The LUCID Model and Its Role in Supporting Land Use Planning Processes in Southern Ethiopia

ILRI PROJECT REPORT

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1 Introduction

Decision support systems (DSS) are interactive, computer-based tools that are used in a variety of disciplines. They are intended to enable decision-makers to better use information and improve both the process of decision-making as well as the effectiveness of their decisions (Forney et al. 2013). A key aspect of a DSS is that it allows a user to manipulate model parameters and examine their impact on the outcomes of the model in the form of a "what if?" analyses (Power 2005). However, besides using models in decision support as a quantitative prediction tool, such models can aid the understanding of complex situations where the outcome of certain decisions or management strategies is largely unknown. Particularly when we want to target groups that are not familiar with computer modelling, the use of simple, stylized models provides an adequate tool to increase the understanding of complex questions. Such models can effectively raise the awareness for certain outcomes of decisions that might be unexpected or that have not been considered so far.

The International Livestock Research Institute (ILRI) together with the Helmholtz Centre for Environmental Research - UFZ, are using modeling to address decision-making around competition among alternative land uses in pastoral and agro-pastoral drylands. In many regions where livelihoods were overwhelmingly based on mobile livestock keeping or *pastoralism*, a variety of factors such as climate change, the erosion of traditional pastoralist institutions, growth in human population, and land degradation have contributed to increasing competition among alternative land uses. The expansion of settlement areas and the adoption of cultivation, for instance, sometimes result in loss of the most important pastures. There is the possibility of a vicious circle in which declining pastoralist livelihoods results in more people adopting farming and expanding the area of cropland, which results in a reduction in the total area of the highest quality pastures. This further undermines livestock-based livelihoods, which pushes more people to convert more pasture land to crops, and the cycle intensifies.

And this is just one simple example of what are in effect a wide array of complex interactions among livelihoods, wealth and poverty, land productivity, policies and institutions, and changing farming and livestock keeping practices. Land use planning has the potential to mitigate harmful patterns of land use conversion thereby enabling patterns of agricultural production that are more productive, equitable, and environmentally sustainable, but only if it can take these kinds of complex interrelationships into account. The *Land Use Competition in Drylands* (LUCID) model is a joint effort of UFZ and ILRI to use simulation modeling as a tool for supporting land use planning processes to take account of these kinds of dynamics.

2 Competition for Land in Yabello Woreda

Yabello is a Woreda (district) in Borena Zone in southern Ethiopia where traditionally livelihoods have been predominantly based on mobile livestock keeping. A recent multi-stakeholder workshop held in Yabello identified five key challenges affecting livestock-based livelihoods: inappropriate settlement, expansion of cultivation, bush encroachment, lack of livestock markets, and drought (Alemu and Robinson 2015). The first three all result in a reduction of pasture land. This is one of the key challenges to pastoralist livelihoods in Borena Zone: the size of communal pasture land is decreasing due to an expansion of crop cultivation, bush encroachment, land degradation and conversion for other purposes such as settlements (Solomon et al. 2007, Desalegn et al. 2015). The Borana range management system distinguishes between *warra* and *foora* pastures, the former being pastures located closer to permanent water sources and settlements, and the latter being more distant and typically lacking in permanent water. Warra pastures tend to be located on better soils than foora pastures. Within the warra area, each settlement may have one or more communal enclosures which are restricted to use by milk herds only—that is lactating female animals and their young. The land that is converted to cultivation tends to be among the most desirable land, located in bottomland warra areas with better soils and water retention, close to settlements and water sources. This same land is disproportionately important for livestock production, as this is where dry season grazing takes place.

Rain-fed farming in Borena Zone tends to be marginally successful at best: in some parts of Borena Zone, the level of rainfall is at the very lowest threshold at which cultivation is possible, and with the year to year variability of rainfall, in some areas successful harvests are achieved as seldom as once every three years (Oba 1998 cited in Solomon et al. 2007). For most people in this area, farming does not lead to self-sufficiency, whereas it does result in fragmentation of pasture lands (Tache and Oba 2010). By taking up key pasture areas it may also be undermining livestock production and contributing to concentration of livestock onto ever-decreasing pastures and ultimately to land degradation. On the other hand, attempts to limit or even reverse the expansion of cultivation might unduly affect the poorest rural households as these rely on farming for a larger proportion of their livelihood than do wealthier households. Moreover, the soils, rainfall levels and availability of different types of land across southern Ethiopia varies and there are areas where farming may be more viable and less harmful to pastoral land use than others.

One policy initiative which has the potential to create a more rational approach to the conversion of land from one use to another and to strike an appropriate balance in the allocation of land among communal grazing, individual farming, and other uses is Woreda Land Use Planning (WLUP). Guidelines and a manual have been developed, and these pay close attention to the particular needs of land use planning in pastoralist regions. Land use plans could zone different sections of land differently, using zoning categories such as *community planned grazing area* (which could be converted to cropland only if rezoned), and *mixed pasture-farming area* (where allocation of parcels for farming is allowed), thereby ensuring that a required area of pastureland, in appropriate locations, is maintained.

Another policy initiative that is currently in development concerns the registration and certification of communal land in pastoral areas. The Ethiopian constitution and legislation do make provisions which recognize pastoralism as a valid land use and which, in theory, protect pastoralists from being evicted or deprived of the land resources that they have traditionally used. Plans are currently underway to develop a land registration system, which is meant to include systems for registration of communal land in pastoralist areas. Such a system could provide a strong legal basis for protecting key pasture areas and restricting where and how communal pastures could be converted to private use such as for farming.

A third approach relates to various community-based natural resource management initiatives being implemented in pastoralist areas in various parts of Ethiopia. In Borena Zone, including Yabello, these initiatives are aligned to customary institutions and traditionally defined territories. Community rangeland councils have been created for each of the five Borana *dheedas*—range territories—in an attempt to build on and strengthen existing institutions such as the position of *abba dheeda*, literally "father of the range", an elder who traditionally was tasked with coordinating pasture use and resource management across the dheeda territory. The rangeland councils are engaged in establishing grazing plans, including planning of water point development and re-establishing traditional rainy season/dry season division of pastures. However, the strategies adopted by the rangeland councils are constrained by the uncontrolled conversion of key pasture areas to other uses. The ability of the councils to address these issues, moreover, is hampered by fragmentary decision-making and lack of support and recognition for their efforts by the government (Alemu 2015).

Any of these initiatives could benefit from tools to assist in exploring the interactions between different kinds of land uses and the effects of different land use configurations on livelihoods. Alternative policy choices and land use plans are likely to result in different distributions of costs and benefits, different winners and losers. For some stakeholders, the appropriateness or inappropriateness of different options is understood as obvious or as "common sense". Pastoralism is understood by many as being a more ecologically appropriate land use in much of Borena Zone than cultivation; on the other hand, crop farming is recognized as having become quite important to the livelihoods of poor households and is seen by some stakeholders as a trend that should be supported. A challenge for planning is how to bring these seemingly opposing perspectives together in a way that allows decision-makers to appreciate the complex interactions and feedbacks among the factors affecting land use. The LUCID model is meant as a tool to assist decision-makers to consider this kind of complexity.

3 The LUCID Model

The NetLogo platform

NetLogo is a programmable modelling environment that provides a suite of predefined functions and a customizable graphical interface to visualize model dynamics (Wilensky 1999)[1]. It is particularly well-suited to model the development of complex systems—a pastoral grazing system for example—over time. Within a NetLogo model we can simulate the actions and interactions of large numbers of agents in a virtual spatial environment. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from their interaction.

Overview of LUCID[2]

We developed the LUCID model to investigate the dynamic interactions between pastoralist livestock production and cropland expansion in a dryland grazing system. The model captures key elements of the land use dynamics that have been identified from empirical research by the authors, expert opinion, and published research. These elements include the following:

A VIRTUAL LANDSCAPE that represents, in a stylized manner, a landscape in a dryland region where there is competition for land uses, particularly between pastures and cropland. The landscape is spatially divided into different land use categories (pastures, cropland). Underneath, a layer of soil types based on topography (uplands, bottomlands) defines the productivity of the land.

HOUSEHOLD AND HERD DYNAMICS such as herd relocation between pastures, livestock reproduction and herd growth, and the households' decisions to adopt and expand, and in some cases abandon, crop cultivation.

A DYNAMIC VEGETATION MODEL that simulates biomass growth on the pastures which is influenced by precipitation, the productivity of the soil and feeding by the livestock.

[1] NetLogo is available for free download at https://ccl.northwestern.edu/netlogo/download.shtml.
[2] LUCID is available for download at http://www.ufz.de/index.php?en=42265.

By adjusting model rules and parameters, we can simulate different scenarios such as where croplands are allowed to expand or how much pasture area should be reserved for enclosures. In the following pages, we will describe the main elements and processes of the model. They are visualized in a conceptual model diagram in Figure 1.

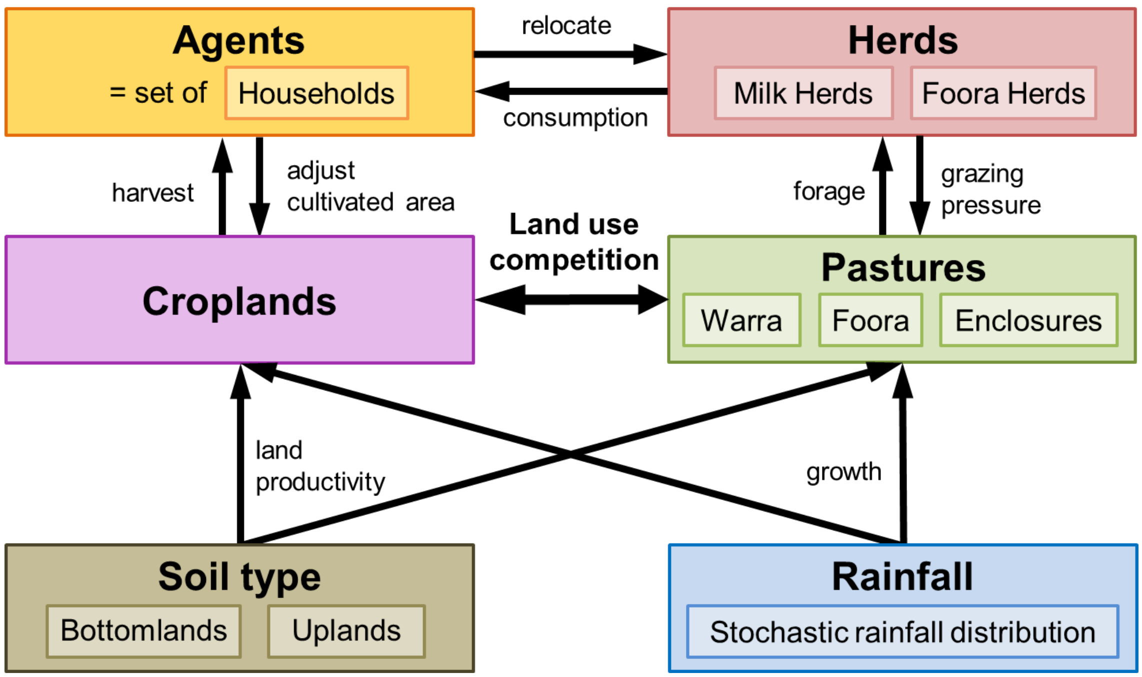

Figure 1: Conceptual diagram of the LUCID model that shows the entities represented in the model and their relationships.

Model entities and processes

A) Soil type

Each patch has a certain soil type that defines its productivity for the growth of both pastures and cropland. We distinguish **three soil types**, namely **bottomlands, uplands and barren**. **Bottomland is more productive** as it is able to hold soil moisture for a longer time. **Upland is** less productive then bottomlands, which is reflected in a lower biomass capacity and reduced biomass growth rate in uplands compared to bottomlands. Barren land holds no capacity for either pastures or cropland and thus is not usable by the households.

B) Rainfall

Besides soil productivity, **rainfall** is the **main driver of vegetation growth**, both for pastures as well as crops. On average, rainfall is low but can fluctuate considerably and droughts can occur frequently. In the model, rainfall is **modeled using a lognormal stochastic distribution** with a given mean and standard deviation. We calculate annual rainfall at the beginning of each year which is then distributed onto each season (rainy/dry season) to contribute to seasonal biomass growth.

C) AGENTS (HOUSEHOLDS)

The main entities in the model are agents that represent a set of households. Each household is assumed to consist of a number of persons, e.g. one household = 6 persons, so that one agent in the model represents a certain number of persons on the ground. Households are assigned to a settlement at the beginning of the simulation. Each household can own **two main assets**: **livestock and cropland**. In every time step, households **decide where to relocate their herds** in order to feed them. This decision is bounded by several factors, such as the current season and the maximum movement distance from the settlement. Once per year, households may **adjust their cultivated area**, i.e. decide whether they will increase or decrease the area. This decision is dependent on the herd size of the households, as mainly poor households and relatively wealthy households expand their cultivated area, whereas households in between may be less likely to expand cultivation (see section E.2) for details).

D) HERDS

Livestock herds are distinguished into **two categories: milk herds** that mainly comprise female and young animals, and **foora herds** that consist of male animals and non-reproductive females. The total herd size of a household L is given by the sum of the milk herd size L_{milk} and the foora herd size L_{foora}. Each herd type has certain properties:

1. **Scale of movement:** milk herds are restricted to warra pastures in every season, but they might access enclosures in the dry season. Foora herds are restricted to warra pastures in the dry season, but may move to foora patches during the rainy season
2. **Limitations of herd size:** It is a priority of each household to maintain a certain minimum milk herd size in order to secure its livelihood. If milk herd size crosses a certain threshold (42 TLU/hh[3]), animals will get shifted to the foora herd and subsequent herd growth will affect the foora herd until a maximum foora herd size is reached (360 TLU/hh). If animals are destocked or die, then at first the foora herd size will be adjusted before animals are taken out of the milk herd.

On initialization of the model, **initial herd sizes L_{init}** for each household are drawn randomly from a uniform distribution within a given range [L_{min}, L_{max}]. **Herds reproduce once per year** according to a given herd reproduction rate r. This rate subsumes both livestock birth and death; we therefore do not explicitly model livestock death except in cases of insufficient forage (see below). Wealthy households, i.e. those households owning a large herd, are usually also more successful in growing their herd, due to their greater capacity to obtain veterinary care, subsidiary feed, additional herding labor, etc. Thus, the individual reproduction rate of each household's herd factors in the household's current herd size, so that poor households have a slightly lower reproduction rate compared to wealthy households.

In every season, **herds need to consume a certain amount of forage** in order to survive. If this forage need cannot be met, i.e. of *forage needed ≤ forage available*, the household needs to destock part of his herd.

E) LAND USE CATEGORIES

LUCID implements **two main land use categories: pastures and cropland**. Both categories can be converted into each other, depending on the decision-making of the households.

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[3] One *TLU* (tropical livestock unit) is commonly taken to be equivalent to 0.7 bovines, 0.1 sheep or goats, or 1.0 camels (Jahnke 1982).

E.1) PASTURES

Pastures provide biomass as forage to the herds. In general, pastures are common property and can be accessed by all herds. However, the spatial distinction of the pastures into warra and foora pastures, and the defining of a certain amount pastures as enclosures restrict the access of livestock to these pastures. Warra pastures are close to the settlements and accessible all year round. Foora pastures are further away from the settlement and only accessible in rainy seasons, and also only to foora herds. Enclosures, on the other hand, are reserved pastures in the warra area and only accessible in the dry season, and only for milk herds. These access rules are summarized inTable 1: Distinction of pasture types and their access rules by season.Table 1.

Table 1: Distinction of pasture types and their access rules by season.

Season	*Pasture type*		
	Foora	*Warra*	*Enclosures*
Rainy season	accessible to foora herds only	accessible to milk herds and foora herds	not accessible
Dry season	not accessible	accessible to milk herds and foora herds	accessible to milk herds only

Underlying each pasture is a simple vegetation model that simulates the dynamics of biomass growth. The model assumes an abstract plant type consisting of two functional parts: green biomass and reserve biomass. Green biomass represents the edible plant parts that serve as the forage for the livestock. Reserve biomass represents all storage parts of the plants that contribute to the regeneration of the plant. Biomass growth is driven mainly by rainfall and grazing.

E.2) CROPLAND

Each household holds a certain amount of cultivated land *C*. Cultivated land is generally located in the warra area and relatively close to the settlements. To reflect this, a minimum and maximum distance of croplands to the settlements can be defined in the model. Therefore, the area that is suitable for cultivation is generally limited, and there can be restrictions onto which soil types expansion is allowed to take place.

The adoption of cultivation amongst Borana pastoralists is widespread, yet remains as a "second-best" livelihood strategy. The focus of livelihoods, or least of desired livelihoods, is still livestock. For wealthier households farming helps to smoothen consumption and reduce the need to sell livestock in order to buy staples, as well as providing an alternative food source for livestock from crop residues; whereas, for poorer households cultivation is also a fallback option adopted because livestock holdings have become too small to provide an adequate minimum income (Tache and Oba 2010, personal communication Shibia 2016). In the model, the poorest households (herd size < 18 TLU/hh) and the wealthiest households (herd size > 48 TLU/hh) will increase the area they cultivate, up to a maximum. However, the wealth of the household, measured by herd size, limits the amount of land that a household can cultivate. For wealthy

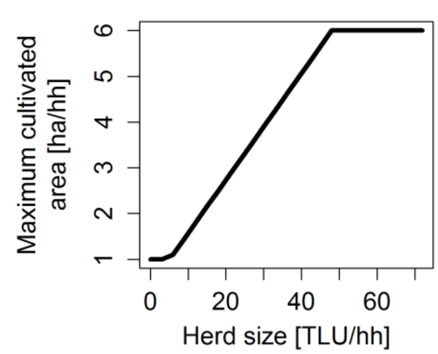

Figure 2: Maximum cultivated area per household depends on herd size of the household.

households, who are better able to mobilize labor, inputs and capital, the maximum is set at a larger value than for poor households (see Figure 2). An absolute maximum is set as 6 ha.

The increase in cultivated area ΔC per household and year can therefore be calculated as follows:

$$\Delta C = \begin{cases} 0.5\ ha & if\ L < 18\ TLU/hh \\ -0.5\ ha & if\ 18 \leq TLU/hh < 48 \\ 1.0\ ha & if\ L \geq 48\ TLU/hh \end{cases}$$

Different scenarios will address which land is converted to cropland, based primarily on bottomland vs. upland, minimum or maximum distances from settlements, and whether community enclosures are available for conversion.

Spatial and temporal scale of the model

The virtual landscape in the model represents a 25 km x 50 km area of an agro-pastoral system. The basic spatial unit, one patch, has a size of 1 km x 1 km, so that in total 1250 patches are represented in the model. The landscape does not represent any particular real landscape but rather is a stylized map that includes the differentiation into different grazing areas – warra and foora pastures – and land use types, namely pastures, enclosures and croplands (see Figure 3). It is meant to represent a typical landscape in Yabello but not necessarily any particular place.

The temporal scale of the model captures the distinctive seasonal cycle of the region: long rainy season, long dry season, short rainy season and short dry season. Each of these seasons corresponds to one time step in the model, so that one year consists of four time steps.

This seasonal time step was chosen, as it represents the natural period of herd movement (Toth 2015).

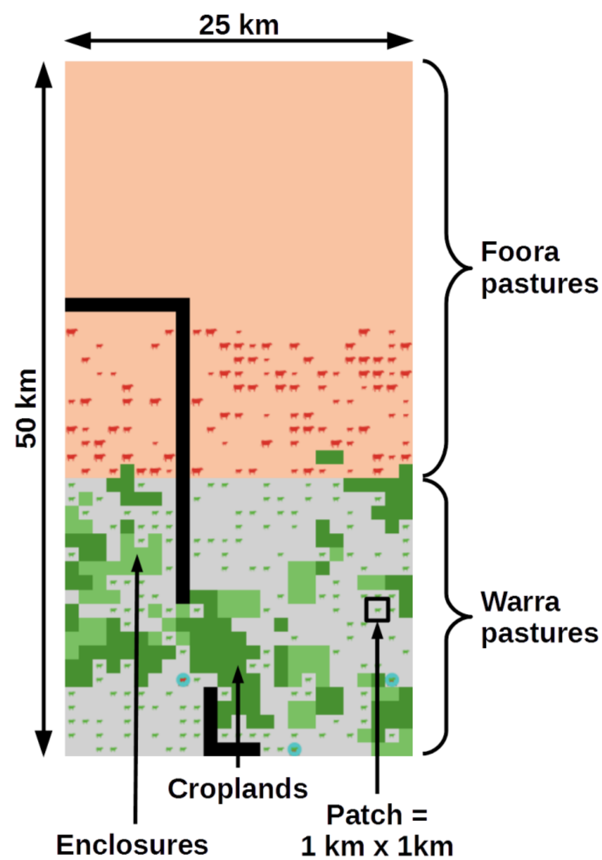

Figure 3: Stylized landscape of the LUCID model showing the differentiation into different grazing regions and the distribution of different land use types.

4 Model Dynamics and Outcomes

Causality and feedbacks

The LUCID model is developed to capture the main feedbacks between the livelihood of the households, their livestock, and the underlying vegetation system.

A main feedback link exists between herds and pastures: as herds feed on pasture biomass in order to maintain their fitness/condition, they exert a certain grazing pressure onto the pastures that affects their capacity for regrowth. Pasture growth is also tightly linked to precipitation, so that both low rainfall as well as high grazing pressure limits the growth of biomass.

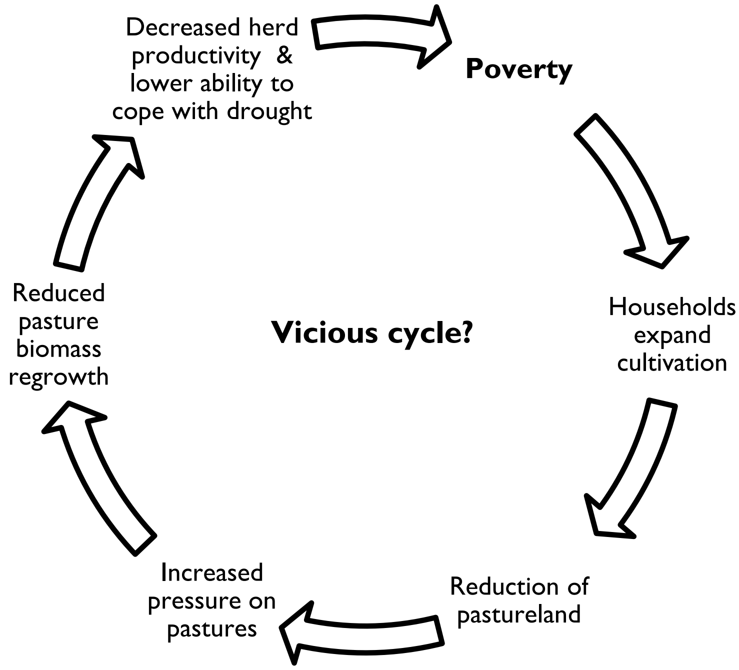

Figure 4: Possibility of a vicious cycle occurring due to inappropriate land use.

If cultivated area expands into pasture land, pressure on pastures might increase, thus reducing their capacity for regrowth. Households that decide to expand their cultivated area out of the need to sustain their livelihood and avoid poverty might in turn challenge the livelihood of households that still subsist from their livestock, creating the possibility for a vicious cycle (see Figure 4). The combined decisions of all households on the micro-level therefore lead to emergent system dynamics on the macro-level that we can observe by means of several outcome measures.

Model outcome measures

We can evaluate the model dynamics across the social, economic and ecological dimension using a set of outcome measures. Using these outcome measures, we can compare different scenarios and assess their impact on the long-term state of the system. An overview of these measures is given in Table 2.

Table 2: Overview of the outcomes measures of the LUCID model.

Outcome measure	*Description*	*Unit*
Herd size	Average herd size across all households, differentiated by herd type (milk, foora, and total)	TLU/hh
Household activities	Number of households that a) engage in crop farming and b) own a milk and/or foora herd, or are left without any livestock.	household count
Cultivated area	Total cultivated area of all households in the system	ha
Biomass	Average amount of biomass across ass pastures, differentiated by pasture type (warra, foora, enclosure)	kg/ha
Rainfall	Amount of annual rainfall	mm/a

Example dynamics of the model

Based on first exploratory analyses of the LUCID model, we present selected outcomes of one model simulation run here. In this run, agricultural expansion was allowed in uplands only, so that nutritious bottomlands were available for livestock feeding. However, no further restriction on the total amount of pasture land that could be converted to cropland was made.

In the course of herd size, we can observe two phases of herd growth followed by a crash (highlighted by grey bars). Average peak herd sizes before both crashes are very similar. However, looking at the number of households that lose their herd during the crash, we see that after the first crash still about half of the households own a herd, whereas in the second crash all households lose their herd. When the crash occurs, biomass on the warra pastures and in enclosures is the limiting factor. This biomass decline is caused by low rainfall years preceding the crash that limit biomass growth as well as the increased pressure on the pasture due to the large amount of cultivated area.

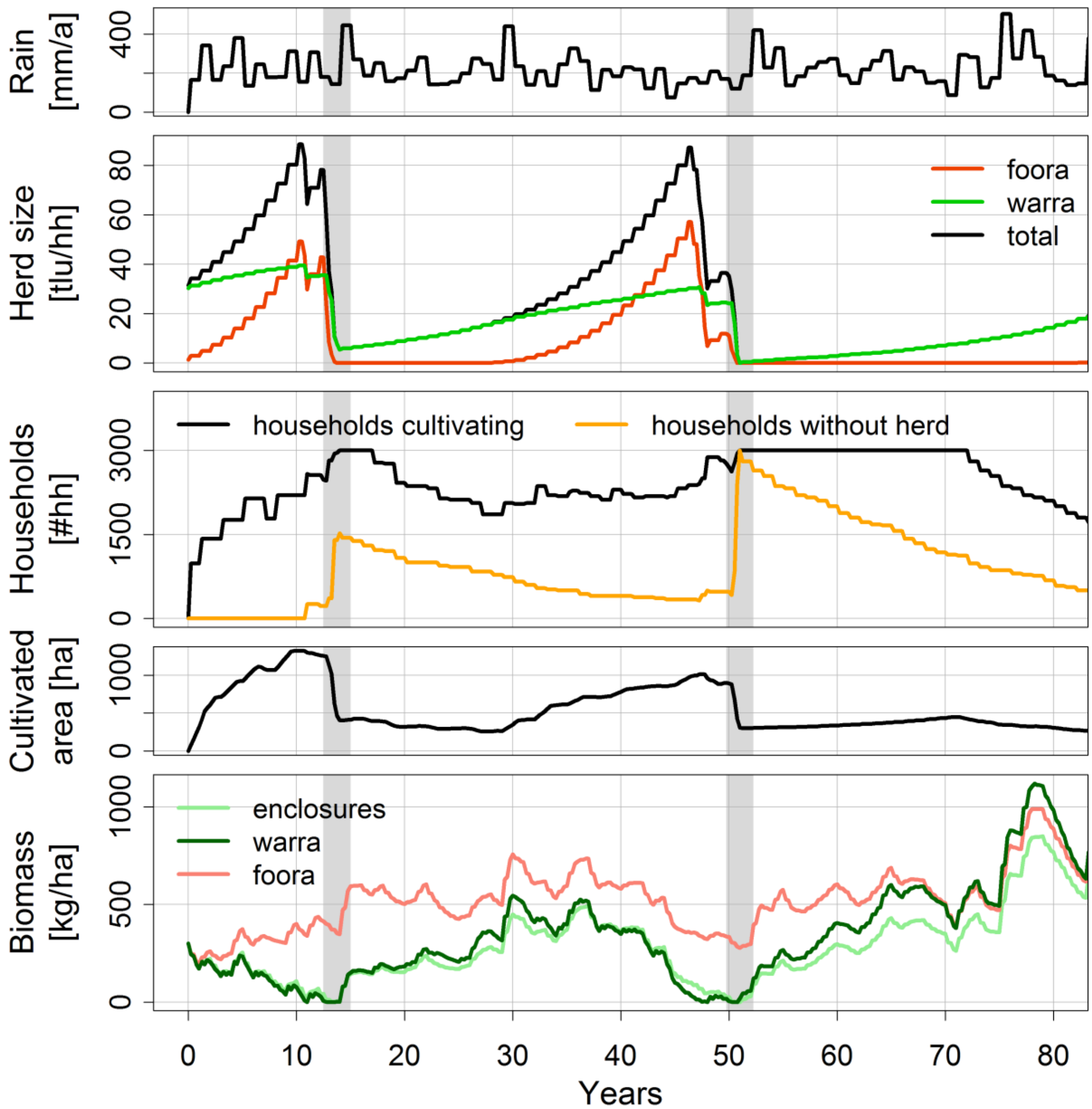

Figure 5: Example simulation run of the LUCID model. Simulation has been run for 80 years. Outcome measures are described Table 2.

5 Next Steps

LUCID allows for manipulation of particular parameters and relationships in the model for easy development of alternative scenarios. In the first half of 2017, the project team will develop a series of alternative scenarios from the LUCID model. The primary way in which alternatives will be structured relates to ways in which the amount of cultivated land is allowed to expand. For instance, alternative scenarios based on reserving different percentages of prime land (bottomland near settlements) for pastures will be compared to each other and to a scenario in which cultivation is allowed to take over the prime lands without imposed restrictions. Land use plans could be used to strike some kind of balance to ensure that sufficient high quality land is allocated to appropriately between grazing and agriculture, especially near settlements. Simulating different approaches to striking this balance will allow decision-makers to consider how the impacts of alternative approaches may differ. These include impacts on:

- Growth in the sizes of livestock herds,
- Ability of households to maintain their herds in times of drought,
- Differences in these kinds of impacts between wealthier versus poorer households, and
- Possible impacts that imposed limitations on conversion of land from grazing to farming may have on poorer households.

In mid-2017 the model and scenarios developed from it will be presented to stakeholders in Yabello, including civil society, community representatives on the dheeda level rangeland councils, and government officials, especially those involved in land issues and agriculture. Discussion of the scenarios developed through the model will allow stakeholders to explore how current and upcoming planning processes such as Woreda land use planning, communal land certification, and the rangeland planning done by rangeland councils can address the challenges of land use competition in a balanced way. The intention is that in this way, the model and the scenarios that are developed will contribute to better-informed planning processes.

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