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

Sircely, J. 2016. Restoring Ethiopian drylands at scale. International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia. https://hdl.handle.net/20.500.11766/4644

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)

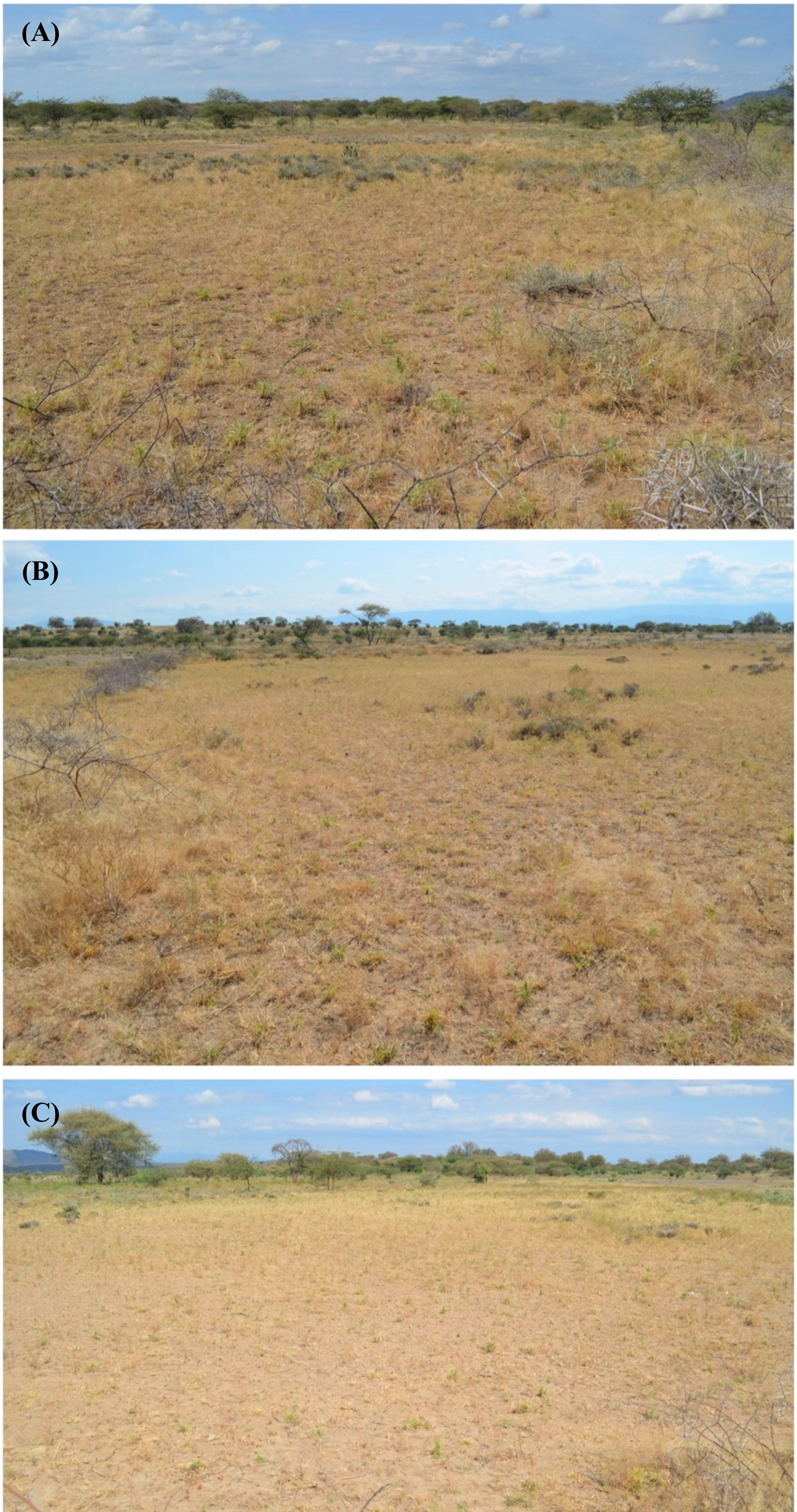

Fig. A1.1. Kajiado, Kenya: Fence-line photos of average resting effects for (A) 2-month resting; (B) 1-month resting; (C) control (no rest) with continuous heavy grazing, July 2018 (outcome 1, 2018 long rains); same location, date, time. Photo credit: ILRI/Jason Sircely.

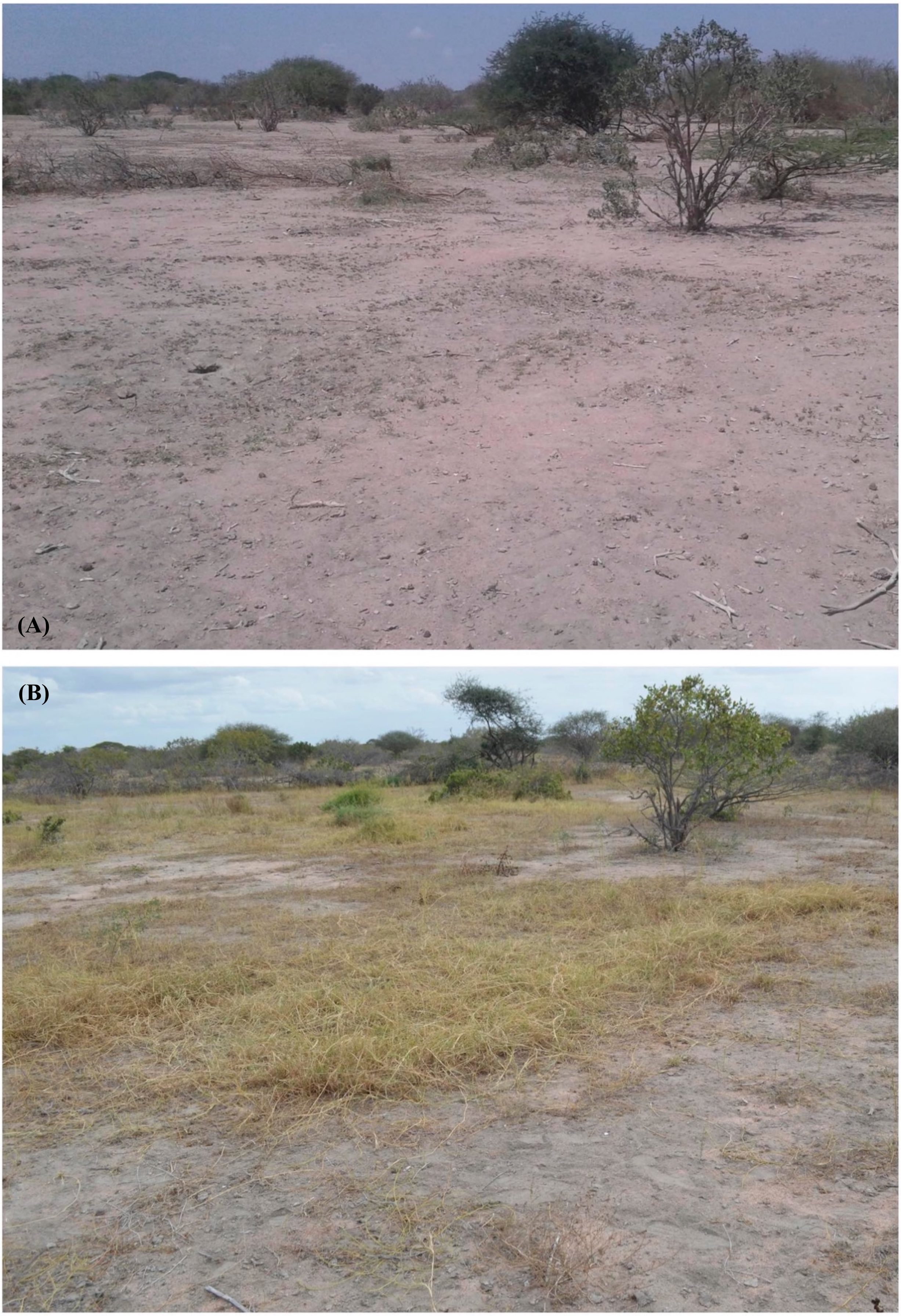

Fig. A1.2. Wajir, Kenya: Before/After photos of resting effects (above average) for 2-month resting in (A) March 2018 (baseline); and (B) July 2018 (outcome 1, 2018 long rains). Photo credit: ILRI/Jason Sircely.

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.