Strengthening Tanzanian Livestock Health and Pastoral Livelihoods in a Changing Climate

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Research Brief
Adapting Livestock to Climate Change Collaborative Research Support Program
RB-08-2012 May 2012

Abstract

Livestock production in semi-arid grasslands is extremely vulnerable to climate change through altered water resource and disease dynamics. These vulnerabilities impact livestock survival and marketability, household livelihoods and health, and wildlife populations by enhancing zoonotic disease transmission pathways. Models that can integrate the interactions between economic choices, resource availability, human and animal health, and climate change will provide an important tool to evaluate adaptive policy and management strategies to climate change impacts. This research brief reports on preliminary modeling efforts to connect climate change, hydrologic-based ecosystem services, and disease transmission as part of a "one health" approach linking landscape management to broader public wellbeing and rural livelihood outcomes in the Ruaha landscape of Tanzania.

Modeling Zoonotic Disease Regulation under Climate Change Scenarios: A scoping model of freshwater resources in the Ruaha Landscape of Tanzania

Background

The Great Ruaha River of Tanzania has been the focus of extensive hydrological study in recent decades because of the economic impact of seasonal drought on hydroelectric power production, wildlife tourism, and rural livelihoods. Irrigated agriculture, uncontrolled water diversions, and livestock grazing in wetlands have all contributed to sustained dry periods of this previously perennial river. In the biologically diverse and economically important Ruaha landscape, livestock production is a particularly crucial source of income, store of wealth, and cornerstone of pastoralist culture. For pastoralist communities dependent on river water, this hydrologic disruption has resulted in direct and quantifiable impacts on the provision of freshwater ecosystem services for drinking, hygiene, and agriculture; as well as an indirect influence on disease transmission among people, livestock, and wildlife.

Facing dramatic reductions in water availability in recent years, the pastoralist communities bordering the Ruaha National Park present an important case study about adapting to declining water resources availability. Communities bordering protected areas are also at an important interface of zoonotic diseases, which can be transmitted to humans from diverse animal species. Water

The Ruaha River and its surrounding landscape. (Photo By Brian Voigt)

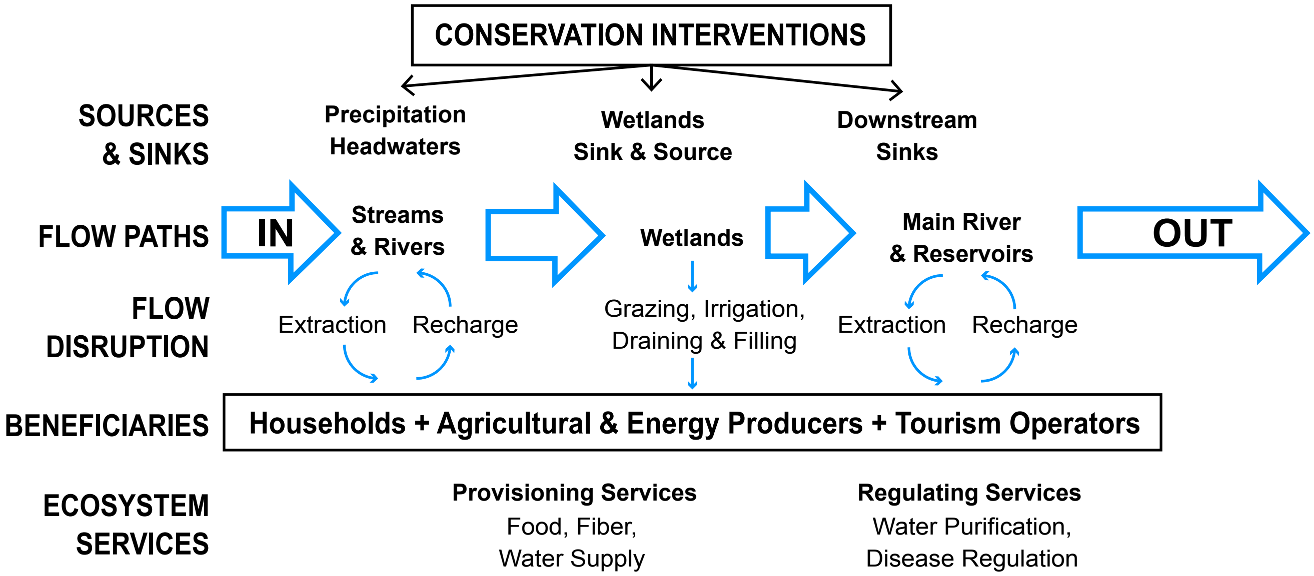

Figure 1: Conceptual diagram of the Ruaha landscape integrated modeling framework.

scarcity increases population interactions around dwindling, concentrated water resources, and thus presents an important causal and spatial link between climate change, hydrological processes, and public health. To help develop greater adaptive capacity in the region, we have established an on-going multi-disciplinary collaboration to model the effects of climate variability on livestock health and pastoralist livelihoods, with the long-term goal of collaboratively identifying sustainable interventions to mitigate the adverse human and animal health effects of climate change.

This research brief documents the initial efforts to develop an integrated model of climate change, the fresh water provided by nature (i.e. the "provision" of freshwater ecosystem services), household livelihoods and infectious disease dynamics. Figure 1 presents a conceptual diagram of the relationship between natural and human systems via the flow of freshwater in general, and the ecosystem services derived from fresh water in particular, including: irrigation for crops and water for livestock and domestic animals; access to surface water for household consumption, cooking, and sanitation; in-stream flows to support wildlife; and the production of hydroelectric power. The challenge is to link landscape level water management to conservation interventions centered on the long-term provision of ecosystem services to local, regional, and national beneficiaries. The following research brief reports on preliminary model development supported by a CRSP seed grant in collaboration with the Sokoine University of Agriculture (Tanzania), Gund Institute for Ecological Economics (University of Vermont, USA), Wildlife Health Center (University of California at Davis, USA), and a network of Tanzanian government and NGO participants.

Integrated Model Development

Interdisciplinary Workshop

We held a modeling workshop in May 2011 at Sokoine University of Agriculture (SUA) in Morogoro, Tanzania, that was attended by 25 participants representing a broad range of scientific and policy perspectives. University participants from SUA and the University of Dar es Salaam represented a cross-section of academic programs, including Departments of Agricultural Engineering and Land Planning, Forest Mensuration and Management, Agricultural Economics, Veterinary Medicine and Public Health, and Institute of Resource Assessment. Key participants from government included the Rufiji Water Basin Office and the Iringa District Veterinary Office. A preliminary modeling framework (see Figure 1) was presented to focus the group discussion. The workshop helped seed interest in developing a multidisciplinary modeling effort, identified additional collaborators, initiated the consolidation of existing spatial data, and identified gaps in available data.

Modeling Ecosystem Services with ARIES

Ecosystem services (ES), the economic benefits provided by nature to humans, are increasingly used to frame tradeoffs in conservation and economic development. With growing interest in using ES for decision-making, demand has grown for methods and tools to quantify ES values. To model the production, flow, and demand for ES related to changing climate, social, and economic development scenarios for the Ruaha landscape, we applied the ARtificial Intelligence for Ecosystem Services (ARIES) modeling platform. ARIES was developed at the University of Vermont's Gund Institute for Ecological Economics (Villa et al. 2009). The ARIES framework differs from other ES tools and methods in four key ways: it can incorporate different types of modeling approaches; it's accessible by internet, so specialized software is not required; it incorporates probabilistic data; and fully accounts for the spatial dynamics of ES flows. ARIES is a modeling platform, rather than a single model, and can be extensively customized to more fully describe the context in which it is being applied.

ARIES Modeling Process

To address the spatial mismatch between the provision and use of ecosystem services, we developed a set of generalized, spatially explicit models to represent the deposition, movement and use of water in the Ruaha landscape. The surface water source model estimates the potential water supply on the landscape from rainfall, springs and ground water flow. Surface water sinks deplete the amount of water available to downstream uses and are modeled as a factor of evapotranspiration, ground water infiltration, and competing water users. Water use by human beneficiaries is modeled for households and agricultural production, including irrigated cropland and livestock. A hydrologic flow algorithm (Johnson et al. 2010) is then applied to move water across the landscape, connecting the source, sink and use locations. The flow model moves water through the hydrologic network and accounts for a decrease in water availability as the flows move away from their source locations.

Freshwater supply is a "provisioning service" with a benefit that provides something useful, such as drinking water. Noting whether the benefit is rival or non-rival determines whether service depletion by upstream beneficiaries limits the quantity available to other potential beneficiaries. This service is considered a rival use, which means that beneficiaries compete with one another for access to this limited resource (e.g. water that irrigates cropland is not available as household drinking water in downstream locations).

Model outputs include maps that define ES source, sink, use and flow locations, and identify critical pathways where one or more ES flows traverse the landscape. These metrics are particularly useful for planning, managing, and restoring ecosystem functions. Model results help measure the efficiency of service delivery by identifying locations where the demand for water resources is not being met as well as areas with an ample supply of water that is not being sought. We can map locations on the landscape that deplete the transmission of water, and create alternative management scenarios to explore the range of possibilities for restoring flows to downstream beneficiaries. Finally, we can map locations where the interaction of livestock, humans and wildlife may change the distribution of zoonotic diseases in the region.

Preliminary Ruaha Landscape Application

To build the preliminary model application, spatial data representing individual model components were collected from both local and global data sources to map sources, sinks, and uses of freshwater ecosystem services. Building on the existing ARIES model library, source, sink and use models were customized to more accurately reflect the Ruaha landscape. A preliminary scoping model was developed and input was sought from local experts at our integrated modeling workshop. There are at least three potential sources of surface water: precipitation, springs, and ground water discharge to rivers. For the scoping model, we used annual precipitation data as the source value of freshwater flows. Surface water sinks include potential evapotranspiration based on land cover characteristics and ground water infiltration based on soil characteristics. Water users were classified into residential or agricultural users. Agricultural uses were further classified by livestock (cattle, sheep, pigs and goats) and irrigated water uses. Residential water use was estimated based on population density from the most recent census of the population, while agricultural water use was defined by global livestock density maps and locations identified as irrigated agriculture in the land cover data.

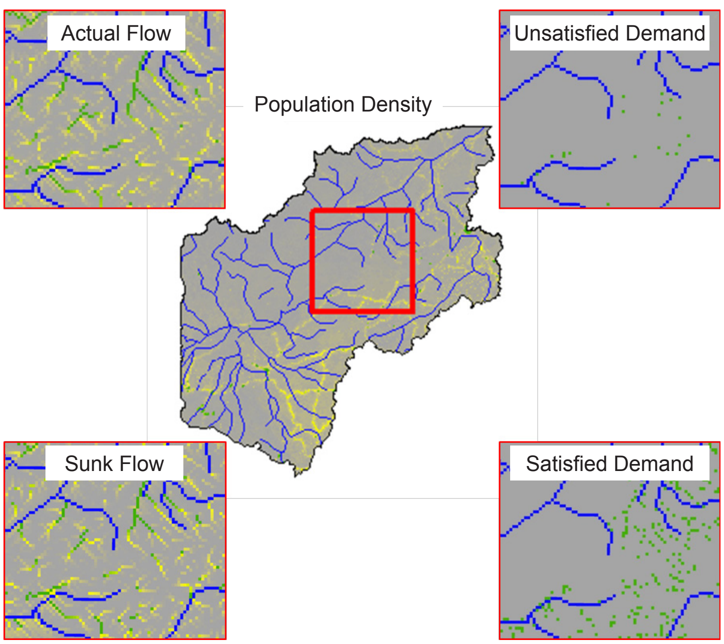

Figure 2: The map of the Little Ruaha watershed with the regional population density is depicted in the center of the figure. The Actual Flow map (top left) depicts the paths of water flow between source and use locations. The Sunk Flow map (bottom left) depicts water lost to evapotranspiration and ground water infiltration. The Satisfied Demand map (bottom right) reveals locations where beneficiaries were able to access surface water supplies. The Unsatisfied Demand map (top right) identifies locations where water flow is inhibited such that it is not able to reach human beneficiaries. Enabling or restoring blocked flows may limit water shortages for these downstream beneficiaries. For each of the maps, the greener the pixel, the greater the quantity of actual surface water flow, sunk surface water flow, unsatisfied demand, or satisfied demand in that location.

The water supply source model determines the maximum quantity of surface water that can be delivered to beneficiaries. The sink model estimates the annual volume of freshwater that is removed from the system due to natural forces and anthropogenic influences. An estimate of the quantity and location of water use by beneficiaries is then calculated by the water supply use model. These three model components (water supply sources, sinks, and uses) are spatially and quantitatively linked by the surface water flow model, which relies on elevation data to determine which way water moves. In the surface water flow model, water moves across the landscape until it enters a stream where it continues to flow downstream until it is used by beneficiaries or reaches the end of the watershed.

The images included in Figure 2 represent a sample of the types of mapped outputs that are generated by a model run. The values in each map use a grey to green color ramp, where grey represents low-end values and green represents the high-end values. In the center of Figure 2 is a map of regional population density. The red box at the center of the region indicates the spatial extent of the remaining maps in the figure, including actual flow, soil infiltration uncertainty, and blocked, satisfied and inaccessible demand for surface water.

Quantifying and mapping the flow of freshwater allows for the identification of landscape locations that provide critical links between source and use locations. These maps also highlight potential conflict areas where the supply of freshwater is insufficient to meet demand, as well as locations that may benefit from landscape interventions to increase freshwater flows. The eventual goal is to combine analysis of actual source locations with probability estimates of zoonotic disease incidence to better understand the potential for the spread of disease.

An irrigation canal in the Ruaha River watershed.
(Photo by Brian Voigt)

Future Work

With the model infrastructure and spatial database in place for the Ruaha landscape, our focus is now turning to developing alternative policy, management, and climate change scenarios. We plan to introduce epidemiology data and pastoral livelihood models at the household and herd level into the ecosystem service modeling framework. Modeling household level decisions will be critical to understanding zoonotic disease transmission between people, livestock, and wildlife. Scenarios involving decisions over water resources, animal husbandry, and wildlife interactions can be incorporated through agent-based models such as DECUMA (DEcisions under Conditions of Uncertainty by Modeled Agents), developed by Boone et al. (2011) in similarly situated semi-arid grassland systems. Ultimately, a fully integrated model could help bridge the gap between water management and policy and human and animal health outcomes.

Further Reading

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Strengthening Tanzanian Livestock Health and Pastoral Livelihoods in a Changing Climate (HALI2)

The HALI2 project was developed to (1) Assess livestock health services and pathogen diagnosis and response capacity and; (2) Create a framework to model adaptation of pastoralist communities to climate change.

Livestock production is extremely vulnerable to climate change in semi-arid grasslands, due to changing water and pasture resources and altered disease dynamics. Disease can have devastating effects on livestock survival and marketability, threatening animal health and livelihoods. In the biologically diverse and economically important Ruaha region of Tanzania, livestock production is an important, yet threatened, source of income, as communities are dependent on the natural resource base and livestock producers already face water scarcity and disease losses. To address the adaptability of livestock systems to climate change, we are performing a capacity assessment of livestock health services; gathering and spatially annotating epidemiologic, economic, geographic, hydrologic, and meteorologic data; and establishing an on-going multidisciplinary team to model the effects of climate change on livestock health and human livelihoods in the Ruaha ecosystem with the long-term goal of collaboratively developing culturally appropriate and agriculturally sustainable interventions in response to climate variability. Integrated models of economic, epidemiologic, and environmental parameters will also help regional planning and decision-makers distribute scarce resources to address the most mitigable effects of climate change. This research leverages infrastructure and collaborations with local scientists and stakeholders established through previous phases of the Health for Animals and Livelihood Improvement (HALI) project, as well as agriculture and modeling resources from the University of Vermont, Colorado State University, Sokoine University of Agriculture (Tanzania), and the University of California at Davis. The proposed work will build collaborations among African and U.S. researchers, develop institutional and local capacity for health services and inter-disciplinary modeling, and engage the pastoralist communities that will be most affected by climate change.

The Adapting Livestock Systems to Climate Change Collaborative Research Support Program is dedicated to catalyzing and coordinating research that improves the livelihoods of livestock producers affected by climate change by reducing vulnerability and increasing adaptive capacity.

This publication was made possible through support provided to the ALS-CC CRSP by the Bureau for Economic Growth, Agriculture, and Trade, U.S. Agency for International Development, under the terms of Grant No. EEM-A-00-10-00001. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development or the U.S. government.

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