestock is the main form of capitalization for rural population. Beyond their agricultural value, cattle also have a social dimension through the payment of the bride price, locally called *lobola*. Such data justifies the choice of focusing our efforts on cattle. Although foraging resources are a crucial driver, the cattle herding calendar is largely determined by agricultural practices (Valls Fox et al in Prep). The agricultural calendar obviously depends on weather patterns, both on a large and a fine scale as plowing strategies and revised almost daily by local farmers. We can broadly distinguish three phases of cattle grazing. During the agricultural season (November-May), cattle are actively herded in order to minimize incursions on fields. Not every owner sends his cows in the SF, and some favor the communal grazing areas that present less risks of predation. Cattle herded out of the communal area feed approximately from 11 am to 16 pm in the Forestry and natural water pans shape the herding movements. The date from which livestock can roam freely in the communal area is annually defined by local traditional leaders, and is called *xotshela*, meaning "release" in SinNdebele. Once the date is chosen, farmers have to make sure all their fields will be harvested in time. From *xotshela*, all cows are released in the villages and roam free, feeding on grass and crops residues left in the fields, and drinking either in communal dams or at boreholes. Crops residues are often partly stored within the homestead and used to feed cows around the kraal. Towards the end of August, cattle start going unguarded in the forest. During this time, they usually go deeper and herders are often forced to go and collect them, sometimes more than 7 Km away from the boundary of the SF. This general pattern is shared by the majority of cattle herds, but on an individual scale, cattle herding strategies are complex mechanisms that involve personal histories of owners and herd-boys, a perpetual consideration of dynamic environmental parameters, the proximity of homesteads to the forest, and neighbors' strategies.

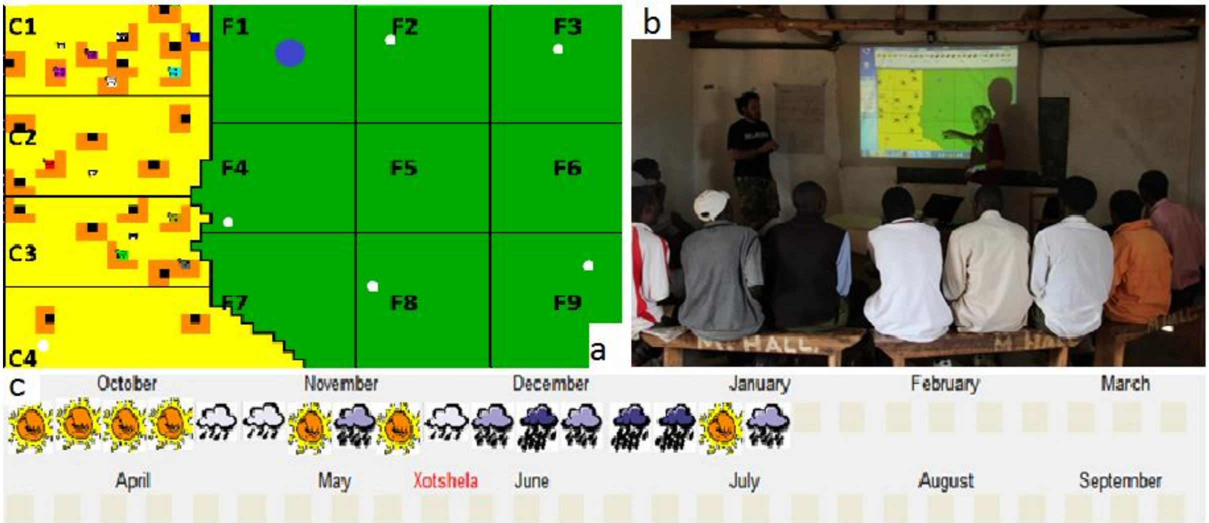
Creation of a launch version of the Role Playing Game

The V0 was brought by the researchers as an entry point to initiate the co-design process. Starting the co-design process with an object that already took the form of a RPG was more engaging and accessible to participating local farmers than starting with a conceptual model. The main challenge was to come up with a game that was realistic enough to legitimize us as facilitators of the ComMod process, catch the interest of the future co-design team members by showing the potential outcomes of their participation and encourage them to improve it. The V0 was computer-based and developed using CORMAS, a simulation platform developed by the CIRAD (Le Page *et al.* 2012). The V0 was built according to our observations. The V0 was a first simplified representation of the studied system, because a complex object would have been harder to appropriate, deconstruct or improve by the future team. Although the V0 set the basics of the future game, it was voluntary incomplete and contained discordances with reality that would help engaging the debates with participants. Starting with an incomplete and partly discordant representation of reality also helped highlighting the need for local actors' help to fill in the knowledge gaps, therefore breaking the "foreigner white-male positionality of researchers" (Stringer *et al.* 2006). This section describes the main features of the V0. Complementary information is provided in the appendix 1.

Following Barnaud's advice (2012), the virtual environment was not realistic (*i.e.* not representing exactly the study area), to allow stakeholders to create a distance from reality and issues that come with it, such as the conflictive authorized distance allowed for cattle in the SF. In other words, a conceptualized environment was chosen for stakeholders to project themselves in a conflict-free environment within which they could project their own rational about cattle herding. The virtual environment proposed (Fig 4.3.a) consisted in a grid and exposed similar characteristics with reality, *i.e.* a communal area where farms were located, and a forest. The environment was separated in 13 paddocks, which were the fundamental spatial elements. Each communal paddock had a borehole and one had a water pan (C4). The 6 other water pans were located in the forest (F1, F2, F3, F4, F8 and F9). Recorded daily rainfalls from the 2012-13 rainy season measured in the study area were transformed in weekly rainfalls, and we arbitrarily distinguished four types of weeks: dry weeks (<5mm), small rain weeks (5 to 20mm), medium rain weeks (20 to 40mm) and heavy rain weeks (>40mm). The rainfall calendar was displayed and updated at the end of the month (Fig3c) - players had to anticipate the rains to make their decisions. The game had a two weeks timestep and at this stage of development, the game only covered one agricultural year, from the beginning of October$_n$ to the end of September$_{n+1}$. Each player was in charge of a farm comprising 5 independent fields (in orange on figure 3a), each one representing one "*umfollow*", the local plowing unit (±0.5 acre). Players were given an initial herd of 5 cows, which corresponds to the average herd size observed. Each player also had a herder that could be sent with its cattle. Only one type of crop was represented in the V0, with two varieties, "short term" and 'long term" that are actually used by the local farmers. The crops dynamic adopted relied on our observations: once planted, short term crops would take 3 months to be ripe, long term crops would take 4 months. The main simplification concerning crops was that these had only two states, growing and ripe and only time was considered to reach the ripe state, rainfalls were not. The 13 paddocks were grazing spatial units with four levels of forage availability (null, poor, medium and high) but no precise submodel of depletion/regeneration had been designed.

Figure 4.3. Description of the launch version of the role-playing-game (V0): virtual environment (a), game setting (b) and rain calendar (c).

- **a.** *The figure shows the virtual environment as players discover it before setting their farms (the computerized farms appears). The communal land (yellow) and the forest (green) are respectively composed of 4 and 9 paddocks. Paddocks numbers are displayed on the figure, but did not appear during the game. Circles represent water pans (blue= filled, white=empty). Each farm is composed of a kraal (black), fields (orange). Each farm has a color; each herd has the color of its farm. Computerized farms are black and don't have any herd.*
- **b.** *The virtual environment was projected on the wall and players had to come to the computer operator to signify their playing decisions.*
- **c.** *The four types of week were represented by symbols: a sun for a dry week with no rains, a light grey cloud for small rainfalls, a dark grey cloud for medium rainfalls and a black cloud for heavy rainfalls.*



The facilitator consulted with the computer operator to empirically update each paddock's level. Cattle had a body condition defined at the herd level that was also empirically updated by the facilitator. Same applied to water pans dynamics. A predator attacking cattle in the forest was included in the V0, and simulated through a drawing system.

The game play was kept simple: At the beginning of each round (month), players had to make individual decisions concerning (i) which paddock their cattle would use for grazing during the coming month and if they would be herded, (ii) their farming decisions (none, planting, harvesting), (iii) their cattle transactions (sell/buy) if any. At the initiation of the game, each player was given beans. These represented both seeds and money. Each action, such as plowing, employing a herd boy or pumping at the borehole had a cost. Harvests were obtained in beans. Finally, the beans were also used to sell/buy cattle. In order to force players to prioritize their decisions, an extra cost was included: the further livestock was grazing, the more players had to pay (1 bean per paddock crossed from the farm location).

Setting-up a co-design team

The co-design team gathered three researchers and 10 villagers, 9 men and 1 woman who were proposed to join the team, either because we knew them personally and thought they would provide relevant insights, or because the headman, the local representative of traditional authorities, trusted them. They ranged between 39 and 57 years old. All but one were household heads, three were village heads, one was the secretary of a village head, two were involved in dip-tank committees, one was the local chairman of a community project developing goat husbandry, and four were simple villagers. They originated from the different villages of the study area. Our local translator was also part of the team.

The iterative co-design of the Role Playing Game

The first workshop was the moment when the different members of the future team meet each-other and join around a common objective. Creating an atmosphere of mutual trust is necessary, as much as creating a fair and balanced arena between researchers and non-researchers. The Magoli community hall was chosen for the venue because the local members of the team could easily come to that place and would feel confident there.

Once the different members of the team were introduced, we presented the research project and the specific objectives of the co-design process. It was made clear at the beginning that the game was opened to suggestions and that each participant could propose new rules during the game. After exposing the principles of the V0 by asking a local member to play a test month, the rest of the first day was used to play with all the members (Fig.4.3b). A first debriefing was done at the end of the day, during which the team shared impressions about the game and decided a list of topics to be discussed the day after. The second day of workshop was dedicated to a collective re-design of the Game (Appendix 1). Local members of the team proposed a series of improvements and modifications. Rules concerning livestock predation by lions were entirely re-designed. A major constraint to agriculture was absent in the V0 and added by local members: elephants. A simplified elephant behavior was designed by the team, along with field protection modalities. The addition of diseases was proposed but finally abandoned. Rules of costs-benefits were also improved, and the cattle selling/purchase rules were formalized. The crop submodel wasn't satisfying for most of the members of the team, and was therefore intensively discussed and re-designed. The idea of having only one type of crop was kept, but development stages were added, along with the possibility of crop failures due to droughts or floods. Absent in the V0, a new action was added: when harvesting, players would be able to either collect crops residues and feed their cattle later with it, or leave them in the fields where any cattle could eat them. The local members of the team asked for the availability of a weather forecast at the beginning of the month. They justified by explaining that in real life they had access to short term weather forecast, either through newspapers, radios or traditional weather forecasting methods. The game should therefore display the weather forecast of the first week of each month. Finally, the biggest contribution of this first workshop to the game concerned livestock grazing management. The subdivision of the environment in paddocks was kept, so was the rule that each player could use 1 paddock per month to graze his cattle. A completely new submodel of grazing resources dynamics was designed and worked around the notion of carrying capacity. It was decided that the effects of grazing on a paddock would depend of the land use, with slightly better pastures in the forest, and on the season. The name *Kulima Kufuma* ("farming to get rich" in ChiNambya, one of the local languages) was chosen by local members of the team at the end of the first workshop.

Following the first workshop, the V0 was modified to include the team decisions about the game. The first co-designed version (V1) was born. Two other workshops were held, one in November 2014 and one in April 2015. Each workshop resulted in a new version of the game (V2 and VF). During these workshops the core of the game (*e.g.* rules, submodels) were collectively re-designed and re-thought in order to create a game that was realistic and that could easily be played by naïve villagers. Some of the final submodels were collectively built during workshops, some were tabulated functions designed by researchers and validated by the team (Annex 1). A second climatic year also relying on meteorological data collected in Hwange (1921-22) was added, proposing a much contrasted climatic year with low rainfalls and dry spells. A full game session was thus covering 2 years played one after the other, the "good year" first (2012-13), followed by the "bad year" (1921-22). The co-designers also thought about the best physical support for the game. Computer-free (V1) and computer-based (V0, V2, VF) versions of the game were tested. From a projection on the wall (V0), the game became a horizontally projected playing board with pawns to move (V2, VF), enhancing interactions between the game and the players, and among the players. In all members' opinion, the use of pawns together with the automation of processes over which the players do not have control made the game easier to understand by potential naïve players and also more fun and faster to play. Additionally, the computer support allowed the record of every playing decision. These records took the form of tables that could be used to replay each playing session and analyze playing strategies.

At the end of the third workshop, the team agreed that the game was ready to be played by other villagers. Almost a year after initiating the co-design, the game had been radically transformed and a new name was proposed by local members of the team: *Kulayinjana*, meaning "teaching each other" in ChiNambya.

From the co-design of the game to the co-facilitation of gaming sessions

The RPG was initially built as a research tool. The use of a co-designed RPG with naïve players was one of the challenges of our approach. Pushing participation further, 5 local members of the team volunteered to facilitate the playing sessions with villagers. Working in pairs, 2 decided to be game supervisor (announcing players the different phases during the game), 2 decided to be in charge of transactions (collecting tokens and giving harvests and managing cattle sales) and 1 volunteered to records minutes. Two days were dedicated to the preparation of playing sessions. An introduction speech for the game was collectively written in ChiNambia and in SinNdebele (the main local languages) and a blank game was played as training game with workers of a neighboring hotel as players.

Four playing sessions were organized (Fig.4.2), and a total of 28 villagers played *Kulayinjana*. Playing sessions were held in local languages. The villagers (here after referred to as players) were chosen by the facilitators and the researchers, covering the different villages of our study area. Players were neighbors or friends and except for 2 players, direct family links were avoided.

Evaluating the co-design process and the final game

Four dimensions of the ComMod process were assessed: (i) the effective inclusion of local actors' views of the system, (ii) the extent to which the co-designed game reached local members' expectations, (iii) the scientific effectiveness and relevance of the co-designed game and (iv) its usability with naïve players and effectiveness in gathering relevant data to model and simulate cattle herding.

Two questionnaires were designed. These contained opened questions not to restrain opinions to predefined answers, along with ranking questions. Individual questionnaires were carried with local members of the co-design team (N=10 villagers + 3 researchers) once the VF was produced. The co-designer questionnaire assessed the team members' opinion about the initiation of the process, the workshops, the final game and their perspective about this participatory process. Villagers who played the game (N=28) in May 2015 also answered a specific questionnaire for them to evaluate the final version of the game. Their questionnaire contained opened and ranking questions. The players' questionnaire covered their experience of the game, their opinion about the game and the facilitation of the gaming session.

Results

Initiating and achieving a "fair" team work

When asked about their motivation in joining the process, 6 local members answered that it was curiosity and the will to learn, 3 answered that they wanted to share ideas and 1 wanted to help researchers that he knew. All the members of the team acknowledged a high degree of freedom in giving individual ideas during the co-design of the game and everyone could recall at least one personal idea that had been kept in the final game. As one local member remarked, "it was said to be our game, and we made it like that". The atmosphere during the workshops was given an average ranking of 8.5/10 (±1.5).

A collective effort towards consensus

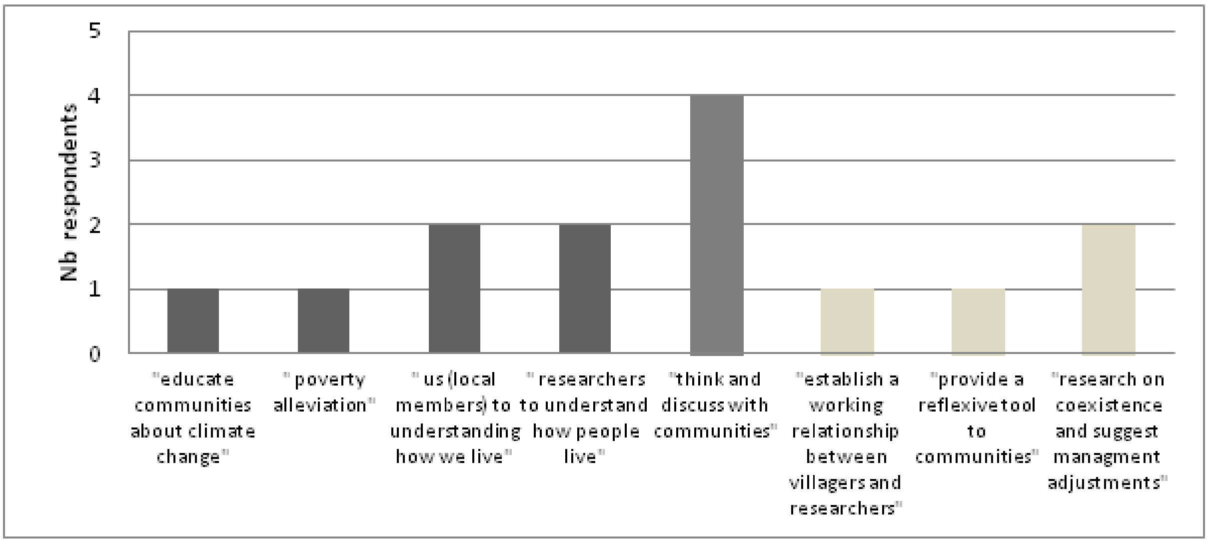
The first two versions of the game were judged too slow by 70% of the team. The direct use of pawns to signify decisions (55%) introduced in the V1 and the choice of a central game board improved the interactions between players for 70% of the team. Nevertheless, the V1 was computer-free, which made playing too fastidious for 69% of the team members as all updates (including the updating of crop status) had to be done manually. The strengths of the upgraded version cited by the team members were the fastening of the game (69%), its clarity (42%) and the fact that the consequences of playing actions could easily be monitored and recorded (38%). When asked about the final version of the game, the whole team declared being satisfied, with a few of them suggesting possible improvements such as the inclusion of seasonal rivers proposed by three local members, or the use of alternative sources of climatic information, such as played birds songs that "[they] use here to know when it is about to bring rain, they are our reporters". This last suggestion was supported by one of the researchers and echoes previous research (Perrotton *et al.* in prep). The three researchers of the team agreed on the necessity to pursue the calibration of the foraging submodel.

From "Farming to be rich" to "Teaching each other": appropriation of the game and emergence of endogenous objectives

The analysis of questionnaires highlights the appropriation of the process by local team members during the participatory process. One year of collaboration led the 10 local members to find their own objectives of the game (Fig. 4.4). Hence, at the end of the co-design, only 20%

of the local members (N=10) still saw the RPG as a tool for researchers to understand local farming strategies, which was the initial objective. The co-design process and its product was transformed by local actors into the creation of an endogenous reflexive tool that could help local team members understand their own strategies, and the communities to “think and discuss”, “educate (themselves) about climate change” and “alleviate poverty”. One of the members explained how creating the game had “opened [their] minds widely and [led them to] think more”. Local members also saw an opportunity for them to better understand their own life.

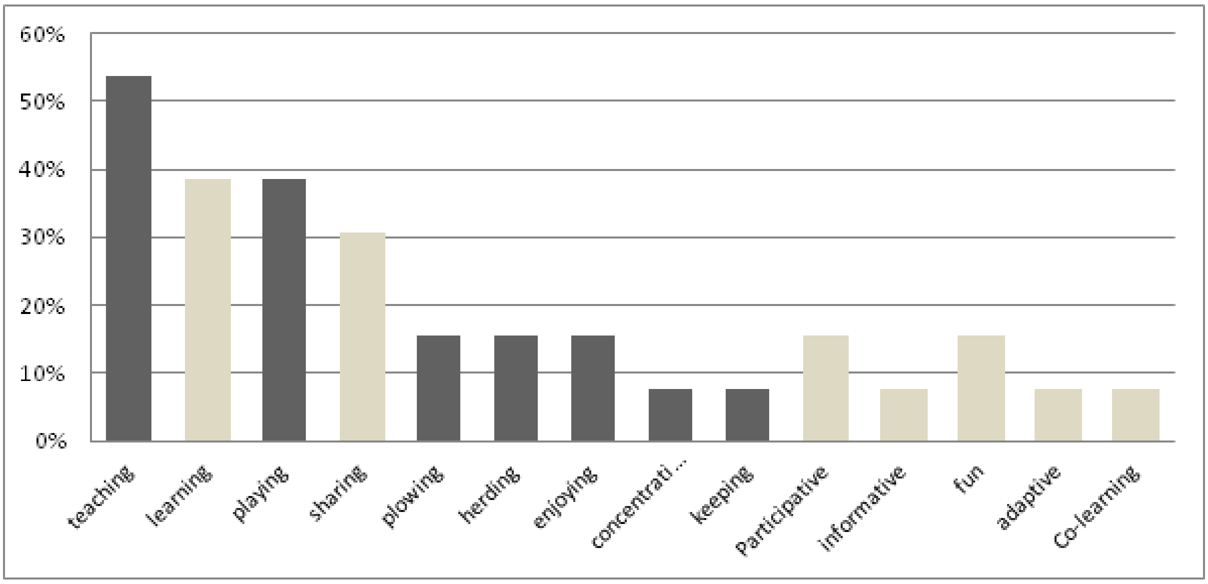
Figure 4.4. Objectives of the game as perceived by the team members. *The black columns correspond to the local members' opinions (N=10), the grey columns correspond to the researchers’ answers (N=3).*



The changing of the name of the game marked this appropriation process as “teaching each other” translates local objectives and put the local member at the heart of an active co-learning process. Unsurprisingly the main objectives mentioned by researchers were coherent with the initial research objectives: establishing a working relationship with local communities and study coexistence within the study area. Nevertheless, the researchers also discovered and added new objectives along the process such as providing local communities with a reflexive tool they could use to share knowledge and plan activities among themselves, thus re-appropriating the process they initiated and extending its original framework.

The key words used by the 13 team members confirm this (re)appropriation (Fig.4.5). The majority of "teaching" and "learning" echoes both the initial and emerging objectives. The use of "sharing" by a third of the team or to lesser extents "participative" and "adaptive" and "co-learning" illustrates the very essence of this participatory process. Other key words were related to the nature of the co-designed object, such as "playing", "enjoying" and "fun", or its topic with words like "plowing", "herding" and "keeping".

Figure 4.5. Key words given by team members to summarize the game and its creation. *Each member was asked to give three words. The black columns correspond to the local members' answers, the grey columns correspond to answers shared by local members and at least one researcher.*



Volunteering to facilitate playing sessions was part of the appropriation process by local members. Three said that they were proud of the game and wanted to show and confront it to other villagers' opinion, one openly assumed the educating dimension of the game and wanted to "help [his] community to improve the way people drive their cattle", and the last one saw it as a training to "be a leader". All acknowledged that facilitating improved their understanding of the game. If the game was to be played again, all agreed to facilitate again.

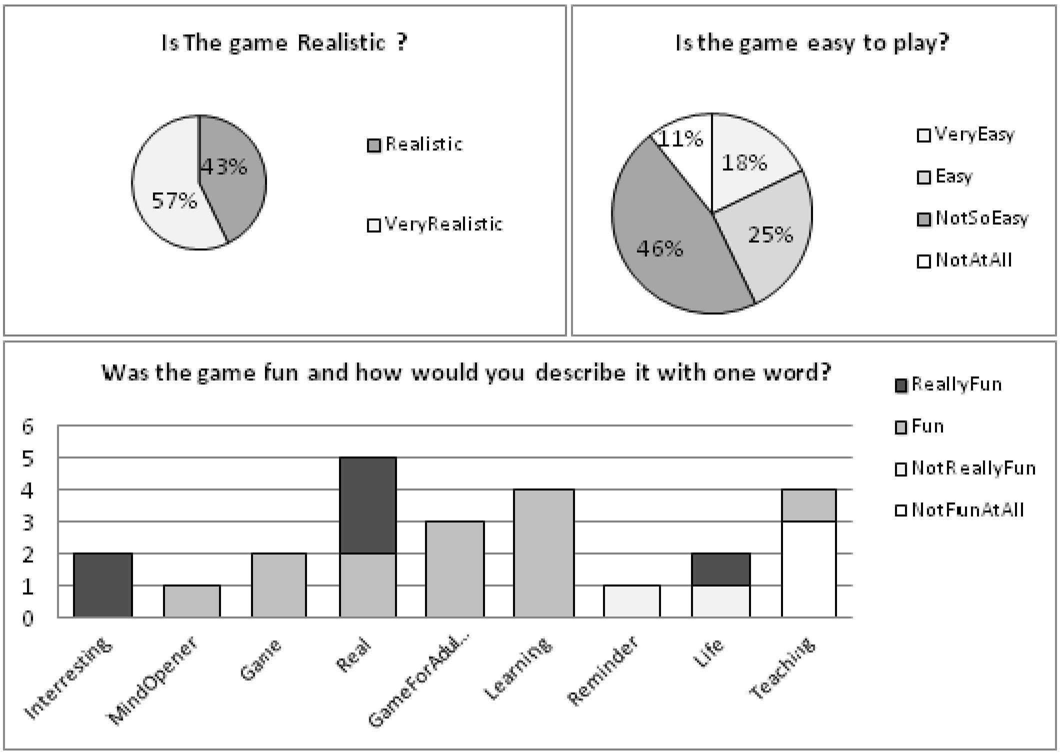
Model vs Reality: a validation of the game by naïve individuals

As shown in Figure 4.6, the game was very easy to play for 5 players (18%), easy for 7 players (25%), not so easy for 13 players (46%) and not easy at all for 3 players (11%). Note that the majority of participants who declared that the game was either fun (61%) or very fun

(21%), used words like "real", "life", "mind opener", "learning" and "teaching"to describe the game. As expressed by a player, "it's not a game, it's [their] real life, and life is not always fun". Hence, the 11% for whome the game was not fun at all and the 7% for whome the game wasn't really fun used words like ""life", "reminder" (of their lives) and "teaching" to describe a playing experience that was closer to training than playing.

Although they mentioned some differences with reality, none of the players answered negatively to the question about the global realism of the game. Opinions about possible differences between the game's submodels and reality varied between the submodels. Unsurprisingly, the climate submodel (based on empirical data) was realistic or very realistic for 93% of the player. 82% of the players validated the crops dynamics submodel, although two thought the game was missing crop raiding birds such as the queleas (*Quelea quelea*).

Figure 4.6. General comments about the game by players. *The title of each chart corresponds to the question asked to the players***.**



Among the 18% of players who noted some differences, 3 explained that crops do not grow the same everywhere and that the game should include different types of soil and 4 thought that crops were ripening faster in the game than in real life. Wildlife in the game presented no difference at all or slight differences with reality for 85% of the players. Some players thought that the game's lions were attacking too often (11%), others not enough (21%). The confinement of lions to the forest was criticized by 18% of the players who acknowledge occasional attacks in the communal area. Three players (11%) answered that elephants would enter the communal land more often in reality, but cause less loss than in the game.

Although validated by 68% of the players, the livestock submodel was the one obtaining the most shared opinions from the players, with 32% of the players mentioning real differences between their gaming experience and reality. These differences were not always explicit and for some players it was just a feeling. The main remark concerned not the submodel as such, but the playing conditions and pointed at the herding costs in particular. Indeed, during the game player were asked to pay for each paddock crossed, a cost that was designed as a proxy for the energetic cost of movement, but that was apparently not matching the reality as perceived by some players'. Players who could point precise differences explained that the difference of pasture availability between the communal land and the forest was underestimated in the game (16%), that livestock body condition was decreasing too fast in the game (26.3%), or that on the contrary livestock was staying "fat" longer in the game compared to their experience of real life (26.3%). Finally, a comment was shared by 17% of the players who suggested that unlike in the game, not all farmers have cattle and that this was the origin of social interactions (lending, fostering and bartering) missing during the playing sessions.

Local strategies gathered through playing Kulayinjana

Out of the 28 players, 61% acknowledge having reproduced « exactly » their farming and cattle herding strategies while playing and 36% declared that their playing strategies were "almost" similar to their real life strategies. The differences were said to be due to the discovering of the game for 66% of the players. Only 4% of the players answered that their playing strategies were "not really" similar to their actual practices. The computer-based nature of the game allowed researchers to automatically record all individual strategies of all playing sessions. The general pattern of cattle herding identified and described in the ethnography was reproduced by players, therefore confirming our field observations. For instance, if the choice of a *xotshela* (release) date never appeared in playing sessions, the rule of sending livestock daily in the forest during the agricultural season and waiting for harvests to be finished was globally reproduced and respected. Deviant strategies occurred, and were explained by the players during group discussions conducted after playing sessions and individual questionnaires. Playing sessions are currently being analyzed and will result in cattle herding strategies simulations (Perrotton et al in prep).

Exploring the potential alternative uses of Kulayinjana

When asked about the potential future use of *Kulayinjana*, all the members of the team acknowledged a need to organize more playing sessions to involve more villagers in a sharing/thinking process. This echoes players' opinion about their playing experience. All the players thought playing *Kulayinjana* was useful (75%), or very useful (25%) for them and was an occasion to improve their practices (8%), train (8%), open their perspectives (12%), learn (28%), or think (40%). Local members also proposed using the game in schools "so that children grow up with a better understanding of cattle herding", and researchers considered using the game as a teaching tool for academics. Both researchers and local members of the team thought the audience of the game could be extended to other stakeholders of the SES, such as National Parks officers, Forestry Commission managers and veterinary services. Bonds were created between local members and researchers, and working as a team to either improve the game or design other games was expressed by 70% of the team. Two potential topics for future games emerged from the designers' questionnaires. Three local members proposed to focus on interactions with wildlife, particularly crop raiding and predation, but also conservation to "try to find solutions". Two local members expressed a real concern about the loss of trees in the communal land, and thought that a game focusing on trees management could address the matter. Such result is to put in perspective with the emergence of local objectives described in a previous paragraph.

Discussion

With this work we had the objective of extending the traditional scope of participatory research by involving local actors not only in the co-production of results, but also in the co-design of the research tool itself. Our ambition was to include local knowledge and perspectives in a shared conceptual representation of reality taking the form of a role playing game. This research tool being a game, using it relies on the participation of local farmers. The challenge was therefore to deal with these two dimensions of participation.

Achieving participation and appropriation

Participatory processes are long (Mansbridge 1973), and ours took more than a year. As expressed by d'Aquino and Bah (2013), the success of a self-design process depends on the facilitator's awareness of the social background. The long ethnographical fieldwork that took place with the same community before the RPG co-design participated to the success of the endeavor. It provided crucial information about the context, practices and coexistence issues in our study area, and was the first step of our collaboration. Like Becu *et al* (2005) we assume that the ethnographic approach enables a more trustful relationship between researchers and local actors. Through these months of sharing life of rural populations, we became part of the local social network, which obviously played a role in the motivation of local members of the team to join the process. The consensus within the co-design team around the VF and the members' appreciations of the co-design process are indications that we achieved the creation of a fair relationship between researchers and local actors to create a RPG together. The reason lies at the very core of our method. The efficiency of participation relies on appropriation by local actors involved (Chlous-Ducharme and Gourmelon 2011). The method described in this paper is flexible by nature and gives a high degree of freedom to local members. Once the process was started, the co-design process and the team were maintained as collective and as non-hierarchical as possible, therefore empowering the local members involved (Desouza 2012). The definition of endogenous objectives is both resulting from and enhancing appropriation, so was the will of local members to facilitate playing sessions.

Throughout the process, the co-design team produced a game reflecting local actors' reality. It was successfully used with naïve players who, although surprised to be asked to play a game, all understood it and reproduced their actual strategies to a certain extent.

The added values of a role playing game

One could wonder what the game's added value is, compared "classical" approaches to understand and model cattle herding strategies, such as ethnographical fieldwork or the use of GPS collars on livestock. First, our ethnographical fieldwork highlighted a general pattern relying on rules that were validated with the game. Nevertheless, playing sessions showed variations in peoples' behaviors. Variations between the general pattern and actual practices are sometimes thin and often are small adjustments respecting their general strategies (Bennett 1976). They can easily be missed during conventional interviews, but not when they are actually played. The theory of *situatedness* (Clancey 1997) stands that knowledge can only be represented once a person has actually put his or her knowledge into use. If individuals are key elements of a system, behaviors are influenced by collective dynamics. A knowledge elicitation exercise must therefore include these two dimensions. We don't argue that it is necessarily the best solutions, but a co-designed RPG is a relevant tool. Unlike individual interviews, the game brings players to play in a representative virtual *alter ego* of their reality (situated actions), and triggers collective as individual actions having potential actions on the others. When used with a modeling exercise, the added value of a participatory design of a RPG is that while co-designing the game, the team actually co-formalizes a virtual environment and defines a first step of parameters to include in the model and that will belong to or interact with the agents.

The question of the relationship between what happens during the game and reality must be asked (Daré 2005), that is do players reproduce their reality or do they use the game as a training arena. As explained in our results, the playing strategies were recorded and discussions and individual questionnaires were conducted after playing sessions. The analysis will be the object of a future publication (Perrotton et al in prep) that will determine cattle herding strategies and simulate them.

The emergence of new objectives and the social responsibility of projects facilitators

The RPG presented is a boundary object built by heterogeneous actors coming from different social worlds, but joining together to produce a shared representation of reality. The empowerment during the process and the appropriation of the game led local actors to define their own objectives, and researchers to define new ones. Engaging local stakeholders triggers social dynamics (Gurung *et al.* 2006) and gives responsibilities to project researchers. When given an arena to think, conceptualize, share and implement their ideas, local actors develop their own objectives. As suggested more than three decades ago by Rittel and Webber (1973), when dealing with local problems, every action engaged is consequential and outcomes are often irreversible. Emergent objectives have to be considered, discussed and prioritized within the team and a balanced dynamic has to be found to satisfy all stakeholders. As shown in this paper, the life of a boundary object can transcend the achievement of initial objectives. In our case, although we obtained the data needed to proceed to the next steps of our research, it is our responsibility to answer local partners' expectations. The main challenge will be to produce a computer-free version of *Kulayinjana* that could be played by local communities without our technical support (generator, computer and video projector).

Towards a formalization of research tools co-design

In the field of environmental sciences, participation has become so inescapable that some authors spoke out of the *tyranny of participation* (Cooke and Kothari 2001). Participatory empirical modeling still needs to be framed and formalized. The last point of our discussion highlights the lessons learnt from our work.

A good awareness of the context: A time of observation and immersion is necessary, or at least greatly advisable. Beyond contextual information, it represents the first steps to create links between the project facilitators and local stakeholders. This step will have consequences on the engagement of local actors, and the effective collaboration within the working team (Mathevet *et al.* 2011).

Building legitimacy: The question of the legitimacy of external agents to conduct participatory processes was highlighted by Barnaud and Van Paassen (2013). Social-ecological systems are complex systems and involving actors is not neutral. Power asymmetries must be considered when engaging local stakeholders, resulting for the authors in the dilemma of participation. When designers of a participatory process claim a neutral posture, ignoring these power asymmetries, they are accused of being manipulated by the most powerful stakeholders, therefore reinforcing asymmetries. On the other hand, what is their legitimacy when non-neutral posture empowering particular stakeholders? Such dilemma isn't solved with a method, but by being reflexive about our posture (Daré *et al.* 2010, Barnaud and Van Paassen 2013). Transposed to our study, local communities and protected areas managers are all equally concerned by coexistence issues and the choice could have been to involve them equally. Other research activities are conducted by our team with HNP and SF authorities, and while it legitimizes us in their eyes it also leads rural communities to see researchers as conservation agents. With the objective of initiating collaboration between researches and local actors in the study area, we chose to start by involving rural communities only, and assume this posture. Our legitimacy was built according to ComMod view, which is that legitimacy as the product of an iterative and adaptive co-construction between local actors and researchers (Barnaud 2013). Our choice of living in one of the villages is in accordance with this position. We don't claim that our approach was the "right" one, but the positive perception of the co-design process by local team members, the appropriation that occurred and their expressed will to pursue collaboration are good signs of an acquired legitimacy.

Simply prepare complexity: Co-designing a model with people that are not used to manipulate such object is challenging. The initiation of participation will define the relationship between participants for the whole co-design process. The popular "Keep It Simple Stupid" (KISS) encourages one to start with the simplest possible model, and only move to a complex one if forced to. As argued by Edmond and Moss (2005), it is sometimes critical to start with a model that relates to the target phenomena in the most straight-forward way possible, which is rarely simple. In the case of a co-design with profane actors, we advocate for the use of a simple launch version, like the V0 we used. Simplicity serves 3 purposes: easing the understanding of the project expectations by local members, legitimizing the researchers and facilitate the improvement process. The choice of elements put in and left out of it is critical. They have to show your knowledge of the system, without over-influencing the design. The V0 brought for the first workshop displayed enough elements to show local members our understanding of the system, although and observed elements of the SES studied were willingly left out. Beyond simplicity, the V0 was incomplete. This eased the initiation of a critic/re-design dynamic from local members. Starting simple doesn't mean keeping it simple and this launch version has to be designed for complexity, in other words, the launch version is a complex structure of simple elements articulated around obvious gaps. The participation process will then consist in filling the gaps and adding new elements.

Conclusion

This paper presents the use of participatory modeling to co-design a research tool with local members of a rural community, in accordance with the Companion Modeling approach. Although it is a long process, the participatory design of research tools and empirical models to study wicked problems is possible. The RPG built is the result of a year of iterations and was successfully played by naïve villagers. This ComMod process was initiated as a response to the need of a relevant tool to understand the wicked problem of coexistence between a protected area and rural communities. We proposed to test a methodology and this papers drawn lessons contributing to the formalization of such endeavors.

Any action on wicked problems, either research or management, is consequential and therefore is potentially never-ending. Our results suggest that although a consensus was reached and relevant data obtained, the collaboration engaged should not stop at the end of our project.

Social processes were initiated, human bonds were created and local members have high expectations concerning future collaborations. More research has to be done to formalize methods to evaluate the consequences of participatory modeling of wicked problems, and on the robustness of the results. A particular focus will have to be done on the effects of participation on SESs and their inertia on the long-term.

We assume that co-designed research tools approach offers promising perspectives in collectively addressing a wide range of environmental wicked problems. non-exhaustive list of potential urging environmental issues could be: human-wildlife conflicts, soil erosion, deforestation or over-fishing

CHAPTER 5. *Kulayinjana*: The model, preliminary results and perspectives of modeling

WHAT IS THIS CHAPTER ABOUT?

As described in chapter 4, the role-playing game we co-designed with members of the rural communities living in our study area is computer-based, and supported by an agent-based model. The model itself is the central result of our work, and must therefore be described in details. Agent-based models were early criticized as generally being poorly documented, making any evaluation hard to do. This led to the elaboration of a standardized way to describe the objectives and structures of such model: the ODD protocol (Grimm *et al* 2010). It consists in describing first the Overview of the model, its Design characteristics, and finally the Details of the model's functioning.

The first purpose of a game is to be played. *Kulayinjana* was played several times in May 2015. During these playing sessions, we gathered key data allowing us to start understanding cattle herding strategies in the area.

This chapter is composed of three sections:

- The first section is an ODD description of the game/model that was co-designed.
- The second section presents the preliminary results of the first three playing sessions and proposes a first method to analyze cattle herding strategies.
- The third section discusses the modeling perspectives, emphasizing the benefits of pursuing work with the model.

Kulayinjana: Overview-Design-Details (ODD)

The description of the model is based on the updated version (Grimm et al. 2010) of the ODD protocol that was originally proposed by Grimm and his colleagues in 2006.

Purpose

Through bringing players to re-enact their real life farming activities (field*cattle management) in a virtual environment mimicking their reality, the purpose of the game was to understand the use of the landscape through cattle herding and the drivers of cattle herding (*i.e.* climate, crops production calendars, perception of depredation risk). The game itself can have several uses. Originally designed as a research tool for researchers to collect data about agricultural practices and coexistence between protected areas and communal land it is also a potential educational tool for rural communities to share knowledge and collectively think about their practices (cf Chapter 4).

Entities, state variables and scales

Cells are the elementary spatial entities of the model. The whole space is divided in two Zones, the first one representing Communal Land and the other representing Forest. Some forage is available in both zones. In the communal land, Households manage Farms. A farm is made up of an aggregation of 6 cells: 5 Fields adjacent to 1 Kraal (enclosure for cattle). In the model, a Household is either controlled by a human player (played household) or connected by the computer to a played household (computerized farm; it behaves then as a clone). Played households own Cattle, a herd of 5 Cows that can be guarded by a Herdboy. Each Cow has a status (*thin*, *medium* or *fat*) that changes over time according to how the cow fed. GrazingAreas (also called paddocks) represent the management units for cattle herding in the model. Grazing areas are aggregates of cells. There are 4 grazing areas in the Communal Land and 9 grazing areas in the Forest. The level of forage of each grazing area is *null*, *depleted*, *medium* or *good*. It changes according to the load of cattle, the season and the rainfall. Some grazing areas have Waterpans. When these water pans are not dried out, they are used to water the cows located there. On their Fields, played Households can grow 2 varieties of Maize (short-term and long-term). When harvested, crop leftovers, called Machanga, represent a source of food for the cows. Wildlife (lions and elephants) are likely to cause some disturbance to the cattle and the crops of the households.

An overview of the overall structure of the model is provided by a UML class diagram (see figure 5.1).

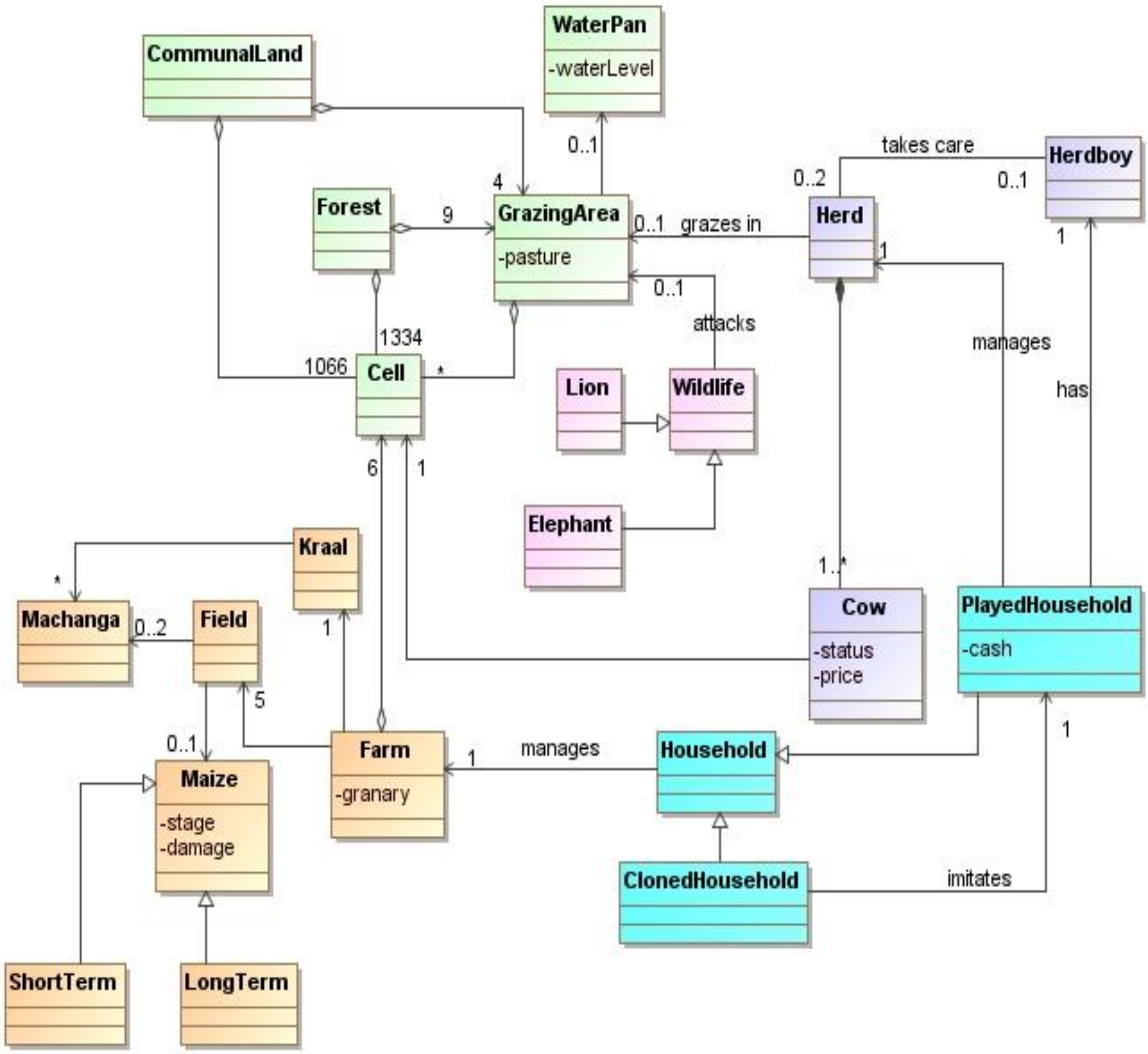


Figure 5.1. Class diagram of the *Kulayinjana* model.

Players have two objects of decision making at the beginning of each month: their cattle and their fields. Concerning cattle, they have to choose in which grazing area they will graze, and if they will be guarded or not, that is if they put a herdboy with the herd or not[71]. At the

[71] In the area, cows are usually grazing during the day, and gathered in the kraal at night we're the Kraal serves as a protection. In the model (and in the game), only active phases of cattle herding are considered, and nights are not simulated.

beginning of the month, players can also decide to buy or sell cattle. Concerning their fields, at the beginning of each month players can decide toplow or harvest their fields. Fields can only be harvested if the maize is either mature or dry, but in the first case, harvesting implies building a granary for the maize to dry up. All of these actions obey specific cost/benefit rules. These rely on tokens that are distributed to, or given back by players. There are two types of tokens, small ones (ST) and big ones (BT). A big token equals six small ones. The balance of tokens is stored in households' *cashboxes*. The main parameters of the model are listed in table 5.1. The way these parameters affect the various processes is explained in the "details" subsection (last part of the ODD protocol).

Entity	Parameter	Value	Unit
GrazingArea	cattleOverloadThreshold	10	cow
	protectionAtNightAgainstElephants	3	small token
Cow	fatteningThreshold	6	satiation index
	wastingThreshold	3	satiation index
	marketPrice_Fat	18	small token
	marketPrice_Medium	12	small token
	marketPrice_Thin	6	small token
Cattle	herdboyCost	1	small token
	grazingAreaCrossingCost	1	small token
	wateringCost	1	small token
	damageMaize_Cattle	25%	expected yield
Wildlife	damageMaize_Elelephant	50%	expected yield
Maize	damageMaize_Climate	100%	expected yield
	establishmentCost	6	small token
	yieldIncome	12	small token
	Machanga	2	small token
	machangaFeedingCapacity	1	satiation index
Household	initialCashbox	48	small token
Farm	granaryCost	1	small token

Table 5.1. Model parameters.

The time step of the model[72] represents one day. The game covers two agricultural years, from the beginning of October ($year_1$) to the end of September ($year_2$). Players' decisions are done only at the beginning of the month. To complete a game session, 24 rounds of decisions have therefore to be achieved. The virtual environment (Fig.5.2) referred to as "the map" is a grid of 60*40 square cells. The size of a cell was defined by the design team so that one cell represents one "*umfollow*", that is the surface that one farmer can plough in one day. Therefore, the cells' area is 0.5acre (45m*45m). The total surface covered by our virtual environment is 2400 cells, that is 1200 acres.

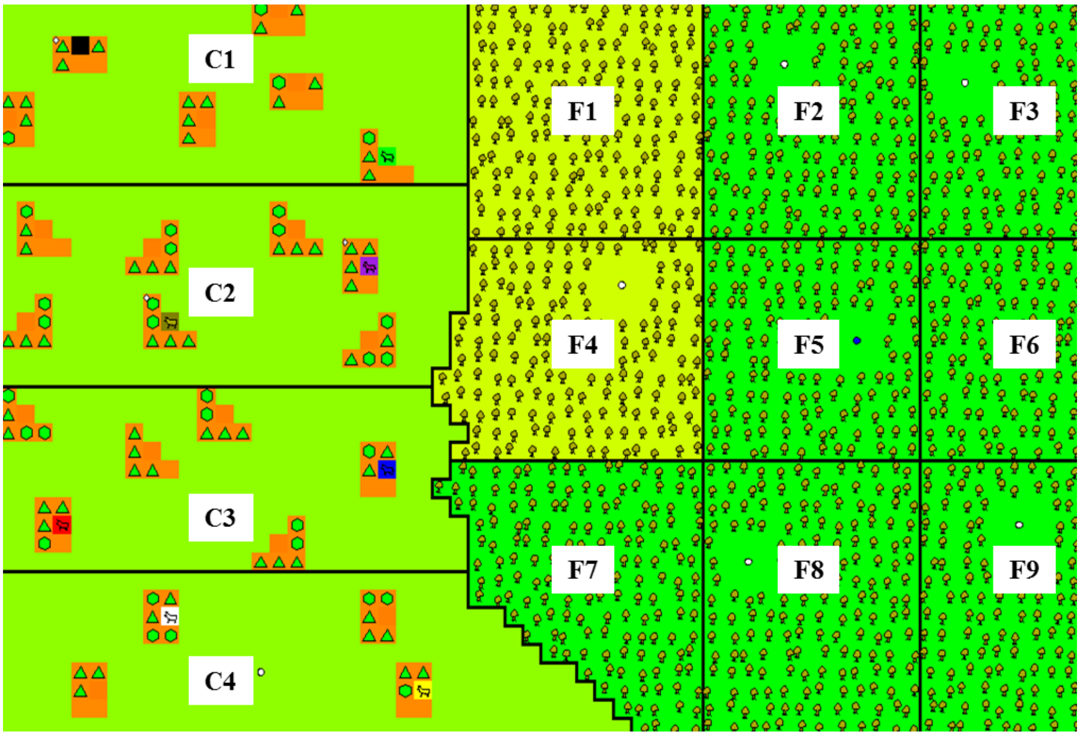


Figure 5.2. The virtual environment. *The virtual environment is divided in 13 GrazingAreas numbered C1 to C4 in the communal land, F1 to F9 in the forest. Each played Farm has its Kraal colored according to the player in charge (2 played Farms by communal GrazingArea),* the 5 fields appearing in orange (5 orange cells around the Kraal). *Farms with no Kraal are clones managed by the model. The green entities seen on fields represent growing Crops (triangles are short term maize; rounds are long term maize). _The figure shows three of the four different forage levels: "poor" (F1 and F4); "medium" (C1 to C4). and "good" (F2, F3, F5, F6, F7, F8 and F9). These levels change during the game according to players' actions.*

[72] The playing time step is a month, that is that players make their decisions at the beginning of the month. The model supporting the game has a daily time step. In other words, the model does 30 time steps between each round.

Process overview and scheduling

The model presented here supports a role-playing game and as a result, is not run "continuously", but is stopped and resumed for players to make their decisions (Fig.5.3).

At the beginning of the game, players choose from predefined locations which farm they want to manage. Then the simulation is scheduled by month.

At the beginning of the month, a weather forecast is given for the first week. Players notify with pawns if they want to plant Maize. Players put a pawn on each field they want to plow, knowing that each field can only have one growing Maize at a time. There are two types of pawn, corresponding to the two type of Maize. If some of the Maize is ready to be harvested, the players can choose to harvest. In that case, they have to notify if they leave the crop residue in the field (can be used by any Cattle), or if the crop residue are stored within the Kraal. To do so, they use pawns that they directly put on the game board. Players also decide in which GrazingArea they want their Cattle to graze daily for the next four weeks, and if they will be guarded by a Herdboy[73].

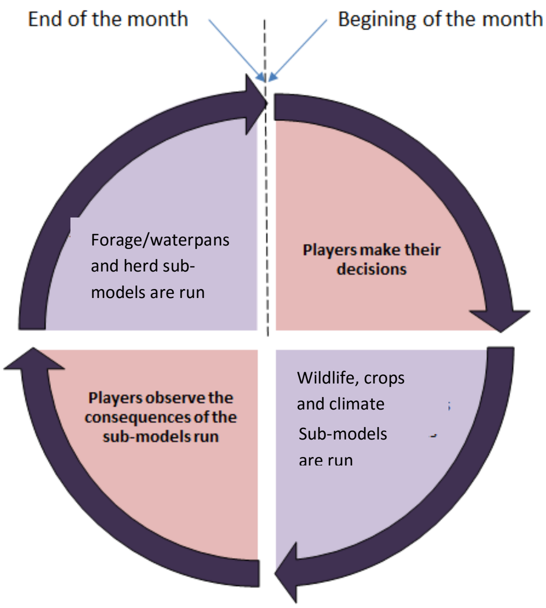


Figure 5.3. Sequential mobilization of the sub-models during the playing session. *A round of playing, that is a month in the model, is done in four steps. Purple phases represents moments were the model is run, pink phases are moments when the model is paused. The model is constituted of different sub-models, controlling specific dynamics (see next paragraphs). These sub-models are mobilized at specific steps of the month, as showed by the figure.*

[73] See foot note 71.

Once all the decisions are entered by the computer operator (Fig. 5.4), the model is run for 30 time steps (a month).

<u>During the month</u>, the climate is updated weekly. Players have access to a table displayed in the game's interface where the amount of rain is retrospectively shown (Fig. 5.5). <u>Maize</u> entities are updated daily by the computer (stages, failures).

<u>At the end of the month</u>, the Cattle damage sub-model is run (cattle entering fields); the <u>Wildlife</u> sub-model is run (lion attack and elephant crop raiding); <u>Cattle</u> statuses are updated according to the forage level of the <u>GrazingArea</u> they were using; the forage of every <u>GrazingArea</u> is updated. The number of cattle owned by players is updated along with cattle conditions. So are the sizes of <u>Waterpans</u>. Finally, the cashboxes of the 8 played households are updated.

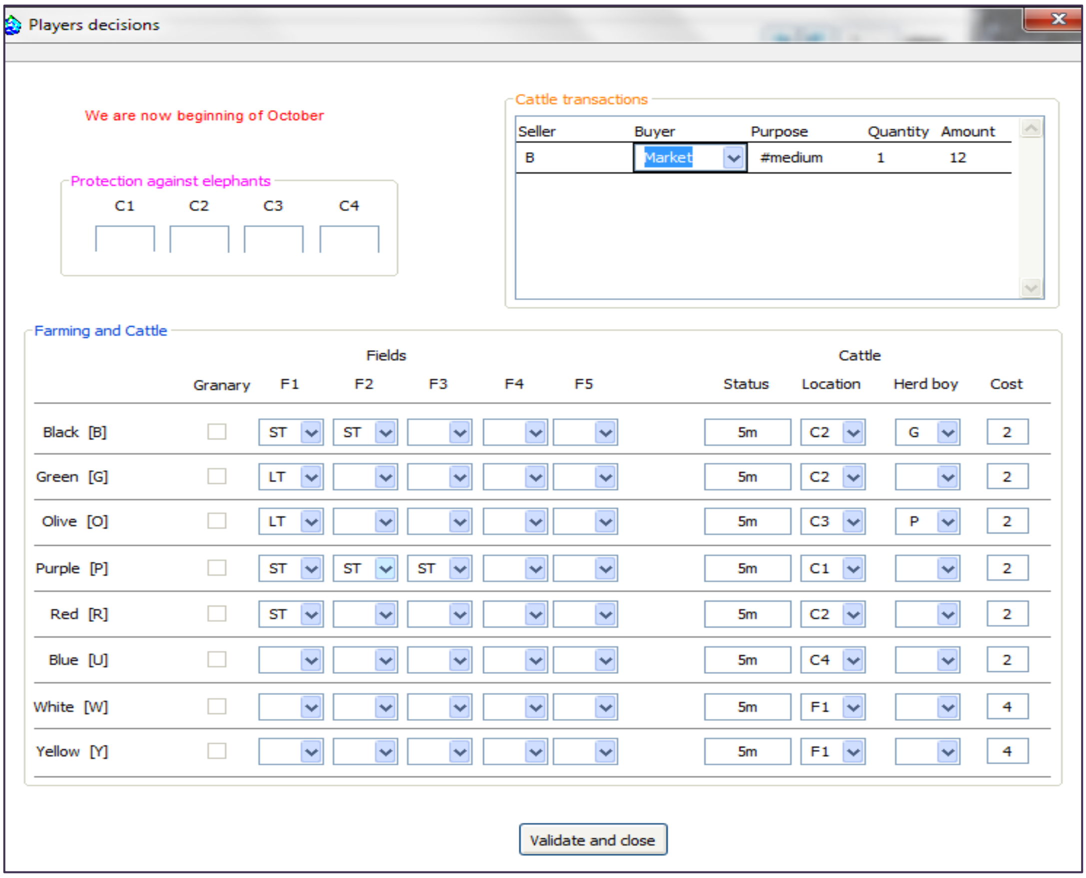


Figure 5.4. Interface used by the computer operator to enter players' decisions at the beginning of each month. *The "protection against elephants" can be filled with the initials of the players paying to protect a communal GrazingArea (in this case no one protected any). The "cattle transaction" box deals with cattle sales and purchases (here the Black player sold a medium cow to the market and earned 12ST). The "Farming and Cattle" relates to crops and cattle herding. Here for instance, the black players decided to plant two of his fields with short-term maize and to put his Cattle -guarded by the Green herdboy- in C2.*

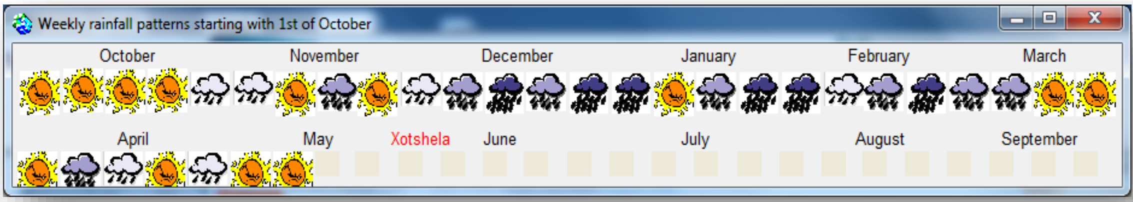


Figure 5.5. The weekly rainfall calendar. *The sun corresponds to a dry week, a light cloud represents 5-20mm of rain, a grey cloud represents 20-40mm of rain, the dark cloud represents +40mm of rainfall. The first of June is indicated as* xotshela, *a Ndebele word meaning "to push", that corresponds to the historical traditional date when cattle are released freely in the fields to eat the crops leftovers.*

Design Concepts

The game was co-designed by researchers and representatives of the local community studied, with the objective of proposing a role-playing game mimicking local for players to reproduce their actual practices (Chapter 4). The agents' behavior is not programmed, but is left open for players to make choices. The consequences of players' decisions are public. The players can therefore learn and adapt.

We assume that players make, to a certain extent, their decision following the same rationale they would use in the real life. The extent to which they reproduce their actual practices is assessed through a post-playing questionnaire.

<u>Uncertainty</u> is part of the model supporting the game. Wildlife actions for instance are based on probabilities, and players must consider risks while managing their cattle and fields. Similarly, when they have to make decisions, players do not know in advance the rainfalls of the coming month, except for the first week that is announced with a "weather forecast". Assessing the way players deal with such uncertainties is one of the objectives of the game.

Being implemented as a role-playing game, <u>interactions</u> among agents are central. Players are free to talk during the gaming session, including talking together to advise or seek advice, congratulating or mocking, coordinating or working together. In particular, they can make agreements to share the cost of guarding their cattle and the cost of guarding their communal paddock at night to prevent crop raiding by elephants.

The played households have similar characteristics at the beginning of the game. The players manipulate or own the same entities (5 fields, 5 cows) and have the same initial number of tokens. Nevertheless we assume that a diversity of strategies and objectives will be exhibited during the gaming sessions, reflecting heterogeneity in the decision-making processes and objectives among the participants. Eliciting player's strategies and objectives and relating them to their strategies and objectives in their "real-life" is the heart of the post-game debriefing.

Some stochasticity is found in the Wildlife and the Cattle damage sub-models. The same predetermined sets of "random" events are used for each gaming session. standardizing the randomness is needed to ensure the comparability of the playing sessions.

The observation of the gaming sessions is supported by the use of the computer. All playing decisions are recorded, along with environmental parameters. Furthermore, supplementary information can be extracted from playing sessions through the replay function of the simulation platform used (CORMAS). Additionally, a member of the facilitation team records social interactions by taking pictures and collecting minutes later on organized in snippets of conversation relevant to various themes to be discussed during the post-game debriefing. After playing, questionnaires are administered to all participants. These enable us to produce decision matrices and choose relevant variables to distinguish cattle herding strategies (cf second section of this Chapter).

Implementation details

The model was developed through several participatory workshops (Chapter4). The computer part was implemented with the Cormas simulation platform. The game was played 4 times and the playing sessions involved a total of 28 players.

Initialization of the simulation

The initialization of the simulation was always the same. The model is initiated at the beginning of October. All the farms, played (8) and cloned (15), are located by default. There are two played farms in each communal GrazingArea (Fig.5.6). Thanks to a name-drawing system, each participant in the playing session is asked to choose which Farm he wants to manage. Each players receives an initial cashbox of 48 small tokens (ST) that he will use to play (plant, drive his cattle, etc). Finally, each player starts with a Cattle herd of five medium Cows. At the start, communal and forest GrazingAreas all have "medium" forage. All the herds are in their respective Kraals, and all Waterpans are empty, except the one located on F5.

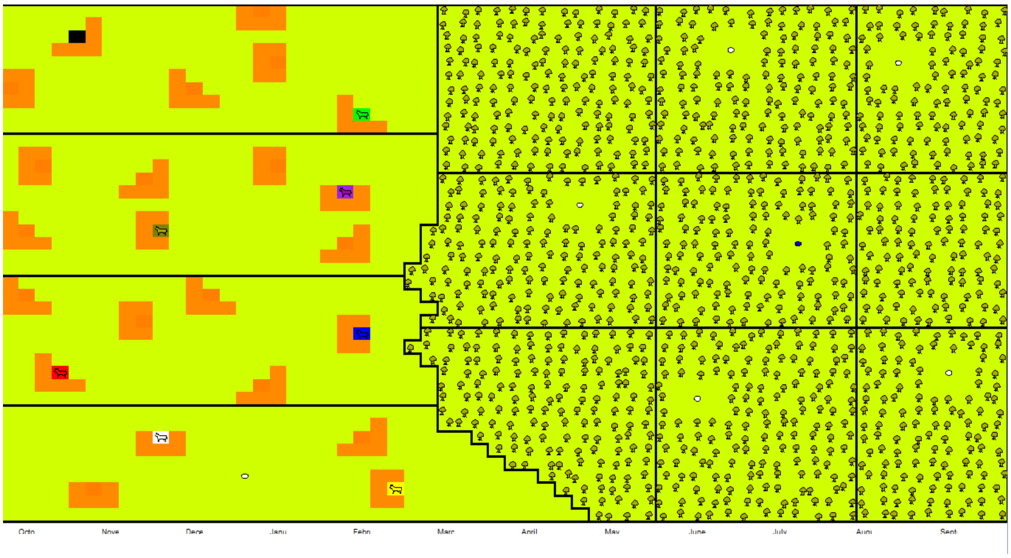


Figure 5.6. The virtual environment at the initiation of the model/playing session.

Input data

The model used weekly rainfall input data. Rainfall records were obtained in the study area. Two contrasted climatic years (Fig. 5.7) were used to produce a continuous 2-year dataset: a first “good year” (2012-13), measured by ourselves in the study area, is followed by a “bad year” (data from 1920-21), measured in the study area by the Rhodesian meteorological services. As showed in figure 5.5, the two sets of empirical data used for the rain sub-model propose very contrasted climatic conditions. The “good rains” year is characterized by abundant rainfall throughout the rainy season, with a total of 733mm, while the “bad rains” year only offers 531mm through erratic and low rainfall. This weekly rainfall was transformed into four types of week (Fig.5.5): “dry” (<5mm); small rain (<20mm); “medium rains” (20 to 40mm); “big rains” (>40mm).

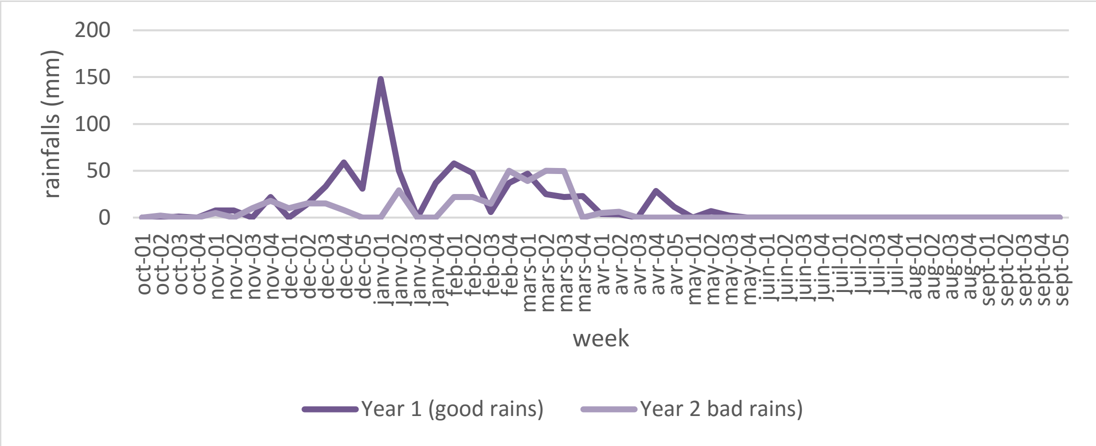


Figure 5.7. Weekly rainfall data. *The figure shows the two sets of data used for the rain sub-model.*

Details for crop sub-model

This sub-model controls crops dynamics and weather-related failures. There are two types of Crop. They have the same productivity, but differ by their growing dynamics. Once planted (stage: *seed*), both short-term and long-term types germinate after the first non-dry week (stage: *germinated*) and remain in that stage –prone to rain washing– for two months, until they evolve to the "shooting" status. Crop types differ by the time needed to change from the stage *shooting* to the stage *mature*: 1 month for the short-term variety against 2 months for the long-term variety. The transition diagrams are represented in figure 5.8. Players can harvest their crops when they are either "mature" or "dry". Nevertheless, when players harvest "mature" crops they must build a granary, unless they already have one.

Crops are sensitive to drought. Between the moment they are planted and the end of December, three consecutive weeks without rain cause a loss of 100% of every growing short-term crop. Long-term crops are more resistant, they need four weeks of drought to be destroyed. On the other hand, during the *germinated* stage of development, crops are also sensitive to floods, and both types will be destroyed (100%) by three consecutive weeks of heavy rains.

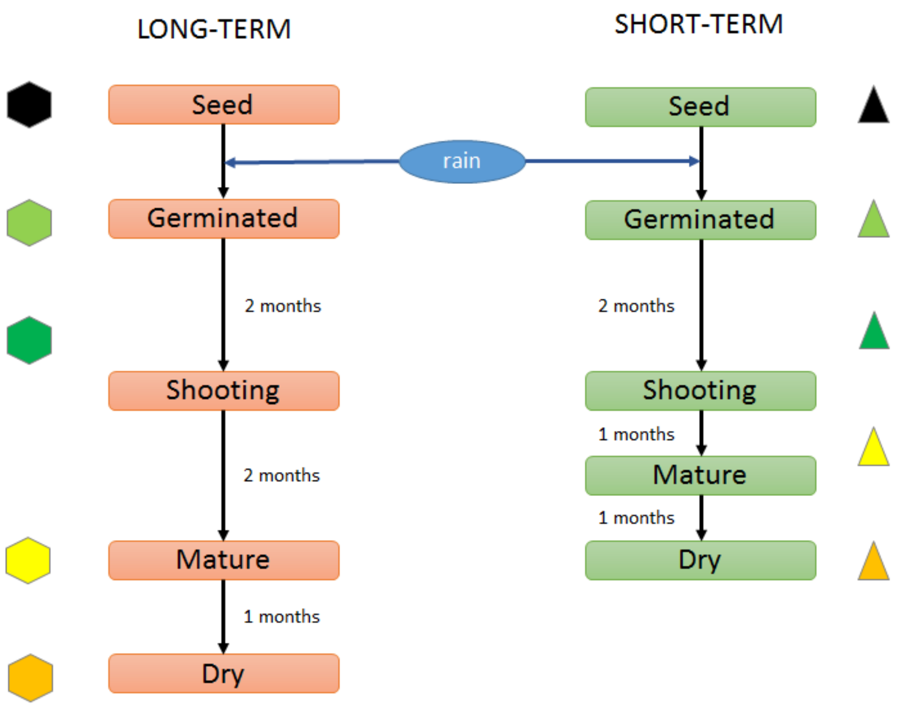


Figure 5.8. Crops transition diagrams.

Details for elephant damages

The module related to damages made by wild herbivores (only elephants are represented in the model) to crops is run at the level of grazing areas. Each month, grazing areas that are not protected by players and containing at least one field with a mature maize have 94/100 chances of being attacked by elephants. When elephants attack, all the farms are not impacted the same way. The first line of farms (Fig.5.9) will have up to three fields damaged, whereas the other farms of the grazing area will only have one field attacked. An attack will cause a loss of 50% of the yields. By protecting their grazing area, players decrease the chances of having elephants attacking to 6/100. Attack of Elephants are represented on the visual interface of the game (Fig. 5.9), and losses caused by elephants are represented by a blue diamond on the corner of each attacked field.

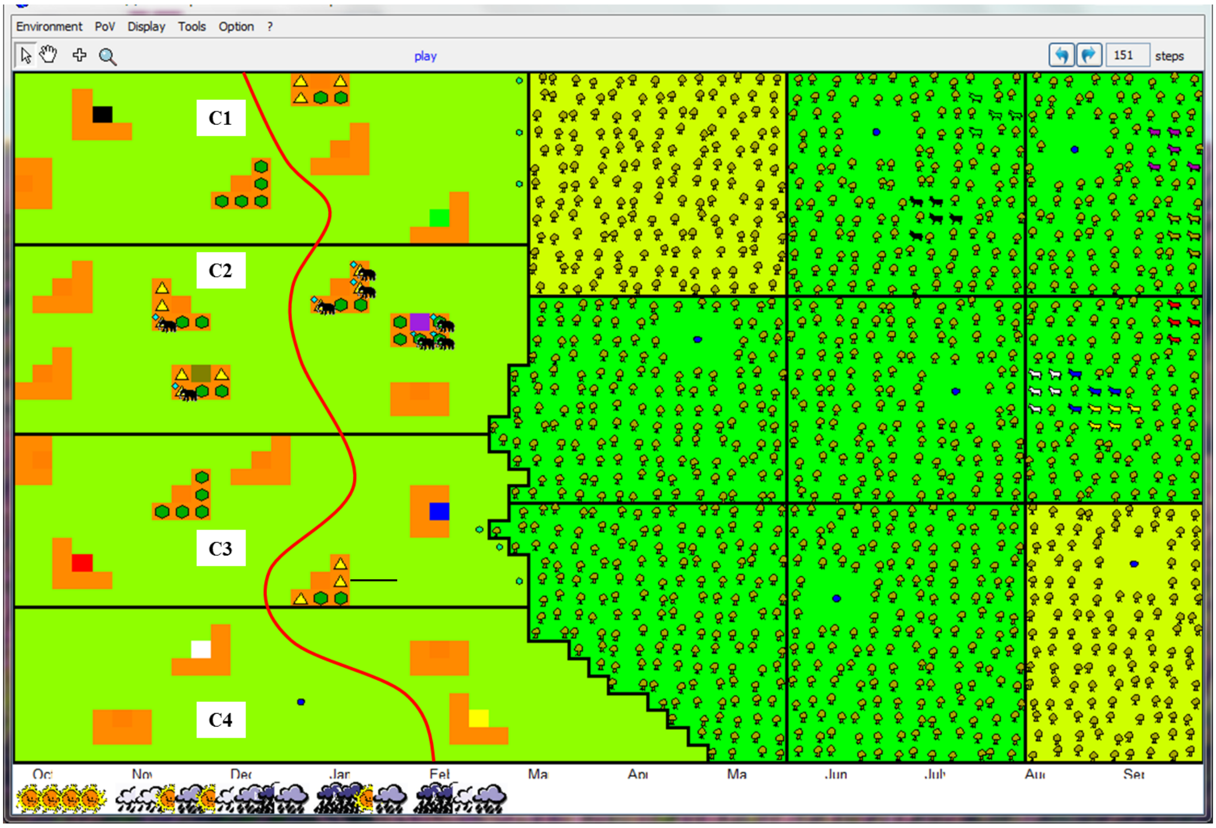


Figure 5.9. Elephants' damages. *Grazing areas with mature maize (here C1, C2 and C3) are prone to crop raiding by elephants. C2, which was not guarded (no small green circles at the edge between the communal land and the forest) was attacked by elephants. Farms located on the right side of the red line are considered as the first line of farms. These farms are more heavily impacted by the attack.*

Details for cattle damages

In Chapter 2, we described the rule according to which cattle cannot be released freely in the village before a particular date: *Xotshela* (usually the 1st of June). Nevertheless, it was collectively agreed that the game would contain no enforcing mechanisms, but that the players themselves would be free to discuss, apply and respect this rule or not during the game. Therefore, in the model supporting the game, cattle can graze anywhere anytime and when grazing in the communal area during the agricultural season, cattle entities can enter fields and cause agricultural loses if these contain crops. Unguarded cattle (without herdboy) will enter a randomly picked field with growing maize, and cause 25% loss of the yield the owner would have get from the maize entity growing there. Repeated loses caused by cattle or wildlife will ultimately destroy maize entities. A given cattle can enter only one field per month. Once the module is run, the visual interface is updated: a message is displayed on the game's interface to inform the players: "*Player…your cattle entered the field of player…*"; the cattle entity is displayed on the field it entered and the losses are represented on the field (Fig.5.10); the loses are stored and the yields the player will get when he harvests are modified.

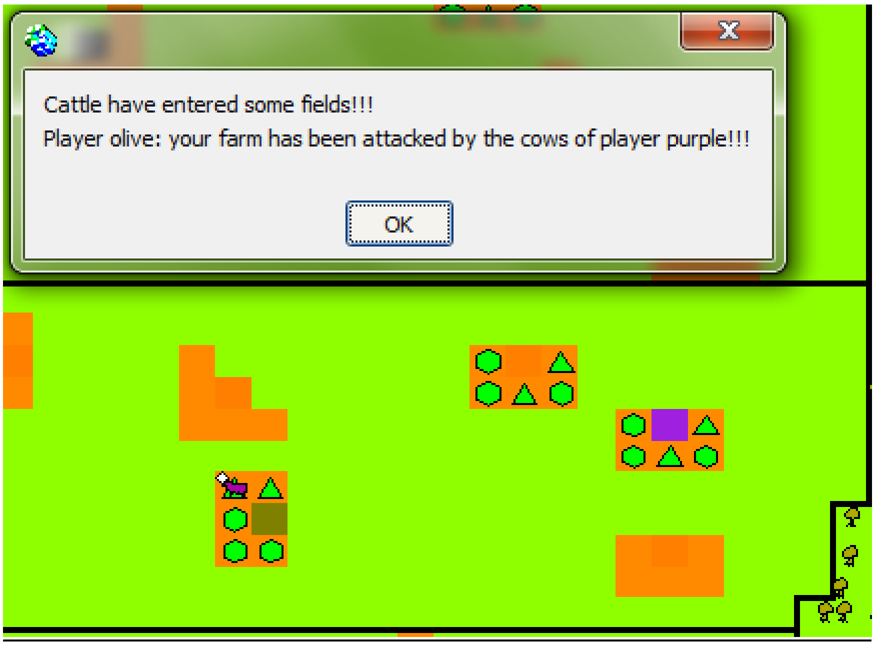


Figure 5.10. Cattle entering a Field. *The cattle of the purple player were left alone to graze in this communal paddock containing growing fields. They entered a growing field of the olive player. The white lozenge on the corner of the field of the olive player signifies a loss of 25%.*

Details for cattle status dynamics

Every month, the level of satieation (0, 1 or 2) of a cow is determined accordingly to the level of forage of the grazing area where the cow was located. When cows are feeding on crop residues (*machanga*), the satiation is set to the number of *machanga* eaten (max. 2). The status of a cow depends on how it fed during the last three months: when its accumulated satiation is 6, its status increases, whereas when the accumulated satiation of a cow is less or equal to 3, its status decreases.

Details for cattle predation by lion

The predation sub-model was entirely re-designed during workshops. This sub-model is applied at the level of a grazing area. To allow comparison of the role-playing game sessions, the randomness assigned to this process was eliminated by pre-defining the occurrences of cows being killed by a lion in the forest. Numbers are given in table 5.2.

Subareas in the forest	**Occurrences of presence of cattle in the subarea area at which a kill will be considered**
Nearby forest (F1, F4, F7)	3 8 14
Middle forest (F2, F5, F8)	2 5 9 12 16
Deep forest (F3, F6, F9)	1 2 4 6 7 9 11 12 14

Table 5.2. Predefined timing for cattle predation by lion.

In the nearby forest, every 5-6 times some cattle will be there, a kill by the lion is considered. In the middle forest, the periodicity is decreased to every 3-4 times, whereas in the deep forest, the periodicity is set to every 1-2 times. The frequency of grazing and the distance to the forest's edge are therefore the two factors taken into consideration to trigger the event "lion's kill" in the forest. Once such a kill is considered, its actual realization depends on the presence of herdboys. When all cattle are guarded by a herdboy, the probability that the kill fails is 2/3. Otherwise, the kill will occur and it is 30 times more likely to happen to a non-guarded cow than to a cow being guarded.

Details for forage level in grazing areas and water levels in water pans

These two sub-models rely on tabulated functions. The forage level of each grazing area is updated at the end of each month according to: (i) the month, (ii) the rainfall of the current month, and (iii) the number of cows that grazed during this month. Furthermore, a specific function was designed for each climatic year (Fig. 5.11 and Fig.5.12). An additional feature was decided during the co-design of the model: the four communal grazing areas (C1, C2, C3 and C4) would never reach the "good" level of forage, but would remain "medium" at best.
The size of the water pans is also updated at the end of the month. It is not influenced by the number of cows drinking, but relies on a tabulated function designed according to monthly rainfall (Fig. 5.11 and Fig.5.12).

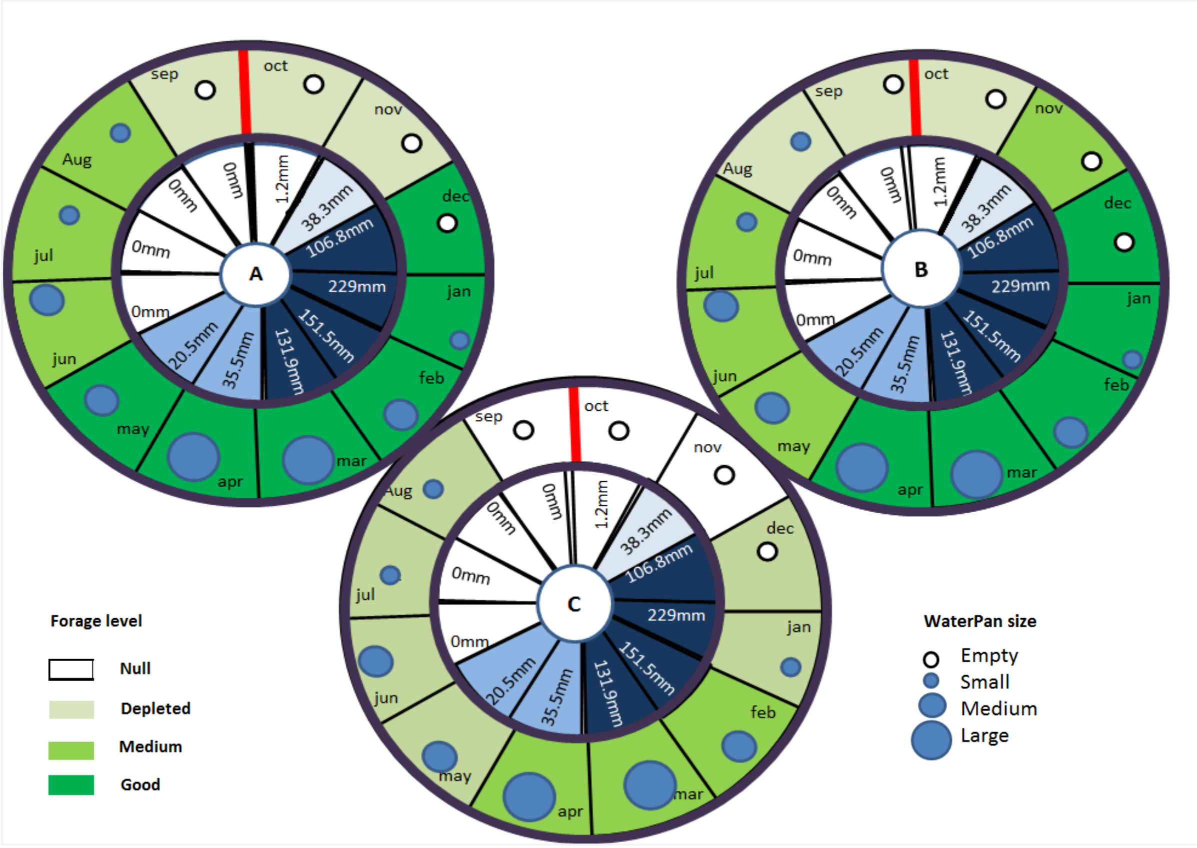


Figure 5.11. A representation of the tabulated function controlling the forage level of grazing areas and the size of water pans for the "Good Rain" year. *The three diagrams represent the forage level at the end of each month in a given grazing area according to the number of cows grazing during the month. A: no cow grazing; B: between 1 and 10 cows; C: more than 10 cows. The circles in each month represent the size of water pans. Monthly rainfall is given on the inner wedges.*

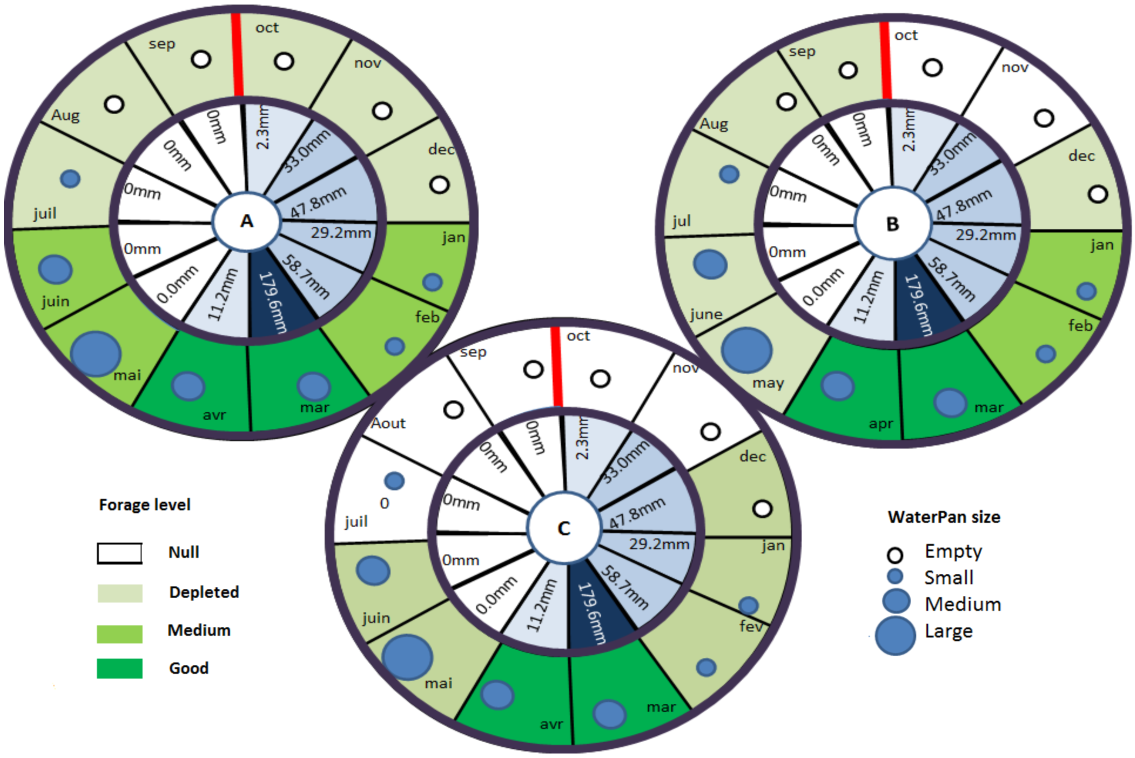


Figure 5.12. A representation of the tabulated function controlling the forage level of grazing areas and the size of water pans for the "Bad Rain" year. *The three diagrams represent the forage level at the end of each month in a given grazing area according to the number of cows grazing during the month. A: no cow grazing; B: between 1 and 10 cows; C: more than 10 cows. The circles in each month represent the size of water pans. Monthly rainfall is given on the inner wedges.*

Choice, design and parametrization of the sub-models

All sub-models were either collectively designed, or proposed by researchers and modified/validated by the other members of the team. The testing of each sub-model was done through the co-design process. Each version of the game was tested (played) by the team, collectively discussed and modified/validated.

Playing sessions: preliminary results and perspectives

Four playing sessions were organized at the Magoli community hall in May 2015, and a total of 28 players were invited to play *Kulayinjana*. As explained in chapter 4, the organization of playing sessions was done jointly by a researcher and local members of the co-design team. The setting of the room is described in figure 5.13.

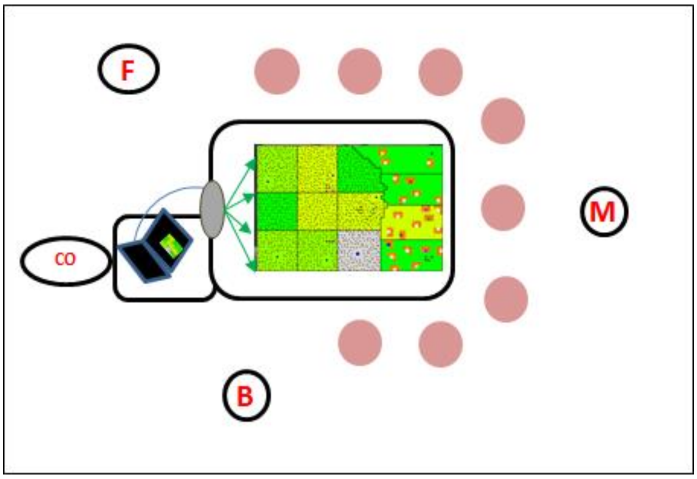


Figure 5.13. Setting of the playing sessions. *The game board was projected horizontally on a central table around which up to 8 players would stand. Four members of the co-design team were needed for playing sessions: F: facilitator; CO: computer operator; B: Bank; M: Minutes recorder*

Each of the four facilitators had a particular role:

- Computer operator: (a researcher) *Enter players' decision in the computer interface (beginning of the round); update the virtual environment (end of the round).*
- Facilitator: (a local member of the team) *inform players about the different playing steps to follow (beginning of the round); describe the consequences of players' actions: gains, losses, predation, etc. (end of the month).*
- Bank operator: (a local member of the team) *Collect payments relative to players' actions: herding, planting, "life expenditures", buying cattle, etc.; "pay" the players when they harvest their fields or sell cattle (beginning of the round).*

- <u>Minutes recorder:</u> (a local member of the team) *Record minutes during the game, including any element that could be relevant for further collective or individual discussions.*

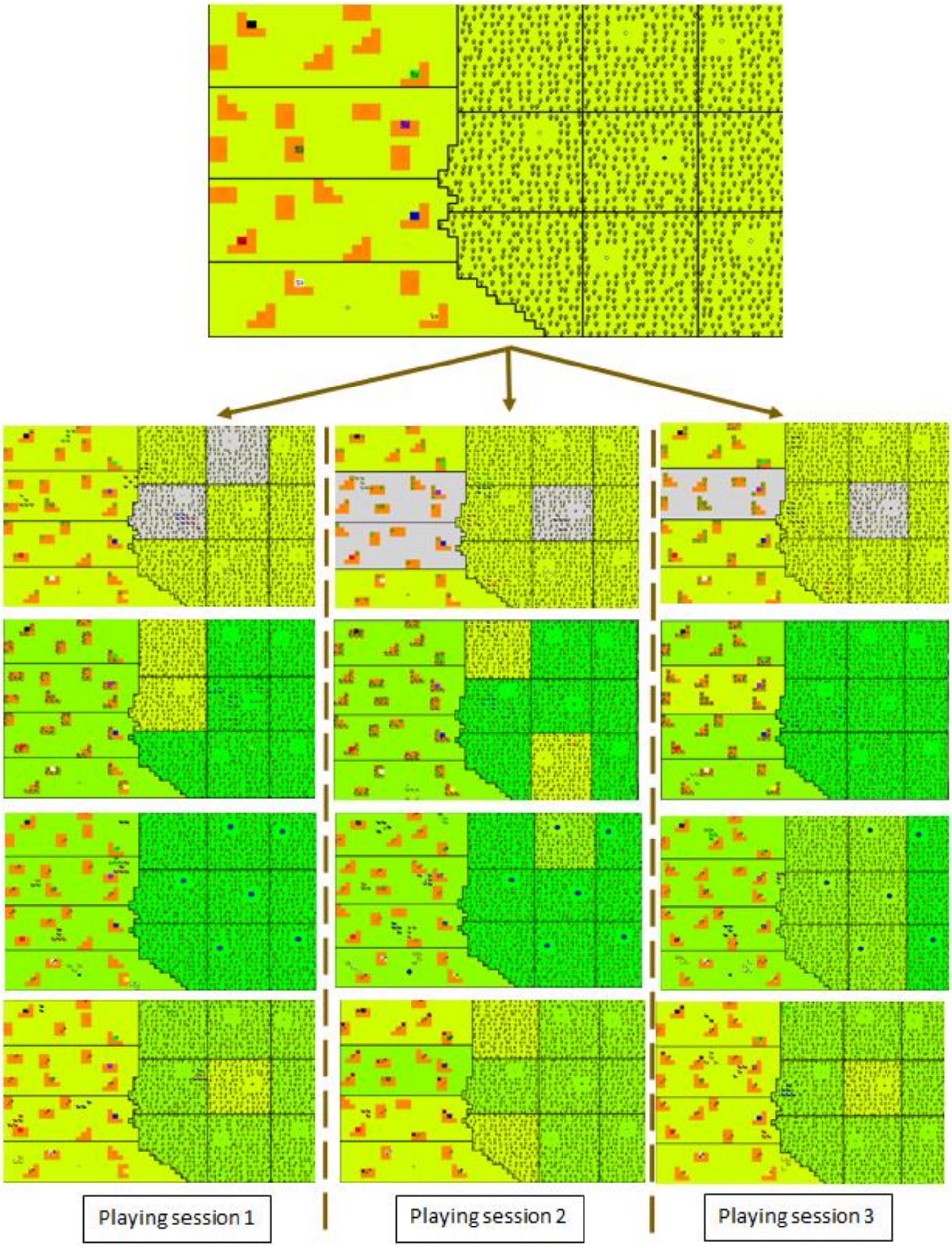


Figure 5.14. Compared evolutions of the virtual environment in the three playing sessions (year 1 only). *The first image represents the initiation of the game, that is October. We selected four months showing the different evolution of the virtual environment between the playing sessions, with from top to bottom: November, January, June and September.*

Each session was held on one day and involved playing the game twice. The morning session consisted of discovering the game and its rules, and playing a first year that was the "good rains year". The second year, the "bad rains year" was played by the same players in the afternoon. Players were chosen by the local members of the team, two each for every playing session.

Picture 5.1. The facilitator describing the playing board before starting the game in *Magoli (01/05/2015, A. Perrotton).*

As illustrated by figure 5.14, starting from a common initial situation, the three playing sessions showed different evolutions of the virtual environment. This section describes the players' strategies during playing sessions. All the decisions made by players were recorded during playing sessions, and complemented by individual questionnaires. Among the various questions asked to players, some concerned their opinion about the game (Chapter 4), and others were about the factors considered during playing in their decision making processes. Their answers enabled us to produce a decision matrix, and to choose variables to analyze (Tab.5.3). We propose here a set of exploratory analyses of the first three playing sessions (N = 24 players), the fourth one was set aside because it involved only four players. After a first analysis of questionnaires, it appears that a shift occurred in players' strategies concerning cattle herding between the first and the second "year" of the game. The game was easy to understand and reproduced players' reality (Chapter4), and they re-enacted their actual herding and farming strategies when the first climatic scenario was played. While playing the second year, players "played" more, and changed their herding strategies to save more tokens. More analyzes are needed to assess this shift and measure the differences between the first and the second climatic scenario. Our objective in this section is to give the reader a general overview of played cattle herding strategies and we assume that those of the first year are therefore more representative, this is why only these are presented. Analyzes were first run at different scales, considering all the players (N = 24) or on the contrary distinguishing playing sessions, some presenting monthly evolution of measured variables and some grouping observations according to the three seasons previously defined. We selected the most relevant figures.

Picture 5.2. Players grouping their cattle in the forest during the month of December. *(30/04/2015, A. Perrotton)*

Fields management:

The agricultural season was defined as the months during which at least one player had crops in at least one of his fields. As showed in figure 5.15, the first playing season differed from the second and third ones with a shorter agricultural season. While players from the second and third playing sessions had crops growing from October to April, players from the first playing session only used their fields from November to march. In other words, none of the participants from the first playing session practiced dry planting. Moreover, one of the players from the third playing session started plowing even earlier the second year, and chose to sow maize in September.

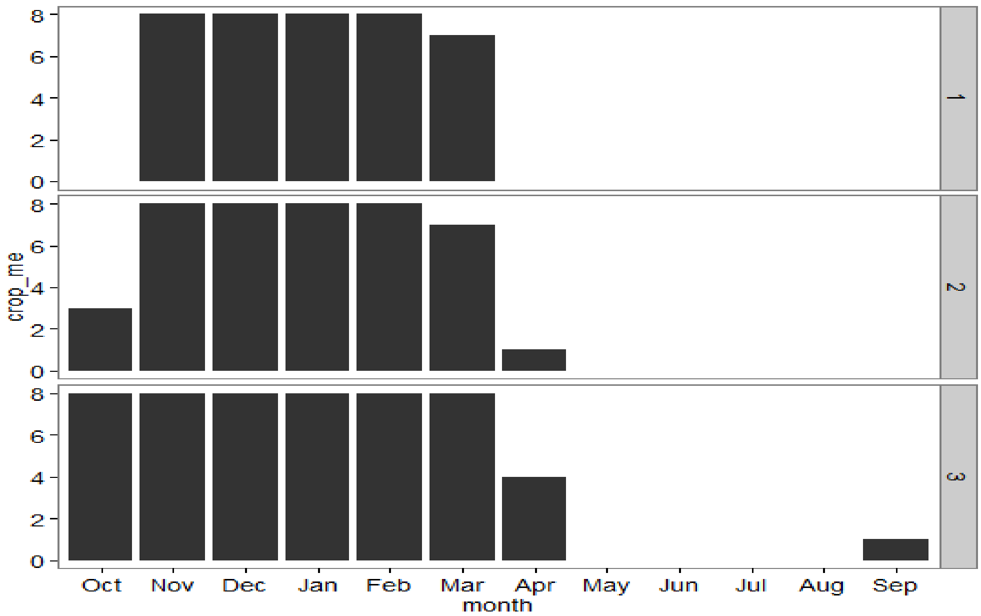


Figure 5.15. Crops management. *Number of players having crops in their fields for every playing session (1, 2 and 3),*

A total of 41 fields were planted or replanted during the first playing session, 45 in the second playing session and 41 in the third playing session. The type of crops planted and the repartition of planting events also differ between playing sessions (Fig.5.16). The planting patterns were similar in the first and second playing sessions, with a higher number of fields planted in December, while players from the third playing session planted mostly in October and November. The proportion of short and long-term crops planted were different during the three playing sessions, with respectively 77.5% / 22.5%, 48.8% / 41.2%, and 53.6% / 46.3% in the first, second and third playing sessions. Finally, players started by planting short-term crops in the first two playing sessions, while players from the third playing session started the agricultural season with both types of crops, but mostly long-term crops.

Harvests were completed in the beginning of April during the first playing session, while players from the second and third playing sessions harvested their last fields early May (Fig.5.15).

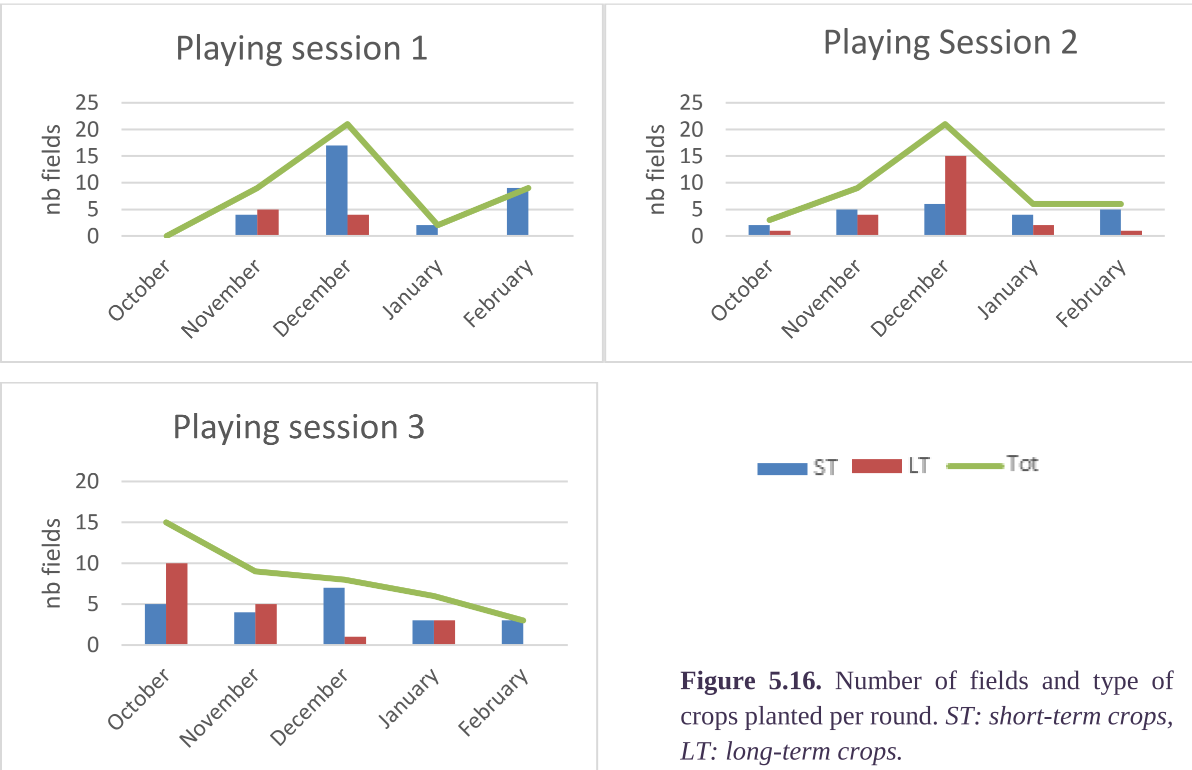


Figure 5.16. Number of fields and type of crops planted per round. *ST: short-term crops, LT: long-term crops.*

In *Kulayinjana*, players have two possible choices concerning crops residues (*Machanga*), they can either leave crops residues in their fields and any cow grazing in the grazing area can consume them, or store them in their kraal and feed their cows at their convenience (Fig 5.17). Players from the first playing session mostly harvested in April and left the majority of crops residues in their fields. On the opposite, players from de second and third sessions favored storing crops residues in their kraals. Players have no control on residues left in fields, as the model is programed so that cows grazing in a portion of the communal area with crops residues available will eat them in priority. Stored residues are given when players want their cows to eat them. The management of stored residues shows different patterns between the three playing sessions (Fig.5.17), with all the players from the first session having finished their stock by the end of June while players from the second session did not use them and those from the third session slowly used their stored residues from June to September, two of them still having some at the end of played year.

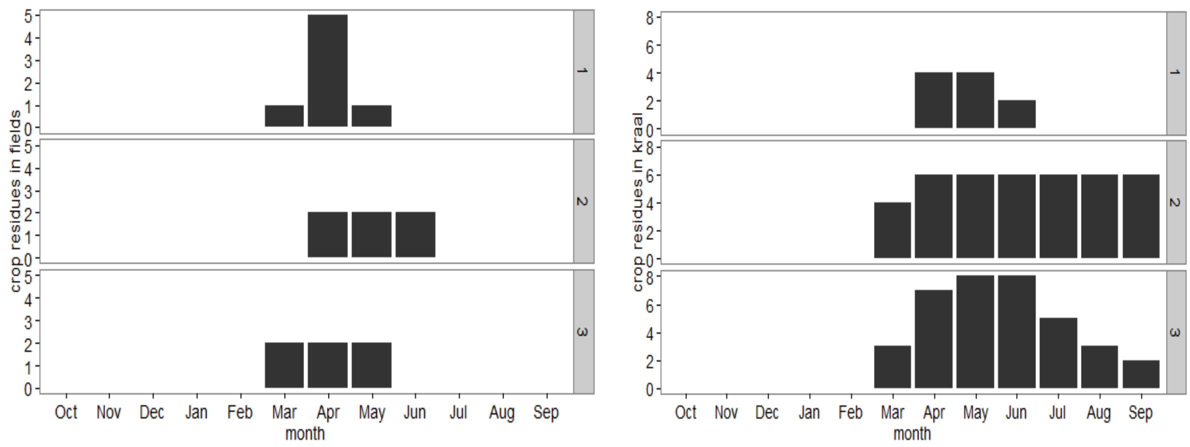


Figure 5.17. Management of crops residues. *The three charts on the left represent the number of players having crops residues in their fields, the three charts on the right represent the number of players having crops residues in their kraal. For both type of crops residues management, the three playing sessions are represented (1, 2, 3).*

Cattle herding:

The analysis of cattle herding strategies focuses on the opposition between communal and forest grazing areas. The objective is to gain a better understanding of the way cattle used these two types of grazing areas throughout the game. In average, during the twelve months covered by the first climatic scenario, each one of the 24 players:

- used 4.17 different grazing areas (min = 3; max = 7),
- moved his cattle from one grazing area to another one the month after 7.7 times in average (min = 5; max = 11),
- spent 1.4 round per grazing area (min = 1, max = 7).

For a given herd and a given round, the variable *dist_kraal* measures the distance between the communal grazing area where the kraal is located and the one where cattle are sent to graze. When projected in relation to the distance to the boundary, that is how far inside the forest cattle are, a clear pattern emerges (Fig. 5.18). During the three playing sessions, players tended to either use their own communal grazing area, or to send their cattle in the forest. Large movements of cattle were almost never observed within the communal area. When "forced" to send their cattle out of their communal grazing area, players seemed to have optimized the distances and therefore the cost of grazing (1 small token for every grazing area crossed from, *cf.* previous section).

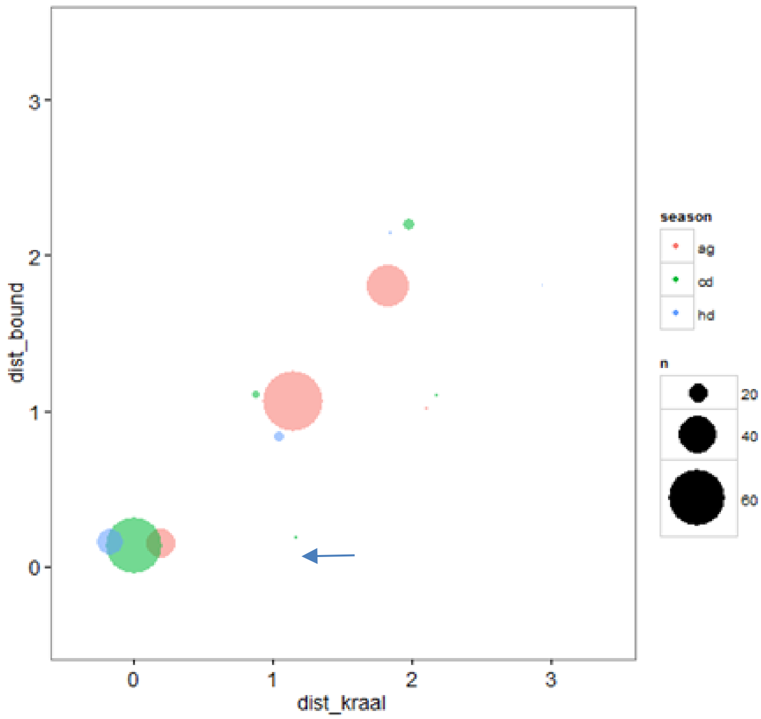


Figure 5.18. Distance to the boundary in function of the distance to the kraal. *The figure represents, for each round of play, the distance between the grazing area used by cattle herds and the boundary of the forest and the distance between the grazing area used by cattle herds and their kraal (communal grazing area of origin). The number of observations are represented by the size of the circle, and the season concerned by the color of the circle. The blue arrow points at the only observation of a herd sent in a communal grazing area other than its "own".*

The general pattern of grazing observed during the playing sessions corresponds to the one described in chapters 3 and 4 (Fig.5.19). During the agricultural season, 88% of players sent their cattle to graze in the forest, all but one keeping cattle in the first or second line of grazing areas. Although the forest was used all year long by players, a significant shift happened after the end of harvests.

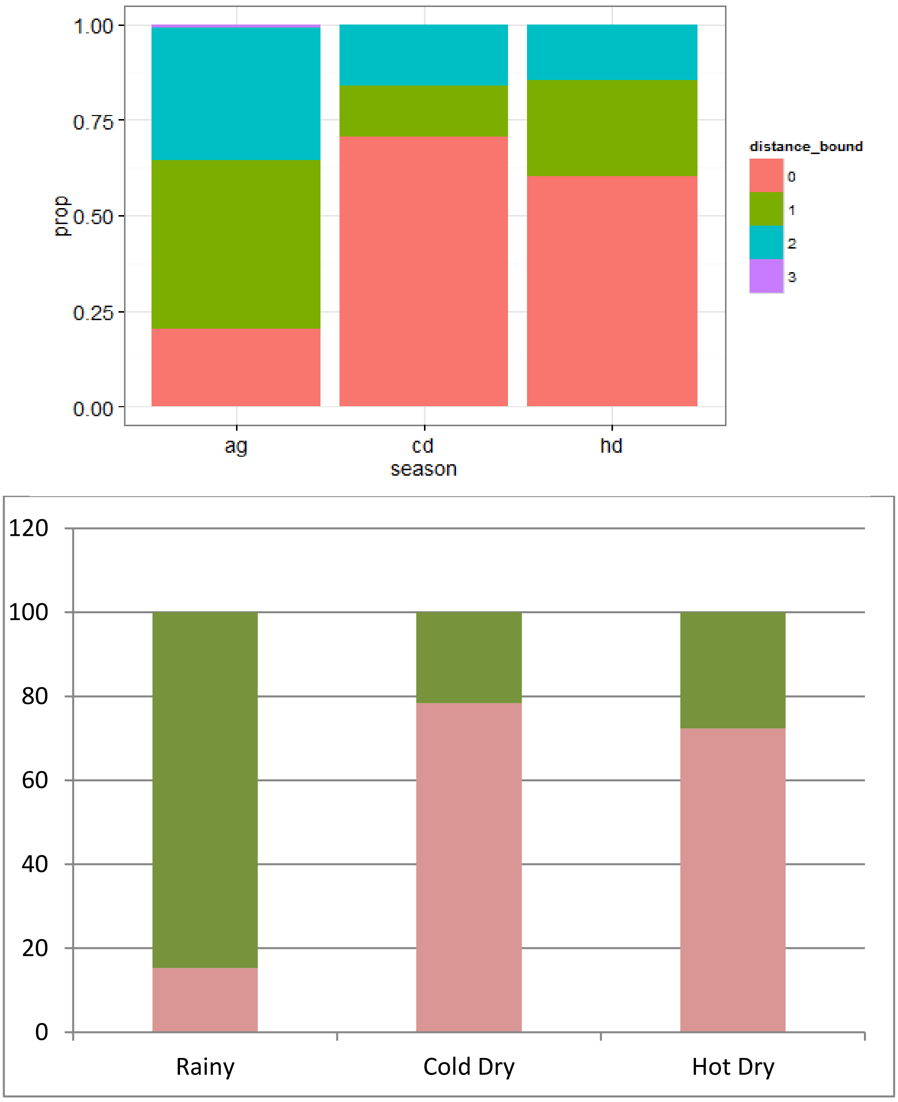


Figure 5.19. Played strategies and GPS collars.

Up: The figure represents aggregated data from the three playing sessions and is shared between the three seasons (Tab. 5.3).The use of the environment is characterized by the distance to the boundary of the forest. Communal grazing areas are coded as '0', grazing areas F1, F4 and F7 are coded 1, grazing areas F2, F5 and F8 are coded 2, and grazing areas F3, F6 and F9 are coded 3.

Bottom: The figure represents the percentage of time spent in the communal area by 11 cattle followed by Valls-Fox et al (in Prep) in the same villages with GPS collars.

Indeed, as showed in figure 5.19, during the cold and dry season, about 70% of cattle herds grazed in the communal land, this figure being reduced to about 60% during the hot and dry season, when the forage level of communal areas became too low (see previous section), and crops residues decreased. The strategies observed in the playing sessions are consistent with results obtained by Valls-Fox et al (in Prep). During their study, conducted in the same area with some of the villagers, they deployed 11 GPS collars, and monitored cattle for over a year. By comparing the two graphs, we can observe a similar yearly evolution of the use of the environment by cows. Indeed, Valls-Fox et al show that cows spend 84.72% of the grazing time in the forest during the rainy season (that corresponds approximately to the agricultural season), 21.63% during the hot and dry season during which cows feed on crop residues and 27.63% during the hot and dry season. Such consistency with GPS collars participates to the validation of the use of the RPG to elicit cattle herding strategies.

The avoidance of communal grazing areas during the agricultural season was not observed to similar extents across playing sessions (Fig.5.20). The maximum avoidance rate was observed in the second playing session with only two players leaving their cows in the communal land in October, and one in November, when all players had growing crops. During the first playing session three players decided to drive their cattle in communal land although all players had growing crops.

Figure 5.20. Grazing in the communal land despite growing crops. *The figure represents, for each playing session (1, 2, 3) the presence of growing crops in the grazing area used by cattle. Black stars represent the number of cattle herds entering fields.*

Players from the third session are those who used communal grazing areas the most, despite the presence of growing crops. Having cattle grazing in the communal area presents risks of incursions in fields and agricultural losses. It is therefore not surprising to notice that only one incursion happened during the second playing session. As explained in the previous section, when actively herded, cattle do not enter fields. That explains why although cattle spent more time in the communal land during the agricultural season in the third session than in the first one, less incursions were observed because all but one player used herdboys to look after their cattle.

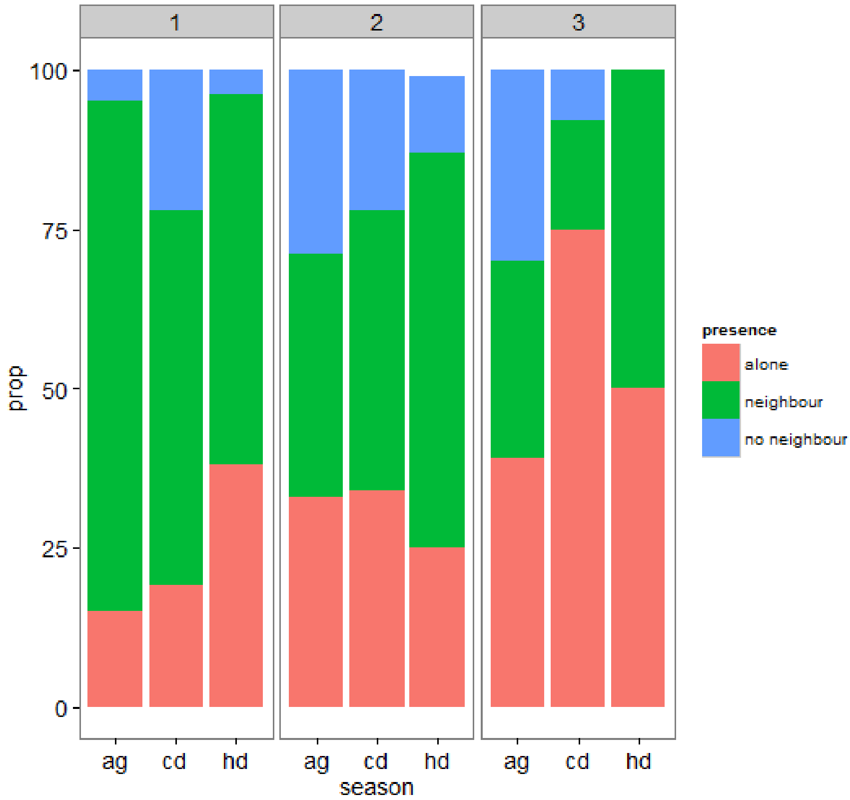


Figure 5.21. Simultaneous use of grazing areas according to the season. *Three configurations distinguished: a given herd can be either alone in the grazing area (pink), share it with other herds including the direct neighbor, or share it with herds coming from other communal grazing areas. From left to right: First playing session, second playing session and third playing session.*

According to answers given during after playing questionnaires, neighbors' strategies were considered by players in the choice of the grazing area to use every month. We defined three possible configurations (Fig.5.21). The first possibility was that a player would choose a grazing area so that his cattle would graze alone. This strategy was dominant during the third playing session, particularly during the cold and dry season when players kept their cattle in the kraal and fed them with crops residues (Fig.5.17). The second possibility was to use the same grazing area with their direct neighbor (Black with Green, Olive with Purple, etc; see Fig.5.2). This strategy was dominant throughout the season during the three playing sessions. Finally, players could also share a grazing area with other herds that did not belong to their direct neighbor. This configuration was less observed, with a maximum of 30% of players during the agricultural season of the second and third playing sessions.

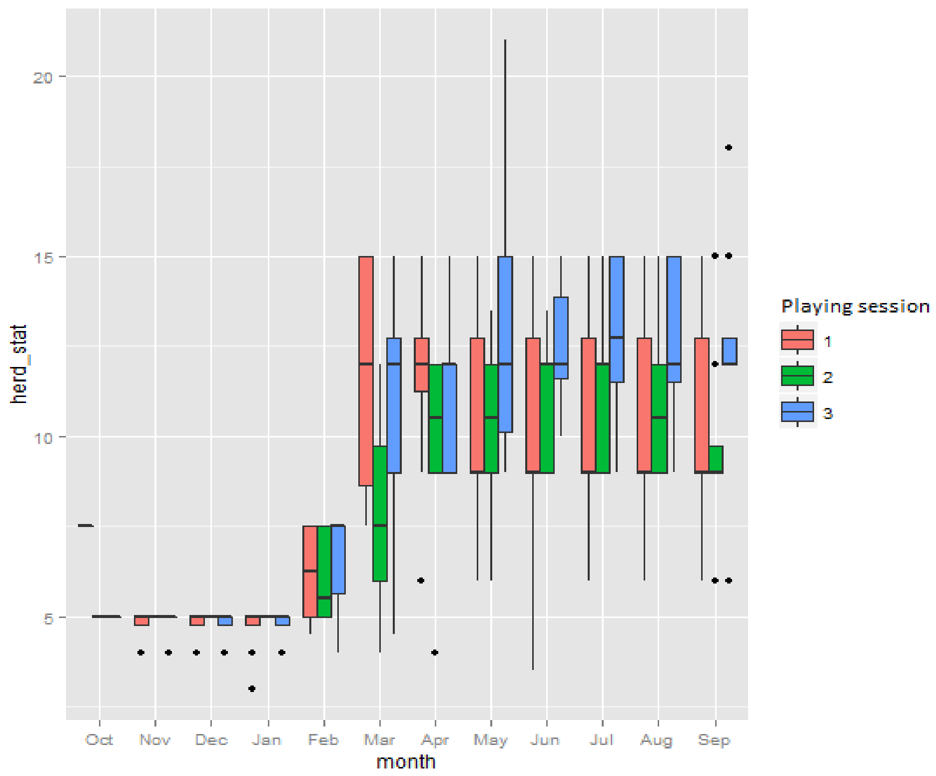


Figure 5.22. Evolution of cattle herds body condition throughout the year. *The first playing session is represented in red, the second one in green and the third one in blue.*

As described in table 5.a, we aggregated the individual body condition of cows (thin, medium, fat) into a value characterizing the herd as a whole. From October to September, the herd condition generally increased for all the players (Fig.5.22). The three playing sessions show the same pattern from October to January, with a stable average herd condition value. Differences between playing sessions appear from February. Players from the third playing session showed the best average herd body condition. A first explanation can be found in the different farming-herding patterns observed between the three playing sessions. Players from the first session quickly finished crops residues (Fig.5.17) and that forced them to drive their cattle through low forage grazing areas (Fig.5. 12) which impeded the fattening of their cattle, while players from the second and third playing sessions could compensate the natural forage degradation by feeding their cows with crops residues, either in the fields (second playing session), or stored in kraals (third playing session). The second explanation is to be found in predation by lions in the forest and cattle sales and purchases (Tab.5.4). At the end of the game, there were respectively 31, 26 and 37 cows left in the first, second and third playing sessions. Players from the first playing session suffered from more predation (4 kills), and although less cattle were sold than during other sessions, less were bought too, leading to a loss of 15 points of herd status. Players from the second playing session only suffered from two lion kills, and massively sold cattle (17), including fat ones. These were not compensated by purchases and it led to an aggregated loss of 34 points of herd condition. Finally, players from the third session lost 3 cows, sold 7 cows, but bought 7 cows including 2 medium and 3 fat ones, leading to a loss of herd condition of 3.5 points only.

Playing session	Cattle killed	Cattle sold	Cattle bought	aggregated loss/ benefit
1	3 thin + 1fat	4 medium + 2 fat	1 fat	-15
2	1 thin + 1 fat	4 thin + 5 medium+ 8 fat	4 thin + 1 medium	-34
3	2 thin + 1 medium	2 thin + 4 medium + 1 fat	2 thin + 2 medium + 3 fat	-3,5

Table 5.4. Cattle “leaving” and “entering” the game. *For each playing session the number of cattle killed, sold and bought was recorded. The aggregated loss/ benefit was calculated by multiplying the number of cattle by their relative body condition factor.*

Toward the characterization of herding strategies:

Defining the variables

The objective of designing and implementing the game was to understand cattle herding strategies of rural households living on the edge of a protected area, in order to produce an autonomous simulation model (agent-based model). As Fig.5.14 shows, each playing session led to a different evolution of the environment, and different strategies (at least when observed). Beyond the description of playing sessions, we therefore needed to elicit the rationale behind herding choices. To achieve this objective, a second round of analysis was done, using multiple correspondence analyzes, or MCA (R software, library ade4).

A set of 22 variables was built to conduct these analyzes (Tab. 5.4 and 5.5). Some of the variables used in the analyzes are constitutive of the model, and were therefore directly measured during the playing sessions. Among these are the forage level in grazing areas, the zone where the grazing area is located (Forest Vs Communal land), or the cost related parameters of chosen grazing areas (presence/absence of water). Individual questionnaires administered after playing sessions were analyzed to confirm the relevance of this first group of variables, and identify additional parameters players considered while playing. Although some of the variables suggested by the players were directly measured during playing sessions, not all were, and therefore used the "replay" function offered by Cormas to measure them. Indeed, this simulation platform allows to « replay » recorded simulations. The various events happening during playing sessions (players decisions; wildlife attacks; sales and purchases of cattle, etc) were recorded, and each game could therefore be "replayed". The replay allows use to re-enact and visualize a playing step by step. By doing so, we could record these supplementary variables. The variables confirmed or suggested by players during the interviews are indicated by a "*" in Tab.5.4 and Tab.5.5.

MCAs were centered on the grazing areas used by players (N = 288; 3 Playing sessions *8 players * 12 rounds). We wanted to see the relationship between these active variables characterizing the chosen GrazingAreas. In other words, we wanted to see if we could identify types chosen GrazingAreas, and by projecting supplementary variables, see the when players would choose such or such type of GrazingAreas. Prior to the MCAs, the original set of 22 variables was therefore decomposed into a first subset of 11 active variables defining the GrazingArea chosen by players at every round of the game (Tab.5.4), along with a second subset of 11 supplementary variables (Tab.5.5) that once projected on the ACM results, would highlight in which conditions players chose a particular type of grazing area.

Variable	Description	Values
Zone	Zone in which the GrazingArea is located	C (communal); F (forest)
SurfWater*	Surface water available in the GrazingArea	1 (natural waterpan with water) ; 0 (no waterpan, or empty waterpan)

Forage	Forage level	0 (null); 1 (poor); 2 (medium); 3 (high)
ForageGain	Forage level gained compared to the forage level found in the communal GrazingArea of origin	0 ; 1 ; 2 ; 3
DistKraal	Distance to the Kraal	0 ; 1 ; 2 ; 3 ; 4 ; 5
DistBound*	Distance to the boundary between the communal land and the forest	When the herd is grazing in the forest, distance to the boundary: -F1; F4; F7-->dist_bound=1 -F2; F5; F8-->dist_bound=2 -F3; F6; F9-->dist_bound=3
KillPrev	Occurrence of a kill during the previous month	0 (no); 1 (yes)
Crop	Presence of growing crops in the GrazingArea	0 (no); 1 (yes)
Residues*	Presence of open access crop residues in the GrazingArea	0 (no); 1 (yes)
OtherHerds*	Other herds sharing the GrazingArea	-The herd is alone: 0 -The herd is with the direct neighbor's herd (from the same communal GrazingArea): 1 -The herd shares paddock with herds other than the direct neighbor's: 2
ForagePrev	Forage level of the previous GrazingArea used	0 ; 1 ; 2 ; 3

Table 5.4. Active variables. *The variables presented in the table characterize the GrazingAreas chosen by players, and are the variables used to run the MCA. All are categorical variables.*

The second subset of variables, or supplementary variables, describe the context in which the cattle herding decision was taken, that is in which conditions the GrazingAreas were chosen (Tab.5.5). Among these we can find some of the player’s parameters such as the status of his fields or the condition of his herd. We also find more general variables such as the season, the month, or the weather forecast that is given at the beginning of the round.

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Variable	Description	Values
Player	Id code of the player	B ; G ; P ; O ; U ; R ; Y ; W
Season*	-Hot and dry Season (sc): 1st August to the month when the first field is planted; -Agricultural season (ag): End of hd to the month when the last field is harvested; -Cold and dry (sf): end of ag to end of July.	sc ; cd ; sf
Round	A round of play is a month in the model.	1 to 12
Forecast	Weather forecast given at the beginning of the round	dry ; small ; medium ; big
CropMe*	presence of growing Crop in the player's fields	0 (no) ; 1 (yes)
CropNeigh*	presence of growing Crop in the neighbor's (same communal GrazingArea) fields	1 (no) ; 1 (yes)
ResFieldMe*	presence of growing Crop residues in the player's fields	0 (no) ; 1 (yes)
ResKraal*	Presence of Crop residues in the player's Kraal	0 (no) ; 1 (yes)
ResFieldNeigh*	presence of growing Crop residues in the players' neighbor's (same communal GrazingArea) fields	0 (no) ; 1 (yes)
HerdStat*	Aggregated body condition of the herd = nbr cows *body condition factor Body factor small=1; Body factor medium=1,5; body factor fat=3	0 to 30
CowEntField	Did the player's herd enter any other player's fields the previous round?	0 (no) ; 1 (yes)

Table 5.5. Supplementary variables. *The variables presented in the table characterize the condition in which GrazingAreas were chosen by players. All are categorical variables.*

Preliminary results and perspectives of autonomous simulations

Here we present the results of the MCA run with the data base compiling the three playing sessions (N=288). The scatterplot showed by Fig.5.23 highlight the repartition of the different values of the 11 active variables in the factorial environment.

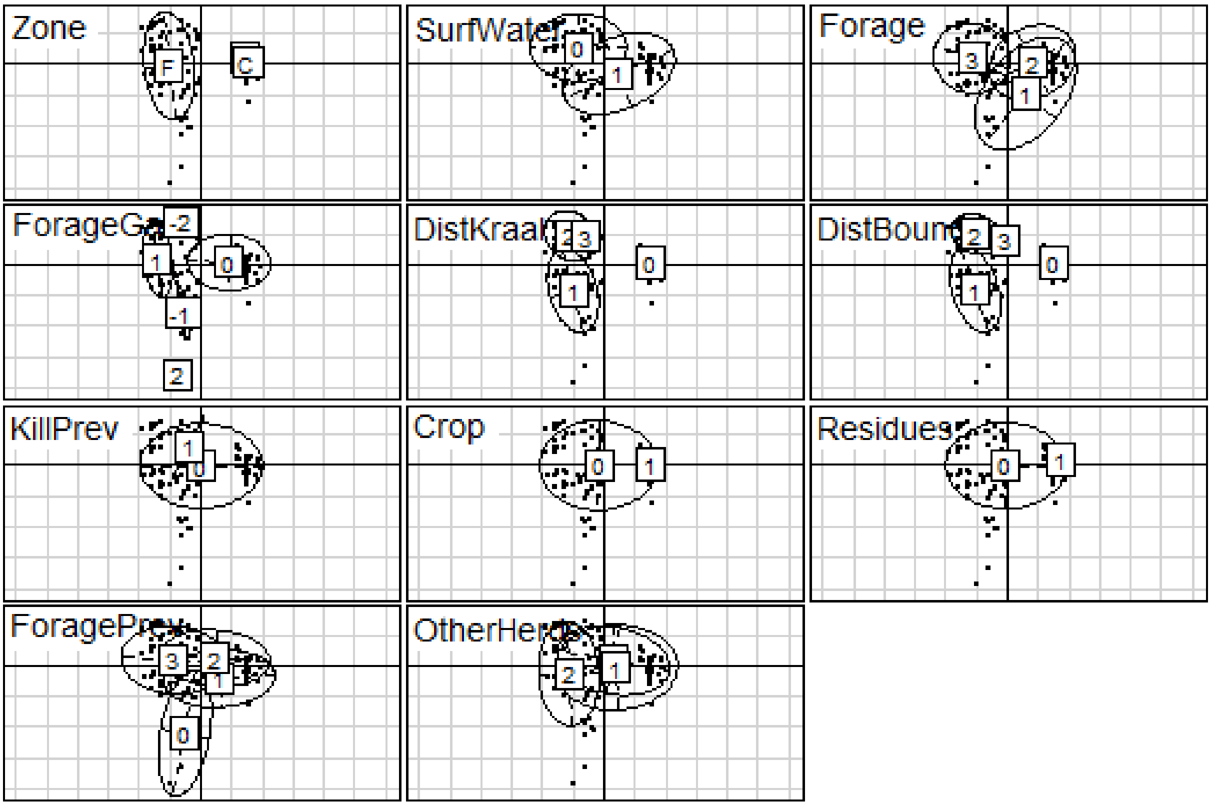


Figure 5.23. Scatter plot of the multiple correspondence analysis conducted on the first three playing sessions. *The 11 plots represent the repartition of the 288 GrazingAreas and the positions of the different values of the active variables.*

The MCA allows us to distinguish the importance of the Zone in the characterization of GrazingAreas, the Forest (F) and the Communal Area (C) being each one on a side of the first axis. GrazingAreas chosen by players seem to have offered better forage levels in the Forest, this is partly due to the avoidance of the forest during the end of the hot season, which tend to finish the available forage in the Communal land. The ForageGain, DistKraal and DistBound variables, when observed simultaneously, show that players using communal GrazingArea usually used their own GrazingArea (where their farm is settled), therefore having a null gain, along with null distances. The kill history of the GrazingArea, or the other herds present do not appear as relevant variables to characterize chosen GrazingAreas.

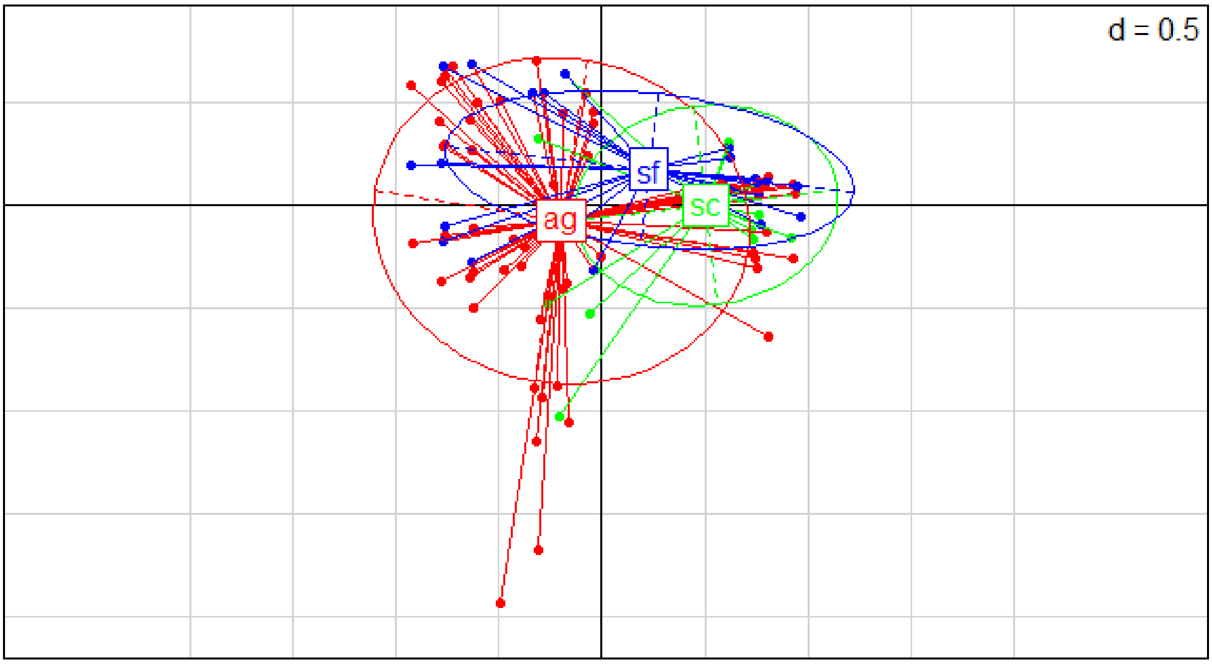


Figure 5.24. Projection of the 3 seasons. *The 3 circles gather together the chosen GrazingAreas according to the season during which they were chosen.*

As Figure 5.24 shows, the GrazingAreas chosen during the three different seasons vary slightly. During the hot and dry season (sc), players mainly sent their herds to graze in communal GrazingAreas. Our field observations and interviews lead us to state that such strategy is used to avoid predation in the forest. As stated by a villager: "*I only send my cattle in the forest when it is necessary [*to avoid damages in fields*], but I prefer when they stay around"* (a man in Magoli, May 2015). The majority of GrazingAreas chosen during the agricultural season (ag) were in the forest, although some players preferred keeping their cows in the village. The cold and dry season corresponds to a transition during which some players preferred keeping their herds in the forest in order to save the crop residues for later, while some brought the herd back in the village straight after harvesting.

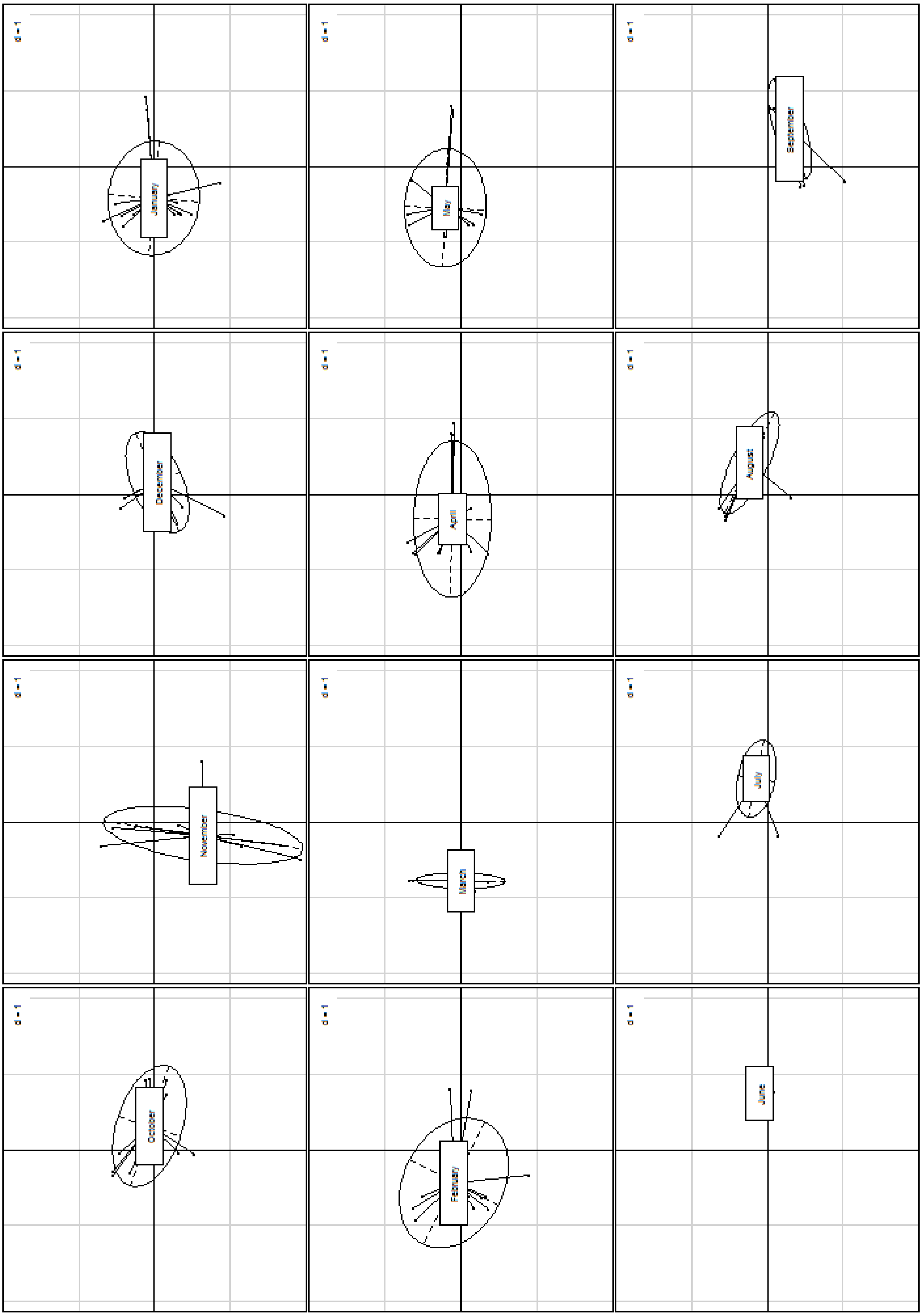


Figure 5.25. Projection of the 12 months played. *The 12 plots are projection of the chosen GrazingArea, month by month (October to September, from top left to bottom right). The scale being the same for all plots, we can visualize the difference in the cohesion of choices between months.*

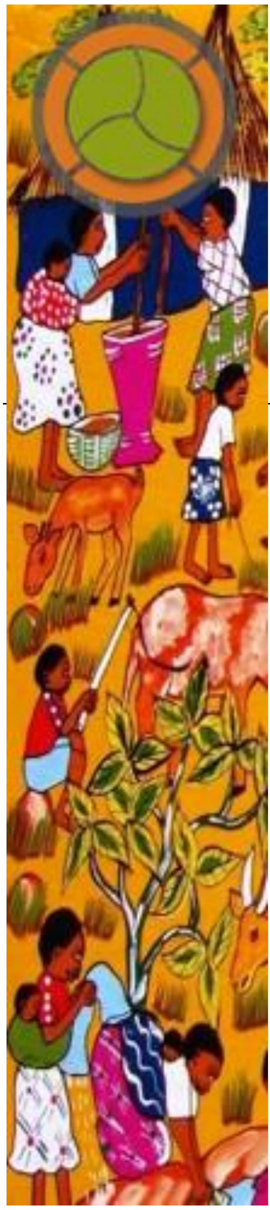
Another way to visualize the changing of herding strategy was to use another supplementary variable: “month” (Fig. 5.24). Keeping in mind that the points on the left side of the factorial environment are located in the forest, and the ones on the right are located in the communal area, we can first confirm the observations made in the previous paragraph. In terms of autonomous behavior, Figure 5.24 adds an interesting insight: while some of the months show rather “dispersed” GrazingAreas, that is points forming a large ellipse made of different types of GrazingAreas (including forest and communal), some show a relatively smaller dispersion. At this point of our analyses, we consider using this to distinguish two broad types of autonomous behavior. First is a “deterministic” one for the months were players showed similar and clear choices. During March, agents would send their herds in the Forest only, while in June, July and September, they would keep them in the Communal Area. During the other months, a first possibility would be to adopt a “probabilistic” behavior where agents would a use the dominant Zone (for instance the Forest in November), but with a certain probability of using the other Zone, this probability being proportional to the dispersion rate of the ellipse showed in Fig. 5.25. Another approach would consist in exploring the details of how and why some of the months show more diverse herding strategies than others. Going back to ethnographical data is necessary at this point, and narratives gathered during our fieldwork.

Perspectives

The first section of the chapter shows how we collectively designed a relatively complex game. If playing rules are simple, the agent-based model supporting *Kulayinjana* is far from simple. Although the final version of the role-playing game satisfied all the co-designers, its implementation was a major challenge. Indeed, through the organization of playing sessions, we could verify if our objectives were reached. In chapter 4 we showed that the game was easy to understand and that players globally agreed with the way their reality was represented. The game being a research tool, the results described in this chapter give the reader an overview of the type of data gathered. The differences between strategies implemented by players between the first and the second climatic year need to be further investigated. The game involved costs of playing, in particular concerning the choice of the grazing area to use. This was a choice from us to "force" players to make decision, to choose and show us their priorities. Nevertheless, it might have led to the shift mentioned earlier, that is this changing of strategy players did from a first year during which they re-enacted their actual strategies, to a second year during which they "played" more and optimized their budget (tokens). This was also probably triggered by the way we articulated the two parts of the playing session: by having a break between the two years, during which we counted tokens. Things could have been different if the two years had been played in a row. Analyzes will have to be done to assess this possible change of playing rational.

If more time and work is needed to finalize and run autonomous simulations, the work presented in this chapter will be useful to achieve it, for several reasons. First, results of multiple-correspondence analyzes are promising and we assume that such approach will allow us to distinguish and categorize types of cattle herding strategies that will be translated into agents' behaviors in an autonomous agent-based model. By using an agent-based model to elicit local strategies, we eased this translation. Indeed, the "observations" (recorded games) already take the form of agent decisions in the model supporting the game, minimizing the loss of information we could have experience if we had to translate heterogeneous observation into a standardized “language”. Secondly, the agent-based model is already partly built. The virtual environment and its dynamics are already designed (the sub-models of the game).

Once built, the agent-based model will enable us to run longer term (10-20 years) simulations, which was not possible during playing sessions. Indeed, a group of 8 players could only play two years in a day-long playing session. Furthermore, we could only introduce one type of change (the rainfall conditions) to address how players adapt –or-not- their strategy when they experience changes during playing sessions. With the agent-based model, different scenarios could be simulated. Some of these scenarios are already identified, and some were even proposed by players, such as different climatic patterns or the modification of the right of access to the forest grazing area, for instance by prohibiting the access to the deepest parts of the forest, or to a particular forest grazing area by reserving it to “lodging” to promote touristic activities.



CHAPTER 6. General Discussion

WHAT IS THIS CHAPTER ABOUT?

This final chapter presents the general discussion and the conclusion of this PhD thesis. In the past three years, we implemented an interdisciplinary approach bringing together political ecology (chapter 1 and 2), ethno-ecology (chapter 2 and 3), and agent-based modeling (chapter 4). This will of integrating different disciplines was eased by the fact this PhD was funded by and conducted within a large research project (ANR SAVARID, work package 5) that promotes interdisciplinarity and involves notably ecologists, epidemiologists, veterinarians and modelers. Over the course of our work, we could therefore interact with researchers from various disciplines.

At the end of this long process we came up with a role playing game that was used to record herding practices *in situ* (situated knowledge, chapter 4). Through the co-design process, the local team members developed their own perception and objectives of the game, and as a result, we collectively produced more than a research tool.

This discussion will draw lessons from our work and analyze the benefits of participatory approaches, and in particular the added values of the use of role playing games to address social ecological issues.

The appropriation processes are also discussed, along with the moral responsibility of researchers to guaranty the transfer of the result of participation to local members of the co-design team.

A relevant approach to study wicked problems and model complex decision making processes

Virtual worlds: getting out of the "catch-22"

In J. Heller's novel "Catch-22" (1961), the main character tries to leave the army on a "section 8" declaration claiming he is insane. However, although this section is the legal way for him to reach his objective, the military rules also say that if you try to prove that you are insane, this proves that you are not. Inspired by this novel, a "catch-22" is a paradoxical situation from which an individual cannot escape because of contradictory rules. The solution to a common problem can fail and despite eventual losses (time, money, etc.), it does not matter much to the subject-system, or to the course of society. Among the ten characteristics of *wicked* problems is the fact that every action is consequential (Rittel and Webber 1973). For managers or policy makers, this means that implementing a solution to a *wicked* problem will leave "traces" that cannot be undone. In other words, you cannot try plan A and have plan B in case plan A fails, because plan A will change the system in a way that is likely to make plan B irrelevant. This is the "catch-22" of *wicked* problems: you cannot learn about the problem without trying solutions, but every solution is consequential.

The same applies to researchers who want to study, and therefore propose solutions to, a *wicked* problem involving human beings and their real lives. *Wicked* problems limit the feasibility of experimentations. Every modification of the system – including experimentations – has lasting consequences that may spawn new wicked problems. Transposed to our work, exploring alternative coexistence scenarios, for instance shutting down the villagers' access to the Sikumi Forest, or extending it – both of these could provide a solution to the concerns expressed by local actors – present risks of critically impacting local actors' livelihoods. Once such consequences are observed, they cannot be undone and any attempt to reverse or correct them will modify the system again, without "resetting" it to the previous state, and could create new problems. If policy-makers or managers are responsible for their actions, their position and their mandates give them some sort of legitimacy to change the system. Researchers are most of the time exogenous actors of the system studied. What is their legitimacy to potentially irreversibly modify a social-ecological system to which they do not belong? Throughout this thesis, we have insisted on the necessary reflexivity of the researcher. Assuming responsibility for one's impact on the system as a researcher is part of this reflexivity.

Still, experimentation is part of research processes. How can we get out of the deadlock we are facing when dealing with reality? We assume that a solution is to conduct research in an experimental reality, a virtual reality. In a virtual environment we can try plan A, reset and try plan B. The consequences of each experiment can be recorded and lessons drawn without impacting the real subject system. In other words, what we need is a model, a conceptualized version of the reality studied. More than conceptual models, we need simulations. As stated by Sterman (2002), conceptual models are not sufficient to understand the way complex systems work. For the author, there is no learning – therefore no solutions – without feedback, without the knowledge we get from our actions. If that feedback cannot be obtained through experimentation, because it is too costly, too slow or unethical, or because the consequences of our decisions take too long to be observed or might transform the system studied and create new problems, simulation is the main and perhaps the only way to "discover for ourselves how complex systems work, where the high leverage points may lie" (Sterman 2002 p. 525). As such, simulations are to a dynamic model what experimentations are to the reference system. Different definitions of "simulation" can be found in the literature (Treuil et al. 2008). The one that best represents our approach is probably Shannon's (1998 p. 7), which states that "*simulation is the process of designing a model of a real system and conducting experiments with this model to understand and/or evaluate various strategies for the operation of the system…it is critical that the model be designed in such a way that the model behavior mimics the response behavior of the real system to events that take place over time*".

As one challenge is met, another appears: how can we design this virtual *ersatz* of reality? How can we capture the essence of the reality as seen by actors? And how can we represent actors and make them "live" in this virtual reality? A model is necessarily a simplified version of reality and as such, "all models are wrong" (Box 1976). We need a way to build a model that is "fruitfully wrong" (Epstein 2008) and takes into account the "right" parameters influencing local actors' practices and perceptions of the issue at stake, while satisfying the researcher's expectations, the first one being having a model that mimics the reference system so that simulations enable us to understand the system and provide recommendations. The participatory design of a virtual environment and role-playing games, computer-based or not – we tried both in our work – is relevant. Based on our work and on the literature, the following sections will discuss how such approaches enable researchers to deal with the major constraints to our understanding of *wicked* problems: uncertainties.

Co-designing a context-based research tool: strategical negotiation of uncertainties

Over the last decades, uncertainty has become highly topical to natural resources management and environmental science (Pahl-Wostl 2007, Brugnach et al. 2008).Three categories of uncertainty can be distinguished. First are the epistemic uncertainties related to the lack of knowledge about a given system (we do not know everything), and the ontological uncertainty related to the intrinsically unpredictable nature of social-ecological systems (our scientific understanding does not allow us to predict all of the dynamics and properties) (Walker et al. 2003). When looking at the interactions between actors of a social-ecological system, a third type of uncertainty appears: the ambiguities coming from the fact that different actors will have different views and opinions of a given reality, therefore voicing different but still valid interpretations (Dewulf et al. 2005, Brugnach et al. 2008). This type differs from previous types of uncertainty as it is not based on an incomplete knowledge, but on the fact that there are many possible interpretations for a given situation. In our case, the rural communities, the protected-area managers and the researchers each have their own frame, *i.e.* their own sense-making process that mediates the interpretation of reality by adding meaning to a situation (Weick 1995), and each actor has his own reality.

Over the past decades, the perception of uncertainty has changed in the research community. Uncertainty is no longer something to get “rid of”, but is accepted as an inherent and necessary part of life, definitional to the problem at hand (Brugnach et al. 2008). Ways to deal with and model uncertainties have been developed, most of the time relying on formal and quantitative methods using statistical analyses (*e.g.* with confidence intervals, probability distributions, etc.).

Picture 6.1. Team discussion after playing the third version of the game. *These collective discussions are at the heart of our approach.*

When applied to epistemic or ontological uncertainties, such approaches can provide useful results, for instance probabilistic estimates of flood events (Chen and Yu 2007) or probabilistic climate forecasts (Gneiting et al. 2007). Nevertheless, when uncertainty arises not only from a lack of knowledge, but also from the fact that the problem studied is ill-defined, information is incomplete and not quantifiable, and that different legitimate views of the system exist – in other words when we deal with *wicked* problems – a probabilistic transformation of uncertainty is impossible (Allen et al. 2011). This multiplicity of uncertainties contributes to the “wickedness” of social-ecological problems, and is a major challenge for decision-makers and for researchers willing to study, understand and ultimately simulate social-ecological dynamics.

Once we acknowledge the multiple frames of a problem (Susskind et al. 2012), and the necessity to integrate local actors to address wicked problems (cf. post-normal science, Chapter 2) the next question is therefore “how do we deal with these frames and the uncertainty they create?” Should researchers maintain their own frame and complement it with those of other actors? More than a technical choice, we believe that the choice of a frame is part of the necessary reflexivity of the researcher (Daré et al. 2010). It is a postural decision through which the researcher questions himself. The researcher's frame relies on academic knowledge, and is supposed to be a neutral vision of the reality of the system. Nevertheless, the notion of neutrality, that is, that science stands free of moral, political and religious values, is widely criticized (relevant examples are given by Philip Kitcher in "Science, Truth and Democracy" (Kitcher 2003)). In a post-colonial perspective, the "foreigner white-male positionality of researchers" (Stringer et al. 2006) needs to be broken to initiate a fair collaboration between researchers and local actors, and the authoritarian scientific frame impedes this necessary process. Furthermore, scientific knowledge is incomplete (epistemic and ontological uncertainties) and the researcher's frame is by nature insufficient. The alternative solution would be to directly adopt local actors' frames. But those of which actors? What about power games? Barnaud (2013) warned about the dilemma of participation (Chapter 4), that is, the difficult choice of adopting the view of particular actors and either risking being "manipulated" by powerful actors – thus reinforcing their position – or modifying existing power relationships by arbitrarily favoring one type of actor. In the latter case, what is our legitimacy to do so? Hence, choosing local actors' frames is not a solution either.

In the work presented here, we chose to apply one of the strategies to deal with uncertainties: the negotiation approach (Leeuwis 2000). Uncertainty is inevitable and should be included in the research process, so we decided to strategically transform it with local actors. Our research tool is a role-playing game, that is, a virtual *erzatz* of reality, and we needed to include some sort of uncertainty in it. Co-designing the game was therefore a way to collectively negotiate a consensual uncertainty. Our vision of the system, that is our frame, necessarily differed from those of local actors. The ethnographical fieldwork contributed to a partial understanding of endogenous frames, but a deeper understanding of local frames was necessary. An exogenous research tool used to collect data and simulate a social-ecological system is a manifestation of the researcher's frame, and using it with people having different frames would generate ambiguities. Co-designing a role-playing game to collect data for modeling, and not directly running the simulation model, was a way for us to optimize the inclusion of divergent frames in the model. As explained in Chapter 4, we decided to initiate the co-design process with a launch version, but most of the game's sub-models were collectively chosen and shaped. From a relatively high level of ambiguity-related uncertainty due to the different frames used by researchers and local actors to analyze reality, we created collaboratively a consensual frame. The three types of uncertainty were negotiated. For instance, researchers did not know how cattle grazing impacted forage availability in the study area, nor the specific composition of the grazing lands used (epistemic uncertainties), or how regeneration worked (ontological uncertainties). To cope with our lack of knowledge, we collectively negotiated a forage sub-model for the game based on the crossed experiential knowledge of researchers and local members of the team who are custodians of the system. As the exact dietary regime of cattle is complex, multifactorial (age, diseases, physiological and reproductive status) and adaptive in space and time, we proceeded in a similar way to negotiate the sub-model describing the dynamics of cattle body condition.

"Did you really need the game to model how people live?"

Over the course of this PhD, we presented our work to academic audiences several times, and more than once we were asked this question. The ethnographic part of our work was crucial and provided key knowledge about the system. Could it have been sufficient to reach our objectives? Our answer is "no". Actually, not only would ethnographical fieldwork not have been enough, but the use of the role-playing game enabled us to corroborate some of our observations, such as the use of the forest as a way to avoid loss of crops due to incursions in fields, or the existence of three seasonal herding patterns – mostly herded in the forest during the agricultural season, in the communal area during the cold and dry season, and un-herded in the forest during the hot and dry season (Chapters 4 and 5) – while bringing in additional information. Cattle-related decision-making processes are complex. As explained in Chapters 2 and 3, cattle husbandry and herding strategies are normed and structured in our study area. Owners and herders have to respect a set of endogenous norms (defined by the communities) concerning cattle herding inside the communal area, such as *xotshela*, the date before which cattle should not be left to stray in the village, and exogenous norms (defined mostly by the Forestry commission) concerning the use of the protected area, such as the maximum distance within the forest that cattle have access to (although this fluctuates somewhat). By talking with people we could understand these rules, and we began observing discrepancies between the rules and the actions. Differences between normative rules and observed/real practices are very common. Adapting Simon's (1947) perspective, what matters for modeling human activities is how people are observed to behave, not how they are supposed to. In a very normed coexistence situation – with written rules and enforcing entities (forestry rangers, police, traditional authorities) – studying these discrepancies is challenging, because they are hard to observe (informants will do what they are supposed to do, say what they are supposed to say). The structure and functioning of the role-playing game puts players in a situation where their actions impact the environment, which will impact them in return. Asking villagers to play their own roles, in an artificial environment coherent with their reality, allowed players to take a step back from their reality, offering them a "freedom" arena where they could act freely. Of course, one could wonder if, in that case, the strategies played are representative of "real" strategies. The role-playing game was complemented by discussions and individual interviews and the results allowed us to answer this question in the affirmative (Chapters 4 and 5).

Agents in a simulation, just like human beings, act with a procedural rather than substantive rationality (Edmonds and Meyer 2013). Procedures, or practices, are sequences of actions that agents/humans use to deal with tasks in order to achieve an objective. At every step of the simulation, an agent will be confronted with different possibilities and will make a decision according to his previous actions, their consequences and his final objective. We assume that human beings do the same, and we need ways to bring human actors to re-enact these sequences. As formalized by Bennett (1976), human behaviors can be seen as adaptive strategies with objectives reached not through employment of an optimal sequence of actions, but through permanent contextual adaptations that will modify the social-ecological environment (the resulting effects are called "primitive effects"), therefore implying new adaptations.

In the case of cattle herding – but the same principle could be applied to any use of natural resources– the role-playing game made it possible to observe these sequences. As explained in Chapter 4, the use of a role-playing game echoes the theory of situatedness (Clancey 1997), as it leads players to make decisions in a virtual environment mimicking their reality (to a certain extent). This virtual environment is reactive and dynamic, and from their playing decisions will emerge unique situations to which they will have to adapt. Thus, in a relatively short amount of time, local actors can play several years with alternative scenarios and be confronted with a greater diversity of situations than an interviewer could conceive of, unless he has time to devote decades of fieldwork to it.

Seen at a different scale, the use of a role-playing game, whether computer-based or not, also has the advantage of making it possible to observe several individuals behaving simultaneously. From their interactions we can hope to observe emerging properties of the modeled system. This idea of emergence has had a powerful influence on some branches of the natural sciences and also has obvious resonances in the social sciences (Gilbert 2002). Indeed, the relationship between individual action and emergent properties of the system (environmental dynamics, social and spatial structures) is a fundamental issue in social-ecological systems. The concept of second-order emergence (Gilbert 1995) describes how individuals can recognize, reason about and react to the institutions that their actions have created (first-order emergence). The state of a given system results not only from properties of individuals, but also from feedback loops from higher levels, and these cannot be predicted by only looking at small-scale individual dynamics. To use the famous adage, "the whole is more than the sum of parts". Observing these emerging properties through real-life experimentation is almost impossible. Beyond obvious ethical questions about the justness of the manipulation of peoples' lives for a relatively selfish purpose (conducting our research), one can easily imagine how complicated it would be to set up an experimentation in which several dozen individuals would be monitored – even if only once a month — with the environment (climate, state of pastures, etc.) assessed at every time step, along with all the linked activities such as management of fields (type of plowing, types of crops used, surface planted, origin of the seeds, growing status of fields, etc.) or of cattle (grazing areas used, cattle condition assessed, selling/buying, prices, seller/buyer, etc.). The use of a computer-based role-playing game is a pertinent alternative because all of these parameters can be monitored and recorded by one person at every time step (Chapter 5), and the direct interactivity between players' behavior and the virtual environment allows the observation of emergent properties.

The relation between ethnographic fieldwork and the role-playing game is bi-directional. In our case, observations and interviews enabled us to initiate the co-design process (Chapters 3 and 4). The launch version of the game was designed according to gaps that needed to be filled by local members of the team. Not all of these gaps were "real" gaps of knowledge; some were artificially left in order to confirm (or not) our understanding of the system. When co-designed, a role-playing game can therefore contribute to a corroboration of researchers' observations from within the society studied. Later on, when the game was played, villagers implemented strategies that were partly coherent with our observations, in other words, the general patterns of cattle herding described in Chapter 3 were observed during the playing sessions (Chapter 5). We say "partly" because, while playing, villagers showed practices that did not exactly match the official rules (norms), or our field observations. For instance, several players used alternatively the forestry area and the communal area during the agricultural season, whereas in real life, cattle herding involves inter-individual agreements that limit such rapid adaptation. Another example is the shift in herding practices observed during the "bad rains" scenario. Although levels of forage were low in the communal area, several players kept on avoiding the forest (Chapter 5). What seemed to have happened is that villagers learned and adapted to the game's constraints, for instance the cost/benefit rules and preferred saving their tokens (the game's currency). Hence the necessity of researchers to have a minimum knowledge of the study area before initiating such a process, and the crucial role of collective discussions during workshops, and individual questionnaires during post-playing questionnaires.

To summarize, we do not belittle the efficiency of more classical approaches to eliciting knowledge such as participatory observation and interviews. We also implemented some of these techniques and our work is partly rooted in theory from the human sciences. Instead of opposing our approach based on the co-design of a role-playing game and other approaches, we insist on their complementarity in understanding social-ecological dynamics, with the role-playing game as an interactive way of cross-checking and completing observations.

A tool for researchers…and local actors

When engaging himself in a participatory process, the researcher acknowledges his need for local actors' insights to reach his objectives. As demonstrated in previous paragraphs, scientific uncertainties can be addressed through knowledge sharing and negotiation processes. The result of a participatory process – a role-playing game in our case, but many other forms can be taken – is a "boundary object". Introduced by Star and Griesemer (1989), the notion of "boundary objects" refers to artefacts that allow actors belonging to different social worlds to work together and achieve shared objectives (Trompette and Vinck 2009). During the co-design process, the participants are invited to project elements of their reality, and each one will have his own vision of the object. In our case, we showed in Chapter 4 how the role-playing game we used had multiple dimensions. The appropriation process happening during the co-design led the different members of the team to consider different objectives to achieve with the game. Indeed, although we (researchers) initiated this project to achieve our own research objectives, and (following the principles of the companion modeling approach) made these explicit to all participants (Daré et al. 2010), local actors' objectives emerged. This point was already discussed in Chapter 4, but we would like to insist here on the opportunities that result from such a process of appropriation. Using a popular metaphor (although a bit dark), the role-playing game is like Dr. Frankenstein's creature: we lacked key parts to create our "monster" (epistemic uncertainty), and we resorted to parts from other people (local knowledge and frames). Along the design process, we somehow lost control, with the emergence of local actors' objectives. To us, appropriation of the object by local actors is proof of a fair collaboration in which lay actors and researchers are equals. In our case, local members of the co-design team saw the game as a tool to educate communities and enhance collective reflections about farming and herding strategies. The game is ours, not as "we the researchers" but as "we the 13 people who worked together". Strong human relationships were built and we believe that as researchers, it is our moral duty to make sure that, even after the end of this PhD project and the end of our funding, we do our best for local members of the team to achieve their objectives. The final version of our role-playing game is computer-based and its implementation requires a video projector, a computer and electricity. There is a need for a collective modification of the game and we hope to create a role-playing game that would stay with rural communities and could be used by them without intervention of the researchers. Such a transfer was for example done by Garcia-Barros and Vandermeer (2013). Answering local actors' requests, their game, initially built and used to educate coffee producers and explore the consequences of their pest management practices (*Aztecas Chess*), was transformed into a standardized board game and transferred to local actors who build, sell, and play it for both recreational and educational purposes. Another example about local actors "taking over" a role-playing game in adapting it to serve their own objectives is given by d'Aquino and Bah (2014), with a role-playing game that was used by local actors to participate in the design of a new land use policy in Senegal.

Participatory approaches acknowledge the shortcomings of top-down approaches, which are not efficient in proposing relevant research or actions in an uncertain world (Chambers 1994), and aim to turn local stakeholders from passive objects to active actors of research, management of natural resources or development (Eversole 2003). At the end of the playing sessions, some of the local members of the team explained how other games could be created to address other concerns, for instance tree management. Thanks to the participatory design process implemented to elicit cattle-herding practices, we could therefore start identifying potential topics of research suggested by local actors themselves.

Perspectives for Transfrontier Conservation Areas

In this last part of our general discussion we discuss the potential contribution of the participatory modeling and simulation presented in this thesis to the study and management of Transfrontier Conservation Areas (TFCAs), especially concerning cattle-related coexistence issues.

Across Southern Africa, the creation of protected areas has contributed to the preservation of large areas that became the cornerstone of local tourism industry (see for instance Akama 1996, Murphree 2013, Peter Sai et al. 2015). Although most conservation policies in the region were designed and adopted during the colonial period, they have generally been maintained and supported by post-colonial governments as political and economic assets by the “new politico-economic” elite (Murphree 2013). In the second half of the nineteenth century “fortress conservation” (Duffy 2000), excluding rural populations from areas where they often used to live (West et al. 2006b) and depriving them from the use of natural resources, started to face severe criticisms. Eventually, this historical paradigm of conservation was replaced by the alternative paradigm of Community-Based Natural Resources Management (CBNRM), which is embedded in the idea that a sustainable use of natural resources can be reached if the stewardship of natural resources is put in the hand of those who live with it (particularly rural communities). CBNRM relies on the assumption that rural communities will invest in conservation if they derive benefits from it, a result that can be encouraged through the creation of local management institutions empowering these communities. Although promising, the implementation of CBNRM faced serious obstacles and results have often remained below the set objectives (Emerton 2001). Two major factors behind this relative lack of success were identified. First, the heterogeneity in social and ecological conditions impedes collective decisions (Murphree 2012).Indeed, the “community”, central to CBNRM, is often assumed to be socially and culturally homogeneous, but as shown by Mukamuri *et al* (2013), community-based projects often fail because a “collective” appears to be absent in heterogeneous local communities. The second constrain to the achievement of effective CBNRM was mostly political. As highlighted by Murphree and Taylor (2009) and Murphree (Murphree 2013), the devolution of political power and tenure rights to local communities is rarely achieved at the appropriate local level, leaving local communities with no negotiating rights, making them spectators of agreements made between governments and the private sector. In economically, politically and ecologically insecure situations, these communities have logically turned to short-term survivalist strategies which serve neither the interest of the populations nor the persistence of the environment. At the turn of the twenty-first century, the appropriate way to guarantee an efficient conservation and to promote long term and substantial rural development still remains to be found. The old “fortress conservation” was assumed by many to be an ineffective colonial heritage (West et al. 2006), but governments have failed (or refused) to devolve land and resource ownership to communities on the peripheries of protected areas.

In recent years, TFCAs have emerged in southern Africa as the new alternative to meet both conservation and development objectives. As explained in Chapter1, TFCAs are massive ill-defined areas (Mukamuri et al. 2013) created to link protected areas of various types across large landscapes, both within and between countries. For instance, the Kavango-Zambezi (KAZA-TFCA) where our study area is located, covers an area of over 400 000 squared kilometers and spreads across five countries (Fig.1.4). The establishment of TFCAs is based on three arguments. First, by transcending national borders, they will contribute to the mitigation of international antagonisms and promote cooperation on the African continent. Secondly, they will restore ecological continua and promote a more integrated approach of landscapes across colonially drawn boundaries that hampered conservation objectives. Finally, they can be an antidote to the historical marginalization of boundary areas and represent the engine for socio-economic development of rural communities living at the edge of protected areas (Murphree 2013). By taking conservation beyond the boundaries of protected areas, TFCAs form heterogeneous mosaics of land uses including National parks, Forests, private conservancies, CBNRM area and farming communal farmlands (*cf.* Fig.1.3 and 1.4), and their different governance systems.

There are several concerns regarding TFCAs. The first type of concerns can be described as “institutional”. Their formation is clearly “top-down” and essentially politically driven, whereas their actual contribution to biodiversity conservation and development is often limited (Cumming et al. 2013). Furthermore, when drawing on ecological thinking to argue for TFCAs – for instance the potential restoration of migration corridors – conservationists often forget the people living in these areas. The discourse supporting TFCAs emphasize a “win-win” situation, largely inspired by CBNRM. Nevertheless, direct participation of rural communities was rarely attempted, and the devolution of political powers and tenure rights, whose non-occurrence is identified as one of the major reason of CBNRM failures, does not appear to be achieved (Andersson et al. 2013b). TFCAs provide an additional layer in the hierarchy of ecological scales and institutional levels influencing local dynamics (Cumming et al. 2013). The constraints to conservation and development therefore operate at four levels (Fig.5.1), making TFCAs extremely complex social-ecological systems (SES). International treaties and conventions already framed conservation in protected areas, and these agreements have been translated and implemented at the national scale. Inserted in between these two levels, TFCAs aim to link and create synergies beyond countries' boundaries. All levels are linked by feedbacks, and TFCAs influence both international levels (Fig.5.1). Going down in scale, "everyday" management decisions are done at the local level, and are dependent on local resources. Feedbacks from local levels are always weaker than the constraints imposed by higher levels. This situation is one of a typical scale "mismatch" between institutional, management, ecological and social dynamics (Maciejewski et al. 2014).

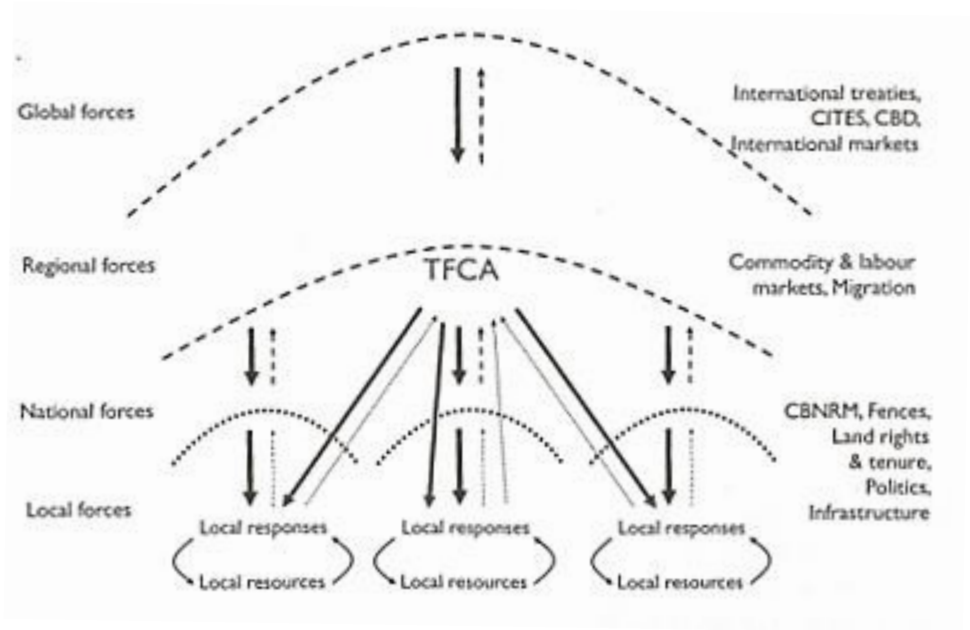


Figure 6.1. Local responses, constraints and opportunities in Transfrontier Conservation Areas (extracted from Cumming *et al* 2012)

Concerns of the first type of concerns impacts the way local issues are managed. TFCAs intend to restore ecological continua, and this is for instance achieved through the establishment of corridors linking individual protected areas (Metcalfe and Kepe 2008b). Although these corridors do not necessarily have any protection status, they virtually expend the interfaces between farming and wildlife areas. Focusing on interactions between cattle-protected areas, we can expect that TFCAs will increase the interactions between wildlife, livestock and human beings. Although positive interactions exist, there are major concerns concerning livestock predation by wild carnivores, livestock-wild herbivores competition for resources, and domestic animals-wildlife disease transmission (De Garine-Wichatitsky et al. 2013). Adaptive management of protected areas management is urgently needed.

We explained earlier (Chapter1) how the management of TFCAs involves multiple institutional levels, with actors having different agendas and objectives. The actual trend in natural resources management is “adaptive management” (AM) (Rist et al. 2013), and in this final paragraph we discuss how AM can be applied to TFCAs, and how our work could contribute to it.

AM is an approach that emphasizes learning through management where knowledge is incomplete and when, despite uncertainties, managers and policy makers must act (Allen and Garmestani 2015).

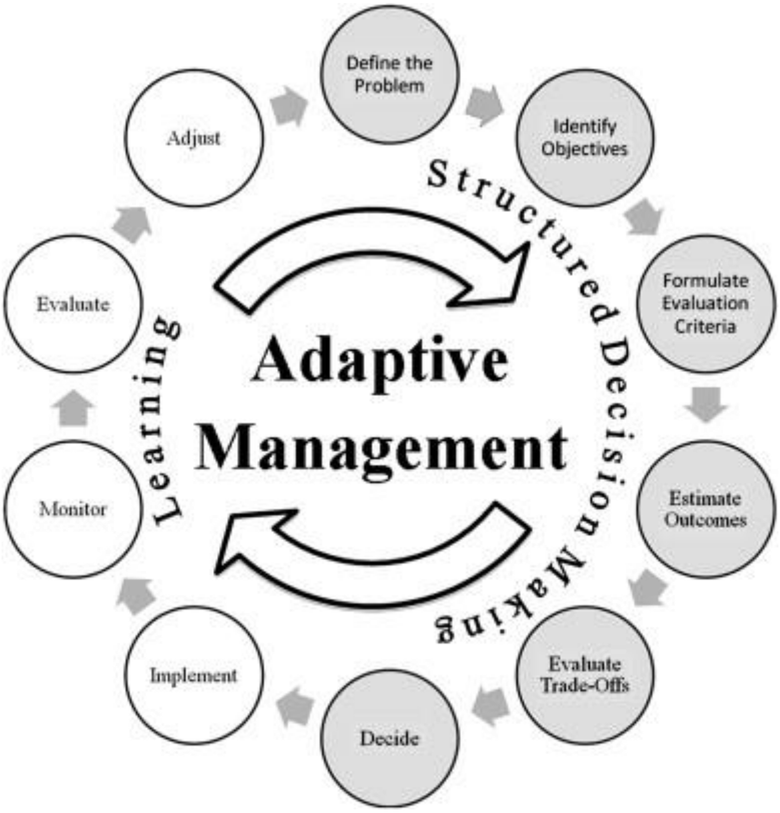


Figure 6.2. Adaptive management (extracted from Allen *et al* 2011).

In the case of TFCAs, uncertainties are many. Using the three types of uncertainties described earlier in this chapter, managers and policy makers have to deal with:

1. Epistemic uncertainties directly linked to the complexity and heterogeneity of landscapes involved and about which we lack scientific knowledge,

2. Ontological uncertainties because we do not necessarily know how ecological and social dynamics will be impacted by TFCAs. The establishment of wildlife corridors for instance will surely impact rural livelihoods and protected areas to an extent that is hardly predictable.

3. Ambiguities because the multiple-level institutional frameworks involve actors who have different visions, purposes and expectations concerning TFCAs.

Engaging communities living within TFCAs in AM could contribute to the improvement of the TFCA management. Decisions about TFCAs not concern only protected areas, but also the rural communities that sometimes represent the majority of the land concerned. Some advocate for collaborative AM (Susskind et al. 2012), including a wider range of stakeholders in the management process, in order to avoid inadequate decisions and adverse social-ecological outcomes (Rist et al. 2013), such illegal settlement, illegal resources appropriation, illegal hunting or smuggling (Andersson et al. 2013b) that can disrupt both conservation and development. As explained in Chapter 2, a major benefit of participation is that through the combination of knowledges provides a more complete overview of the SES of interest, and provides social, ethical and political values that cannot be gained through scientific approaches only (Stringer et al. 2006). Local communities can play an important role in all of the steps of AM (Fig.5.2). As custodians of the land, their opinions about which social-ecological issues to address needs to be considered. The implementation, monitoring and evaluation of management decisions can be shared between "experts" and local communities who are as concerned by the outcomes as the other actors.

We identify three major constraints to the collaborative AM of TFCAs, and advocate for the adoption of participatory designed role playing games and agent-based simulation models as a possible way to cope with these constraints. First is the diversity of actors involved in TFCAs. TFCAs are an example of polycentric governance systems (Nagendra and Ostrom 2012), where decision making is dispersed from the local to the global level (Fig.6.1). Lower levels need to be organized not to be "victims" of the higher levels. Protected areas can distribute fortune and misfortune to rural communities (Brockington and Wilkie 2015), and these do not necessarily wish to collaborate to conservation activities that they consider as threats to their livelihoods. This is a major constraint to collaborative AM in TFCAs. An improved mutual trust could be achieved through the creation of local extended peer communities (De Marchi and Ravetz 2001), collaborative AM teams involving protected areas' managers, researchers and local communities. Instead of starting by defining the problem (Fig.5.2), the extended peer community would start by defining a shared vision of the system to manage. Participants could explore each other's reality, collectively learn, and eventually start bringing down the social burden of conservation's history. This would happen at a very small scale, take time, and strong political will… but it the stakes are high and it is worth trying. The difference between CBNRM and the participatory approach proposed is that we do not argue for a transfer of power (that governments cannot or do not want to achieve), but for a sharing of power.

When related to cattle, which are at the heart of rural livelihoods around TFCAs, trust and commitment are necessary. We showed the potential of our approach to bring local objectives to emerge. These can be "small" objectives, but achievable and leading to "small wins" that participate to virtuous cycles deepening trust, commitment and understanding (Ansell and Gash, 2012). It is highly unlikely that rural communities will comply to any management decision threatening their livelihoods.

Uncertainties are unescapable, and they originate both in the "natural" world and human undertakings (Tyre and Michaels 2011). Interdisciplinarity should therefore be the rule and collaborative AM must involve academics whose expertise cover more than ecology, biology and other environmental sciences. We discussed about how the participatory design of a boundary object role-playing game like the one we developed enables participants to share knowledge, and therefore reduce or negotiate uncertainties. Understanding cattle herding strategies and the way(s) rural communities use their environment is the first step to better designed management strategies. These strategies are complex and adaptive, but can be documented with an approach like ours. Furthermore, the flexibility of co-designed models (or games) allows the inclusion of topics and sub-models, that can be brought-in by participants. In areas where disease transmission between domestic livestock and wildlife is a concern, concerned actors can propose the inclusion of disease outbreaks sub-models. The same applies to predators, veld fires or any other social-ecological concern.

Finally, social-ecological dynamics are complex and the consequences of a management decision cannot always be observed at the scale at which managers operate. The traces left by the implementation of a management decision can threaten local livelihoods and the landscape to conserve. The trial-error mechanism promoted by AM (Allen and Garmestani 2015) must therefore be questioned. We showed how resorting to simulation models and virtual realities provides an escape from the "catch-22" of wicked problems through the co-design of models mimicking the reference system. Trials could then be done through simulations of management scenarios.

General conclusion

At the origin of our work was the question of the coexistence between a protected area and the rural communities living in its periphery. Spending time living in the study area, partly within the villages where these communities live led us to realize the complexity of addressing this issue. Uncertainties were high and different angles could be chosen. The central role of cattle in interactions between the two areas considered quickly appeared and we decided to focus our attention to cattle herding practices. Adopting a post-normal approach, putting interdisciplinarity and participation at the heart of our work, were for us a way to cope with the inherent complexity of social-ecological dynamics and with the gaps in lacks of knowledge. In order to study cattle practices and with the capabilities necessary to model them, we co-designed a research tool that took the form of a role-playing game. This game is the central result of our work., and its implementation allowed us to better understand how people living next to the Sikumi forest drive their cattle using the forest. We provided insights into the future step this work should take, and particularly the simulation of cattle herding practices in an autonomous agent-based model. In the last chapter of the manuscript, we discussed our work and showed, among other things how such an approach is relevant to the study of *wicked* problems, and initiated a reflection on the potential applications in the study and management of Transfrontier conservation areas.

This PhD study is now finished, but the dynamics it has triggered will hopefully be maintained. We believe that much can still be done. Beyond the construction of an agent-based model that should be continued in the months to come, we intend to build on our experience and to continue collaborating with the local members of the co-design team. Scenarios will be explored and our knowledge and understanding of cattle herding strategies will be developed. The model supporting the game still needs improvements, for instance concerning the forage levels dynamics. We engaged ourselves in a collaboration that goes beyond this research project and this should not be "wasted". Locally, the next step will be the presentation of the game to protected areas' managers in the study area. Although these are only "intentions" for now and depend on funding, an implementation of the game in other areas of Zimbabwe was suggested, and should be done jointly with some of the local members of the co-design team. Cattle-related issues on the edge of protected areas are found elsewhere in the country and we assume that the game could be a central asset in future studies.

Picture 7.1. The *Kulayinjana* (extended) team.

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APPENDIX 1. ITERATIONS AND CO-DESIGN OF KULAYINJANA

Four successive versions of the game were produced during the Co-design process. Each iteration was the occasion to play the latest version of the game, to validate, reject, improve or redesign every element, from the material support to the sub-models. The final version of the game (VF) therefore includes elements from the different intermediate versions (V1 and V2), and elements from the launch version (V0) were also kept throughout the process. The evolution of the Game is described in Table A.1.1.

Table A1.1. From V0 to VF, evolution of the Role Playing Game. *Each version of the game is represented by a color, grey for V0, blue for V1, red for V2 and yellow for VF. Each line represents an element of the game. A changing of color signifies a modification of the element.*

		Launching V0	**Kulima Kufuma V1**	**Kulima Kufuma V2**	**Kulayinjana VF**
GENERAL	**Material support**	Computer-based.	Computer-free.	Computer-based.	Unchanged.
	Facilitators	A facilitator, a computer operator, a bank (researchers)	Unchanged.	Unchanged.	A facilitator, a bank and a computer operator (locals+researcher).
VISUAL INTERFACE	**Board**	Grid projected on a screen.	Paper board on a central table.	Projected on a central table.	Unchanged.
	Virtual environment	Grid: 60*40 cells Two land uses : Communal area Vs Forest.	Unchanged.	Grid size maintained but village extended.	Unchanged.
	Rain calendar interface	Weekly rainfalls displayed *a posteriori.* Update every 2 weeks.	Unchanged.	Unchanged.	Unchanged.
THE FARMS	**A played Farm**	Free location. 5 fields.	Unchanged.	The farms' location is imposed , the players choose which farm they want to manage.	Unchanged.
	Players' Assets initiation	5 medium cows; 18beans	Unchanged	Unchanged	Unchanged

	Player's assets acquisition	Cows can be sold/bought during the Game; the cow bought has to be with the same body condition than the herd.	A cattle market was added (sell/buy). It is opened only three times per year; A granary must be bought (1 bean) to store the early harvests; The granary is lost at the end of each year,	Players can sell/buy cows every months, to the market or to other players; Granary maintained.	Unchanged
	Players' Cards/Pawns	A cattle card where the number of cows is written and updated, along with the status of the caws Tokens and beans to pay for the different actions	Each player has a cattle herd pawn on the board Each player has a herder pawn	Unchanged	Unchanged
	Computerized farms	10 computerized farms with pre-coded actions, no cattle	NA	15 computerized farms, no cattle. Each computerized farm reproduces the field management of a played farm	Unchanged
PLAYING	**Duration of a game**	A game covers 1 Agricultural year (Octn-->Septn+1)	Unchanged	A game covers 2 Agricultural years (Octn-->Septn+2), with two climatic year.	Unchanged
	Time step	Two weeks (a game includes 24 rounds)	One month (a game includes 12 rounds)	Unchanged	Unchanged
	A round	<u>Begining of month:</u> Choose a paddock for cattle to graze (herded or not);Buy/sell cattle;Plant/harvest crops <u>Mid-month:</u> Predators and elephants actions are ran;Fields are updated <u>End of month:</u> Cattle status are updated;Grazing resource of paddocks are updated;Possibility to sell/buy cattle	<u>Begining of the month:</u> weather forecast for first week of the month available; Choose a paddock for cattle to graze (herded or not); Sell/buy Cattle; Plant/harvest; Crops stage are updated by the players themseV0es. <u>End of month:</u> Predators and elephant actions are ran; Cattle status updated; Grazing status updated.	Unchanged	Unchanged
SUBMODELS	**Rain**	Rainfall Datar : 2012-13 rainfall measured in the study area ; Weekly rainfall classification:	Unchanged	Dry year added : 1921 rainfalls measured in the Hwange district.	Unchanged

		dry (<5mm); small rain (<20mm); medium rain(20 to 40mm); big rains (>40mm)			
	Waterpans and boreholes	1 borehole/communal paddock with permanent water; 7 Waterpans: C4, F1, F2, F3, F4, F8, F9; Water pans have 4 levels: dry, small, medium, full; Empirical update of water pans.	Boreholes maintained; New water pans positions: C4, F2, F3, F4, F5, F8, F9; Tabulated function for waterpans dynamics; No influence of cattle on water pans.	Boreholes and waterpoints maintained; New Tabulated function for waterpans dynamics designed by experts and validated by the team.	Unchanged
	Grazing level in paddocks	Four levels of grazing: Nul, Poor, Medium and High, No particular submodel, the grazing level of paddocks is empirically updated by the facilitator	Unchanged	Grazing levels maintained; New empirically based function designed by experts and validated by the team.	Unchanged
	Crops	One "crop" with two types: short term & long term; Fields are individualized and can be planted anytime of the year; Two stages of crops: growing and ripe; No influence of rain on crops; Long term crop: 3 months to be ripe/ Short term: 2 months to be ripe.	Four stages for crops: seed, growing, mature, dry; Long term crop: 4 months to be ripe, 1 month to get dry; Short term: 3 months to be ripe, 1 month to get dry; Crops can be harvested if mature or dry.	Unchanged	Unchanged
	Cows	The body condition applies the whole herd and has 3 levels (can't die): thin,medium, fat; Initial value is "medium"; A thin cow is worth 6 beans, a medium cow is worth 12 beans, a fat cow is worth 18 beans;	Body conditions paramters maintained; Co-designed submodel for body condition: A month spent in a "poor" or "Nul" paddock will decrease the body condition of 1 level; A month spent in a "good" paddock will increase the body condition of 1 level.	Cows have individual body condition. Grazing in a "medium" paddock --> no change in body condition; 1 month in a "good" paddock --> increase status At least 2 consecutive months of nul paddock -->decrease status	Unchanged

		No submodel designed, the facilitator will update each player's herd's body condition empirically.			
	Crops depredation by cattle	NA	An herd in a communal paddock during the agricultural season has 1/10 chances of entering a neighbor's field if not herded; destruction rate= 100% of the field.	Depredation risks maintained Destruction rate =25%	Unchanged
	Crops failure	NA	*Droughts*: between october and december, Short term crops fail (100%field) after 3 weeks without rain, long term crops after 4 weeks; Hydric stress has no effect after December; *Floods*: Three consecutive weeks of heavy rain will destroy every seed or growing field.	Unchanged	Unchanged
	Crops residues	NA	Crops residus can be left in the field (shared use) or kept in the homestead (individual use); Kept residues can be given to cows anytime.	Crop residues parameters maintained; Crops residues from 1 field can feed 1 cow for a month	Unchanged
	Wildlife				
	Predator	1 type of predator: lion. Attacks only in the forest . Double drawing system: a. each paddock has 1/10 chances of having a lion hunting b.If the lion hunts in a paddock hosting cattle, one herd is drawn randomly and the owner loses a cow. If the lion hunts in an unoccupied paddock, nobody loses cattle.	Predator maintained; Only unherded cattle can be attacked; Max 1 attack/month. attacks chances: - F1/F4/F7: 1/20 - F2/F5/F8:1/15 - F/F6/F9:1/10	Tabulated function: F1/F4/F7: 1 cattle killed from 3rd, 8th and 14th herd using one of these paddocks F2/F5/F8: 1 cattle killed from 2nd, 5th, 9th, 12th and 16th herd using one of these paddocks F3/F6/F9: 1 cattle killed from 1st, 2nd, 6th, 7th, 9th, 11th, 12th and 14th herd using one of these paddocks.	Unchanged

	Elephant	NA	Elephants attack at the paddock level. A paddock having at least 1 mature crop has 1/10 chances to be attacked by elephants. When a paddock is attacked, each player will lose up to three fields. Players can spend 1 bean to protect their paddock, this protection lasts a month.	An unprotected paddock has 94/100 chances to be attacked, a protected paddock has 6/100 chances to be attacked. Each field attacked loses 50% of the crops. Farms close to the forests have 3 fields attacked; the other farms have 1 field attacked.	Unchanged

ABSTRACT

It is now widely accepted that human beings and their environment are intertwined parts of a complex and dynamic system. Several analytical frameworks have been developed to study these systems, and in this work we adopted the Social-ecological System (SES) framework. The plurality of actors within a SES brings with it the question of coexistence. Indeed, the different actors sharing common resources do not always have the same objectives, practices and cultural values. While the different actors can collaborate and produce positive outcomes, there are many examples of land use conflicts around protected areas throughout the world. About 15 percent of the world's terrestrial area has some kind of protected status. Human-wildlife conflicts, crop raiding, livestock predation, poaching, illegal harvesting of natural resources, the list of conflictual issues taking place at the edges of African protected areas is long. These issues are "*wicked*" problems, characterized by scientific uncertainties, by conflicting cultural values and by interconnections with other problems. While the positivist paradigm charges researchers to discover an objective truth (even though they realize that single truths and single solutions do not exist), the constructivist approach of post-normal science (PNS) assumes that reality is socially constructed, and studying and addressing *wicked* problems therefore requires insights on local stakeholders' perspectives. In this PhD study we focused on interactions between the Sikumi Forest (SF), a Zimbabwean protected area, and the rural communities living at its periphery. More particularly, we focused on the tensions related to cattle-herding practices. Rural communities have legal access to the forest, but although communities and Sikumi Forest managers both get benefits from the agreement, none is fully satisfied and concerns are expressed on both sides. The situation shows characteristic of *wicked* problems: the difficulty to frame a precise problem; great uncertainties about the studied SES; incomplete scientific knowledge; competing cultural values and objectives; and interconnection of the issue of coexistence with other problems. In order to understand and ultimately simulate cattle-related interactions between rural communities and the protected area, we implemented a companion modeling (ComMod) approach. We co-designed a participatory research tool taking the form of a role-playing game (RPG) enabling us to elicit cattle-herding strategies. Several steps were necessary, including intensive ethnographic fieldwork, the creation of a co-design team involving researchers and members of the local communities, and the conducting of several iterative workshops. Three years after the beginning of this PhD study, we succeeded in producing an operational RPG that was used with naïve villagers (i.e., villagers who were not involved in the co-design). This PhD thesis shows how the use of virtual worlds (RPG) allows researchers to cope with the catch-22 of wicked problems, i.e., that any action transforms the context and potentially brings more problems. The co-design of the research tool allows us to deal with one of the major characteristics of wicked problems: uncertainties. In the participatory design of the RGP, uncertainties were collectively reduced and negotiated. Participation led to the appropriation of the co-designed object by local actors. As a result, our project went beyond the initial ambitions to produce a multi-dimensional tool, of which we necessarily lose control. Finally, our work allows us to propose elements for the formalisation of empirically-based modelling. In a wider perspective, we believe that with the emergence of Transfrontier conservation in Africa, participatory approaches like ours can provide alternative ways to study and manage coexistence between protected areas and their peripheries.

RESUME

Le fait qu'Homme et environnement sont les éléments de systèmes complexes et dynamiques est aujourd'hui largement accepté. Des cadres théoriques ont été développés pour étudier ces systèmes, et au cours de notre travail nous avons adopté celui des Systèmes Socio-Ecologiques (SSE). La pluralité des acteurs vivant au sein d'un SSE amène logiquement à la question de la coexistence entre ceux-ci. En effet, différents acteurs ont souvent des objectifs différents reposant sur des représentations de l'environnement, des pratiques et des systèmes de valeur différents. S'ils collaborent et obtiennent des bénéfices de la coexistence, force est de constater que les situations de conflit sont nombreuses de par le monde. Aujourd'hui, 15 % des terres émergées mondiales sont 'protégées' d'une manière ou d'une autre. Conflits homme/faune, prédation du bétail, pertes agricoles, braconnages divers, la liste des tensions entre aires protégées africaines et leurs périphéries est longue. Ces conflits peuvent être vus comme des « problèmes pernicieux », caractérisés par la présence simultanée de valeurs culturelles divergentes et de nombreuses incertitudes sociales ou scientifiques. Là où le paradigme classique, positiviste, invite les chercheurs à chercher une vérité objective et absolue, les sciences « post-normales » (SPN) abordent la réalité comme le résultat d'une construction sociale, et reconnaissent donc l'existence d'une pluralité de réalités. La participation d'acteurs locaux dans nos démarches scientifiques permet de prendre en compte ces réalités. Cette thèse est focalisée sur les interactions entre la Foret de Sikumi (FS), une aire protégée zimbabwéenne, et les communautés rurales vivant à sa périphérie. Nous nous sommes intéressés aux tensions liées aux pratiques de conduite du bétail. Les communautés rurales vivant dans notre zone d'étude disposent d'un droit d'accès légal pour emmener leurs animaux paitre dans la forêt, et bien que villageois et gestionnaires de l'aire protégée trouvent des bénéfices dans cet accord, aucun n'est réellement satisfait et des inquiétudes et désaccords sont exprimés de part et d'autre. Nous retrouvons là les caractéristiques des problèmes « pernicieux » : difficulté à identifier le problème de manière définitive ; incertitudes scientifiques et sociales ; valeurs culturelles conflictuelles et liens avec d'autres problèmes. Pour comprendre et modéliser les interactions entre acteurs à travers la conduite du bétail, nous avons mis en place un processus de modélisation d'accompagnement (ComMod). Nous avons co-construit un outil de recherche participatif sous la forme d'un Jeu de Rôle (JdR) nous permettant d'étudier les stratégies locales de conduite du bétail. Plusieurs étapes ont été nécessaires : observation directe de ces pratiques ; création d'une équipe de co-constructeurs mêlant chercheurs et membres des communautés rurales ; co-construction en tant que telle au travers d'ateliers itératifs. Trois ans après le commencement de cette thèse, nous disposons d'un JdR opérationnel. Nos travaux montrent comment l'utilisation d'environnements virtuels permet aux chercheurs de s'extraire du paradoxe majeur des problèmes pernicieux : toute action modifie le système et donc le problème, sans jamais le régler. La participation d'acteurs locaux nous a permis de redessiner une vision commune des incertitudes sociales et scientifiques au travers de processus de négociation. Nous montrons comment le résultat de notre effort collectif dépasse les ambitions premières et la manière dont le chercheur doit nécessairement perdre en partie le contrôle de l'objet construit au profit des partenaires locaux. Nos travaux fournissent des éléments pour la formalisation d'approches visant à construire des modèles empiriques. Finalement, nous exprimons notre conviction que des approches comme la nôtre sont pertinentes dans le cadre de la gestion des aires protégées, particulièrement avec l'émergence des parcs transfrontaliers en Afrique australe.