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Research

Deriving scalable measures for restoration of communal grazing lands

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ABSTRACT. Participatory action research in communal grazing lands can inform end users on cost-effective methods for restoring land to improve local livelihoods and environmental quality in terms of reduced degradation and enhanced ecosystem services. A multi-stakeholder process involving producers, development practitioners, and researchers is demonstrated for conducting action research to restore degraded communal grazing lands in East Africa. Producer-managed trials provided actionable evidence on brief resting durations and reseeding in pastoral rangelands in Kenya, and on improved forages and weeding in grazing exclosures in the Ethiopian highlands. The usefulness of this evidence is demonstrated through quantitative data and stated or revealed preferences of livestock producers. Local land management institutions and government and civil society practitioners confirmed the utility of the results to land management practice and policy, while spontaneous local up-scaling of improved forages in exclosures affirmed their scalability. These results are attributable to elements of the action research process, including prioritization of practical producer needs, close involvement of local institutions able to take action, collaborative design of producer-managed trials, and generation of evidence applicable in scaling. Among the restoration options tested, those more successful in trials and preferred by producers tended to have moderate (or low) costs, complexity, time to returns, and risk, suggesting possible optimization of trade-offs among options, such as between the potential performance of an option and its risk. Robust options that balance consistency with effectiveness may be good candidates for scaling. In communal grazing lands facing varied constraints to restoration, using research methodology responsive to institutional stakeholders at and above local level is an effective strategy for deriving scalable restoration approaches for win-win gains in livelihoods and the environment.

Key Words: *action research; communal land; exclosure; grazing; local institutions; rangeland; research-in-development; resting; scaling*

INTRODUCTION

Degradation affects many communal grazing lands, and is most feasibly reversed through collective restoration by resource users seeking an ample and consistent livestock feed supply. Yet even in their frequently debilitated state with weak market integration, these lands significantly support the livestock sectors that contribute approximately 37% of agricultural gross domestic product (GDP) in Kenya (Behnke and Muthami 2011) and 45% in Ethiopia (Behnke and Metaferia 2011). As degradation, climate change, land fragmentation, and other factors exacerbate forage scarcity, some local institutions are ready to invest in management of communal grazing lands (Tyrrell et al. 2017, Flintan et al. 2019, Nganga et al. 2019) and may inspire efforts elsewhere.

Management of communal grazing lands has long been viewed as challenging, where the "tragedy of the commons" is often presumed to reign, and little economic production generally assumed, although these assumptions are rarely substantiated. Management approaches and policies to address degradation in communal grazing lands include eliminating grazing through exclosure for cut-and-carry fodder production (zero-grazing) and prescribing of stocking rates. More recently, facilitative approaches for improving grazing management such as community-based rangeland management (Reid et al. 2014) and participatory rangeland management (Flintan and Cullis 2010) focus on facilitating local institutions to lead collective action to restore communal grazing lands. All of these strategies—exclosure, stocking at carrying capacity, and facilitative approaches—are viable in a variety of agro-livestock systems. However, in dry landscapes carrying capacity is of little to no practical use (Behnke and Scoones 1992, Campbell et al. 2006) whereas cut-and-carry exclosure is only viable on smaller, more productive sites, and risks individualization and fragmentation of rangelands, which can weaken the larger management system (Nyberg et al. 2019). The relative advantages of each strategy varies with intensification and privatization, emphasis on livestock versus crops, and aridity. Each strategy has constraints in communal grazing systems, for example, exclosures displace grazing elsewhere and require labor and transport for cut-and-carry, low and high stocking rates respectively create opportunity costs and degradation risks, and coordinating large herds with many owners incurs transaction costs. These constraints may seem overwhelming in pastoral rangelands, yet local institutions can rapidly improve forage availability, through even partial or incremental measures applied to large areas (Sircely and Seidou 2018). In light of the promise these lands hold for both economy and environment, governments and civil society often struggle to identify and implement practical measures for restoring communal grazing lands.

The general goal of participatory action research and adaptive land management is to enact a process of iterative learning from empirical observations over time, with decisions made in response. In climatically variable dry savanna and desert rangelands, degradation and restoration are difficult to measure and predict, and therefore useful to baseline and monitor, to precisely measure success and adapt management (Reynolds et al. 2007, Teague et al. 2013). Action research and adaptive management are useful in rangelands and other complex adaptive systems where multi-faceted spatiotemporal dynamics produce cumulative effects and

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emergent behavior, often rendering a priori predictions poor or coarse, e.g., "take half, leave half". Because restoration is best led by local land management institutions in communal grazing lands, action research with these institutions is ideally suited to assessing feasible restoration.

Scaling of land restoration is often elusive (Svejcar et al. 2017), and capacity, finance, and investment risk significantly constrain restoration scaling (Thomas et al. 2018). Avoiding constraints is one strategy for providing scalable options that are effective, simple, inexpensive, locally available, and produce benefits quickly. Options providing rapid initial returns can accelerate community buy-in to restoration in working landscapes such as communal grazing lands (Yami et al. 2013). These and other characteristics of restoration options may influence how easily they scale (Hartmann and Linn 2008a, Hermans et al. 2021), and options with singular performance are rare yet desirable. Improving the efficiency of restoration options implemented at large scales, such as exclosure, is strategic to those programs.

Networks of institutions are important in up-scaling agricultural innovations (Hartmann and Linn 2008a, b, Reed et al. 2011, Hessel et al. 2014). Innovations that fail to scale often share a common neglect to meaningfully engage with institutions at multiple scales (Pretty 1995). However, local institutions and larger networks are not always engaged at the front end of agricultural development research, preventing their involvement in framing the agenda or methodology. Because communal grazing lands and the forage and browse they provide are common property resources, locally representative institutions are essential to their management (Ostrom 1990), and involving these institutions enables research to build upon local knowledge and approaches. Scaling restoration falls to governments and NGOs, and including their operational lens is valuable. Research with institutions at and above local level helps meet the goals and information needs of land managers (Briske et al. 2011) and decision makers to enable wide-scale application.

Here we demonstrate a "research-in-development" (Coe et al. 2014) approach to action research for scaling restoration in communal grazing lands, in which research trials are conducted in the course of ongoing government or non-governmental organization (NGO) initiatives. Producer-managed trials are conducted in a variety of local contexts, with explicit contrasts between restoration options to generate "options-by-context" evidence on which options work in which contexts—where, for whom, and when. Multi-stakeholder communities of practice (CoPs) formed to implement trials enable co-learning among complementary knowledge sets to provide evidence on land restoration useful in up-scaling.

Our goal was to generate evidence on potentially scalable approaches for restoring communal grazing lands to improve livelihoods alongside environmental condition. Multi-stakeholder action research trials on land restoration were conducted within CoPs including producers (herders and farmers), local land management institutions, regional or local government or NGOs, and researchers. The approach may be seen as simulating restoration action by local institutions under the facilitation of projects or programs seeking to make investments in land restoration with tangible returns feasible under short budget cycles of one to three years. We demonstrate how action research with local institutions yielded information practically applicable in scaling cost-effective measures for (i) rehabilitating dry pastoral rangelands, and (ii) enhancing the productivity of grazing exclosure in the Ethiopian highlands, and apply these experiences to examine how collaborative research can generate scalable restoration measures for win-win improvements in livelihoods and the environment in the demanding contexts of communal grazing lands.

METHODS

Prioritization through trial design

The action research process followed a framework with a structured set of steps, from initial assessments to attempts at scaling (Table A1.1). A literature review (Sircely 2016) and a review of government and NGO experience prioritized restoration options and gave an initial list of around 30 potential research partners in Kenya and Ethiopia. Candidate partners in different geographies were selected for research needs assessments, during which local land management institutions willing to host the research and able to act on the results were identified.

The research process and results reported here focus on three sets of sites and government or NGO research partners selected during the assessments (Table A1.2). Local institutions managed the research on the ground, specifically Shompole and Olkiramatian Group Ranches in Kajiado County, Kenya, Burder Community-Based Natural Resource Management Committee in Wajir County, Kenya, and multiple government-formed exclosure user groups in Amhara Region, Ethiopia. For these sites, the respective research partners were the South Rift Association of Land Owners (SORALO), the Livestock Production Office of the Wajir County Department of Agriculture, Livestock and Fisheries (DALF), and the Amhara National Regional State Bureau of Agriculture (Amhara BoA). Draft protocols for action research trials were developed, circulated to research partners, and partners' comments incorporated. A further step of research adaptation vetted protocols, indicators, and assumptions with producer institutions to ensure applicability in the research localities and similar areas elsewhere. Trial designs were influenced by herders, farmers, local producer institutions, and research partners (Table A1.3). For more information on the local institutions, the research partners, and their roles in the research, see Appendix 1.

Multi-stakeholder action research trials

Final trial designs (Table 1) were firmly grounded in local management systems and current science. Trials were formalized in experimental protocols for action research trials managed by producer members of local institutions (Sircely et al. 2020).

In Kajiado and Wajir in Kenya, to achieve pastoralists' long-term goal of increasing grass quantity and quality for milk production, the restoration options likely to give the greatest benefit were cost-effective measures for rehabilitation of large rangeland areas. The options selected were "short-resting" of degraded pastures for one or two months at the beginning of the long and short rainy seasons with nested reseeding plots (four restoration treatments total), which were compared to normally grazed controls (Table 1) with heavy continuous grazing given the close proximity of the research areas to permanent settlements and water access. Resting

Table 1. Summary of action research trial designs.

Site	Land use	Action research trial	Restoration options tested	Research location *n*	Research area *n*	Research area (ha)	Total research area (ha)	Treatment *n* per research area	Control *n* per research area	Total *n*
Kajiado County, Kenya	Grazing, high intensity (wet season areas)	Short-resting and reseeding	Early season resting for 1 or 2 months, reseeding of 5 range grasses	14	14	5.3	74.2	3	2	112
Wajir County, Kenya	Grazing, high intensity (dry season areas)	Short-resting and reseeding	Early season resting for 1 or 2 months, reseeding of 5 range grasses	6	17	0.25	4.25	1	1	51
Amhara Region, Ethiopia	Cut-and-carry exclosure	Exclosure productivity improvement	Plowing and planting of 2 improved forages, and weeding	23	26	0.084	2.2	1	1	104

in the early growing season or "spelling" is useful for several reasons (Ash et al. 2001, Bray et al. 2014, Hunt et al. 2014), here mostly for regeneration and reinvigoration of grasses, and to modestly increase forage availability from the end of the rainy season into the early dry season. Increasing vegetation cover provides additional ecological benefits to soil surface microclimate, infiltration, and control of runoff and erosion (Mayor et al. 2019), with long-term benefits (if repeated) to forage quality. Low-cost options like short-resting may be valuable in pastoral areas in East Africa and elsewhere.

In Amhara Region in Ethiopia, improving the productivity of existing grazing exclosures (cut-and-carry fodder production; no grazing) by planting improved forages and weeding were proposed to benefit farmers through fodder production for animal feed or sale. Exclosures in Amhara enhance ecosystem services including infiltration of rainfall (Rossiter et al. 2017) and erosion control, along with carbon storage and nutrient retention. Where feed is increasingly limited, productive exclosures are an alternative during periods of scarcity, yet in exclosures heavily degraded from past grazing and erosion, fodder production is often poor. The specific options selected were to plow and plant exclosures with two indigenous improved forages—*Pennisetum pedicellatum* (Desho or Kyasura grass) and *Chloris gayana* (Rhodes grass)—versus weeding the existing grasses to remove unpreferable or problematic species (three restoration treatments total). Productive exclosures can benefit farmers' livelihoods on top of environmental gains, and would support major government and NGO initiatives on sustainable land management.

Trial details

In the short-resting and reseeding trials in Kajiado and Wajir, baseline spatial cover was recorded using the Land Potential Knowledge System (LandPKS) "stick point" protocol (Riginos et al. 2011) in March 2018 at the end of the short dry season. As the 2018 long rains commenced, resting areas were bush-fenced (using thorny branches) and closed to grazing for one to two months. The same areas were rested again for another one to two months during the 2018–2019 short rains (Sircely et al. 2020). Cover measurements were repeated after the long rains in July 2018, and after the short rains in January–February of 2019. Outcome measures were timed to capture persistent resting effects after one to two months of grazing following resting, benefits that persist into the dry season and contribute to land restoration, as opposed to temporary vegetation effects disappearing within one to two weeks of grazing, and contributing little or not at all to restoration.

The final set of research areas (Table 1) comprised 14 research areas of 5.3 ha in Kajiado near 14 settlements using three standard LandPKS plots of 60 × 60 m (Riginos et al. 2011) per resting treatment, with two control plots outside. A comparable plot design was used in Wajir, where extensive shrub cover required smaller research areas of 0.25 ha, each with eight 25-m LandPKS transects (four per resting treatment), and two 25-m control transects outside, for a total of 20 research areas near 7 settlements. All one month and two month resting replicates received nested reseeding plots of 10 × 10 m in Kajiado (one per treatment *n*), and 25 × 3 m in Wajir (two per treatment *n*). Reseeding of five drought-tolerant range grasses—*Cenchrus ciliaris, Cymbopogon pospischilii, Enteropogon macrostachyus, Eragrostis superba,* and *Sehima nervosum*—in mixture at a seeding rate of 10 kg/ha before the onset of the 2018 long rains was conducted by ripping the soil with hand tools to 1 cm depth, scattering seed in the depression, and lightly covering with soil. Reseeding was assessed in terms of success vs. failure, with success defined as ≥ 20% of the reseeded area occupied by reseeded grasses.

For "resting effects," the benefits of resting, the central indicator was total vegetation cover, including leaves, standing stems, and litter. As measured here, total vegetation cover is an integrative indicator for: (i) cover of standing forage and browse; (ii) litter cover produced during the study season and later shed or trampled; and (iii) the influences of plant and litter cover on grass regeneration and related ecosystem processes involving soils and water. Litter is included here to span benefits to both land restoration and livelihoods, while reporting to producers at project end did not include litter (Sircely 2019a, b). Including litter avoided discounting persistent restoration benefits of grass produced yet trampled, because outcomes were measured during the early dry season after one to two months of grazing (post-resting). Combined standing and litter cover is the inverse of bare soil or bare ground, an indicator with greater statistical power in variable rangelands that links to remote sensing (Guerschman et al. 2015). Less than 5% of litter was produced in previous seasons. Virtually all plant species and biomass in these rangelands are locally used for feeding livestock. A secondary indicator was the percentage of area with gaps in canopy cover of 1 m or larger, an indicator of spatially mediated ecosystem processes such as

Table 2. Kajiado and Wajir, Kenya: Resting effects in terms of total vegetation cover and % 1 m canopy gaps from ANCOVA (Outcome = α + β1(Baseline) + β2(Treatment) + ε), excluding the reseeding treatment.

			Vegetation cover (% cover)					Canopy gap percentage (% 1 m gaps)				
					Background seasonal change in % cover (Control intercept)	Further increase in % cover with:				Background seasonal change % 1 m gaps (Control intercept)	Further decrease in % 1 m gaps with:	
Site	Season	Rainfall favorability	*df*	R^2 (*adj.*)		1 month rest	2 month rest	*df*	R^2 (*adj.*)		1 month rest	2 month rest
Kajiado	Long rains 2018	Good rains	108	0.021	49.62	10.08 ^{ms}	11.53*	108	0.081	8.72	-9.20*	-14.44**
	Short rains 2018-2019	Poor rains	108	0.204	23.54	1.17	7.58*	108	0.100	0.04	-2.65	-13.26*
Wajir	Long rains 2018	Poor rains + inundation	47	0.172	21.65	6.59	10.26*	47	-0.022	76.46	-2.45	-4.55
	Short rains 2018-2019	Poor rains (drought)	47	0.047	19.95	4.84	4.96	47	-0.043	74.97	2.40	3.30

* = P < 0.05, ** = P < 0.01, (^{ms} = P < 0.1)

erosion (Mayor et al. 2019), also by the stick point method (Riginos et al. 2011).

Statistical analysis of resting effects focused on the net outcome of vegetation evolution through the rainy season and its persistence into the early dry season following re-opening to grazing, with resting areas compared to heavily and continuously grazed controls. Outcomes in terms of total vegetation cover and % 1 m canopy gaps were analyzed relative to baseline for each individual plot, using analysis of covariance (ANCOVA) with baseline values as a continuous predictor (Altman and Gardner 2000) and treatment as a factor (control, one month rest, two month rest) using R version 4.0.2 (R Development Core Team 2013).

In Amhara, the exclosure productivity improvement trial was conducted in 24 grazing exclosures (cut-and-carry fodder production; no grazing), a comprehensive set of government-mandated exclosures in eight *woredas* (districts) of West Gojjam and Awi Zones (Table A1.2). Research areas of 0.084 ha (Sircely et al. 2020) were located randomly inside these exclosures (avoiding gullies or woody cover), with one research area in most exclosures, and two research areas in all exclosures larger than the mean area of 7.78 ha (Table 1). Research areas covered on average 3.84% of total exclosure area. Baseline biomass was recorded in March 2017 in the Ethiopian highlands dry season, with the same measures repeated in the early dry season of November 2017, and again in November 2018 (data reported from 2018). Treatments were compared to controls managed as usual (cut-and-carry; no grazing) in unimproved portions of the study exclosures, with mixed grasses, forbs, and weeds varying from high-quality grasses (e.g., *Andropogon abyssinicus, Cynodon dactylon, Pennisetum glabrum*) to inedible invasives (e.g., *Lamarckia aurea, Senna didymobotrya*). Outcomes were analyzed in terms of peak, end-of-season biomass yield, crude protein (CP) yield, and nutritional content (CP and in vitro digestibility) of forages locally preferred for cut-and-carry livestock feeding using univariate analysis of variance (ANOVA) in R version 4.0.2 (R Development Core Team 2013).

After two trial rounds, stated or revealed producer preferences provided additional evidence on restoration. Producer members and leaders of local institutions in Kajiado and Wajir ranked restoration option performance (stated preferences) and assessed up-scaling viability. In Amhara exclosure user groups were offered minimum support (*C. gayana* seeds and *P. pedicellatum* root cuttings were provided free of charge by Amhara BoA, and transport for cuttings by International Livestock Research Institute) to begin willing and independent up-scaling (revealed preferences).

RESULTS

Short-resting and reseeding trial

Resting effects from two months of rest were generally observed in terms of an increase in total vegetation cover in both Kajiado and Wajir, and in Kajiado a decrease in % 1 m canopy gaps (Table 2, Figs. 1 and 2). Resting for two months produced consistent benefits, except under drought conditions, while one-month resting effects were weaker and less consistent. Increase in vegetation cover from resting was influenced by seasonal rainfall favorability, climate, and soils. Because reseeding was only in small, nested sub-plots inside the research areas, reported resting effects exclude the reseeding treatment. Reseeding appeared initially successful in Kajiado (Table A1.4) for all five grass species, under both one- and two-month resting, in all research locations, though most died by the following short rains. In Wajir reseeding failed entirely (Table A1.4); only a few seedlings survived. In both sites *Cenchrus ciliaris* established and survived at the highest rate among the five reseeded grasses.

In Kajiado near Lake Magadi, the 2018 long rains were the heaviest in over a decade, and with forage in surplus, two months of rest produced a substantial and persistent 23.2% increase in total vegetation cover over un-rested controls (Tables 2 and 3, Fig. 1, Fig. A1.1). Resting effects from ANCOVA are given by coefficients for the difference between the control *y*-axis intercept (background seasonal change) and the *y*-axis intercepts for one-month and two-month resting. Multiplying the coefficient for two months of rest (11.53; Tables 2 and 3) by 100 to convert percent cover into m²/ha, two months of rest produced an average additional 1153 m²/ha of vegetation cover over controls. One month of rest gave a marginally significant ($P < 0.1$) 20.3% increase over controls (1008 m²/ha). Gains in cover involved all plant growth forms, virtually all of which serve as livestock feed, especially annual and perennial grasses of variable forage quality

Table 3. Kajiado, Kenya: Vegetation cover model summary for short-resting (excluding the reseeding treatment). Covariates were added to the base ANCOVA vegetation cover model (Outcome = α + β1(Baseline) + β2(Treatment) + ε) presented in Table 2.

Base model, or covariate added to base model	*df*	*F*	R^2 (adjusted)	Covariate Δ R^2	Control (intercept)	Baseline effect ± SE	Covariate effect ± SE	1 month resting effect ± SE	2 month resting effect ± SE
A. Long rains 2018									
Base ANCOVA model	108	1.786	0.021	—	49.6	0.25 ± 0.21	—	10.08 ± 5.72 ^{ns}	11.53 ± 5.76*
Salty soil (+/-)	107	7.931	0.200	0.179	57.3	0.32 ± 0.19	-20.28 ± 4.04*****	10.23 ± 5.17 ^{ns}	11.80 ± 5.20*
Rocky soil (+/-)	107	4.734	0.119	0.098	53.3	0.39 ± 0.20	-16.02 ± 4.45***	10.38 ± 5.42 ^{ns}	12.06 ± 5.46*
Flooding (+/-)	107	3.135	0.071	0.051	38.2	0.30 ± 0.21	13.79 ± 5.25	10.17 ± 5.57 ^{ns}	11.69 ± 5.61*
Grazing (TLU/day)	107	4.150	0.102	0.081	-8.4	0.48 ± 0.21	20.57 ± 6.27**	10.59 ± 5.48 ^{ns}	12.43 ± 5.52*
Distance from town (km)	107	1.520	0.018	-0.002	45.7	0.33 ± 0.23	0.51 ± 0.60	10.24 ± 5.73 ^{ns}	11.82 ± 5.77*
B. Short rains 2018–2019									
Base ANCOVA model	108	10.458	0.204	—	23.5	0.73 ± 0.14	—	1.17 ± 3.72	7.58 ± 3.75*
Salty soil (+/-)	107	10.133	0.248	0.044	26.4	0.76 ± 0.13	-7.65 ± 2.83**	1.23 ± 3.62	7.68 ± 3.64*
Rocky soil (+/-)	107	8.824	0.220	0.016	24.8	0.78 ± 0.14	-5.45 ± 3.02 ^{ns}	1.28 ± 3.68	7.76 ± 3.71*
Flooding (+/-)	107	7.773	0.196	-0.007	23.8	0.73 ± 0.14	-0.30 ± 3.53	1.17 ± 3.74	7.57 ± 3.76*
Grazing (TLU/day)	107	10.104	0.247	0.043	37.4	0.65 ± 0.14	-2.77 ± 1.03**	0.99 ± 3.62	7.25 ± 3.64*
Distance from town (km)	107	7.962	0.201	-0.003	25.8	0.69 ± 0.15	-0.30 ± 0.39	1.08 ± 3.73	7.41 ± 3.76 *

* = P < 0.05, ** = P < 0.01, *** = P < 0.001, **** = P < 0.0001, ***** = P < 0.00001, (^{ns} = P < 0.1)

Fig. 1. Kajiado, Kenya: Estimation of resting effects in terms of total vegetation cover and % 1 m canopy gaps (excluding the reseeding treatment), and effects of post-opening grazing intensity on outcome–baseline difference in vegetation cover.

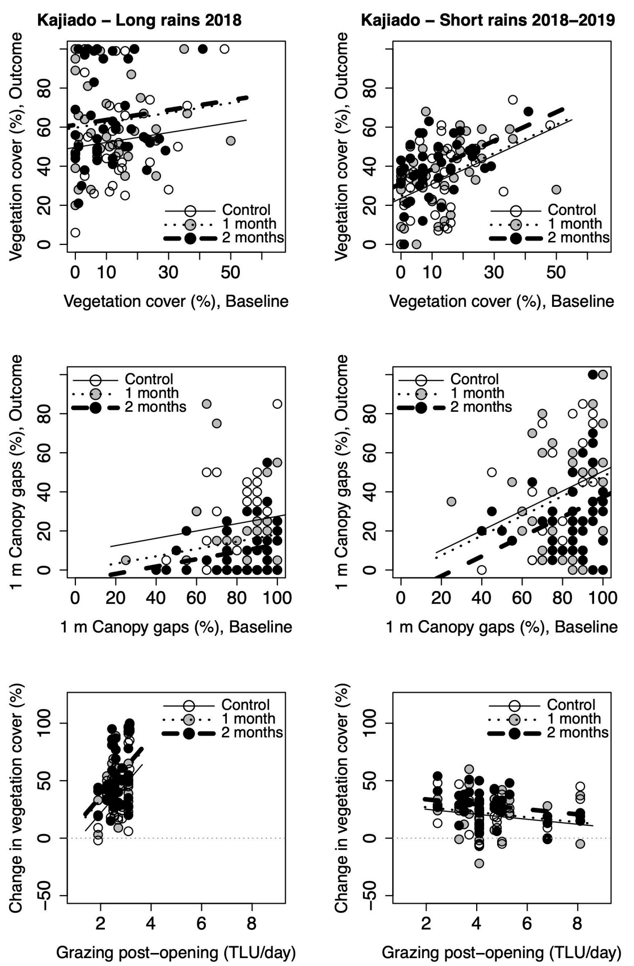


Fig. 2. Wajir, Kenya: Estimation of resting effects in terms of total vegetation cover and % 1 m canopy gaps (excluding the reseeding treatment), and effects of post-opening grazing intensity on outcome–baseline change in vegetation cover.

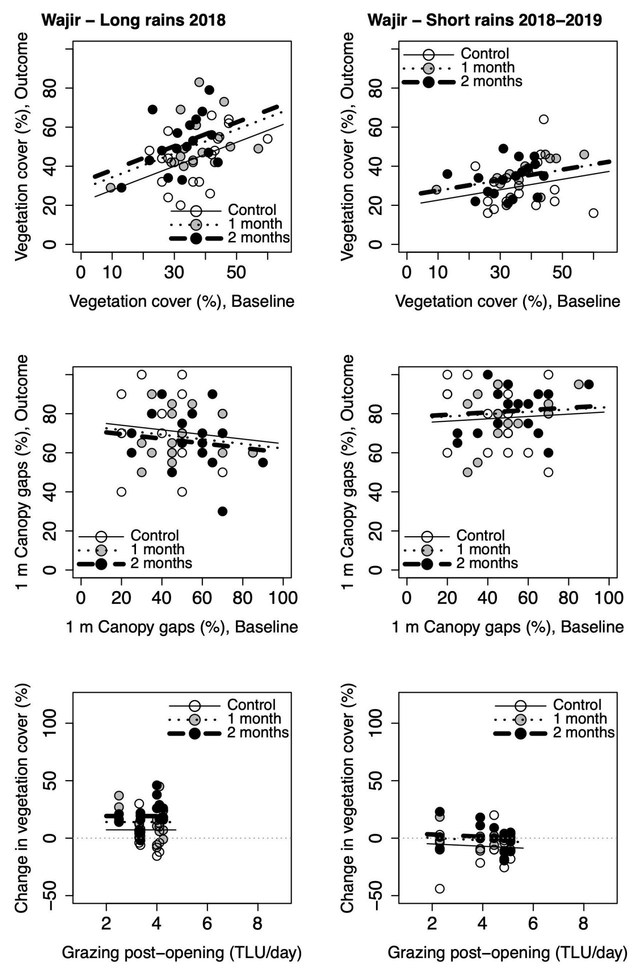


Table 4. Wajir, Kenya: Vegetation cover model summary for short-resting (excluding the reseeding treatment). Covariates were added to the base ANCOVA vegetation cover model (Outcome = α + β1(Baseline) + β2(Treatment) + ε) presented in Table 2.

Base model, or covariate added to base model	*df*	*F*	R^2 (adjusted)	Covariate Δ R^2	Control (intercept)	Baseline effect ± SE	Covariate effect ± SE	1 month resting effect ± SE	2 month resting effect ± SE
A. Long rains 2018									
Base ANCOVA model	47	4.456	0.172	—	21.6	0.61 ± 0.19	—	6.59 ± 4.40	10.26 ± 4.48*
Flooding (+/-)	46	3.843	0.185	0.014	26.9	0.60 ± 0.19	-3.44 ± 2.58	6.59 ± 4.36	10.22 ± 4.44*
Grazing (TLU/day)	46	3.275	0.154	-0.018	22.9	0.61 ± 0.20	-0.35 ± 3.24	6.59 ± 4.44	10.26 ± 4.53*
Distance from town (km)	46	3.844	0.185	0.014	20.0	0.57 ± 0.19	0.26 ± 0.20	6.57 ± 4.36	10.10 ± 4.44*
B. Short rains 2018–2019									
Base ANCOVA model	47	1.829	0.047	—	19.9	0.27 ± 0.15	—	4.84 ± 3.36	4.96 ± 3.42
Flooding (+/-)	46	3.161	0.147	0.100	12.7	0.28 ± 0.14	4.79 ± 1.88*	4.84 ± 3.17	5.02 ± 3.24
Grazing (TLU/day)	46	1.459	0.035	-0.012	23.8	0.27 ± 0.15	-0.92 ± 1.43	4.84 ± 3.38	4.97 ± 3.44
Distance from town (km)	46	1.905	0.068	0.020	18.6	0.24 ± 0.15	0.21 ± 0.15	4.82 ± 3.32	4.83 ± 3.38

* = $P < 0.05$

(often the moderately preferable perennials *Sporobolus cordofanus* and *Aristida adoensis*), and shrubs and small trees to a lesser extent. Vegetation cover varied with land potential, as more productive soils without significant rock or salt content showed the greatest increase (Table 3). More productive sites attracted more livestock (and wildlife) after re-opening the resting areas, causing grazing intensity to be positively associated with increasing vegetation cover (Table 3, Fig. 1). After the resting areas were opened to livestock, an estimated average of 2.7 tropical livestock units (TLU) of cattle and shoats visited them daily in the long rains (TLU equivalents: cattle = 0.7; goats and sheep = 0.1; other = 0.4). In the following short rainy season, because of poor rainfall and forage scarcity, grazing after re-opening increased, rising to 4.6 TLU daily (a 70.4% increase). After two months of rest vegetation cover increased more modestly, by approximately 750 m²/ha, a greater relative increase over controls at 32.2%. With forage in deficit, vegetation cover increased less at higher grazing intensity, and again somewhat less on rocky and salty soils. One month of rest had no measurable effect, because of poor rainfall causing heavy grazing after re-opening.

In Burder Ward in Wajir, unlike elsewhere in East Africa, the long rains of 2018 were not heavy but poor, with initial showers followed by extensive flooding for one to two weeks by the Upper Ewaso Ng'iro River, and effectively no further rainfall (both inundation and poor rainfall inhibit range production). Two months of rest yielded a 47.4% increase in total vegetation cover over controls, or roughly an additional 1000 m²/ha (Tables 2 and 4, Fig. 2, Fig. A1.2). The increase came from annual and perennial grasses (often including the moderately preferable perennials *Aristida adoensis, Setaria desertorum,* and *Sporobolus ioclados*), shrubs and small trees, all of which are used as livestock feed. Areas rested for one month showed no significant effect, although vegetation cover was 30.4% higher than controls. Resting effects were depressed by poor rainfall and forage scarcity generating heavy grazing after re-opening, although no linear effects of grazing were observed (Table 4, Fig. 2). Grazing intensity changed little from the estimated average 3.6 TLU of camels, cattle, shoats, and donkeys grazing daily during the long rains, to 4.2 TLU/day in the short rains. Rainfall did change, from poor rains to drought. Areas previously flooded (in the long rains) gained more cover than other areas, with no effects of resting or other covariates.

In both Kajiado and Wajir, the consensus among pastoralist members of rangeland management institutions was that two months' rest was effective and that one month was not viable, confirming the trial results. These views did not vary among sites or settlements hosting the research locations. Ninety-three percent of settlements indicated they would recommend the resting approach to their institutions. Two months' rest with reseeding was, at first, ranked higher than without reseeding, seemingly disagreeing with researcher recommendations, as producers assumed a non-existent free or cheap source of range grass seed from NGO or government. Once confronted with the high cost of seed—US$100 per ha—producers in Kajiado and Wajir ranked resting for two months (without reseeding) as the preferred feasible option.

Exclosure productivity improvement trial

In Amhara in the Ethiopian highlands, exclosures in higher topographic positions tended to have red soils (nitisols), often shallow or rocky, without major seasonal flooding. In these sites, given degradation prior to closure and poor grass composition, improved forages gave the best results. *Pennisetum pedicellatum* had by far the greatest biomass and crude protein yield (Table 5, Fig. 3, Fig. A1.3) of any treatment and a high success rate (Table 6). *Chloris gayana* was successful in productive highland sites below ~2500 m in elevation, though due to a variable success rate, not at greater biomass than controls or the weeding treatment after two years (Table 5, Fig. 3).

Benefits of weeding were not detected over two years. Some exclosures, mostly in wetlands, had pre-existing grasses excellent as cut-and-carry fodders (e.g., *Pennisetum glabrum*) that provide hydrological regulation and habitat for biodiversity. Weeding remains the most relevant option for these exclosures, as both improved forages were problematic. *C. gayana* failed entirely, effectively degrading the plowed area, especially in valuable wetlands. *P. pedicellatum* often failed in wetlands, but its success might pose an invasion risk.

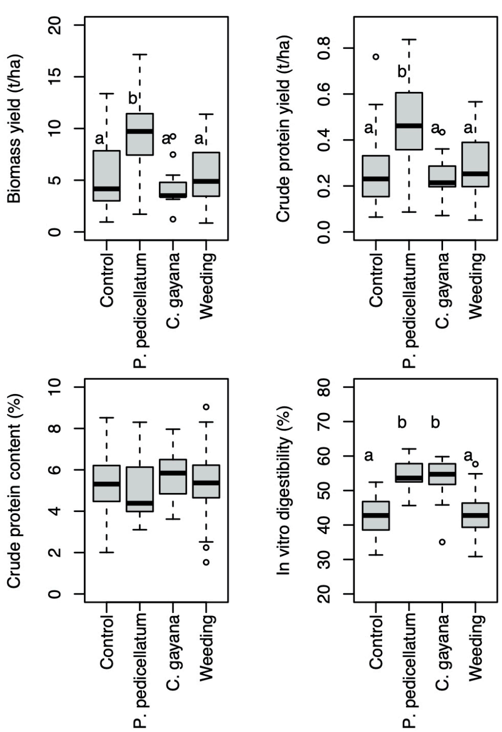
In trial year 2, several exclosure user groups were ready to begin up-scaling, providing evidence from revealed preferences. A majority of user groups willingly up-scaled their preferred treatment with no significant external support. Eleven exclosure user groups up-scaled improved forages (Table 6, Fig. A3; 45.4% of user groups), while two groups up-scaled weeding, for overall

Table 5. Amhara, Ethiopia: Effects of productivity improvement treatments in grazing exclosures on biomass and crude protein yields, and covariation with edaphic factors from ANOVA, as compared to controls of unimproved, pre-existing exclosure vegetation.

Base model, or covariate added to base model	*df*	*F*	R^2 (adjusted)	Covariate ΔR^2	Control (intercept)	Covariate contrast	Covariate effect ± SE	Weeding effect ± SE	*C. gayana* effect ± SE	*P. pedicellatum* effect ± SE
A. Biomass yield (t/ha)										
Base univariate ANOVA (no covariate)	66	7.9	0.230	—	5.3	—	—	0.323 ± 1.02	-1.06 ± 1.11	3.85 ± 1.03***
Soil color (type)	64	10.1	0.396	0.167	7.6	Black - Brown Black - Red	-1.98 ± 1.05 ^{ms} -3.49 ± 0.78****	0.323 ± 0.90	-1.07 ± 1.00	3.98 ± 0.92****
Soil constraint	64	9.1	0.371	0.141	6.4	Flooding - No constraint Flooding - Shallow soils	-0.45 ± 0.91 -3.89 ± 1.10***	0.323 ± 0.92	-1.18 ± 1.03	3.72 ± 0.94***
Topographic position	63	10.2	0.446	0.216	7.8	Bottomland - Footslope Bottomland - Midslope Bottomland - Upland	-2.25 ± 0.89 * -2.71 ± 1.16* -6.25 ± 1.18****	0.323 ± 0.86	-1.05 ± 0.95	3.79 ± 0.88****
B. Crude protein (CP) yield (t/ha)										
Base univariate ANOVA (no covariate)	66	6.2	0.185	—	0.28	—	—	0.008 ± 0.06	-0.05 ± 0.06	0.19 ± 0.06**
Soil color (type)	64	6.3	0.277	0.092	0.36	Black - Brown Black - Red	-0.02 ± 0.06 -0.13 ± 0.05**	0.008 ± 0.05	-0.04 ± 0.06	0.19 ± 0.05***
Soil constraint	64	7.6	0.322	0.137	0.34	Flooding - No constraint Flooding - Shallow soils	-0.02 ± 0.05 -0.20 ± 0.06**	0.008 ± 0.05	-0.05 ± 0.06	0.18 ± 0.05***
Topographic position	63	8.4	0.393	0.208	0.41	Bottomland - Footslope Bottomland - Midslope Bottomland - Upland	-0.11 ± 0.05* -0.15 ± 0.06* -0.32 ± 0.07*****	0.008 ± 0.05	-0.05 ± 0.05	0.18 ± 0.05***

* = P < 0.05, ** = P < 0.01, *** = P < 0.001, **** = P < 0.0001, ***** = P < 0.00001, (ms = P < 0.1)

Fig. 3. Amhara, Ethiopia: Effects of productivity improvement treatments on yields of biomass and crude protein from grazing exclosures, and forage quality differences among treatments in terms of crude protein content and in vitro digestibility, as compared to controls of unimproved, pre-existing exclosure vegetation.



54.2% of user groups engaged in spontaneous up-scaling. A household survey found that user groups who up-scaled improved forages had fewer livestock (R^2 = 0.183, df = 25, P < 0.05) and used less grass and hay from outside exclosures (R^2 = 0.152, df = 25, P < 0.05) than other user groups. They also tended to have less cropland and to use the target exclosure often (statistically insignificant associations). Most improved forage scaling was in sites potentially suitable for crops (Table 6).

Planting *P. pedicellatum* throughout the 18 exclosures that do not experience seasonal flooding could have produced the greatest project-level payoffs in terms of tons of additional fodder and its direct value in local *woreda* or *kebele* markets (US$36.82 per ton in 2017). A hypothetical analysis (Table A1.5) indicates that by year 2 this approach would have generated approximately 3038 tons of additional biomass with a total direct local market value of US$111,871 (ETB 4,135,986). Although *C. gayana* was viable in productive sites < 2500 m, short-term costs are possible (Table A5).

DISCUSSION

Short-resting and reseeding: trials to scaling

In the two rangeland sites and pastoral areas elsewhere in East Africa, drought, organization, and heavy stocking are major constraints to land restoration (Reid et al. 2014). Action research yielded useful evidence on the ecological and secondary forage benefits from the briefest effective resting of rangelands, and confirmed the difficulty of reseeding under short-term grazing protections. In ranching systems, restoration typically involves resting for entire annual growing periods or longer, often combined with fire, reseeding, and fertilization (Bray et al. 2014, Hunt et al. 2014). The closest comparison to short-resting from

Table 6. Amhara, Ethiopia: Improved forage mean biomass yield, gross site success rate, and spontaneous up-scaling results by soil type × soil constraint groups.

Soil type (color)	Soil constraint (if any)	Improved forage species	Biomass yield (t / ha)	Success rate (%)	Best option (s)	Number of research locations	Number of up-scaling locations	Improved forage (s) up-scaled (number of sites)	Total up-scaling area (ha)
Eutric Nitisol, Ne (red)	Poor soil (rocky/ shallow)	Desho (*P. pedicellatum*)	5.6	86	1. Desho	4	1	Desho (1)	1
		Rhodes (*C. gayana*)	2.3	38					
	None (arable)	Desho (*P. pedicellatum*)	10.4	100	1. Desho; 2. Rhodes	8	6	Desho (5), Rhodes (6)	1.375
		Rhodes (*C. gayana*)	3.7	100					
Pellic Vertisol, Vp (black)	None (arable)	Desho (*P. pedicellatum*)	12.4	83	1. Desho; 2. Rhodes	6	3	Desho (2), Rhodes (1)	1.2
		Rhodes (*C. gayana*)	5.8	100					
	Inundation (annual)	Desho (*P. pedicellatum*)	—	33	1. Weeding	3	0	—	—
		Rhodes (*C. gayana*)	—	0					
Humic Nitisol, Nh (brown)	Inundation (annual)	Desho (*P. pedicellatum*)	6.4	100	1. Weeding	3	1	Desho (1)	0.1
		Rhodes (*C. gayana*)	—	0					

ranching is early growing season resting or "spelling,", usually for three or more months to maintain or improve pasture condition and livestock production (Ash et al. 2001, Bray et al. 2014, Hunt et al. 2014); even two months of rest can maintain tropical pastures in good condition, or help improve pastures in moderate condition (Ash et al. 2011). Short-resting in pastoral areas is brief primarily because in more degraded and more heavily grazed portions of unfenced communal pastoralist rangelands with large mobile herds, long resting periods can be unrealistic. Short-resting has the primary goal of land restoration, while modestly increasing forage availability. Where other restoration options may fail, the main function of short-resting is to provide minimum space and time for the rangeland ecosystem to slow degradation and begin restoration.

The substantive and persistent effects from two months of rest in both Kajiado and Wajir, the weakness of one-month effects, and the absence of resting effects during drought in Wajir, indicated that resting duration, seasonal rainfall favorability, and aridity each influenced resting effectiveness. To contribute to restoration, resting effects needed not only to occur, but also to persist through at least one month of grazing into the beginning of the dry season (two months of grazing for one-month resting). Temporary ecological or forage benefits measured immediately after resting would contribute little or nothing to restoration. Persistent resting effects are likely to improve key ecological functions mediated by spatial cover of vegetation and bare soil, most importantly regeneration and reinvigoration of grasses (as well as soil surface micro-climate, infiltration, and soil retention). Persistent effects secondarily indicate modest forage benefits from short-resting, beyond the one to two months of grazing during the end of the rains (by when continuously grazed controls had been effectively stripped clean) and early dry season. Most cover gains came from annual and perennial grasses, from the seedbank or perennial organs. Forage quality in rested areas was limited by the mature stage of grasses, and because animals avoided more mature stems, likely consumed in the dry season. If large areas were rested, e.g., thousands of ha, the modicum of forage provided by resting might improve livestock production or reduce mortality rates.

Seasonal rainfall and aridity influenced resting effects. During droughts no resting benefits are expected with no rain to fuel vegetation growth, as in the short rains in Wajir (and more likely that livestock enter and graze resting areas). At the opposite extreme, heavy rainfall in the Kajiado long rains produced stronger effects. The influence of aridity can be seen from the long rains in Wajir, where with less rainfall and heavier grazing (and in several locations, one to two weeks inundation), two months' rest produced resting effects similar to Kajiado that season. Resting in Wajir demonstrated the capacity of arid rangelands such as Burder (300 mm/yr) to rapidly produce biomass because of high temperatures and desert species composition capable of exploiting brief moisture availability (Ruppert et al. 2012). Arid rangelands likely need less rain than semi-arid areas for a similar resting benefit. These sites cannot represent all rangelands with similar climates; resting benefits vary with soils and vegetation, and can be reduced under forage scarcity.

By using rainfall favorability and aridity as coarse guides for decision-making, the results from Kajiado and Wajir can together constrain likely outcomes from two months of resting in arid and dry semi-arid rangelands with mean annual precipitation (MAP) in the range of approximately 250–600 mm/yr in East Africa. A total resting benefit of 1000 m^2/ha or more of additional vegetation cover can be expected in seasons of good or poor rainfall in arid areas (e.g., MAP 250–400 mm/yr), or in seasons of good rainfall in dry semi-arid areas (e.g., MAP 400–600 mm/yr). Resting benefits in semi-arid areas will likely be somewhat lower in seasons of poor rainfall. The impossibility of resting during drought remains a point of emphasis. By design, these estimates of resting effects are conservative, especially because the research areas were close to permanent settlements and water, are heavily grazed (Tyrrell et al. 2017), most degraded, and likely least responsive to restoration. Resting benefits should be higher than those reported here with favorable rainfall in arid rangelands like Wajir, in areas with high land potential such as riparian pastures, and in less degraded portions of a rangeland. Resting effects only occur with resting of pastures that would normally be grazed in the early rainy season, and do not apply to pastures not grazed in the early rainy season (dry season areas, drought reserves, exclosures).

Reseeding failed in both rangeland sites, as nearly all reseeded grasses had died after the one-year study. Range reseeding is known to be challenging (Svejcar et al. 2017), requiring favorable rainfall as in the Kajiado long rains. Persistence of reseeded grasses likely requires additional rest beyond two months in two successive rainy seasons. Studies from more mesic East African rangelands on reseeding of exclosures or paddocks (Mureithi et al. 2014) or under long rest of up to three years (Eba et al. 2014) are similar to restoration in ranching. However, these studies are of limited use wherever long rest is costly and unrealistic for pastoralists, most studies do not report resting times for reseeding, and few focus on unirrigated arid rangelands like Wajir. For efficient reseeding of various grass species in East African rangelands, further study is needed to identify minimum resting times required, during which seasons, and how its timing varies with land potential, especially in arid zones. At minimum, additional post-grazing rest during one or more dry seasons after short-resting and reseeding would reduce mortality of reseeded grasses from repetitive re-grazing.

Implementation of short-resting in pastoral East Africa would follow the decisions of local rangeland management institutions, here, two group ranches in Kajiado (with formal authority) and a natural resource management committee for a ward (government administrative unit) in Wajir (informal). As in regulating grazing, settlement locations, and other management decisions (Nganga et al. 2019), these institutions can set a process and persons responsible for deciding which areas are rested, when, and for how long. Though a resting plan is needed in advance, the resting decision must be taken flexibly by persons in the area, given actual rainfall received, to conduct resting early in the rainy season and obtain the full benefit. If good rains do not materialize, resting can be rescinded. Longer periods of rest, e.g., the entire rainy season, would be more effective and assist range reseeding, but in areas with heavy grazing longer rest is often not feasible. Because short-resting is best conducted without fencing (rather, "social fencing") and decisions on location and size can minimize enforcement, the costs of short-resting come mainly from transactions: organization, communication, sensitization. If transaction costs are mitigated, short-resting is a flexible, low-cost option even in tough situations where community organization and ownership are not strong.

The resting trial is secondarily able to inform application at larger scales of hundreds to thousands of hectares in rotation over time. In rotational resting, degraded rangelands are rested, for short or long periods, in large or small portions, in a shifting pattern over multiple seasons to encourage ecological regeneration (Danckwerts et al. 1993). By using short-resting to avoid costs from longer rest, priority areas can be rested for short periods at the beginning of the rains, in rotations covering new areas each season. Rotational resting could also assist large-scale reseeding. Governments and NGOs often struggle with natural resource management in pastoral rangelands, and with short timelines and limited budgets often support small-scale approaches such as exclosure, fodder farming, and hay-making. Though potentially valuable, these approaches can produce rangeland fragmentation (Nyberg et al. 2019) and only influence the larger rangeland through increasing feed availability (positive) and displacing grazing to remaining pastures (negative). Short-resting provides a practical, low-cost approach for achieving modest ecological and forage benefits over large areas, which slow degradation, initiate restoration, and provide limited immediate benefits to livelihoods, in a simple manner as tested here, through rotational resting, or in rotational grazing.

The primary end users of short-resting are the rangeland management institutions responsible for planning and management on behalf of residents and users. In pastoral Kenya, these institutions include grazing committees, natural resource management committees, group ranch committees, traditional or customary rangelands, conservancies, environmental management committees, rangeland users' associations, and water resource users' associations (Reid et al. 2014, 2016, Kanyuuru et al. 2017, Nganga et al. 2019), among others. Pastoralist associations, government agencies, and NGOs support dissemination of information on rangeland restoration for up-scaling to new areas, and can facilitate restoration action by local institutions.

Exclosure productivity improvement: trials to scaling

The dramatic success of *Pennisetum pedicellatum* (Desho or Kyasura grass) in improving exclosure productivity within a two-year period demonstrates that formerly overgrazed and degraded communal lands can be transformed into productive sources of cut-and-carry fodder at low cost. *P. pedicellatum* established and grew even on rocky hillsides, and appears to be an excellent choice except in wetlands, where it poses invasion and degradation risks. The traits of *P. pedicellatum*—propagation through cuttings, strong establishment, exceptional biomass production even on poor soils, and tall stature for efficient cut-and-carry—resemble its relative *Pennisetum purpureum* (elephant or napier grass; Kariuki 1998), which spread spontaneously throughout the Kenyan highlands over the past three decades (Staal et al. 2002), where smallholder dairy now relies heavily on *P. purpureum* grown mostly in waste areas such as roadsides, field margins, terraces, and portions of farms with low fertility.

Planting *Chloris gayana* (Rhodes grass) was usually successful, though less productive and less consistent than *P. pedicellatum*, and less productive than pre-existing grasses. Because no fertilizer was used, and some sites planted late (exact dates could not be confirmed), the success rates and biomass production of *C. gayana* are under-estimated, and more representative of poor exclosure management (good management is common, but cannot be assumed in scaling). *C. gayana* had the disadvantages of being constrained to more moderate elevations and land suitable for cropping, a limitation given ongoing sub-division of communal land into cropland for residents in greatest need. *C. gayana* may have higher crude protein (CP) content than *P. pedicellatum* on average, but here no differences in CP or in-vitro digestibility were observed.

Weeding effects over two years were not detected. Weeding likely has weak benefits over multiple years, difficult to measure in variable grasslands. Still, weeding is the only feasible and sustainable option in wetland exclosures, and can be included in user group by-laws. Soil degradation from plowing is a threat to valuable wetlands, and large-statured grasses such as *P. pedicellatum* may pose a biological invasion risk.

The willingness of exclosure user groups to up-scale inside their exclosure with no significant external incentive reconfirmed the suitability of *P. pedicellatum* and *C. gayana* for improving exclosure productivity. Most user groups up-scaled *P. pedicellatum*, or both *P. pedicellatum* and *C. gayana*. There is rarely only a single relevant option for restoration, and a mix of grass species hedges establishment risk and can produce fodders for different seasons or livestock types, e.g., oxen versus calves. All grasses require an appropriate cutting frequency to optimize forage quality, and some fertilizer to replace nutrients lost in cut fodder. *P. pedicellatum* has low fertilization needs, a major advantage. Because use of inorganic fertilizers in perennial grasses requires annual re-application to prevent loss of production from stopping fertilization (e.g., Pallett et al. 2016), manure is recommended for communal exclosures lacking exclusive private incentive. In user groups that up-scaled improved forages, some farmers have transferred these forages to individual plots (Sircely and Zerfu, *personal observation*); full individual adoption has yet to be confirmed. Large-scale planting of forages in plots or in waste areas such as field margins and cropland terraces would reduce runoff and erosion at watershed scales.

In Amhara National Regional State in Ethiopia, government agencies and NGOs implement grazing exclosure (or area closure) for environmental rehabilitation. The views of these stakeholders were documented in a 2017 draft scaling strategy (Sircely, Wondie, Temesgen, et al. 2017, *unpublished manuscript*), reconfirmed in a regional forum in March 2020 that found elements of the strategy being applied. Some of these stakeholders use information from the exclosure trial, including Amhara Bureau of Agriculture, with whom this research was conducted alongside the Community-Based Integrated Natural Resource Management Project (CBINReMP) funded by the International Fund for Agricultural Development (IFAD).

At the federal level in Ethiopia, the primary avenues for applying the exclosure trial results are the federal and regional implementing agencies using the integrated watershed management (IWSM) approach (Desta et al. 2005) of the highlands-wide Sustainable Land Management Programme (SLMP), which CBINReMP also followed. Because exclosure is a significant component of IWSM, the results can be applied in hundreds of *woredas* (districts) across the highlands in similar climates. Exclosures can benefit livelihoods with the introduction of higher quality indigenous fodders like those here, ideally alongside fodder trees. In wetlands with high-quality grasses, weeding can be included in user group by-laws. Only a few varieties of grasses uniquely suited to smallholder cut-and-carry like *P. pedicellatum* and *P. purpureum* have been validated through action research. These grasses may be a major "low-hanging fruit" to dramatically increase fodder production and environmental services from communal and individual lands across the highlands at a low cost to government and farmers.

Characteristics of options and relevance to scaling

In any specific agricultural context, the characteristics of an option determine its performance and cost, and affect perceptions of producers, influencing its likelihood of scaling (Hartmann and Linn 2008a, Hermans et al. 2021). The suites of options tested here share several characteristics within the larger "option space" of all possible restoration options for extensive rangelands or semi-intensive exclosures, notably simplicity, rapid initial returns, and minimal cost. Compared with the full suite of all restoration options possible, the options tested would be unlikely to give maximum potential performance, i.e., maximum performance or productivity or effectiveness assuming no constraints other than land potential and climate. For example, maximum performance might be attained in dry East African rangelands by resting for one to three years, with brief yet heavy periodic grazing, mechanical soil and water conservation structures, and repeated reseeding using manure fertilizer and a high seeding rate, e.g., 20 kg/ha, double our trial rate. In highland exclosures, maximum performance might be achieved through high-yielding, higher quality grasses such as *Brachiaria* spp. cut at optimal frequency, planted with fodder shrubs such as tree lucerne (*Cytisus prolifer*), and annual fertilization. Scaling these high-performance or more intensive options would require alleviating multiple constraints on communal lands lacking private exclusive incentive.

Performance is only one concern of producers. Cost, risk, complexity, compatibility, and observability of benefits affect adoption and scaling (Hermans et al. 2021), and more intensive options generally carry higher costs (Amadu et al. 2020). Placing the options tested here within the "option space" of each trial reveals apparent trade-offs in which, as the potential performance of options increases from near zero toward the maximum, possible gains in performance are counterbalanced by increasing cost, risk, complexity, and time required for initial and full, long-term restoration returns.

Among the options tested, the most potentially productive options—two months' rest with reseeding in rangelands, and *C. gayana* in exclosures—were not the best options based on trial data and producer preference. These options are more costly and complex, incur appreciable risk, and may be slow to give returns. Nor were the best options the least potentially productive: one month rest in rangelands (without reseeding) and weeding in exclosures. These options cost the least, are simplest, and carry least risk, but give few returns and slowly. Rather, our data (trials, preferences, uptake) suggest that herders in Kenya and farmers in Ethiopia gauged and responded to trade-offs among characteristics of restoration options by selecting options entailing moderate risk. The best options balanced moderate risk with intermediate potential performance, but also had moderate (or low) costs, complexity, and time to full returns. Time to initial return was also low for the best options, a key advantage. The sooner tangible benefits from restoration begin to flow, the more likely that herders or farmers will continue to make the sacrifices needed for restoration to succeed (Yami et al. 2013).

The observed pattern of options with intermediate potential performance carrying moderate risk cannot be readily generalized. We intentionally tested options with low costs, wait times, complexity, and risk, yet the most potentially productive options often remained out of reach, and seem unlikely to scale.

If constraints facing these options change, the calculus of decisions will too. Range reseeding might take off if affordable seeds become available to Kenyan pastoralists, while user groups willing to invest labor and manure in communal exclosures might plant *C. gayana* in addition to *P. pedicellatum*, as observed in Amhara. Strengthening institutions through facilitative multi-stakeholder approaches (Flintan and Cullis 2010, Jachimowicz et al. 2017) can ameliorate organizational constraints. Where critical constraints facing restoration cannot soon be lifted, a natural alternative is to seek options that can succeed in spite of those constraints, such as those tested here.

Action research for scaling: lessons on process

Restoration options with the greatest long-term returns to ecosystems and society are the central tools of sustainable restoration (WOCAT 2007, van Andel and Aronson 2012). Land restoration is difficult and uncertain, even in well-resourced situations (Svejcar et al. 2017). Improving livelihoods through land restoration is another step removed, implying time-lags and further amplifying uncertainty (Teague and Barnes 2017). Restoration in common pool resource systems needs to provide tangible goods to users benefitting from the resource base (Ostrom 1990), with economic gains often a strong motivator. In slow-recovering dry rangelands or degradation-prone humid grasslands, restoration of communal areas warrants due diligence and careful calibration to identify modest investments with substantial benefits. A strong start is helpful, including accepting existing constraints, combining complementary knowledge and experience of researchers and producers, and early and earnest local engagement. Nurturing local ownership over the research enhances its relevance, implying similar relevance in comparable contexts elsewhere.

To any service provider, the client comes first. Options were selected and trials designed to inform collective action by local institutions with minimal or no support. The options are moreover strategic to major existing policy and programmatic frameworks in the focal countries and production systems. In this two-tiered general scaling approach, local institutions such as rangeland management institutions and exclosure user groups are the primary end users, with secondary end users the government or NGO facilitators who introduce and support new or modified restoration options. These two tiers of institutions—local and government/NGO—may together form scaling pathways if their networks at multiple scales, that are also linked vertically, are harnessed to move research into practice over large areas (Hartmann and Linn 2008a). In the Ethiopian highlands, forage transfer from exclosures to individual plots is a third-tier scaling mechanism.

Fitting the context is key. Intensification, privatization, emphasis on livestock versus crops, and climate each influence the priorities and strategies of livestock producers. Local institutions operate on vastly different scales, with contrasting structures and processes for taking decisions to set and implement by-laws according to the objectives and scales of management. Normally, for technical or biophysical restoration options to succeed, local institutions need to provide oversight. Otherwise, restoration success will be short-lived.

Building on experience elsewhere reduces uncertainty. Inclusion of *P. pedicellatum* in the exclosure trial in Amhara was inspired by the spontaneous adoption of its relative *P. purpureum* throughout the Kenyan highlands (Kariuki 1998, Staal et al. 2002). The short-resting approach tested in Kajiado and Wajir derives from grazing practice confirmed in recent decades through large-scale experimentation and monitoring (Ash et al. 2001, 2011, Bray et al. 2014, Hunt et al. 2014).

Simulating end user actions is a unique advantage of action research. Restoration options were tested by real actors, using feasible actions, over realistic timelines. The measured returns to these actions are more realistic than estimates from researcher-managed trials or modeling. Local institutions easily managed the trials, and building upon these institutions increases the likelihood that restoration is accepted by and potentially benefits larger numbers of people, in a shorter period of time, than by working with isolated individual producers.

Action research for scaling: lessons on research methodology

Mixing knowledge and experience among stakeholders is a potent combination for difficult resource management problems (Sircely 2019c). Researchers provide global knowledge and experience, which may or may not suit local conditions. Producers have local knowledge and experience, useful in vetting global ideas. Government and NGO staff at local to regional levels provide implementation experience and can link researchers to producers. In the multi-stakeholder trial design process, each stakeholder group influenced the design (Table A1.3), enhancing both the internal and external validity of the research.

Action research trials may be optimized by using the minimum experimental controls necessary to accurately measure treatment effects. Well replicated field experiments balance internal with external validity (Roe and Just 2009), producing estimates of treatment effects that are both accurate and generalizable. Internal validity is provided by experimental design and controls, while external validity is provided by working within real systems and the variation they exhibit. A major role of researchers is to resolve causality by controlling variables to which outcomes are most sensitive, that are easy to control, or require some level of expert knowledge (Table A1.3, columns 3 and 4). Producers introduce variation to variables that are outcome-insensitive, difficult to control, or require mostly local knowledge (Table A1.3, column 5), and the absence of controls provides a sample more representative of similar actors and areas. Attempts to control these variables might be considered over-controlling, compromising external validity. Moreover, options with a large effect size will not require stringent controls. Both internal and external validity improve with appropriate use of statistics, such as the use of ANCOVA to quantify resting effects, an approach borrowed from medical trials (Altman and Gardner 2000).

In light of the uncertainties inherent in land restoration, common pool resource management, and smallholder livelihoods improvement, conservative estimation of treatment effects may be desirable for scaling. During research design, multiple decisions avoided over-estimating treatment effects (i.e., conservatively under-estimating effects) in terms of trial design, measurements, and calculations. Conservative estimates will under-promise and over-perform in scaling, while the contrary can compromise ethics in research and development. Similarly, revealed preferences (actual up-scaling, as in Amhara) are more realistic than stated preferences (desired up-scaling). In agricultural development it is often lamented, "pilots never fail, pilots never scale." In scaling, effects are generally weaker than in researcher-managed trials on-station or on-farm (Franzel and Coe 2002), yet might be similar to our moderately controlled, producer-managed in situ trials.

CONCLUSION

Action research documented the restoration benefits of short-resting in pastoral rangelands, and of improved forages in grazing exclosures. Local institutions overseeing land management, members of these institutions, and government and NGO facilitators confirmed the usefulness of the results for restoring degraded communal grazing lands. Pastoralists in Kenya supported their rangeland management institutions applying short-resting, while in the Ethiopian highlands simply conducting the trial resulted in spontaneous up-scaling, affirming apparently eminent scalability.

In this three-level, multi-stakeholder approach for land restoration action research in communal grazing lands, process was significant. Practical needs and objectives of producers were prioritized from the beginning, enhancing relevance to end users. Producers were members and leaders of local land management institutions, often willing and able to convene collective restoration. Multi-stakeholder trial design integrated local-to-global knowledge and experience. Trials were producer managed, enhancing applicability under the conditions producers face. The implementation simulation approach provided robust estimates of likely performance under up-scaling. Close alignment with policies and programs enables up-scaling by existing local institutions. Despite the major social and ecological differences among sites, the consistent yet flexible action research framework tailored trials to contrasting conditions, and revealed similar scaling pathways.

Characteristics of restoration options influenced performance and preference, indicating possible optimization of trade-offs between potential performance and risk. Among the restoration options tested, the best options tended to have moderate (or low) costs, complexity, time to initial and full returns, and risk. Any optimal options that are both effective and consistent may be good candidates for scaling.

Action research evaluation of agricultural and land management options can reveal which options work best in which contexts. Multi-stakeholder action research through local institutions is particularly useful in communal grazing lands, other common pool resource systems, and other systems facing wide sets of constraints. By ensuring that research practically supports livestock-based livelihoods alongside improvements in environmental quality, restoration of communal grazing lands can be an efficient mechanism to achieve win-win benefits for producers and greater society.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12848

Author Contributions:

All authors contributed to designing the research. B.O. Abdisemet, A. Kuseyo, I.N. Nganga, J.M. Somare, T. Tolessa, and A. Workneh performed the research. J. Sircely analyzed the data and wrote the paper.

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Data Availability:

The data/code that support the findings of this study are openly available in Harvard Dataverse at https://doi.org/10.7910/DVN/Y9R5P8

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Appendix 1. Supplementary online material for Sircely et al. 2021, "Deriving scalable measures for restoration of communal grazing lands"

1. Additional Methodology

Research prioritization through trial design—additional information

A research framework with a structured set of steps guided the action research process, beginning with initial assessments and concluding with attempts at scaling (Table A1.1). To prioritize restoration options for research, a literature review (Sircely 2016) and a review of experience of government and NGO practitioners (Table A1.1, Step 1) were conducted by researchers from the International Livestock Research Institute (ILRI). The experience review gave an initial list of potential research partners in Kenya and Ethiopia (approximately 30 agencies and organizations) with a common interest in restoring land to enhance both local livelihoods and environmental condition.

Table A1.1. Action research framework for scaling land restoration in communal grazing lands.

Steps in action research for scaling			Functions of each step	
Step	**Description**	**Scale**	**Primary function(s)**	**Secondary function(s)**
1	Prioritization of research for local assessment	National — Kenya and Ethiopia	Constrain possible restoration options for research	Begin identifying potential primary research partners in government and civil society
2	Research needs assessment	Local/ Individual settlements	Qualitatively prioritize restoration options based on producer priorities and policy/programmatic applications	Start building local ownership over the research; identify local institutional partners
3	Research agreements with development partners	Local	Agree clear terms for the research with government and/or NGO partners	
4	Draft action research protocol development	Local	Provide restoration action research trial protocols for research partner comment	Modify research protocols based on partner feedback
5	Research adaptation and initiation	Individual settlements	Adapt action research protocols to local conditions, and begin the trial	Document local livelihoods and management; identify field supervisors
6	Action research protocol finalization	Local	Provide final restoration action research protocols	Document local adaptation of research protocols
7	Action research trial implementation	Individual settlements	Conduct the restoration action research trials	
8	Site-level scaling strategy development[†]	Local	Compile stakeholder views into a draft scaling plan for wider comment	
9	Action research trial refinement and local up-scaling	Local	Seek further changes to research protocols; up-scale successful restoration options as feasible	Document possible local scaling pathways and approaches

[†]In Kajiado and Wajir no site-specific scaling strategy was developed, as the local institutions operating over large scales were directly involved in the research, enabling direct provision of information to institutional leadership for action.

Following initial discussions, candidate research partners in different geographies were selected for research needs assessments. These potential government and NGO partners were all actively conducting development initiatives at local level, ranging from 2-year projects to long-term support. These partners were sought out to support liaison with local institutions and producers, and to provide training and oversight to the local institutions managing the trials. Research needs were assessed in potential research partners' respective areas of implementation to qualitatively prioritize restoration objectives according to the perspectives of herders, farmers, and government and NGO practitioners working in the local area (Table A1.1, Step 2). Focus group discussions with herders and farmers comprised on average 10 participants per focus group, with 5 or more focus groups per potential research site. Interviews and focus groups recorded the views of 5-10 government and NGO practitioners per research site. Both focus groups and interviews were semi-structured and centered around several key considerations in land restoration: effectiveness of restoration options, feasibility and constraints, consistency of perceptions among and within stakeholder groups, and site-specific drivers of change, challenges, and innovations. This approach to assessing research needs ensured that a large suite of local stakeholders brought their views to bear on research priorities, and furthermore began the process of melding producers into a nascent community of practice (CoP). In each site, a CoP linked researchers directly to a government or NGO research partner, who in turn linked directly to local institutions' leadership and membership.

During the assessments, local land management institutions willing and able to host the research were identified. Since our focus was degraded communal grazing lands, and communal lands usually require collective action for restoration, we sought local or 'community' institutions representing residents and resource users. Our approach was to work with any and all willing existing institutions in the research sites, without regard to their 'strength' or other indicators of institutional capacity, which would add bias in scaling. Local land management institutions varied greatly in size and scale. Pastoral rangeland management institutions in East Africa working at the level of group ranches (communal ownership), government divisions, or traditional or customary rangeland divisions cover hundreds to thousands of km^2, with thousands to tens of thousands of residents and users. The scale of institutions was much smaller in the Ethiopian highlands, where local management institutions comprised government-designated user groups engaged in grazing exclosure for cut-and-carry fodder production on communal lands now closed to grazing by government mandate for land rehabilitation. User groups included exclosure user groups, youth groups, and participatory forest management (PFM) groups managing grassland areas, in exclosures with a mean area of 7.78 ha and mean membership of 164.5 households. At this stage, two potential sites and partners were discontinued for statistical and practical reasons. Although promising restoration options were being practiced in these areas (Guji Zone of Oromia Region, and Afar Region in Ethiopia), existing implementation did not provide sufficient replication to enable statistical analysis, nor could new experimental treatments be tractably introduced due to high costs.

The research process and results reported here focus on three sets of sites and research partners selected during the research needs assessments in Kajiado County and Wajir County in Kenya, and in Amhara Region in Ethiopia (Table A1.2). Where necessary research agreements were drawn up with research partners to guide the research by clarifying operations, roles and responsibilities, timelines, and expected results (Table A1.1, Step 3).

Table A1.2. Sites, research partners and local institutions engaged in action research.

Site	Primary research partner	Local land management institution(s)	Administrative areas	Latitude, longitude	Main livelihoods	Agricultural management intensity	Climate	Natural vegetation	Mean annual rainfall (mm/yr)	Elevation (m a.s.l.)
Kajiado County, Kenya	South Rift Association of Land Owners (SORALO)	Shompole and Olkiramatian Group Ranches	Magadi Ward, Kajiado West Sub-County	–1.943°, 36.168°	Pastoralism (semi-nomadic herding)	Extensive	Dry semi-arid	Savanna mixed grass and shrubs	500	600-700
Wajir County, Kenya	Wajir County Livestock Production Office, Department of Agriculture, Livestock and Fisheries	Burder Ward Community-Based Natural Resource Management Committee	Burder Ward, Wajir South Sub-County	1.213°, 40.388°	Pastoralism (semi-nomadic herding)	Extensive	Arid	Desert grassland and shrubland	300	150-190
Amhara Region, Ethiopia	Amhara Bureau of Agriculture (Amhara BoA)	24 exclosure user groups, youth groups, and participatory forest management (PFM) groups ('exclosure user groups')	Bahir Dar Zuria, Dangila, Dangila Zuria, North Achefer, North Mecha, Sekela, South Achefer, and South Mecha Woredas (Districts), in Awi and West Gojjam Zones	11.356°, 37.191°	Mixed farming, crops and livestock	Semi-intensive	Sub-humid to humid	Moist savanna to evergreen forest	1200-1600	1800-2600

The research needs assessments provided coarse-grained information on local management systems and priorities in communal grazing lands to enable ILRI researchers to propose designs for restoration trials. Draft protocols for action research trials were developed, circulated to research partners, and partners' comments incorporated into the protocols (Table A1.1, Step 4). Before rolling out the trials, another round of checks was conducted at local level with partners and producers.

This further step of research 'adaptation' thoroughly vetted protocols, indicators, and significant assumptions to ensure the applicability of the research as intended in the research localities as well as similar areas elsewhere (Table A1.1, Step 5). Draft protocols were explained to leadership and membership of local institutions in another round of 5 or more focus group discussions in each site. During these discussions, we documented how local livelihoods are derived from communal grazing lands, and how those lands and their livestock are managed, to qualitatively check research suitability. At this point, 'field supervisors' residing near the research locations were recruited through local institutions to oversee training and outreach on-site. The adaptation process significantly influenced the design and formed a conduit through which researchers could learn from and flexibly incorporate the local knowledge of herders and farmers in an explicit and practical manner.

Multi-stakeholder action research trials—additional information

Pastoral rangelands in East Africa are mostly extensive communal rangeland production systems, where many pastoralist producers aspire to intensify production. Pastoral areas face a number of impediments to intensification, including increasingly recurrent drought, high transaction costs for managing communal grazing lands with thousands of residents and users, and high stocking rates. Rangeland degradation varies widely, and is usually most severe near settlements, water points, and other pastures receiving little to no rest from grazing. In Kajiado and Wajir, the primary research partners and local institutions (Table A1.2) selected portions of the rangelands grazed heavily throughout the year. Heavy grazing in these areas is due in part to proximity to settlements and water, and due partly to local grazing systems in accordance with rules or by-laws of local institutions based largely on traditional or customary practice, such as the placing of settlements in areas that are inherently unproductive due to poor soils and pasture quality, and where degradation therefore carries a lesser cost. In Kajiado, restoration trials focused on wet season grazing areas of relatively lower pasture quality within the rangeland, which are located close to permanent settlements and water (Tyrrell et al. 2017). In Wajir, trials focused on dry season grazing areas of relatively higher pasture quality, yet similarly close to permanent settlements and water. The precise research locations were set by a group of herders residing nearby each research location, who identified the most degraded portions of the area where rehabilitation is needed most. As such, the short-resting and reseeding trial was targeted to: (*i*) the most degraded grazing areas within these rangelands; and (*ii*) the most degraded portions within those grazing areas.

Western Amhara Region and other sub-humid to humid areas of the Ethiopian highlands can be considered 'semi-intensive' and intensifying, with increasing use of fertilizer and other agricultural inputs, diminishing farm sizes, and contraction of grazing areas and other communal lands. In the highlands, grazing exclosures or 'area closure'—lands now closed to grazing for environmental rehabilitation according to government policy—are widely used where land has been severely degraded or is vulnerable to degradation from grazing. Livelihood benefits of exclosure to user group members are often constrained by poor cut-and-carry fodder quality due to heavy prior degradation, slow natural recovery, infestation by weedy or invasive forbs, grasses and shrubs (e.g., *Lamarckia aurea, Senna didymobotrya*), as well as labor and transport limitations. Improving the productivity of exclosure in the Ethiopian highlands can enhance farmer livelihoods on top of environmental gains from exclosure of degraded lands, and can significantly support major government and NGO initiatives on sustainable land management operating across the Ethiopian highlands.

Sets of restoration options (Table A1.2) were selected in part due to their relative freedom from constraints, which may lend them to willing and perhaps even spontaneous uptake. The criteria used to select potentially scalable restoration options included likely effectiveness, inclusive sustainability, rapid generation of livelihood benefits, simplicity, low cost, local availability, and appropriateness for the degree of system intensification and the direction of the local intensification trend. These low-cost options are likely to exhibit trade-offs with 'potentially maximally productive' options—which though potentially more productive generally incur greater cost and risk—options that may be difficult to scale until intensification proceeds further. Some more 'intensive' options were tested, specifically *C. gayana* in Amhara exclosures and range reseeding in Kajiado and Wajir.

While finalizing the protocols after the adaptation workshops, trade-offs among experimental design decisions that may significantly affect internal and external validity were considered, in seeking designs that do not compromise treatment effects or their generalisability. Beyond the treatments themselves, key decisions included criteria for selecting precise research plot locations, and the stringency of experimental controls. Adjustments made to experimental controls included non-trivial influences of herders, farmers, and research partners (Table A1.3). Significant protocol modifications included the size and arrangement of the research treatment areas—in Kajiado the research areas were reduced from 10.5 ha to 5.3 ha, while in Amhara the research areas increased from a total of 0.032 ha in 5 separate sections per exclosure, to a total of 0.084 ha in a single section. The dimensions of research areas is an important consideration, as smaller and fewer research areas reduce statistical power and flatten variability, while larger and greater numbers of research areas increase operational costs and short-term opportunity costs to producers. In one case a new treatment was added—in Amhara the *C. gayana* treatment was added upon repeated suggestion of farmers. Once the views of producers and government or NGO facilitators were documented and integrated, the final protocols were initiated according to the seasonal calendar.

Beyond identifying research needs and designing action research protocols, local institutions played multiple key roles in the research. Local institutions managed the research trials, with the assistance of practitioners from the primary government or NGO research partners. 'Field supervisors', producer members of the local institutions residing near the research locations, were recruited through local institutions to oversee training and outreach on-site, ensuring adequate sensitization of residents and resource users as to the purpose and approach to the research, and helping to cultivate local ownership over the research. Local institutions and their membership provided feedback and suggestions for improvement after the first round of each trial, assessed the outcomes of the trials in terms of producer preference, and were provided with the quantitative results from the trials. In the case of Amhara, local institutions took the further steps of planning and implementing up-scaling of their preferred treatments within their exclosures.

Table A1.3. Multi-stakeholder influences on action research trial design.

		ILRI and ILRI partner influences	**Producer influences (herders/farmers)**	
Site (primary partner)	**Action research trial**	*Systematized variables*	*Systematized variables*	*Non-systematized variables*
Kajiado & Wajir Counties, Kenya (SORALO; Wajir County Livestock Production Office)	Short-resting and reseeding	Resting and reseeding treatments Species selection, reseeding method in reseeding treatments Plot and assessment design	Treatment area Resting and reseeding dates Preferred vs. non-preferred species	Location of research plots (degraded areas) Fencing of research plots Post-opening grazing intensity Wildlife use intensity
Amhara Region, Ethiopia (Amhara Bureau of Agriculture)	Exclosure productivity improvement	Weeding, re-planting, and plowing/planting treatments Species selection and method of propagation in plowing/planting treatments Weeding frequency Location of research plots (random) Plot and assessment design	Plowing/planting treatments Species selection and method of propagation in plowing/planting treatments Treatment area Plowing, weeding, and planting dates Major weed species to remove Preferred vs. non-preferred species	Plowing and weeding methods Weed species to remove

Trial details—additional information

Short-resting and reseeding trial—Kajiado and Wajir. To prevent over-estimation of resting effects from measuring outcomes immediately after resting—measuring forage likely to disappear within the first week or weeks of grazing which does not contribute to land restoration—outcome measurements were taken 3 months after the resting blocks were first closed. That is, measurements were taken 1 month after the 2-month resting areas were re-opened to grazing, and 2 months after the 1-month resting areas were re-opened. These resting effects are conservative under-estimates because 1 or 2 months of grazing reduces forage cover, with the effects of 1 of month rest particularly under-estimated. Other aspects of trial design reinforced conservative estimation: (*i*) we asked research partners and community members to target the research areas to the most bare, degraded areas (at baseline the central 2 month treatments had 10.98% vegetation cover on average as compared to 14.89% in controls in Kajiado; in Wajir, 32.38% versus 37.15% respectively); (*ii*) in some cases bush-fencing materials were cut from inside the resting areas, which was corrected for by adding back any declines in woody cover > 5%, which could not be explained by other causes; and (*iii*) no fertilizer or other amendments were made.

Exclosure productivity improvement trial—Amhara. Whereas most farmers in the area apply manure when planting forages, here no fertilizer was used in order to conservatively under-estimate exclosure improvement effects, so that the results will be useful should farmers neglect to apply fertilizer, while more committed farmers will be pleased with results above expectations. In some sites, late planting was an unplanned factor that contributed to conservative estimation (precise planting dates could not be verified). Biomass was quantified by visually estimating biovolume in the field (cover and height), and converting biovolume to biomass using site-specific equations developed from a subset of biomass samples taken in November 2017 from the weeding and control treatments (biomass sampled in 2 of 8 1-m^2 quadrats per treatment per research location), and for the improved forage *P. pedicellatum* and *C. gayana* treatments (2 1-m^2 quadrats per location each). Since the baseline indicated significant grass cutting in most sites, ANCOVA with baseline values as a continuous predictor could not be used, and therefore ANOVA was used to analyse peak, end-of-season biomass yield, crude protein (CP) yield, and nutritional content (CP and *in vitro* digestibility) of forages locally preferred for cut-and-carry livestock feeding.

Outliers removed. One research location (settlement) in Wajir (with 3 research areas) where the resting research areas were used as a *boma* (corral) for holding livestock was removed as an outlier; no outliers were detected in Kajiado. In Amhara, a wetland exclosure (containing a single research plot) with exceptionally high productivity (42.1 t/ha for pre-existing grasses; 34.9 t/ha for *P. pedicellatum* by trial year 2; *C. gayana* failed) was removed as an outlier.

Iterative trial refinement and local up-scaling

During the second round of trials between the first and second outcome assessments, changes were solicited from CoPs at the levels of producer members of community institutions as well as the research partners to adaptively modify protocols in response to qualitative first-round outcomes (Table A1.1, Step 9). However, no substantive changes were proposed or enacted. Farmers in Ethiopia did provide recommendations on modifications likely to be useful in scaling. Farmers suggested augmenting planting of *C. gayana* by using oxen to compress seeds onto the soil surface, following local practice for planting of *teff* crops (*Eragrostis tef*). On rocky hillsides, farmers suggested planting 20 cm contour strips of *P. pedicellatum* with 80 cm spacing of pre-existing vegetation.

Local up-scaling potential (Table A1.1, Step 9) was assessed through stated or revealed producer preferences. After two trial rounds, stated or revealed producer preferences provided additional evidence on restoration effectiveness and feasibility. Producer members and leaders of local institutions in Kajiado and Wajir ranked restoration option performance (stated preferences) and assessed up-scaling viability. In Amhara exclosure user groups were offered minimum support (*C. gayana* seeds and *P. pedicellatum* root cuttings were provided free of charge by Amhara BoA, and transport for cuttings by ILRI) to begin willing and independent up-scaling (revealed preferences).

Literaure cited in additional methodology

Tyrrell, P., S. Russell, and D. Western. 2017. Seasonal movements of wildlife and livestock in a heterogenous pastoral landscape: Implications for coexistence and community based conservation. *Global Ecology and Conservation* 12:59–72. https://doi.org/10.1016/j.gecco.2017.08.006

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Sircely, J., I. Nganga, T. Temesgen, and E. Zerfu. 2020. *Introduction to multi-stakeholder action research for restoration of communal grazing lands-ILRI Research Report 63*. International Livestock Research Institute (ILRI), Nairobi, Kenya. https://hdl.handle.net/10568/110395

2. Additional Results

Table A1.4. Reseeding success and failure summary for Kajiado and Wajir in Kenya. Reseeding was conducted once at the onset of the 2018 'long rains' season.

Site	Season	Rainfall	Reseeding success rate† (% of research areas)	Reseeded grasses present (% of research areas)	Reseeded grass species recorded
Kajiado, Kenya	Long rains 2018	Good rains	62.5	92.9	*Cenchrus ciliaris, Cymbopogon pospischilii, Enteropogon macrostachyus, Eragrostis superba, Sehima nervosum*
	Short rains 2018-2019	Poor rains	0.0	21.4	*Cenchrus ciliaris*
Wajir, Kenya	Long rains 2018	Poor rains + inundation	0.0	70.0	*Cenchrus ciliaris, Enteropogon macrostachyus*
	Short rains 2018-2019	Poor rains (drought)	0.0	0.0	na

†Successful reseeding defined as a minimum of 20% of the reseeded area occupied by reseeded grasses

Table A1.5. Hypothetical project-level payoffs from investment in exclosure productivity improvement treatments, assuming full treatment of the entire area within the 24 experimental exclosures in Amhara, Ethiopia, according to soil types and soil constraints, exclosure *n* and exclosure area (ha). These calculations are indicative yet hypothetical since replication within 'soil type × soil constraint' groups was insufficient for formal valuation (for example, weeding 'payoffs' express high error). Δ-Biomass (t/ha change from controls) and success rate (success defined as a minimum of 20% of planted area occupied by improved forages) are observed values from the exclosure productivity improvement trial, indicating observed changes in biomass production over a 2-year period. 'Payoff per unit area' = *Δ-Biomass* × *Success rate*, in units of tons per hectare (t/ha) of additional fodder biomass over and above controls (or below). 'Total payoffs' for the entire project are in tons (t) of additional fodder biomass. Value in US Dollars (USD$) and Ethiopian Birr (ETB) in 2017 are based on mean nearest local market (*kebele* or *woreda* level) value of dry hay at 1.36133 ETB/kg (40.84 ETB/bundle) from surveys conducted with all exclosure user groups (using the present exchange rate of 36.9709 ETB/USD and assuming marketed dry hay contains 50% moisture and 50% oven dry biomass).

Soil type (color)	Soil constraint (if any)	*n*	Area (ha)	Treatment	Δ-Biomass (t/ha)	Success rate (%)	Payoff per unit area (t/ha)	Total payoff (t) assuming mean area (7.78 ha) as standard	Total payoff (t) given actual exclosure area	Total payoff value in USD$ (ETB) given actual exclosure area
Eutric Nitisol, Ne (red)	Poor soil (rocky/ shallow)	4	49.27	*P. pedicellatum* (Desho grass)	3.1	87.5	2.71	84.41	534.58	19,684 (727,741)
				C. gayana (Rhodes grass)	-0.2	37.5	-0.08	-2.33	-14.78	-544 (-20122)
				Weeding	0.3	100.0	0.30	9.34	59.12	2,177 (80,487)
				No treatment (Control)	0.0	100.0	0.00	0.00	0.00	0 (0)
Eutric Nitisol, Ne (red)	None (arable)	8	37.25	*P. pedicellatum* (Desho grass)	6.5	100.0	6.50	404.56	1937.00	71,324 (2,636,903)
				C. gayana (Rhodes grass)	-0.2	100.0	-0.20	-12.45	-59.60	-2,195 (-81,135)
				Weeding	0.7	100.0	0.70	43.57	208.60	7,681 (283,974)
				No treatment (Control)	0.0	100.0	0.00	0.00	0.00	0 (0)
Pellic Vertisol, Vp (black)	None (arable)	6	21.39	*P. pedicellatum* (Desho grass)	5.3	83.3	4.41	206.09	566.61	20,864 (771,343)
				C. gayana (Rhodes grass)	-1.3	100.0	-1.30	-60.68	-166.84	-6,143 (-227,128)
				Weeding	-0.3	100.0	-0.30	-14.00	-38.50	-1,418 (-52414)
				No treatment (Control)	0.0	100.0	0.00	0.00	0.00	0 (0)
Pellic Vertisol, Vp (black)	Inundation (annual)	3	53.75	*P. pedicellatum* (Desho grass)	-10.1	33.3	-3.36	-78.50	-542.33	-19,970 (-738,295)
				C. gayana (Rhodes grass)	-10.1	0.0	-10.10	-235.73	-1628.63	-59,969 (-2,217,102)
				Weeding	1.3	100.0	1.30	30.34	209.63	7,719 (285,370)
				No treatment (Control)	0.0	100.0	0.00	0.00	0.00	0 (0)
Humic Nitisol, Nh (brown)	Inundation (annual)	3	25.05	*P. pedicellatum* (Desho grass)	-0.9	100.0	-0.90	-21.01	-67.63	-2,490 (-92,074)
				C. gayana (Rhodes grass)	-7.3	0.0	-7.30	-170.38	-548.60	-20,200 (-746,821)
				Weeding	0.1	100.0	0.10	2.33	7.52	277 (10,230)
				No treatment (Control)	0.0	100.0	0.00	0.00	0.00	0 (0)

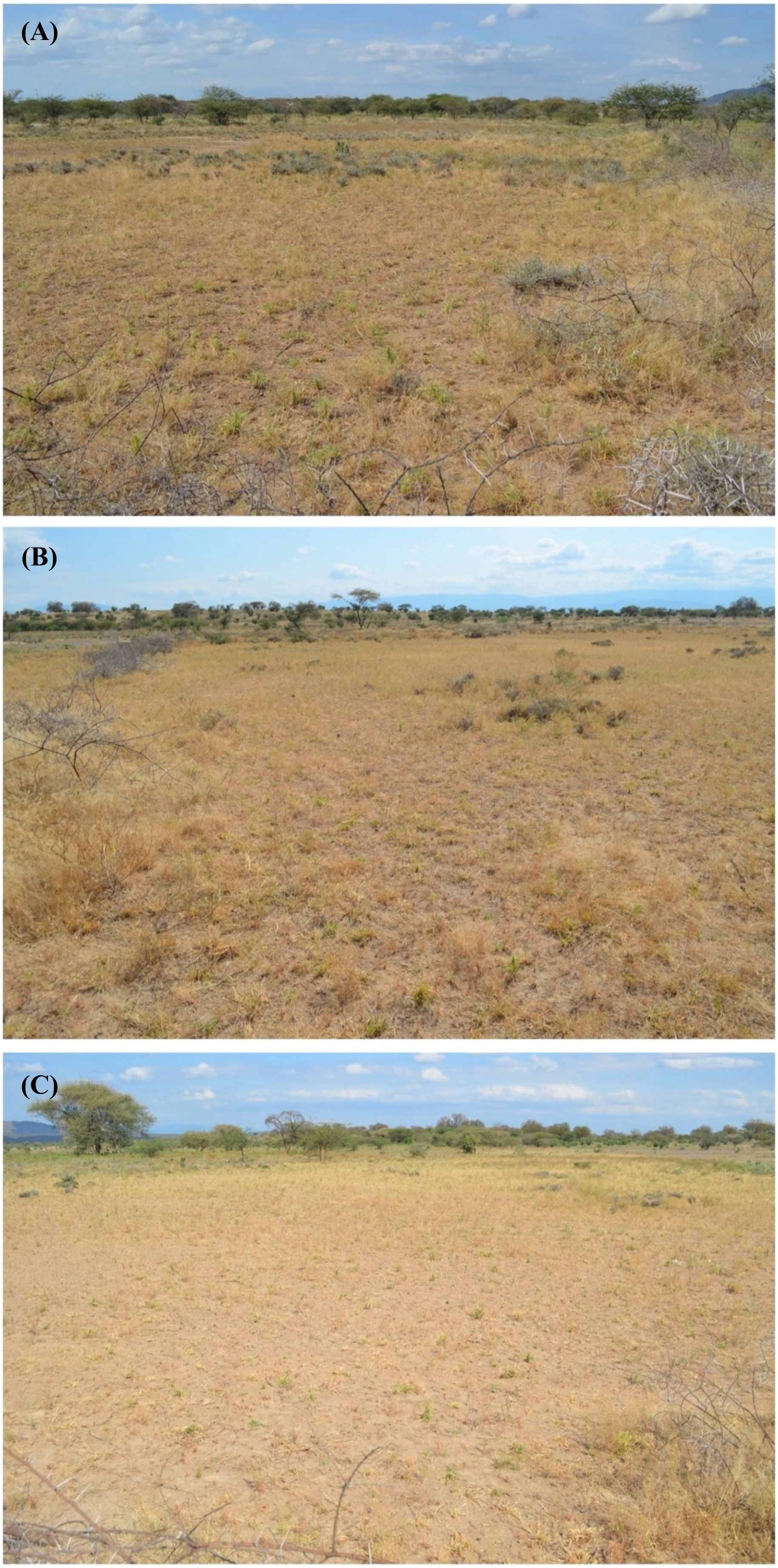

Fig. A1.1. Kajiado, Kenya: Fence-line photos of average resting effects for (A) 2-month resting; (B) 1-month resting; (C) control (no rest) with continuous heavy grazing, July 2018 (outcome 1, 2018 long rains); same location, date, time. Photo credit: ILRI/Jason Sircely.

Fig. A1.2. Wajir, Kenya: Before/After photos of resting effects (above average) for 2-month resting in (A) March 2018 (baseline); and (B) July 2018 (outcome 1, 2018 long rains). Photo credit: ILRI/Jason Sircely.

Fig. A1.3. Amhara, Ethiopia: Exclosure research and initial scaling; (A) foreground shows the research area with *P. pedicellatum* (Desho) at left, *C. gayana* (Rhodes) at right, and weeding to the sides; background shows the up-scaling area plowed for spontaneous independent planting of 50% each of *P. pedicellatum* and *C. gayana* in a total of 0.25 ha, August 2018; and (B) control (unimproved exclosure) from the same exclosure as (A) with *Cynodon dactylon* (couch grass) and heavy weed infestation, August 2018. Photo credit: ILRI/Jason Sircely.