# Resilience, Collapse and Reorganization in Soical Ecological Systems of Africa's Savannahs – Resilience of SES from a Resource-Economics Perspective


## 1.1 Keywords

Keywords (in German): Resilienz, Flusslaufmodellierung, Agentenbasierte Modellierung
Keywords (in English): Resilience, River basin modeling, Agent-based modeling


## 1.2 Countries

Kenya, South Africa

## 1.3 Summary

### 1.3.1 *Summary (in German)*

Verglichen mit der großen Zahl theoretischer und konzeptioneller Studien existieren bislang wenige systematische Ansätze zur empirischen Analyse sozialökologischer Systeme (SES). Das übergreifende Forschungsziel von B2 ist daher die empirische basierte Simulation und Analyse der Resilienz von SES in Kenia (Lake Naivasha Einzugsgebiet) und Südafrika (Thaba Nchu und Kuruman) mittels numerischer Systemmodellierung. In Kenia wird das in der ersten Projektphase erstellte hydro-ökonomische Simulationsmodell zu einem konzeptionell neuen, simultanen Multi-Agentenmodell weiterentwickelt, um flexibel verschiedene Institutionen und denkbare Kombinationen im Wassermanagement des Lake Naivasha Einzugsgebiet angemessen abbilden zu können. Mit Hilfe dieses Modells werden multi-periodische Szenarien simuliert, um die Resilienz des Naivasha-Einzugsgebiets gegenüber meteorologischen Dürren zu quantifizieren. In Südafrika wird das übergeordnete Ziel durch eine vergleichende Analyse zweier sozial-ökologischer Systeme auf gleicher Skalenebene (Weideland-Dorfgemeinschaft), welche beide Änderungen der makroökonomischen Einflüsse von außerhalb der Systemgrenzen ausgesetzt sind (Subventionen). Wir planen, die kommunalen Produktionssysteme in Thaba Nchu (Grasland-Biom) und Kuruman (Savannen-Biom) in die Untersuchung einzubeziehen, um sie in einem komparativen, computer-gestützten Fallstudienansatz zu analysieren. Auf der Basis von Simulationsexperimenten mit Multiagentenmodellen sind wir in der Lage, Unterschiede mehrdimensionaler Resilienz dem lokalen Kontext zuzuordnen. Darüber hinaus ist nur eine vergleichende Fallstudie in der Lage, die entwickelten, fallspezifischen Theorien aufgrund von Gemeinsamkeiten der sozial-ökologischen Systeme zu generalisieren. Die Koppelung unserer Modelle mit denen von A3

ist zentraler Bestandteil unserer Kooperationsstrategie. In dem hier beschriebenen Teilprojekt werden zwei Nachwuchswissenschaftler arbeiten, eine(r) zu Kenia und eine(r) zu Südafrika.

**1.3.2** *Summary (in English)*

Compared to the vast number of theoretical and conceptual studies, empirical work to assess the resilience of SES still seems to be in an exploratory phase. B2 addressed this problem during the first phase of the research unit (RU, FOR 1501) by developing data based numerical simulation models. The overall research objective of B2 for the second phase is to empirically assess the resilience of SES in Kenya (Lake Naivasha Basin) and South Africa (communal livestock systems in Thaba Nchu and Kuruman) using these further developed and integrated numerical simulation models. In Kenya, the hydro-economic basin model will be developed into a conceptually innovative simultaneous multi-agent model to simulate institutional deficiencies in the water management of the Lake Naivasha basin. Multi-period simulations will be carried out for different institutional settings for water management with the purpose of quantifying the resilience of the Lake Naivasha Basin SES towards meteorological shocks such as multi-annual droughts. For South Africa, the same overarching objective is pursued by conducting a comparative analysis of two SES on the same scale (community-rangeland SES), subject to identical macro-economic disturbances from outside the system boundaries (change in subsidization). Communal production systems in Thaba Nchu (grassland biome) and Kuruman (savannah biome) will be investigated in a comparative, computational case study approach. By means of simulation experiments with multi-agent systems, differences in multi-scale SES resilience will be related to specifics of the local context. Moreover, the comparative approach allows for partial extensions of theories, which are thus far only case specific, because of the similarities of the two SES being studied. The coupling of these models with those of A3 is central to collaboration efforts. Two junior researchers will work in this project, one in Kenya and on in South Africa.

## 2. PARTICIPATING INDIVIDUALS / ANGABEN ZU DEN BETEILIGTEN PERSONEN

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### 2.2 Other participating individuals

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*[Comments on participating individuals:* **Dr. Arnim Kuhn** worked as post-doc in phase I of the RU. He is an expert in river basin modeling and will support the proposed research of B2 in Naivasha, Kenya during phase II. **Sebastian Rasch** also worked as a doctoral researcher in phase I and will finish his PhD in 2013. He is an expert in agent-based modeling and will support the research of B2 in South Africa during phase II.*]*

## 3. PARTICIPATING INSTITUTIONS / BETEILIGTE INSTITUTE

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**A. Project Description / Beschreibung des Vorhabens**

[DFG form 54.012 – 1/12]

**Prof. Dr. Thomas Heckelei, University of Bonn**

# I. PROJECT DESCRIPTION / BESCHREIBUNG DES VORHABENS

## 1. STATE OF THE ART, WORK IN PHASE I / STAND DER FORSCHUNG, ARBEIT IN PHASE I

### 1.1 State of the Art

The overall objective of B2 for phase II is to assess the resilience of SES in Kenya and South Africa using numerical simulation models that are innovatively specified to make the best use of collected data. Compared to the vast number of theoretical and conceptual studies, empirical research assessing the resilience of SES is still in an exploratory phase. Apart from the challenge of defining 'resilience of an SES', practical problems arise from the fact that regime shifts in SES are observed with low frequency, while experiments aimed at pushing SES towards critical thresholds are impossible for ethical reasons (Carpenter et al. 2005). One of the first attempts to assess the resilience of SES based on qualitative case studies is made by Berkes and Seixas (2005), who look for factors influencing resilience of five lagoon fisheries on different continents. They identify the role of social learning, organizational and knowledge diversity, and opportunities for self-organization as important clusters of factors for building resilience of SES. On the other hand, breakdown of resource institutions, rapid technological and socio-economic change, and institutional instability across political scales have the potential to weaken resilience. In another case study, Marschke and Berkes (2006) investigate the livelihood resilience of Cambodian fishing communities using a mix of qualitative and quantitative methods. They point out the importance of poverty traps, thereby questioning the positive connotation of resilience, and consequently suggest well-being as a 'culturally appropriate surrogate' for positive resilience.

Sallu et al. (2010) assess the vulnerability and resilience of livelihoods in drylands of rural Botswana in a multi-disciplinary study spanning an investigation period of three decades. They develop 'resilience narratives' based on the analysis of livelihood trajectories and illustrate the combined influence of environmental variation and institutions in determining a household's access to assets and, consequently, its ability to generate more resilient livelihood outcomes. A number of other studies take a historical perspective to work out resilience narratives, as for instance Newton (2011), who gives an account of a 900-year old forest reserve in England. The impact of fundamental changes of Chinese economic policy regimes on the degree of coupling and resilience of pastoral SES in Inner Mongolia is discussed (Li & Li 2012), and for agro-forestry communities in Sichuan (Urgenson et al. 2010). A more structural approach of providing empirical resilience assessments is based on the concept of the adaptive cycle (Gunderson and Holling 2002). A comparative study of five national Pacific salmon fisheries (Augerot and Smith 2010) attempts to determine the current status of each individual fishery within the cycle, while a long-term study of a single Sahelian village since the severe drought of the early 70's monitors the movement of the agro-pastoral SES through the adaptive cycle.

Examples of numerical models explicitly simulating the resilience of SES are still rare. A generic model is proposed by Fletcher and Hilbert (2007) which measures resilience as the "size of the basin of attraction near a desirable equilibrium and the return time following small perturbations". Keeping long-term sustainable production constant across different management scenarios, they identify a strong trade-off between profitability and resilience. Another generic model is applied by Anderies and Hegmon (2011) to simulate development trajectories of prehistoric societies of the US South-West. Schlüter and Pahl-Wostl (2007) use an empirical agent-based hydro-economic model to compare mechanisms of resilience in the semiarid Amudarya river basin in Central Asia. The agent-based structure of applied simulation models allows these authors to quantify the impact of more or less centralized institutional settings on the resilience of water-based SES at different scales. The change and dynamics of monetary returns from water use are used as surrogates for the resilience of the agro-economic subsystem of the SES.

In a review article, Schlüter et al. (2012) claim that numerous recent simulation models are part of an emerging field that one may call SES modeling. SES models have been applied to fisheries, wildlife and rangeland systems, and are borrowing from complex system theory and resilience thinking. SES modeling differs from traditional disciplinary modeling approaches by explicitly taking the coupling of the ecosystem with the social system into account, and by acknowledging the complexity of the human-nature coupled system. Traditional ecosystem models treat the social realm as exogenous, whereas bio-economic models consider resource users. In bio-economic models, rational actors maximize utility subject to resource constraints (figure 1). However, in bio-economic models "[...] diverse actors of the social system are not considered and resource dynamics are generally very simple." (Schlüter et al. 2012). In contrast, SES models account for both heterogeneous decision making and rich ecological dynamics. This implies that the field of SES modeling is necessarily of a multidisciplinary nature. Schlüter et al. (2012) underpin the need for coupling institutional, ecological and economic models as "slowly evolving institutional rules and infrastructure systems interact with faster resource dynamics and even faster economic decisions.".

Especially for resilience assessments, the modeling of resource management institutions, along with ecological and economic processes, should be a part of every SES model. However, the field is still in its infancy ass SES models often lack a strong empirical basis and are rarely context specific with respect to the SES in question. According to Schlüter et al. (2012), the emerging field of SES modeling must tackle this problem in order to provide useful guidance for sustainable management (Schlüter et al. 2012:256).

## 1.2 Experience from Phase I and previous work

### 1.2.1 Research goals of B2 during phase I of the RU FOR1501

Research by B2 was conducted at two sites:: the Lake Naivasha Basin in Kenya, and the communal livestock systems of Thaba Nchu, South Africa; the methodological meta-framework used was identical for both research sites. The overall goal of project B2 was to strengthen the link between natural and social sciences by modeling the interaction between ecosystems, the resources that these ecosystems incorporate, and the human communities using and managing these resources in the described SES. The main analytical tools applied were bio-economic numerical simulation and empirical analysis of the formal and informal institutional designs that are relevant for the regulation of resource use in the study sites.

### 1.2.2 Research activities of B2 during phase I

<u>Hydro-economic modeling (Kenya):</u> The project started with the design of a stylized hydro-economic model based on mathematical programming which is able to reflect the absence of

institutional regulations as the reference situation against which all institutional reforms and innovations can be contrasted. Conventional hydro-economic river basin models are still basically designed as planning models. They use an optimization criterion aggregated across all locations or agents (e.g. basin-wide economic welfare of water users), which is an approach that inherently carries strong institutional assumptions. Specifically, the results of these conventional models imply that water allocation between locations is either a result of welfare-maximizing central planning or, equivalently, perfectly functioning markets for water use rights (Kuhn and Britz 2012). In reality, however, water use in the river basins of developing countries is often only weakly managed through water institutions, if at all. The Lake Naivasha Basin is a case in point, as water use permits and water pricing are mainly imposed on large, commercial users in the riparian zone of Lake Naivasha, while the growing use of irrigation water by smallholders in the upper catchment of the basin is hardly regulated at all. The simulation of this situation of deficient institutional development is difficult to achieve with models that inherently assume central planning or water markets. This new model approach, as discussed in Kuhn and Britz (2012), avoids such assumptions by transforming the non-linear optimization problem (NLP) - where local water shadow prices are not explicitly addressed - into a mixed-complementarity problem (MCP). This stylized model provides the blueprint for the empirical model developed in this project for the Naivasha Basin. Two conference oral presentations and two research papers, one accepted for publication (Kuhn and Britz 2012), and one in the second round of review (Britz, Kuhn and Ferris 2012) are the result of this conceptual effort.

During the development of the conceptual model, data collection for the empirical model was initiated. The numerical model for the Lake Naivasha Basin (Lake Naivasha Hydro-Economic Basin Model, LANA-HEBAMO) requires data from hydrology, agronomy, economics and demography. Most data are taken from official statistics or previous studies. For the latter data source, and for empirical modeling in general, very fruitful cooperation has emerged between this project and the Faculty of Geo-Information Science and Earth Observation of the University of Twente (ITC, Netherlands). ITC has been intensively involved in empirical research in the Lake Naivasha area for almost two decades, predominantly covering hydrological topics, but also agronomy and socio-economic issues. In the course of this research, ITC has accumulated a comprehensive database for the Lake Naivasha catchment. Moreover, ITC facilitated collaboration between this project and other research groups from the UK and Canada currently working in the Naivasha area. In order to exploit synergy effects in data collection, exchange and modeling between these groups, the agronomic and economic projects of this RU (FOR 1501) have formed an informal research consortium regular meetings in the Netherlands or Bonn. The consortium also established its own internal website (https://sites.google.com/site/naivasharesearch[1]). Thanks to the cooperation with ITC, data could be supplied for the LANA-HEBAMO model:: a multiregional, recursive-dynamic model which is able to simulate local, physically interdependent water availabilities in the Lake Naivasha Basin for a broad variety of hydrological, economic or demographic scenarios. The current version is able to reflect surface and lake water flows and use, whereas groundwater is in the process of being included in order to make use of new ITC groundwater data currently being collected in the region. Data on the dynamic crop water use patterns in the catchment of Lake Naivasha werewere collected during the agricultural water user survey (see below) and are currently being transferred to the numerical model. Moreover, LANA-HEBAMO will be transformed so that it resembles a

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model of multiple interacting agents with different objectives similar to the stylized river basin model discussed at the beginning of this section.

Bio-economic modeling (South Africa): For the South African case, the bio-economic simulation model has two long-term goals: (i) to quantify the resilience of SES subject to disturbance regimes, and (ii) to encompass endogenously evolving institutional arrangements on the basis of trust and normative traits. In this way, modelers are able to investigate overall impact on ES by deliberately analyzing measures to build adaptive capacity in the system, i.e. the ability to manage resilience.

The social sub-system including herd dynamics is modeled by an agent based modeling approach (ABM). ABMs constitute a form of generative social science and are able to produce macro-phenomena which are emergent properties of the micro-specification. In combination with ecological modeling, ABMs are able to generate social-ecological emergent phenomena, such as resilience. The potential for emergence is a feature of complex adaptive systems (CAS), among which SES are counted. ABMs are able to mimic CAS in that they generate emergence on the system level. Moreover, the ability to implement boundedly rational behavior of interacting heterogeneous actors is exclusive to this modeling approach. ABMs have proven to be a suitable approach for modeling trust and normative behavior. The social simulation has been combined with a system-dynamics biomass growth model representing rangeland productivity. Productivity and degradation in this sub-model depend on soil characteristics, species composition and is influenced by climate and grazing pressure. The ecological sub-model was developed by project A3 and is informed by the soil science subgroups. To summarize, the coupled ABM-System dynamics model constitutes the bridging capital for the South Africa research teams, as soil science, grassland science, anthropology, history and economics are contributing empirical evidence and functional relations in a multidisciplinary manner.

Institutional economics analysis (Kenya): In August and September 2010, consultations were held with important stakeholders in the Lake Naivasha basin, including the Water Resources Management Authority (WRMA), Water Resources Users Associations (WRUAs), Commercial Horticultural Farms (represented by Lake Naivasha Growers Group, LNGG), and Non Governmental Organizations (WWF and CARE, Kenya). Based on the results of the consultations, a large survey was conducted among 308 randomly sampled landowners and water users in eight out of the twelve WRUAS in the Lake Naivasha Basin between April and August 2011. The visited WRUAs are all located in the upper catchment of the lake, which means that their water use patterns have an increasing impact on Lake Naivasha's hydrology, ecology and economy. Data cleaning was conducted between September and December 2011. Publications prepared cover the following topics:

- In a paper published as a discussion paper (Kyalo-Willy, Kuhn and Holm-Müller 2012), the 'payments for environmental services' system (PES) was discussed which emerged in the Naivasha basin between different user groups in an institutional setting characterized by a weak government and almost no implementation of formal regulations.
- A paper currently undergoing revision for re-submission to the Ecological Economics journal explores how social influence and collective action institutions affect the intensity of investment in soil conservation practices as a driver of adaptive capacity in the Lake Naivasha basin social-ecological system (Kyalo-Willy and Holm-Müller 2012).
- In a recently completed master thesis, the opportunity costs and effects of selected on crop productivity at household level were explored (Zhunusova 2012).

- In addition to the research activities outlined in the proposal, a survey on the drought vulnerability of resource-based livelihoods was carried by a Diploma student (Molitor 2011).

Institutional economics analysis (South Africa): During a preliminary visit in September 2010, a variety of stakeholders were consulted. Specifically, representatives from farmer organizations (Free State Agriculture), government agencies (Ministry of agriculture and fisheries, SALGA), and scientific experts (University of the Free State) were approached. Moreover, informal visits to production systems under different tenure systems were held. The insights gained from the preliminary visit shaped the further research approach. Specifically, the most complex interactions were indentified in 'communal areas', where small scale cattle producers are challenged by issues of collective action in the absence of individual property rights. Several interviews were conducted with local leaders in order to assess general structures within communities.

The findings from those preliminary investigations were used to design a household survey based on the World Bank's living standard and measurement (LSMS) survey scheme. This survey was adapted to the local specificities and expanded to cover institutional variables such as mutual trust or joint resource management practices. The survey was administered to the whole livestock producing population (80), as well as to a subset of non-livestock owners (30) in the community of Sediba (Thaba Nchu) from September to December 2011. The time of survey work corresponded with the anthropologic field work of project A1, which directed and framed the objectives of semi-formal interview questions in B2. Moreover, an additional 300 questionnaires were administered to households in three other villages in the Thaba Nchu region from May to July 2012. Survey results have been analyzed and are in preparation for a publication in cooperation with A1. Key objectives of this work are to:

- Delineate the historical context of common pool resource SESs in the region and derive consequences for the current system regimes;
- Characterize the economic situation of livestock producers on the household level in light of agricultural income as a contribution to total household income;
- Derive mental models of decision makers as a necessary element to inform a simulation model with behavioral strategies of heterogeneous, interacting social agents.

Moreover, a diploma thesis is in preparation with the aim of investigating the adaptive capacity of livestock producers in the communal production systems of Thaba Nchu. Focus groups and in-depth qualitative interviews are planned to elucidate stakeholder changes with respect to appropriation efforts in reaction to climatic and economic disturbances. The aim is to deduct pathways of further research in order to improve the representation of learning capabilities in the simulation model.

### 1.2.3 Results of B2 in phase I

Hydro-economic modeling (Kenya): Results regarding this activity originate from conceptual modeling (Kuhn and Britz 2012) and preliminary versions of the empirical model (Kuhn et al. 2012). The conceptual model studies revealed that:

- Conventional river basin models carry inherent institutional assumptions which bias the results of both the models' baseline and counterfactual scenarios. Specifically, they assume a-priori that water use is centrally managed by planning or markets in order to maximize an aggregate welfare criterion.

- The most important problem of unregulated water use in river basins is that water users with privileged access due to their upstream location have no incentive to save water. Their willingness to pay for water is zero as long as their production capacities do not require all available water.
- This means that upstream users may use water more inefficiently than downstream users, the latter which will be more constrained in their water use than under central planning or perfectly functioning markets for water rights.
- Conventional river basin models cannot reflect this due to their algebraic problem format. The stylized river basin model developed in this project is able to overcome this problem. In a nutshell, the proposed model is able to simulate realistic local water shadow prices.
- Applied to the Naivasha catchment, these insights allow for the analysis of future conflicts over water for irrigation in a more realistic way. In the upper catchment of the basin, water use for irrigation by small-scale farmers, but also by larger commercial outfits, is increasing rapidly. Small-scale water use in particular is not regulated, while large users are obliged to obtain volumetric permits and pay for water.
- First simulations with the empirical simulation model suggest that the marginal returns to small-scale water use practices are likely to be small in comparison to the horticultural industry in the downstream area of the basin. Water pricing schemes oriented to local marginal returns for water would have much smaller structural effects as compared to uniform water prices across the basin.

<u>Bio-economic modeling (South Africa):</u> Insights gained from the conceptual modeling task of communal production systems in Thaba Nchu (grassland biome) are as follows:

- The emerging field of socio-ecological modeling faces two major limitations: (i) SES models lack a common conceptual framework for e.g. measuring resilience, and (ii) they should be more specific to the empirical reality of case studies Schlüter et al. 2012::258).
- The first problem is addressed by devising a conceptual framework of linked resilience scales of SES with the aim of deducting simple and straightforward measures of resilience.
- Resiliencies are measured at the ecological, household, social, socio-ecological and general system identity level. All scales are endogenously linked by dynamic processes in the model.
- Socio-ecological and general systems resilience is understood as emergent properties of complex systems. Thus, the agreed upon tool for representing complex adaptive systems (CAS) was applied: agent based modeling (ABM).
- In order to address the second shortcoming of SES models, model mechanisms are based on empirical insights from the case study.
- Specifically, human decision making with respect to resource use was identified by explorative statistical analysis and econometric modeling, as well as by qualitative data from field studies.
- First simulation results suggest a stable to decreasing stocking rate and a further concentration of households who own cattle in the next 50 years.
- This implies decreasing pressure on the ecological system with a parallel increase of social inequality. Thus, the SES is faced with losing its identity of being a communal production system, while gaining advantages in terms of its ecological resilience.

- There is no single resilience measurement for any given SES. Resilience depends on the scale of measurement.

<u>Institutional economics analysis (Kenya):</u> The following results have emerged from the work done on understanding the challenges that agro-environmental institutions are facing, hence limiting their capacity to enhance SES resilience:

- Formal institutions are weak, based on the observation, for instance, that very few actors have a legal permit for their water abstraction activities.
- The newly created WRUAs are not yet operational: they are top-down institutions lacking self-organizations of users, but their functioning might assist in basin-wide management.
- Volatilities in water levels, siltation, eutrophication and water over-abstraction leading to scarcity were identified as the key environmental challenges driven by both anthropogenic influences and natural conditions.
- In principle, interactions among farms at the lake and farmers at the upper catchments could enhance the robustness of this specific SES by making use of Payments for Environmental Services (PES). A first PES pilot project is in place, but the payment amounts are very small.

<u>Institutional economics analysis (South Africa):</u> Findings from the surveys on living standards investigations of the institutional settings governing resource use in communal production systems of rural Thaba Nchu are outlined, which are followed by a discussion on their implications for resilience.

*Institutional collapse:* External interventions under Apartheid in the form of resettlements to and within the Bophuthatswana homeland led to an erosion of social networks and social embeddedness. During Apartheid, top-down agricultural management schemes hampered the accumulation of social capital and crowded out the intrinsic motivation of stakeholders. The sudden halt of all agricultural services after the fall of Apartheid subtracted all external capital from the system and led to an institutional collapse of the SES. Interview results indicate that decisions making only takes place on an individual level and is based on heuristics.

*Moderate overstocking:* AA relative similarity of herd sizes was observed, which can be attributed to high levels of normative sanctioning. Structural inertia regarding herd size within the village is also reflected by low aspiration levels of respondents with respect to desired herd sizes. Overall, the rangeland faces long-term degradation which is, however, not due to overstocking in terms of exceeding recommended animal numbers, but rather a result of the absence of joint herd management efforts (no fencing, no rotational grazing).

*Decoupling of the livestock SES:* Most households depend, to a large extent, on governmental transfers and remittances from migrant workers. Overall, the limited resource size in conjunction with age-based governmental transfers, normative sanctioning, and migration of workers fostered a process of de-agrarization. This is also a result of the relatively low profitability of, and thus low economic dependence on, livestock production as a means for income generation. Thus, the SES is in an ongoing process of decoupling with respect to the ecological and socio-economic dimensions.

*Implication for resilience:* Resilience cannot be measured on a single scale in isolation. Instead, linked scales of resilience on the household, social, ecological and general system level must be taken into account. Livelihoods of *individual households* in communal production systems display high resilience to ecological changes, and medium resilience to labor market disturbances, due to the high share of transfers (governmental and private) in household incomes. The *social system* in terms of institutional arrangements, including joint grazing management, collapsed after Apartheid and is highly resilient towards reorganization because of the lack of adaptive capacity. The *grassland biome* is more resilient to droughts compared to the bush-savannah biome (see findings of A3) because of its specific species composition and soil characteristics. The overall SES is in a process of decoupling, as it is at risk of losing its identity in the form of ecosystem service utilization.

## 1.3 List of Project-related publications / Projektbezogenes Publikationsverzeichnis

### 1.3.1 Articles published by outlets with scientific quality assurance, book publications, and works accepted for publication but not yet published

Ewert, F., Van Ittersum, M., Heckelei, T., Therond, O., Bezlepkina, I. und Andersen, E. (2011) Scale changes and model linking methods for integrated assessment of agri-environmental systems. *Agriculture, Ecosystems and Environment*, 142(1-2), 6-17.

Gaiser, T., Judex, M., Hiepe, C. and Kuhn, A. (2010) Regional simulation of maize production in tropical savannah fallow systems as affected by fallow availability. *Agricultural Systems* 103(9), 656-665.

Heckelei, T., Britz, W. und Zhang, Y. (2012) Positive Mathematical Programming Approaches – Recent Developments in Literature and Applied Modelling. *Bio-based and Applied Economics* 1(1), 109-124.

Heidecke, C. and Heckelei, T. (2010) Impacts of changing water inflow distributions on irrigation and farm income along the Drâa River in Morocco. *Agricultural Economics* 41(2), 135 -149.

Kuhn, A. and W. Britz (2012) Can hydro-economic river basin models simulate water shadow prices under asymmetric access? *Water Science & Technology* 66(4), 879-86.

Kuhn, A., Gaiser, T. and Gandonou, E. (2010) Simulating the effects of tax exemptions on fertiliser use in Benin by linking biophysical and economic models. *Agricultural Systems* 103(8), 509-520

Storm, H., Heckelei, T. and Heidecke, C. (2011) Estimating Irrigation Water Demand in the Moroccan Drâa Valley using Contingent Valuation. *Journal of Environmental Management* 92(10), 2803-2809.

### 1.3.2 Other publications

<u>Discussion papers and technical papers:</u>

Kyalo-Willy, D., Kuhn, A. und Holm-Müller, K. (2012) *Payments for Environmental Services (PES) and the Characteristics of Social Ecological Systems: the Case of Lake Naivasha Basin*. Discussion Paper 2012, *Series Food and Resource Economics*, University of Bonn.
http://www.ilr.uni-bonn.de/agpo/publ/dispap/download/dispap12_05.pdf

Kuhn, A., van Oel, P. and F. Meins (2012) *The Lake Naivasha Hydro-Economic Basin Model*

*(LANA-HEBAMO) – A Technical Documentation*. DFG Research Unit 1501, Sub-Project B2, Technical Paper 10/2012. http://www.ilr.uni-bonn.de/agpo/publ/techpap/LANA-HEBAMO-documentation.pdf

<u>Conference contributions:</u>

Britz, Wolfgang and Arnim Kuhn (University of Bonn, Germany) *Can hydro-economic river basin models simulate water shadow prices under asymmetric access?* Oral presentation at the International Conference: European Association of Agricultural Economists 2011 International Congress, August 30-September 2, 2011, Zurich, Switzerland.
http://purl.umn.edu/114272

Kuhn, Arnim and Britz, Wolfgang (University of Bonn, Germany) *Can hydro-economic river basin models simulate water shadow prices under asymmetric access?* Oral presentation at the International Conference: “Management of Water in a Changing World: Lessons Learnt and Innovative Perspectives” 12-13 October 2011, Dresden, Germany.

Willy, Daniel Kyalo and Arnim Kuhn, Karin Holm-Mueller (University of Bonn) *Functioning of Water Institutions under Power and Information Asymmetries: Insights from the Lake Naivasha Basin, Kenya.* Poster presentation at the International Conference: "Management of Water in a Changing World: Lessons Learnt and Innovative Perspectives" 12-13 October 2011, Dresden, Germany.

Willy, Daniel Kyalo, Arnim Kuhn, Karin Holm-Müller (University of Bonn) *Options for Improving the Design and Enforcement of Water Institutions in Lake Naivasha Basin, Kenya.* Oral presentation at the International Conference: Tropentag 2011, "Development on the margin" October 5 - 7, Bonn, Germany.

Molitor, Anne-Kathrin, Karin Holm-Müller, Arnim Kuhn (University of Bonn) *Drought Vulnerability in Resource-based Livelihoods in the Lake Naivasha Catchment.* Poster presentation at the International Conference: Tropentag 2011, "Development on the margin" October 5 - 7, Bonn, Germany.

<u>Diploma and master theses:</u>

Molitor, A.-K. (2011) *Drought Vulnerability in Resource-based Livelihoods in the Lake Naivasha Catchment.* Diploma Thesis, Agricultural Faculty, Bonn University, 6th July 2011.

Zhunusova, E. (2012) *Marginal benefits and opportunity costs of environmentally friendly technologies employed by smallholder farmers in the Lake Naivasha Basin, Kenya*. Master Thesis, Food and Resource Economics Programme, Bonn University, 11th October 2012.

**1.3.3 Patents:** *Not applicable.*

# 2. OBJECTIVES AND WORK PROGRAMME / ZIELE UND ARBEITSPROGRAMM

## 2.1 Anticipated total duration of the project

Intended total duration: 3 years; duration of required DFG funding: 3 years.

## 2.2 Objectives

The *overall research objective* of B2 for the second phase is to empirically assess the resilience of SES in Kenya (Lake Naivasha Basin) and South Africa (communal livestock systems in Thaba Nchu and Kuruman) using numerical simulation models.

Research objectives Kenya: The general objective of developing a comprehensive numerical model for Lake Naivasha is to simulate hydrological, ecological, agronomic and economic processes that are relevant for an assessment of the resilience of the Lake Naivasha Basin's social-ecological system (SES). The basin's economy and the livelihoods of its inhabitants are to a large extent based on the resources water and land, both of which are becoming increasingly scarce due to population growth and the boom in floriculture and other irrigated agriculture. The goal of the modeling exercise is to assess the impact of alternative water management institutions (such as water permits, water pricing, or temporary water use restrictions) on the resilience of the water-based basin SES to droughts and other temporary shocks. The following research questions will be addressed for Kenya:

1. How can the resilience of an SES to shocks by droughts be simulated with a river basin model, given the difficulties to assess resilience empirically?
2. Which institutional arrangements (i.e. common water management rules) influence the resilience of the Lake Naivasha SES against water stress due to droughts, and in which direction?
3. Which mathematical problem format is able to simultaneously represent multiple independent actors, the water resource interdependence among these actors, institutional quality, and the highly differentiated, non-linear biophysical processes in a river basin model?

Research objectives South Africa: For the next phase of the RU, there is the need for a theoretical generalization of the developed resilience scale framework. Only comparative case studies are able to arrive at a generalization of theory. Thus, Kuruman's SES in the savannah biome will be investigated in order to advance from a single shot case study towards a comparative case study and analogous computational analysis. In this way, differences of resilience mechanisms can be related to the local specificities, since interventions from higher scales of the panarchy are identical in the national context. That is, comparing two SES, which are subject to the same macro-economic disturbance scenarios, e.g. cuts in state grants, and are investigated with the same methodological framework, enables the generation and generalization of theories of local scale resilience mechanisms. Here, the impact of higher scale intervention can be controlled and deviations in resilience surrogates related to social and/or ecological differences.

Moreover, the research of B2 envisions intensifying the multidisciplinary cooperation between research projects of the RURU. Especially fruitful synergies with the crop science group (A3) during the first phase triggered the formulation of joint research questions with A3 for the next phase:

1. Which kind of institutional set-up is able to improve the ecological, social and socio-ecological resilience of the Thaba Nchu communal SESs?
2. Is the Kuruman SES in a similar process of decoupling and does it exhibit low levels of adaptive capacity similar to the Thaba Nchu SES?
3. How do remittances from labor migration networks, local income opportunities, and biome types impact resilience on different SES dimensions?
4. How do both dynamic systems respond when faced with droughts, cuts in state transfers, variability in food prices, and changing labor market conditions?

### 2.3 Work program including proposed research methods

Methods and work program Kenya: The purpose of hydro-economic modeling is to assess the resilience of the Lake Naivasha Basin SES towards meteorological shocks such as multi-annual droughts. For that purpose, institutional scenarios will be combined with weather scenarios oriented toward extreme weather events of the past hundred years. Resilience will be assessed by looking at the persistence of water-based economic activities during drought. Simulations of the resilience of the Lake Naivasha SES will be carried out using the hydro-economic model (LANA-HEBAMO) that was developed during the first project phase (Kuhn and van Oel 2012). Based on this is conceptual work, alternative mathematical optimization problem formats will be investigated regarding their suitability to reflect institutional deficiencies in basin-wide water management. The mixed complementarity format (MCP, see Kuhn and Britz 2012) will be tested against 'Multiple Optimization Problems with Equilibrium Constraints' (MOPEC, see Ferris and Wets 2012). The use of both MCP and MOPEC in river basin models is completely new and highly innovative, enabling policy analysis under the assumption of imperfect institutions.

MCP basically represents the first derivative of an optimization problem. Formulating an optimization problem as an MCP requires that local shadow price relations are explicitly included into the equation system (Ferris and Munson 2000). This facilitates the disruption of local shadow price relations, as is the case in a river basin with water users that are not subject to institutional constraints (Kuhn and Britz 2012). An extensive literature review confirmed that the MCP format has not yet been used in river basin modeling. Thus, the potential for MCP to represent and address problems where local externalities exist (such as in upstream-downstream settings) has hardly been explored for resource modeling or related economic investigations.

The downside of MCP is that the differentiation of nonlinear models, with respect to the numerous decision variables, often results in very complex first-order conditions (Heidecke, Kuhn and Klose 2008). A new, alternative problem format that avoids this cumbersome process is MOPEC (Multiple Optimization Problems with Equilibrium Constraints). Recent work has developed new extensions to the GAMS modeling language (**G**eneral **A**lgebraic **M**odeling **S**ystem, Brooke et.al. 2010), to facilitate the formulation of MOPEC problems as a special case of the Extended Mathematical Programming (EMP) framework (Ferris et al. 2009).

GAMS EMP provides an automatic transformation of a MOPEC into an MCP by explicitly determining the Karush-Kuhn-Tucker (KKT) conditions of each of the optimization problems and computing a solution of their union with the additional equilibrium condition. The MOPEC framework is very general and can be used to formulate partial or computable general equilibrium models, as well as a variety of Nash Equilibrium models of competitive behavior. Compared to the MCP format, a MOPEC problem is easier formulated, but does not facilitate direct access and manipulation of inter-agent shadow price relations, which may by a disadvantage.

River basin modeling is a highly multidisciplinary activity, as models represent coupled biophysical-economic processes. Therefore the LANA-HEBAMO model requires extensive and detailed input from hydrology (ITC Enschede, see partners) and agronomy (projects A2 and A3 of the RU). As to hydrology, LANA-HEBAMO is designed as a rainfall-driven model, meaning that local runoff is based on a statistically estimated non-linear function of rainfall. Crop response to water (rainfall and irrigation water) will be derived from a specialized model called AQUACROP (see http://www.fao.org/nr/water/aquacrop.html).

Simplified crop yield-water functions will be implemented in the GAMS model based on the results of adapted AQUACROP simulations. These would allow to calculate weather-dependent crop yields in both irrigated and rainfed agriculture, and, based on this, help to enumerate incentives for expanding supplementary irrigation in the Upper Catchment of Lake Naivasha.

Table 1: Time table for hydro-economic modeling in Kenya

| | 2013 | | | 2014 | | | | 2015 | | | | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | II | III | IV | I | II | III | IV | I | II | III | IV | I |
| Model development (turning the existing NLP model into MCP and MOPEC models)<br>Result: Technical documentation, methodological journal article | ■ | ■ | | | | | | | | | | |
| Data collection floriculture (technical coefficients of water use, economic parameters (profitability, investment, assessment of the industry's resilience)<br>Result: journal article | | ■ | ■ | ■ | ■ | | | | | | | |
| Completion of model base run (inclusion of collected data)<br>Result: technical documentation | | | | | | ■ | ■ | | | | | |
| Simulation of alternative institutional arrangements (existing and hypothetical solutions)<br>Result: 2 journal articles | | | | | | | | ■ | ■ | ■ | ■ | ■ |

<u>Methods and work program South Africa:</u> The main objective is to generalize resilience theories generated in the first phase by conducting a comparative modeling analysis between communal production systems in Kuruman (savannah biome) and Thaba Nchu (grassland biome). We pursue that goal by combining the following research methods:

- An application of the developed survey methods (B2) to the communal SES in the Kuruman region will enable the comparison of livelihoods, management practices, household-, agricultural- and social structures in the common framework of the World Bank's living standard and measurement survey (World Bank 15.02.2012).

- Focus group discussions will be conducted in the sense of Walker et al. (2002) in order to elucidate the inner working mechanisms of heuristic decision making and the adaptive elements herein with respect to potential hazards (Walker et al. 2002). This will be achieved by intensively discussing management options and reactions with stakeholders on an individual level with respect to climatic and economic disturbances.
- Role-play exercises in the villages of the two regions will include spatially explicit elements delivering rangeland maps and grazing paths from the perspective of stakeholders. Here, we will follow a similar approach as implemented by Castella et al. (2005), but adopted to specificities of common pool resources and livestock production.
- Analysis of migrant and remittances networks, planned by the anthropological projects (B3, B4) for the next application phase, offers the potential to be included in the economic case study for Kuruman. In this way, multidisciplinary cooperation is enhanced within and over project phases.
- The resilience of an SES is a function of its micro foundations which must thus receive special attention by investigating social structure in depths. A comparative case study of the Thaba Nchu and the Kuruman region is able contribute to the collection of empirical knowledge in the research field by means of SES resilience case studies being carried out world-wide (Walker et al. 2006). Moreover, a comparative analysis of empirically based SES simulation model results will support the methodological advancement in the field of SES modeling (Schlüter et al. 2012).

Table 2: Time table for agent based modeling in South Africa

| | 2013 | | | 2014 | | | | 2015 | | | | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | II | III | IV | I | II | III | IV | I | II | III | IV | I |
| Model structure development<br>(Implement adaptive agent behaviour to environmental change, institutional emergence and social networks from theory)<br>Result: Technical documentation, methodological journal article | ■ | ■ | | | | | | | | | | |
| Data collection Kuruman (LSMS Survey, network analysis, focus group discussions, role-play games)<br>Result: Input data for model + journal article | | | ■ | ■ | ■ | ■ | | | | | | |
| Calibration and adaption to Kuruman data + data from anthropologic network analysis in Thaba Nchu (inclusion of collected data)<br>Result: technical documentation | | | | | | | ■ | ■ | | | | |
| Comparative model runs with institutional emergence and network effects (Kuruman SES vs. Thaba Nchu SES)<br>Result: 2 journal articles | | | | | | | | | ■ | ■ | ■ | ■ |

### 2.4 Internal cooperation and project linkages

Internal and external cooperation with the natural sciences will primarily serve the purpose of informing the numerical modeling systems under development through exchange of data, and the development of joint modeling platforms and resulting publications. For instance, the Naivasha River Basin model (LANA-HEBAMO) is a joint modeling effort by B2 (ILR Bonn) and ITC (Twente). During the next phase, when the modeling focus will shift to agronomic details of the model, A1 and A2 will be closely involved, mainly via an application of the AQUACROP model to the Naivasha catchment. Cooperation with social sciences will focus on the coordination of data collection via surveys (e.g. labor markets, with B4) and the drafting of joint publications.

## 2.5 Other information

Not applicable.

Table 3: Activities and responsibilities in project B2, and linkages to other projects

| **B2** (Resilience of SES from a resource economics perspective) | RCR project linkages | | | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|
| | A1 (Range land soils) | A2 (Wetlands) | A3 (Veg. modeling) | A4 (Veget. ecology) | *B2 (Economics)* | B3 (Commodity chains) | B4 (Networks) | C2 (Media and rituals) | C3 (Instit. change) | ITC Enschede |
| **Activities** | | | | | | | | | | |
| 1. Basin Modelling Lake Naivasha | | | | | | | | | | |
| a) Hydrology | | | | | *x* | | | | | ■ |
| b) Soils and water | ■ | ■ | | | *x* | | | | | |
| c) Crop water requirements | | | ■ | | *x* | | | | | |
| d) World market linkages | | | | | *x* | ■ | | | | |
| e) Labour markets | | | | | *x* | | ■ | | | |
| 2. SES modelling South Africa | | | | | | | | | | |
| a) Rangeland modelling | | | ■ | ■ | *x* | | | | | |
| b) Adaptive capacity | | | | | *x* | | | | ■ | |
| c) Animal nutrition and reproduction | ■ | | | | *x* | | | | | |
| d) Cultural background | | | | | *x* | | | | ■ | |
| e) Labour markets | | | | | *x* | | ■ | | | |

Activity coordinator

Involved staff

Associated staff

## 2.6 Descriptions of proposed investigations involving experiments on humans, human materials or animals

Not applicable.

### 2.7 Information on scientific and financial involvement of international cooperation partners

Informally, cooperation has been established with ITC Enschede (Project: “Earth observation- and integrated assessment (EOIA) approach to the governance of Lake Naivasha, Kenya”) on data exchange, joint publications, a joint website, and stakeholder workshops in Africa. These efforts have been very fruitful for the development of the Lake Naivasha Basin Hydro-Economic Model during the first RCR RU project phase.

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# 4. PROJECT REQUIREMENTS / VORAUSSETZUNGEN FÜR DIE DURCHFÜHRUNG DES VORHABENS

## 4.1 Employment status information

Thomas Heckelei: Full Professor, Chair of Economic and Agricultural Policy, Institute for Food and Resource, Economics (ILR), University of Bonn.

## 4.2 First-time proposal data

Not applicable.

## 4.3 Composition of the project group

Prof. Dr. Thomas Heckelei (ILR, permanent staff)

Dr. Arnim Kuhn (ILR, funding through external grant)

Sebastian Rasch (ILR, funding through external grant)

## 4.4 Cooperation with other researchers

### 4.4.1 Researchers with whom you have agreed to cooperate on this project

Informal cooperation with ITC Enschede (Project: "Earth observation- and integrated assessment (EOIA) approach to the governance of Lake Naivasha, Kenya") on data exchange, joint publications, a joint website, and stakeholder workshops in Africa.

### 4.4.2 Researchers with whom you have collaborated scientifically within the past three years

Prof. Dr. Karin Holm-Müller, Bonn University.

## 4.5 Scientific equipment

Not applicable.

## 4.6 Project-relevant interests in commercial enterprises

Not applicable.

# 5. ADDITIONAL INFORMATION

Articles under peer review:

Britz, W., Kuhn, A. and Ferris, M. (2012) Modelling Water Allocating Institutions based on Multiple Optimization Problems with Equilibrium Constraints. *Environmental Modelling and Software* (second round of review).

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