Modelling the effects of grazing management on ecosystem services in pastoral systems

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Modelling the effects of grazing management on ecosystem services in pastoral systems

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Executive summary

The goal of the project 'Enhancing the value of ecosystem services in pastoral systems' (EVESPS) is for policymakers, planners, farmers and pastoralists to use insights into the roles of ecosystem services in supporting pastoral livelihoods to identify grazing and rangeland management options that will strengthen livelihoods over the long term. EVESPS is a component of a larger project, 'Water, Land and Ecosystems in Africa', led by the International Water Management Institute. EVESPS was designed to contribute to the larger project by identifying the impact of grazing and rangeland management on selected ecosystem services and management approaches likely to feasibly enhance ecosystem service delivery in rangelands.

Rooted in the wider, socio-ecological perspective of the EVESPS project, baseline applications of simulation models were constructed to estimate effects of improved grazing management on forage and water-related ecosystem services. Models were constructed for two sites: Yatenga province in the White and Black Volta river basins in northern Burkina Faso and the Lower Tana river basin in Tana river and Kitui counties in eastern Kenya. The selected simulation platform was the Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998; Neitsch et al. 2011).

Models were developed with stakeholder inputs derived from two two-day workshops, starting with the goals of improved management and envisioning future land use and management of forage and water-related ecosystem services (IUCN 2015; IUCN 2016). Model performance and model assumptions implicit in grazing management scenarios were thoroughly vetted in a second round of two two-day workshops (IUCN 2017a, 2017b). Most stakeholders were present at both workshops, providing useful continuity in the research process.

The first workshop enabled the creation of landscape-scale ecosystem models fitted to the strikingly different livestock management systems in the two sites. Most particularly, Tana river remains a large and intact area dominated by mobile pastoral grazing use. In contrast, Yatenga province is a pastoral area transitioning towards agro-pastoralism, with most land cover in or nearby rainfed croplands. The approach to model development first prioritized ecosystem services and created and then grouped hydrological response units (HRUs) into grazing management units at scales where changes to grazing management are most feasible and effective in each system.

Model outputs examined by stakeholders present at the second workshop indicated a substantive and promising overlap between scenarios ranked highly by the model and scenarios ranked highly by stakeholders. Grazing management in both Yatenga and Tana rivers would likely benefit most significantly from resting of specific, important grazing areas, albeit at vastly different scales. An economic valuation conducted under the EVESPS project (Lutta 2017) suggested significant economic benefits from increased forage production in Tana river, although the value of simulated management effects on water-related ecosystem services requires further resolution. Model debugging, uncertainty analyses and economic valuation are not fully complete and, therefore, the results presented here should be treated as indicative yet draft results. Perhaps most encouragingly, policy avenues to implement improved grazing management are readily available in both Yatenga and Tana river. These ongoing planning and policy processes provide excellent opportunities to which the models presented here are well-placed to contribute.

Model construction and application

Yatenga province, Burkina Faso

Methodology

Yatenga province spans the Black and White Volta river basins (Figure 1), with the basin division passing near Ouahigouya in the centre of the province, in northern Burkina Faso on the border with Mali. Two separate SWAT models were constructed for these portions of the White and Black Volta river basins and were parameterized using a single approach.

These models were calibrated for river flow twice: once based on land use as per usual and a second time after grazing animals were added, both using the Sufi2 algorithm in the program SWAT-CUP (Abbaspour et al. 2007; Abbaspour 2015). Flow calibration used river flow data for all available years from several downstream flow stations on the Black and White Volta rivers. Calibration of forage biomass production was conducted by checking forage production against estimates from global models (G-Range, MODIS) and a synthesis of field data (Prince et al. 1998) along the climatic gradient in the site (precipitation ~550–700 mm/year).

Modelling efforts focused on changes to grazing management in *zones pastorales* (ZPs), a legal mechanism for demarcating dedicated grazing lands in Burkina Faso. Our partner l'Association pour la Promotion de l'Élevage au Sahel et en Savane (APESS) has piloted one ZP (area 53.3 km^2) and planned three more ZPs (with a mean area 33.8 km^2 among the four ZPs). The characteristics of these ZPs were used as a rough template to create new ZPs of similar size (30.3 km^2, 5 × 5 km), distribution and land cover. ZPs were created in 10 out of 13 communes in Yatenga province (Figure 1), exhausting all possible areas of similar size and lacking any significant concentration of houses or croplands.

Since incentives and mandates for improved grazing management seem clearer under ZP than in other segments of the landscape, management change scenarios were simulated only inside the ZPs, assuming that grazing spill over effects to other areas are effectively negligible at landscape scale. The study area has undergone a fairly rapid transformation from nomadic or mobile pastoralism to primarily agro-pastoralism (or even mixed farming) in recent decades and management scenarios were selected to address the means to cost-effectively rehabilitate and improve the quality of the few large grazing lands remaining.

An equilibrium approach was adopted for running scenarios, meaning here that 25 years of weather data were used to run the model under each scenario, allowing dynamics in the management system to reach an approximate medium-term equilibrium. An equilibrium approach excludes some factors that would influence real outcomes (e.g. climate and land-use change) and is a technique most useful for gauging the long-term effectiveness of management options. Model outputs analysed include forage production, consumption and subsidiary effects on water-related ecosystem services—specifically sediment yield, stream flow and percolation to groundwater.

A battery of scenarios was created by combining several cost-effective feasible rangeland management options in ZPs:

(i) permanent grazing exclosure in 10 and 30% of the ZP;

(ii) 'short-resting' of the ZP for two weeks and one month during the wet season; and

(iii) resting from grazing at any time the standing biomass falls below 50, 100 and 200 kg/ha.

A total of 18 management scenarios, including the baseline simulation, analysed the effects of grazing management (Table 1).

Figure 1. SWAT model hydrologic response units (HRUs) for Black (northwest) and White (southeast) Volta river basins, Yatenga province, Burkina Faso.

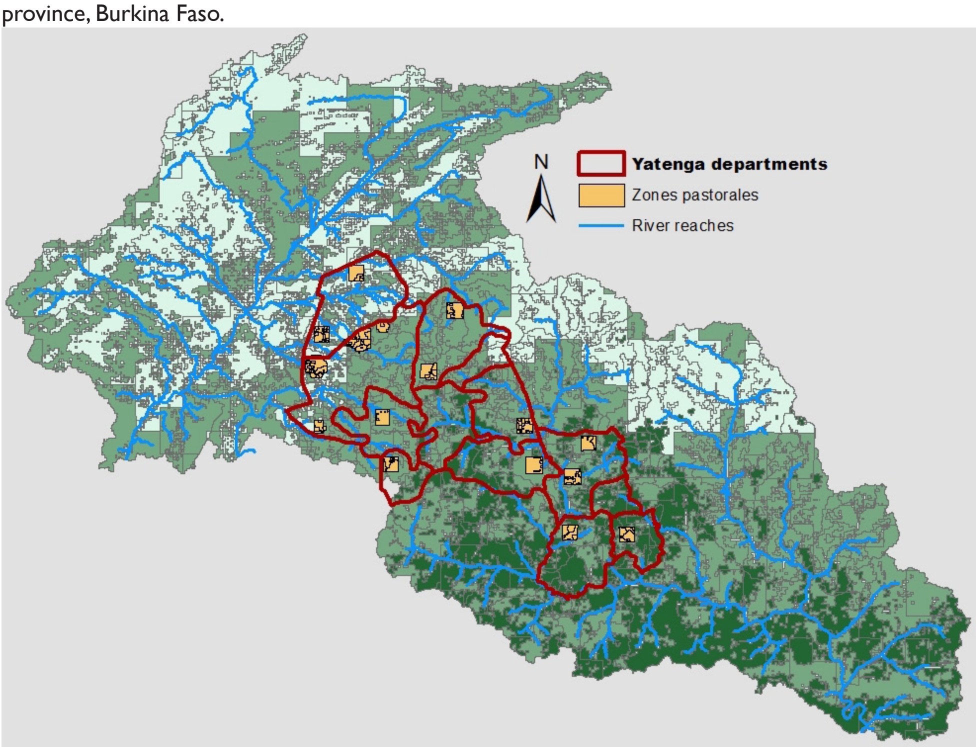


Table 1. Scenarios for Yatenga province, Burkina Faso

Scenario definition	Scenario description
Baseline	ZP management status quo—no permanent exclosure, resting or other grazing restrictions
10% exclosure	10% of ZP in permanent grazing exclosure
30% exclosure	30% of ZP in permanent grazing exclosure
Two weeks rest	Entire ZP rested for two weeks during wet season annually
One month rest	Entire ZP rested for one month during wet season annually
50 kg/ha threshold	Entire ZP rested when biomass < 50 kg/ha
100 kg/ha threshold	Entire ZP rested when biomass < 100 kg/ha
200 kg/ha threshold	Entire ZP rested when biomass < 200 kg/ha
10% exclosure and two weeks rest	10% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually
10% exclosure and one month rest	10% of ZP in permanent grazing exclosure and the remainder rested for one month during wet season annually
30% exclosure and two weeks rest	30% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually
30% exclosure and one month rest	30% of ZP in permanent grazing exclosure and the remainder rested for one month during wet season annually
10% exclosure and two weeks rest and 50 kg/ha threshold	10% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 50 kg/ha
10% exclosure and two weeks rest plus 100 kg/ha threshold	10% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 100 kg/ha
10% exclosure and two weeks rest plus 200 kg/ha threshold	10% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 200 kg/ha

Scenario definition	Scenario description
30% exclosure and two weeks rest plus 50 kg/ha threshold	30% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 50 kg/ha
30% exclosure and two weeks rest plus 100 kg/ha threshold	30% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 100 kg/ha
30% exclosure and two weeks rest plus 200 kg/ha threshold	30% of ZP in permanent grazing exclosure and the remainder rested for two weeks during wet season annually or whenever biomass < 200 kg/ha

ZP: zone pastorale

Results

The model was successful in representing reasonable and realistic patterns of forage production and grazing in the ZPs. For forage production and consumption, the proportion of animals in the ZP during the wet season was one of the most sensitive parameters and downstream effects on water-related ecosystem services co-varied with grazing-induced changes in biomass.

Recommendations for management options to increase forage production with modest reductions in grazing (Table 2) differed along the climatic gradients present in Yatenga province. For example, exclosure was more effective in the higher rainfall and slightly lower temperature areas in the southeastern portion of Yatenga province. In contrast, temporary resting from grazing (two weeks to one month) was more effective in the northwest along the border with Mali, towards the drier side of the precipitation gradient (Table 2), partly due to rapid growth under high temperatures when soil moisture is sufficient, even over short periods of time.

Table 2. Scenario ranks in terms of forage production and consumption

Rank group (1=best)	Scenario	Forage production increase (t/ha per year)	Forage consumption decrease (t/ha per year)	Scenario description
Yatenga province (province averages)				
1	Two weeks rest	0.577	-0.023	Two weeks no grazing
2	30% exclosure	0.385	-0.143	30% grazing exclosure
2	One month rest	0.892	-0.115	One month no grazing
2	10% exclosure/100 minimum/two weeks	0.296	-0.15	10% grazing exclosure; grazing when minimum biomass is > 100 kg/ha; two weeks no grazing
3	10% exclosure	0.152	0.024	10% grazing exclosure
4	100 kg/ha minimum	-0.056	-0.082	Grazing when minimum biomass is > 100 kg/ha
4	10% exclosure/100 minimum	0.069	-0.131	10% grazing exclosure; grazing when minimum biomass is > 100 kg/ha
4	100 minimum/two weeks	0.174	-0.126	Grazing when minimum biomass is > 100 kg/ha; two weeks no grazing
Thiou commune (drier and hotter than province average)				
1	Two weeks rest	0.74	-0.053	Two weeks no grazing
1	100 minimum/2 weeks	0.431	-0.026	Grazing when minimum biomass is > 100 kg/ha; 2 weeks no grazing
2	One month rest	1.04	-0.145	One month no grazing
2	10% exclosure/100 minimum/2 weeks	0.468	-0.078	10% grazing exclosure; grazing when minimum biomass is > 100 kg/ha; 2 weeks no grazing
3	10% exclosure	0.087	-0.047	10% grazing exclosure
3	100 kg/ha minimum	0.083	0.023	Grazing when minimum biomass is > 100 kg/ha
3	10% exclosure/100 minimum	0.155	-0.034	10% grazing exclosure; grazing when minimum biomass is > 100 kg/ha
4	30% exclosure	0.245	-0.157	30% grazing exclosure

Generally, the effects of improved grazing management on water-related ecosystem services were modest, and were largely attributable either to the effects of increased standing biomass on evapotranspiration or its effects on infiltration. Sediment yield reductions below ZPs were sometimes significant (Figure 2). Percolation (Figure 3) and stream flow declined, however slightly, under improved grazing management towards the drier side of the climatic gradient, but more saliently did not appear likely to increase (Table 3). Towards the wetter side of the climatic gradient, percolation and stream flow increased and sediment yield decreased, with improvement in grazing system management, indicating weak synergies of these three ecosystem services with forage production and grazing consumption.

Figure 2. Sediment yield under two weeks of annual rest in ZPs, Yatenga province, Burkina Faso.

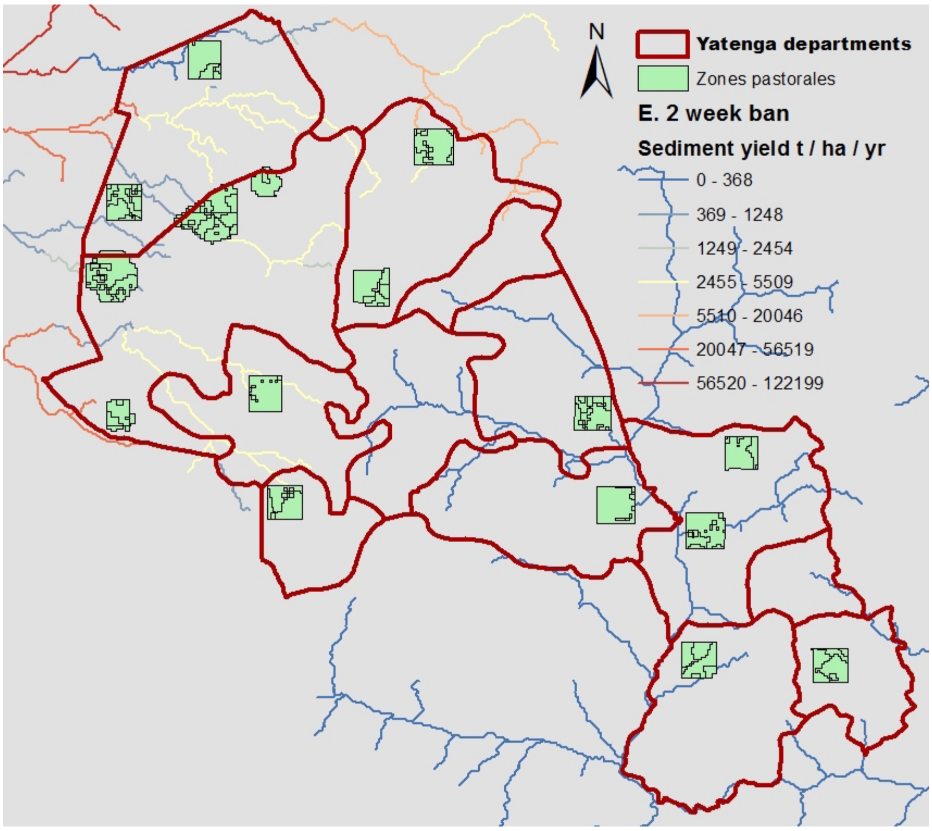


Figure 3. Change from baseline (%) in sediment yield for two weeks of annual rest in *zones pastorales,* Yatenga province, Burkina Faso.

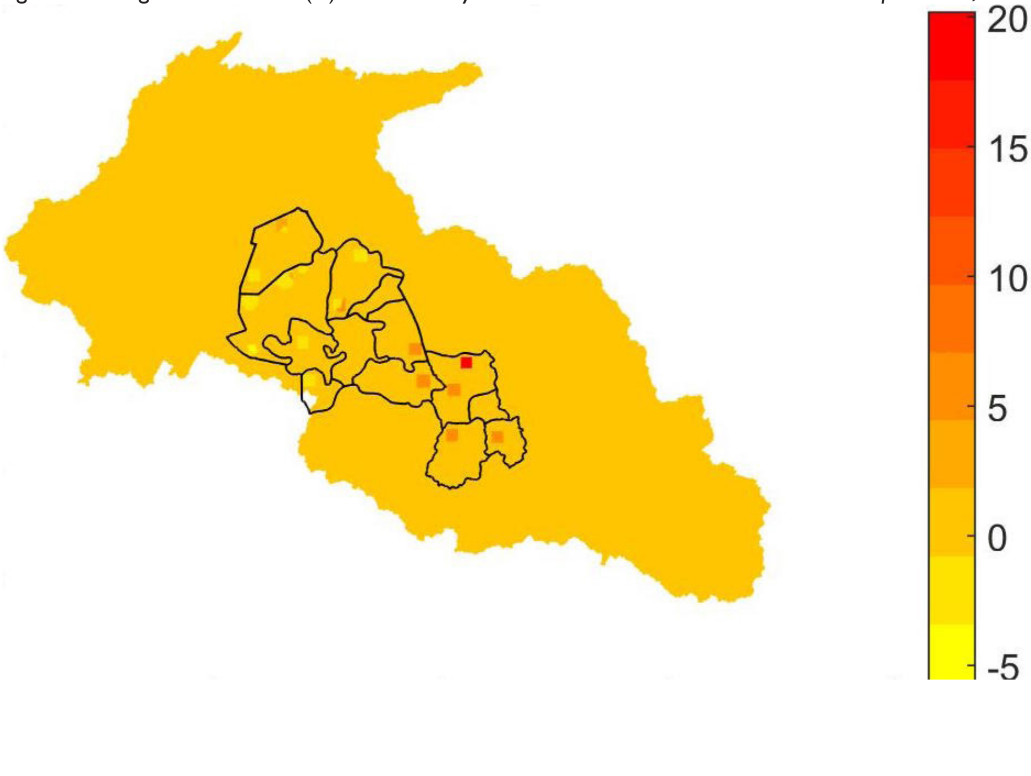
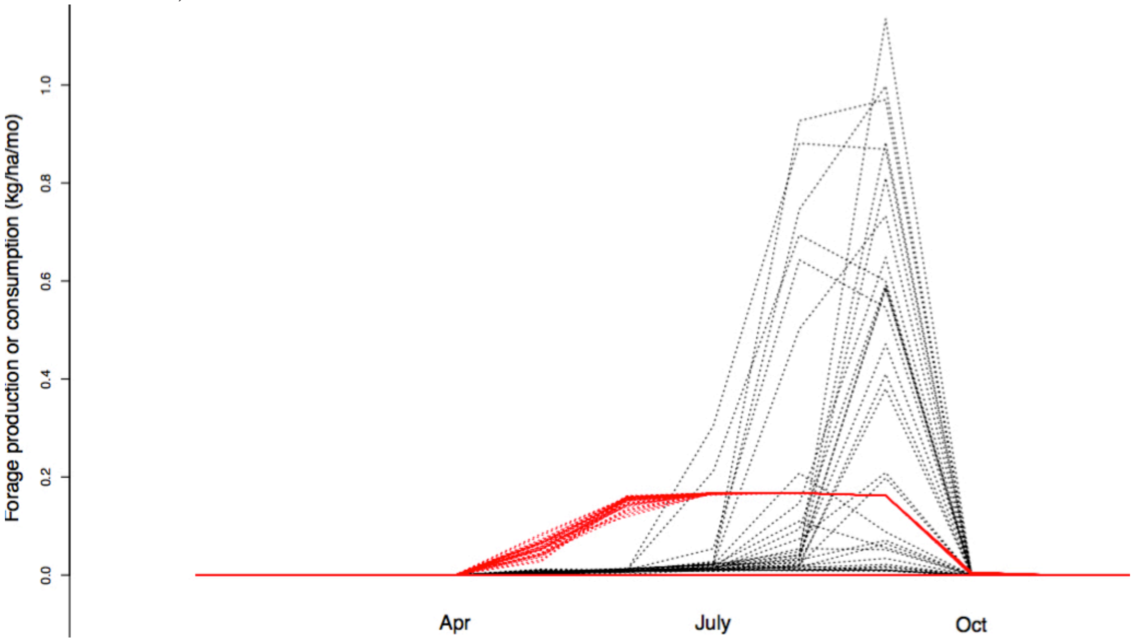


Table 3. Grand mean forage production and indicators of water-related ecosystem services, Yatenga province, Burkina Faso

Scenario	Forage production (t/ha)	Sediment yield (t/ha per year)	Percolation (mm/year)	Evapotranspiration (mm/year)	Stream flow (cm)
Baseline (more or less open/free grazing)	1.17	5,224	106.7	731.9	1.210
30% grazing exclosure	1.55	5,114	105.8	732.9	1.209
Two weeks rest	1.74	5,105	104.9	733.8	1.208
One month rest	2.06	5,100	104.6	734.2	1.207
10% grazing exclosure; grazing when minimum biomass > 100 kg/ha; two weeks rest	1.46	4,941	103.4	735.6	1.206

Figure 4. Evolution of forage biomass (black) and grazing consumption (red) in the existing ZPs in Thiou commune over the course of the wet season, under the baseline scenario.



Note: Each line represents one simulation year.

Lower Tana river basin, Kenya

Methodology

The Lower Tana river basin covers most of Tana river and Kitui counties in eastern Kenya (Figure 5). A SWAT model was constructed and parameterized for the area of the basin between Garissa and Garsen cities. The model was calibrated for river flow twice: once based on land use as per usual and once after grazing animals were added using SWAT-CUP. Flow calibration used river flow data from flow stations in Garissa and Garsen, with flow data from Garissa providing river inflow and Garsen providing outflow in the Tana river delta area near the Indian Ocean coast. The Upper Tana river basin was not simulated. Biomass production was calibrated by checking forage production against estimates from global models (G-Range, MODIS) along the climatic gradient in the site (precipitation ~550–700 mm/year).

Modelling efforts were focused on wet season grazing areas and dry season grazing areas, since Tana River county and surrounding areas are effectively open rangelands, covering thousands of square kilometres. Stakeholder consensus defined wet and dry season grazing areas.

Wet season grazing areas were defined as those areas > 7.5 km from the rivers, crops, forests and swamps in the narrow riparian corridor of Tana river (blue lines and areas in Figure 5), with dry season grazing areas < 7.5 km from the riparian corridor. Changes in grazing management were parameterized only within these wet and dry season grazing areas.

Management options were selected to address the possible effects of creating different rotational grazing and resting patterns, an approach commonly recommended by range managers and as indicated by historical pastoralist grazing movements in the study area. As for the Yatenga site in Burkina Faso, an equilibrium approach to scenario analysis was adopted. Model outputs analysed consisted of forage production, consumption and subsidiary effects on water-related ecosystem services, specifically soil moisture, sediment yield, stream flow and percolation.

Several scenarios were created by combining two essential rangeland management options:

(i) resting of dry season grazing areas for two weeks and for one month during each wet season, for four to eight weeks annually; and

(ii) rotational grazing through shifting animal proportions among the dry and wet season grazing areas during the dry and wet seasons, as specified according to three distinct grazing patterns provided by stakeholders: a baseline (status quo) and two scenarios bracketing the maximum and minimum optimal animal distributions recommended by stakeholders.

All scenarios, including the baseline, reflect a consensus achieved among the pastoralists, farmers, community committee (Kigaruni WRUA, Water Resource Users' Association), NGO and government stakeholders consulted, who were combined into groups of women (one group) and men (two groups). A total of nine management scenarios, including the baseline simulation, were run to analyse the effects of management options (Table 4).

Figure 5. River reaches and the riparian corridor areas used to define a SWAT model for the Lower Tana river basin, Tana river and Kitui counties, Kenya.

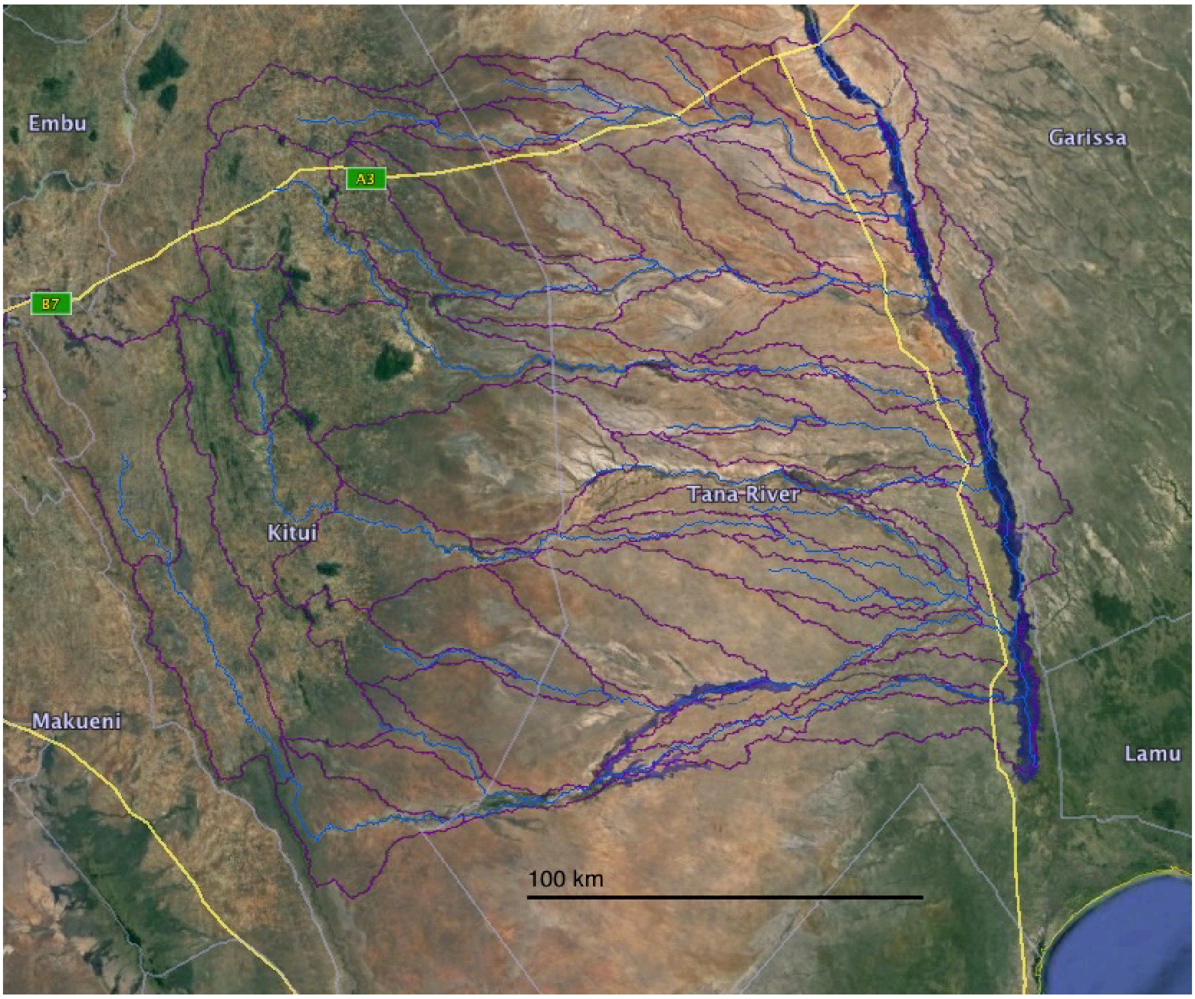


Table 4. Scenarios for Lower Tana river basin, Tana river and Kitui counties, Kenya

Scenario definition	Scenario description
Baseline	Management status quo—baseline animal proportions (50% of animals in dry season grazing areas during dry season and 10% of animals in dry season grazing areas during the wet season), no exclosure, no rest, no biomass threshold
One month rest	Baseline animal proportions (50% of animals in dry season grazing areas during the dry season and 10% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for one month annually (two weeks in each wet season), no exclosure, no rest, no biomass threshold
Two months rest	Baseline animal proportions (50% of animals in dry season grazing areas during the dry season and 10% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for two months annually (one month in each wet season), no exclosure, no rest, no biomass threshold
Improved distribution A (70/30%)	Improved distribution of animals A (70% of animals in dry season grazing areas during dry season and 30% of animals in dry season grazing areas during wet season)
Improved distribution A (70/30%) and one-month rest	Improved distribution of animals A (70% of animals in dry season grazing areas during dry season and 30% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for one month annually (two weeks in each wet season)
Improved distribution A (70/30%) and two months rest	Improved distribution of animals A (70% of animals in dry season grazing areas during dry season and 30% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for two months annually (one month in each wet season)
Improved distribution B (80/20%)	Improved distribution of animals B (80% of animals in dry season grazing areas during dry season and 20% of animals in dry season grazing areas during wet season)
Improved distribution B (80/20%) and one month rest	Improved distribution of animals B (80% of animals in dry season grazing areas during dry season and 20% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for one month annually (two weeks in each wet season)
Improved distribution B (80/20%) and two months rest	Improved distribution of animals B (80% of animals in dry season grazing areas during dry season and 20% of animals in dry season grazing areas during wet season), and dry season grazing areas rested for two months annually (one month in each wet season)

Results

The model successfully generated realistic patterns of large-scale forage production and grazing consumption throughout the landscape and among the two wet and two dry seasons annually. Model performance was only reasonable after animal distributions provided by stakeholders were incorporated, while attempts to use animal distributions well outside the range of values provided by stakeholders produced demonstrably unreasonable results. As such, animal distributions over time and space were sensitive parameters for forage production and consumption. Water-related ecosystem services co-varied with grazing patterns and their influence on standing biomass.

Compared to the baseline scenario, of effectively continuous and open grazing, all scenarios that simulated rotational grazing by means of stakeholder-optimized spatio-temporal animal distributions demonstrated substantial improvements in forage production (including that consumed) in dry season grazing areas (Figure 6).

This increase in forage production may be tentatively valued at nearly USD 1 million across Tana River county (not including Kitui) and an additional 50% increase (USD 1.4 million) with one month of complete resting of dry season grazing areas per year (Table 5). Improvements in dry season grazing areas sometimes came at the cost of increased grazing intensity in some wet season grazing areas, a loss of production in some remote 'hinterlands' that remains to be valued economically. Nonetheless, the net effects on forage production (and consumption) remained positive over the entire landscape. This indicated strong potential for synergy between livestock production and environmental benefits, including water-related ecosystem services and the significant and even critical wildlife that range into and out of the large protected areas in the vast rangelands of the study site.

Stakeholder-provided animal distribution patterns and resting dry season grazing areas for one to two months per year were always beneficial in terms of forage production and grazing consumption (Table 5). Improved distribution B (80% of animals in dry season grazing areas during the dry season and 20% during the wet season) was always superior to improved distribution A (70% of animals in dry season grazing areas during the dry season and 30% during the wet season). Two months' rest was superior to one month, as was one month to no resting. The strongest gains were made under improved distribution B with two months annual rest of dry season grazing areas, one month in each of the two annual wet seasons. Animal distributions and rules to regulate their movement and access, and short-duration resting of dry season grazing areas, should be considered key management options for improving forage and livestock production in Tana river rangelands.

As in the Yatenga site, effects of improved grazing management on water-related ecosystem services were generally modest. Minor reductions in percolation (Figure 7) and modest reductions in soil water content (Figure 8) were largely attributable to the effects of increased standing biomass on evapotranspiration (Table 6), although the actual contributions to groundwater recharge and base flow cannot be determined precisely from these analyses.

Figure 6. Change from baseline in rangeland forage consumption (kg/ha per year) under stakeholder-created scenario 'improved distribution B' (80/20%; no resting), Tana river and Kitui counties, Kenya.

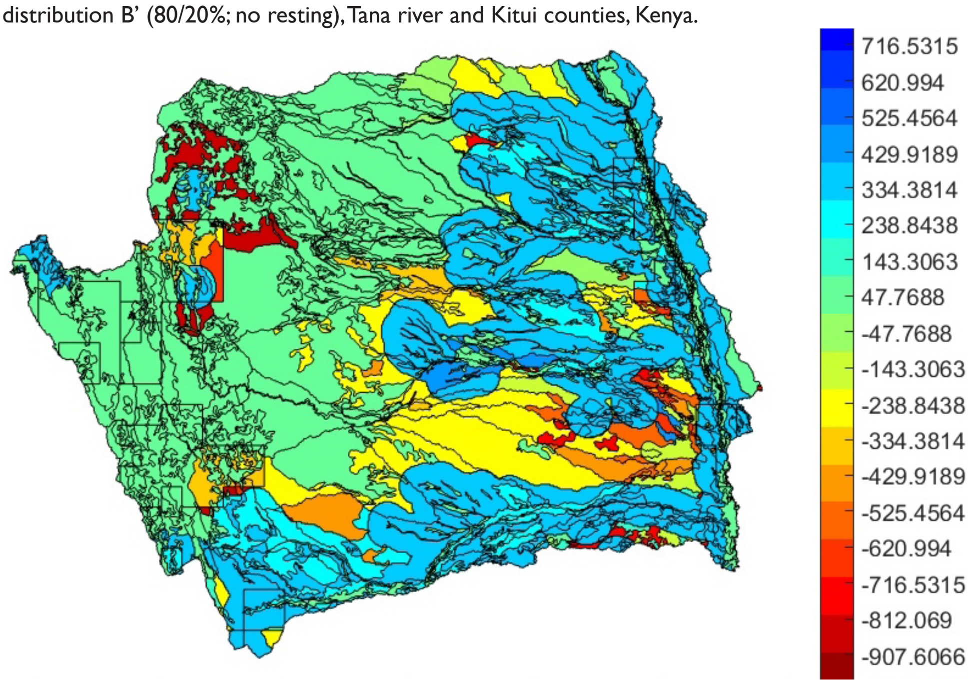


Table 5. Change from baseline in rangeland forage production under stakeholder-created scenarios (with and without one month rest in dry season pastures) and a draft valuation of the change in forage production, Tana River county, Kenya

	Change in forage production from baseline		Economic value (USD)	
Scenario	Change (kg/ha per year)	Change (%)	Per person	Total
Distribution B, one month rest	507	19.7	9.56	1,371,615.58
Distribution A, one month rest	306	11.9	7.69	1,102,596.52
Distribution B (80/20%)	239	9.3	6.77	971,198.73
Distribution A (70/30%)	110	4.3	4.13	591,913.17

Figure 7. Change from baseline in infiltration (mm/year) under stakeholder-created scenario 'improved distribution B' (no resting), Tana river and Kitui counties, Kenya.

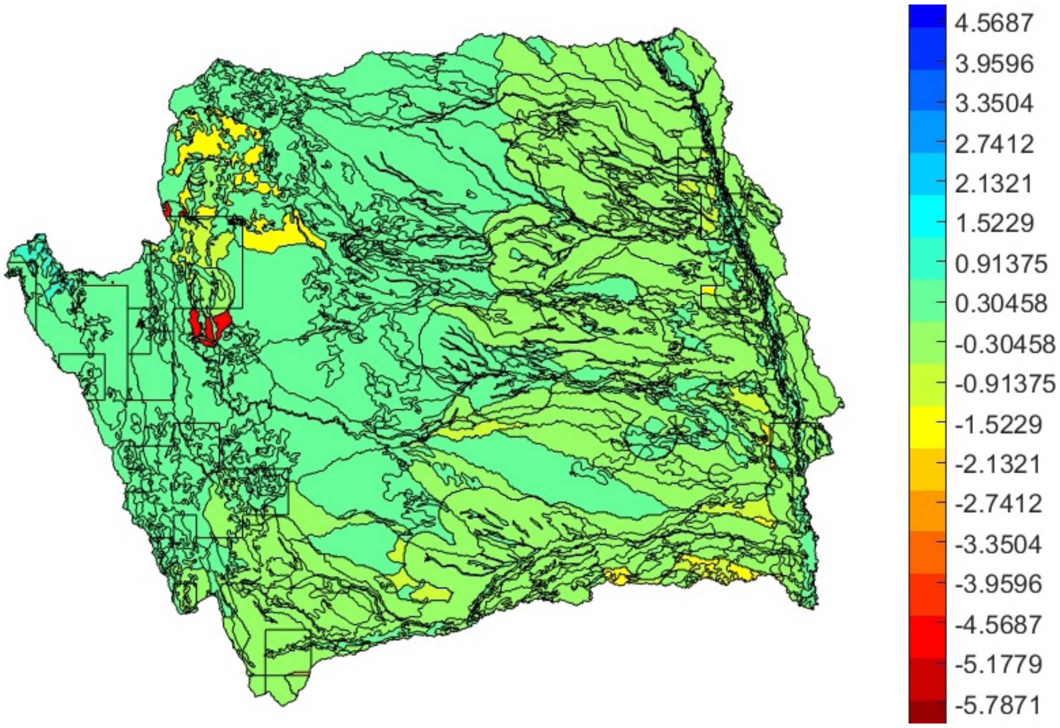


Figure 8. Change from baseline in soil water content (mm) under stakeholder-created scenario 'improved distribution B' (80/20%; no resting), Tana river and Kitui counties, Kenya.

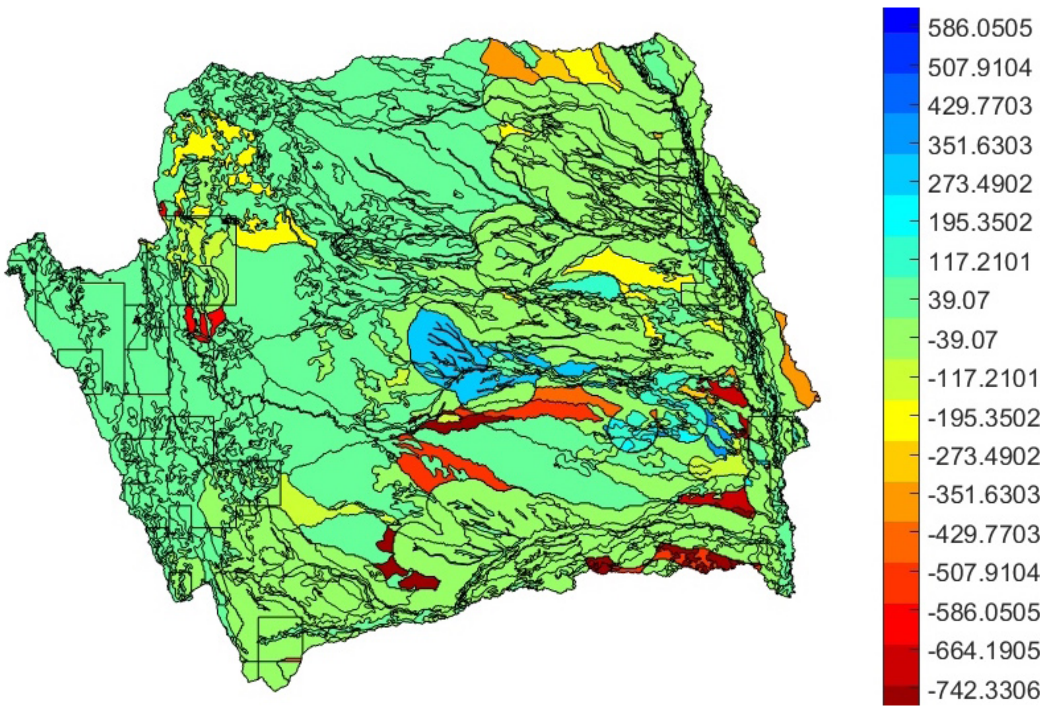
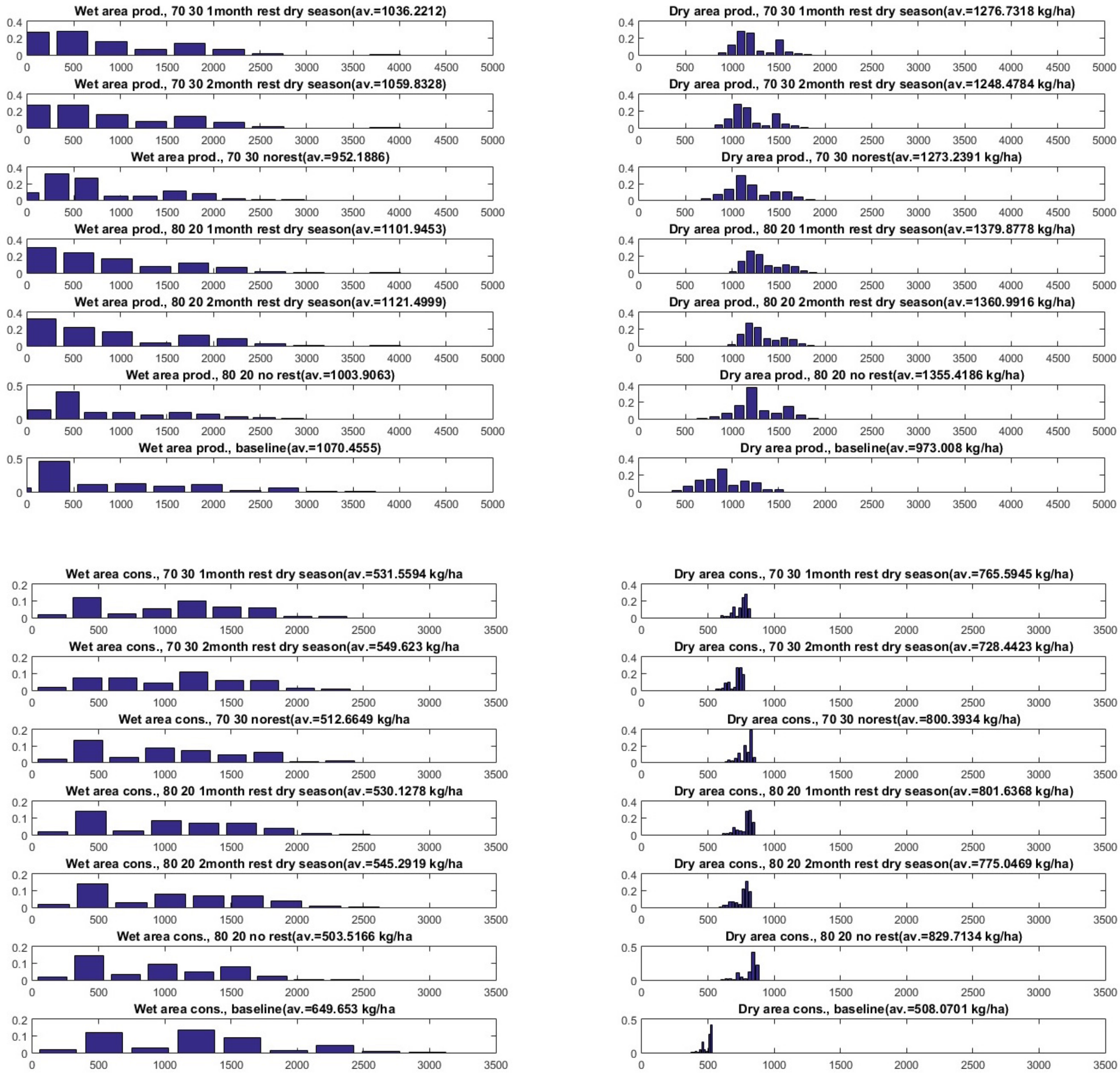


Table 6. Grand mean percolation, soil water content and forage production under stakeholder-created scenario 'improved distribution B', with and without one to two months resting, Tana river and Kitui counties, Kenya

Scenario	Percolation (mm/year)	Soil water content (mm)	Forage production (kg/ha per year)
Baseline	3.59	414.6	976.0
Distribution B (80/20%; no rest)	3.48	376.1	1,076.3
Distribution B (80/20%), one month rest	3.40	353.8	1,212.9
Distribution B (80/20%), two months rest	3.39	353.6	1,218.3

Figure 9. Distributions (for individual HRUs) of forage production and grazing consumption in wet and dry season grazing areas for all scenarios, Tana river and Kitui counties, Kenya.



Stakeholder assessment of models

Yatenga province, Burkina Faso

Stakeholders from Thiou commune and the provincial government ranked model scenarios similarly to the model results in terms of forage production and consumption (Table 2). The stakeholder groups consulted during two consecutive annual workshops included pastoralists, farmers, members and officers of the pastoralist NGO APESS, and provincial government experts. It was generally agreed that most scenarios would be difficult to implement, despite their seeming simplicity. Most scenarios had costs or problems significant enough to render implementation unfeasible, at least short of major alterations to both farming and grazing management in the area.

In Thiou commune, APESS is experimenting with limited exclosure for restoration of degraded land within the existing pilot ZP. In their experience, placing even 10% of the existing ZP into permanent exclosure would be entirely unworkable. The exclosures they currently have are intended to restore the most degraded areas of the ZP, for example, where artisanal gold mining has been conducted. In contrast, the permanent exclosures simulated in the model scenarios are rather geared to increase livestock production by improving dry season forage availability, while also producing environmental co-benefits such as reduced sediment yield and increased percolation.

Thiou is towards the drier side of Yatenga province, where exclosure did not rank highly among model scenarios, corroborating the assessment of the stakeholders. Depending on the composition of grass species, cut-and-carry exclosure production of forage in such dry areas involves significant labour. In Thiou and the other drier communes of the province, the only scenario ranked as feasible was resting the entire ZP for two weeks on an annual basis (Table 2).

The two weeks resting scenario also ranked highest, on average, throughout the province due to the benefits it created in terms of increasing forage production without sacrificing grazing consumption. However, even resting the ZP for two weeks each year would face significant challenges to its implementation. Moving animals outside the ZP to be tethered amid the matrix of crop fields, houses, and woodlands could exacerbate conflict between farmers and herders. Another significant concern of stakeholders was the increased labour required to control animals when outside the ZP and closer to crops or alternatively the increased cost of stall-feeding animals.

Lower Tana river basin, Kenya

Stakeholder-recommended model scenarios gave positive results in terms of forage production and consumption (Figure 6), both of which increased compared to the baseline distribution of animal densities. The stakeholder groups consulted included pastoralists, farmers, members of a community committee (Kigaruni WRUA committee) and experts from NGOs and government (primarily Tana River county livestock production office). Improved distribution B (80% of animals in dry season grazing areas during the dry season and 20% during the wet season) produced greater modelled forage benefits than improved distribution A (70% of animals in dry season grazing areas during the dry season and 30% during the wet season). This confirms both consensus distributions, particularly the final consensus of the second workshop on improved distribution B being the most likely to succeed.

Certainly, two months rest in dry season grazing areas will produce greater benefits than a single month per year. As confirmed by stakeholders as well as basic grazing management knowledge, one to two months rest of dry season grazing areas would produce additional forage benefits, although even one month of rest was viewed as highly challenging to implement. Most stakeholders viewed a one month rest annually as potentially feasible, but voiced significant uncertainty on the likelihood of successful implementation. Most importantly, if owners of large herds were to follow new grazing rules (which they viewed as unlikely), then owners of smaller herds would be more willing to follow and support the new rules; otherwise, the system would likely collapse.

Implications

Yatenga province, Burkina Faso

Field-tested recommendations for ZP management in different ecological and social contexts could form the basis for promotion of improved management in ZPs throughout Burkina Faso. To this effect, discussions with APESS, two other pastoralist-focused NGOs and the Ministry of Animal Resources and Fisheries are ongoing. Improved management would not only deliver potentially significant gains in ecosystem services and their net economic value, but also support the policy initiative of ZP and the role of livestock in livelihoods more generally.

Resolving the economic value of these ecosystem services, forecasting the impacts of their apparent trade-offs and synergies, evaluating model performance and incorporating climate change scenarios from available regional climate models would require further valuation work. Model debugging, uncertainty analyses and economic valuation are not fully complete. Therefore, the results presented here should be treated as indicative yet draft results. Nonetheless, if the model results are qualitatively accurate, the synergies observed in some areas could be large enough to justify investment in rangeland management where significant improvement in ecosystem service delivery can be feasibly achieved.

A key next step is to confirm the duration of resting time required, and the timing of resting during the season, to significantly improve rangeland quality. Plans are in motion to evaluate modelled resting effects against resting effects observed in Yatenga ZPs through rangeland monitoring and experimentation. It is not clear whether a resting time as short as two weeks (or even one month) annually would truly produce a meaningful increase in forage production over the long term. As noted by some stakeholders, re-seeding before the resting period may be required to realize tangible benefits from a short rest, largely through enhanced survival and establishment of grass seedlings of high-quality species (effects difficult to represent with SWAT parameters and inputs).

However, if the re-seeding is not placed under a clear plan of resting, such as the two weeks rest scenario, there may be little point to oversowing in the long term, as frequently observed. To determine spatial patterns in the feasibility and effectiveness of exclosure, it would be worthwhile to test for and document net benefits from exclosure along climatic gradients significant in the savannah ecosystems such as in Yatenga province. Both rangeland science and pastoralist local knowledge point to lower net benefits from exclosure in drier areas (~550 mm/year) than in wetter areas (~700 mm/year). It would be useful, nonetheless, to empirically confirm whether benefit: cost, i.e. net benefits, of exclosure differ along this climatic gradient as dramatically as expected from the model outputs alone.

Lower Tana river basin, Kenya

Field-tested recommendations for the resting of dry season grazing areas and animal distributions determined by consensus among pastoralists along different segments of the river basin could form the basis for improved management of grazing lands to improve both livestock and water productivity. Discussions with Kigaruni WRUA and Tana River county are ongoing and creation of grazing area regulations may occur either as a means to improve water management through government implementation of WRUA plans, to improve livestock production through the upcoming Tana River county animal control bill and/or to secure communal land tenure under the fairly recent national Community Land Act.

Regardless of the legal or policy mechanism, large-scale grazing regulations appear likely to arise in some form in Tana River county in the very near future. Model debugging, uncertainty analyses and economic valuation are not fully complete, and therefore the results presented here should be treated as indicative yet draft results. Still, improvements in grazing management systems appear, from the results presented here, technically quite able to produce significant gains in ecosystem services and their net economic value.

Further analyses would be required to consider the benefits of improved grazing management to wildlife habitat quality, wildlife populations and eco-tourism revenues. Eco-tourism has the potential to become much more developed over coming decades in Tana river and would likely further incentivize and bolster improved grazing management systems.

As in Yatenga, the next step is to confirm the duration of resting required and the timing of resting during the season, to significantly improve rangeland quality. An annual one month rest (two weeks in each wet season) may be insufficient to tangibly improve rangeland quality without re-seeding or other combined investments in rangeland management.

For Tana river, plans are in place to assess resting duration and timing during portions of dry season grazing areas. On the other hand, confirmation of recommended animal distributions for rotational grazing patterns would require large-scale and probably long-term monitoring of stocking rates and rangeland condition.

Over the long term, creating linked rangeland–livestock community-based monitoring systems for Tana River county would be one of the best ways to document how grazing systems influence: rangeland quality; and whether policies not only successfully enhance rangeland conditions, but also successfully increase livestock production and improve environmental quality.

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