Supplementary Information for:

Cooperation in the commons: Community-based rangeland management in Namibia

D. Layne Coppock[1], Lucas Crowley[2], Susan L. Durham[3], Dylan Groves[4], Julian C. Jamison[5], Dean Karlan[6*], Brien E. Norton[7], R. Douglas Ramsey[7]

[1] Department of Environment and Society, Utah State University, Logan, UT 84322-5215, USA. [2] Innovations for Poverty Action, Washington D.C., 20005, USA. [3] Ecology Center, Utah State University, Logan, UT 84322-5205, USA. [4] Department of Political Science, Columbia University, New York City, NY, 10027, USA. [5] Department of Economics, University of Exeter, Exeter EX44LZ, U.K. [6] Kellogg School of Management, Northwestern University, Evanston, IL 60208, USA. [7] Department of Wildland Resources, Utah State University, Logan, UT 84322-5230, USA.[*]To whom correspondence should be addressed. E-mail: karlan@northwestern.edu

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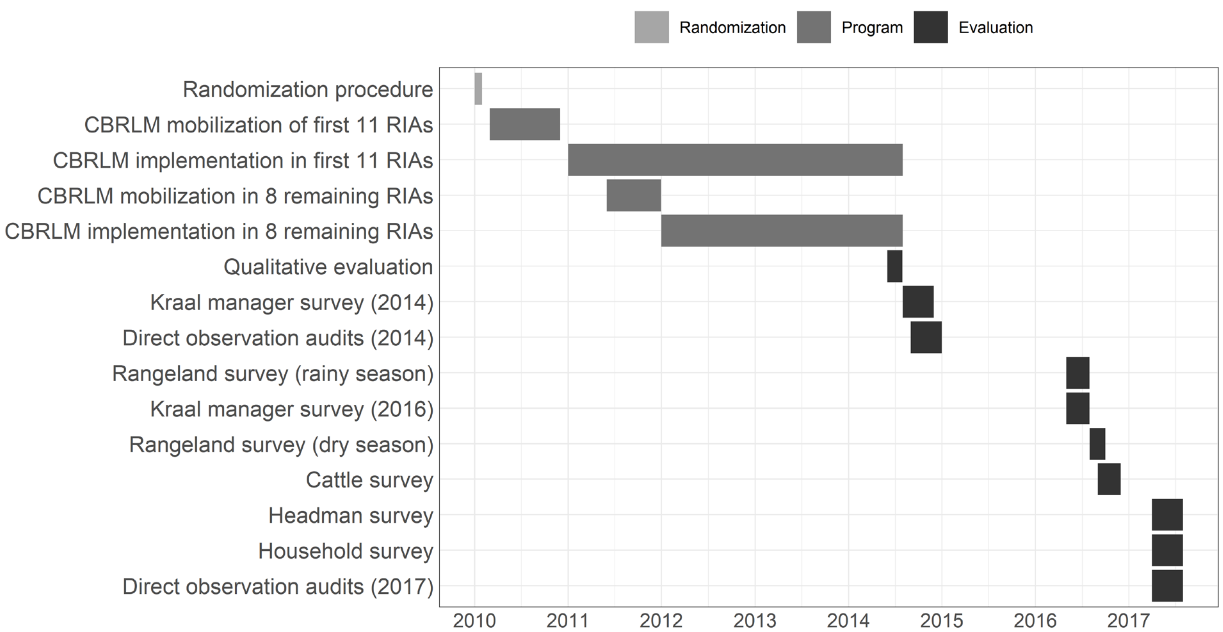
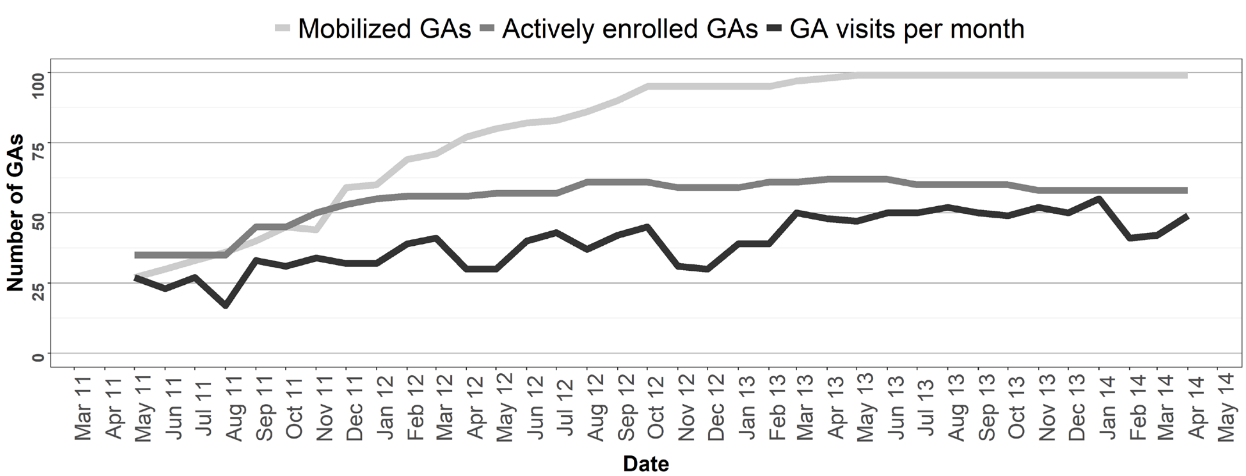
1. **Supplementary Methods**

a. **Study timelines**



Supplementary Fig. 1. Timelines for CBRLM mobilization, implementation, and the research components.



Supplementary Fig. 2. Timelines for GA mobilization, GA enrollment, and GA visits by GOPA staff.

b. Data collection

i. Primary outcome variable definitions

Definitions of social variables depicted in Fig. 2 (see Main Text) and Extended Data Table 1 are as follows:

(a) *Grazing planning* is an index of three variables measuring whether the manager has a grazing plan and whether the grazing plan is written.
(b) *Grazing plan adherence* is an index of two variables measuring whether and for how long the herd manager followed a pre-defined grazing plan while herding cattle.
(c) *Herding practices* is an index of seven variables measuring whether the herd manager follows herding practices recommended by the program, such staying with the cattle throughout the day and herding cattle in a bunch.
(d) *Herder management* is an index of five variables measuring the extent to which the herd owner provides oversight and material support to herders.
(e) *Cattle husbandry* is an index of nine variables measuring whether the herd manager follows cattle husbandry practices recommended by the program, such as vaccinating and deworming cattle.
(f) *Herd restructuring* is a measure of whether herd owners have made any decisions to buy or sell cattle in order to change the structure of their herd, as opposed to reasons such as immediate financial need or sick cattle.
(g) *Livestock marketing* is an index of three variables measuring whether the herd owners sold any cattle, the number of cattle sold, and the total value of cattle sold.
(h) *Community governance* is an index of 12 variables measuring whether respondent perceives their community to be governed by institutional rules.
(i) *Collective action* is a measure of 19 variables measuring whether respondents engaged in collective management behaviors, such as group grazing planning, combined herding, group payment for vaccines.
(j) *Community disputes* is an index of three variables measuring the number of unresolved community disputes with other farmers inside and outside of the grazing area.
(k) *Trust* is an index of two variables measuring whether the respondent trusts other individuals in the community.
(l) *Expertise* is an index of six variables measuring herd manager expertise and access to expertise about cattle husbandry and marketing.
(m) *Self and community efficacy* is an index of four variables measuring herd manager's beliefs that their actions or the actions of their community can influence cattle and rangeland outcomes.

Definitions of social variables depicted in Fig. 3 (see Main Text) and Extended Data Table 2 are as follows:

(a) *Income* is the total income earned by the household per week.
(b) *Expenditure* is the total consumption and expenditure by the household per week.
(c) *Household livestock wealth* is an index of cattle and non-cattle livestock units owned by the household.

(d) *Time use* is an index of six variables representing time spent on economically productive activities by adults in the household (positive) and children in the household (negative).
(e) *Resilience* is an index of six variables measuring the household's resilience to economic hardship, including food security and savings.
(f) *Female empowerment* is an index of three variables measuring economic empowerment of women in the household.
(g) *Meat/dairy consumption* is an index of two variables measuring household consumption of meat and dairy products.

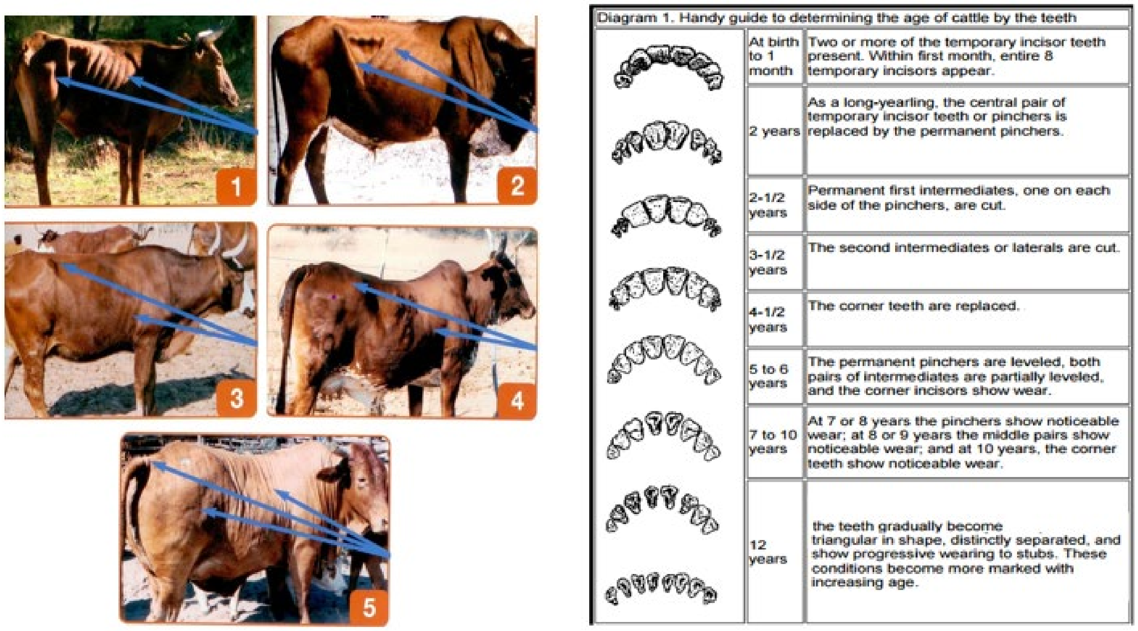
Definitions of cattle variables depicted in Fig. 3 (see Main Text) and Extended Data Table 2 are as follows:

(h) *Cattle herd value* is an index of three variables measuring the value of the cattle herd in total number, total weight, and total market value.
(i) *Herd productivity* is an index of seven variables measuring the health and productivity of the cattle herd, including calving rate, herd expansion, milk production, and average weight and body condition.
(j) *Herd structure* is an index of three variables measuring whether the herd has a higher ratio of bulls to cows, total cattle to oxen, and total cattle to old and unproductive cattle.

Definitions of variables depicted in Fig. 3 (see Main Text) and Extended Data Table 2 are as follows, and methods are reviewed below:

(a) *No site erosion* is the estimated degree of soil surface disturbance;
(b) *Protected soil surface* is the percentage of ground area shielded by plant material or rock;
(c) *Plant litter cover* is the percentage of ground area shielded by dead plant material;
(d) *Herbaceous canopy cover* is the percentage of ground area shaded by grass and forb foliage;
(e) *Perennial to annual ratio* is the ratio of respective canopy coverages for perennial and annual grasses;
(f) *Grass to forb ratio* is the ratio of total grass canopy cover to total forb canopy cover;
(g) *No stinkbush* (*Pechuel-Loeschea leubnitziae*) is an indicator of noxious weedy species, as measured by percent canopy coverage;
(h) *Grass to Aristida ratio* is the ratio of respective canopy coverages for total grasses excluding Aristida and all Aristida species—Aristida in this context are undesirable forage plants; and
(i) *Shrub canopy cover* is the percentage of ground surface shaded by shrub foliage.

ii. Cattle scoring key



(A) (B)

Supplementary Fig. 3. Field guides for (A) assessing cattle body condition scores (1-5) and (B) cattle age[1].

2. Supplemental Text

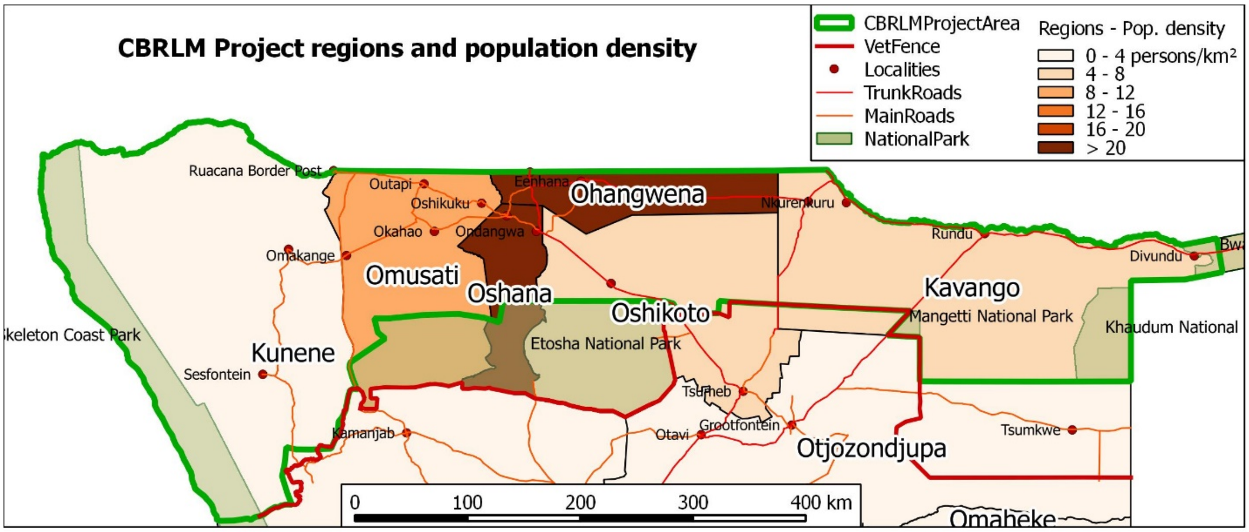
a. Context

i. Social context

Namibia is the driest country in sub-Saharan Africa, and pastoral livestock production is its predominant agricultural system[2]. In the far north of the country, higher rainfall allows for mixed crop and livestock farming. Land holdings in the country fall into two broad categories: a commercial sector under freehold title (44% of the land), and other areas referred to as communal lands (41%) and state lands (15%)[2]. The communal lands are occupied by peoples whose livelihoods have been traditionally subsistence-oriented.

The Community-Based Rangeland and Livestock Management (CBRLM) program took place in Namibia's Northern Communal Areas (NCAs)[3]. The CBRLM was funded under the auspices of the Millennium Challenge Account-Namibia, and was implemented by a consulting firm called *Gesellschaft für Organisation, Planung und Ausbildung* (GOPA)[3]. The CBRLM spanned seven administrative regions including: Kunene, Omusati, Oshana, Oshikoto, Ohangwena, Kavango West and Kavango East. Together these cover an area of about 170,000 km^2 (Supplementary Fig. 4). The area can be approximated by a rectangle that is 800 km long (East to West) and 200 km wide (South to North). The NCAs have a predominantly warm and dry climate with a pronounced seasonal distribution of precipitation. Ecological details are reviewed later in this section.

The NCAs are divided from the rest of the country by the Veterinary Cordon Fence (VCF), which demarcates privately owned ranches of the south from the customary land of the north[4]. Historically, the VCF was erected to limit the spread of foot-and-mouth disease (FMD) and other bovine illnesses originating in the NCAs or southern Angola. While FMD outbreaks are sporadic today and largely confined to the Zambezi region in the far northeast of Namibia, the VCF remains an important political and economic boundary—pastoralists and farmers in the North are not allowed to sell their cattle in the South, with the recent exception of some quarantine camps along the Angolan border.



Supplementary Fig. 4. CBRLM project regions and human population density (*20*).

The majority (55%) of Namibia's 2.1 million inhabitants live in the NCAs[2]. This makes the NCAs, particularly the north-central regions, the most densely populated areas of the country. According to the population and housing census of 2011, there are about 220,000 households in the NCAs, 80% of which occur in rural areas[5]. The dominant ethnic groups include the Ovambo, Kavango, and Herero peoples[2]. Cattle outnumber people in the NCAs; during the last government bovine ear-tagging campaign before CBRLM implementation, the Namibian Department of Veterinary Services estimated 1.4 million cattle across the north[6]. While this constitutes about half of the cattle in Namibia, the NCAs only contain about 25% of Namibia's arable land. Cattle in the North have much less room to graze per head compared to those in the South.

Most arable land in the NCAs is communally owned, meaning that it is the formal property of the state and fencing it is illegal, except for a limited allowance for homesteads and cultivated fields[2]. Historically, the open nature of grazing land in the North has enabled pastoralists to practice seasonal transhumance in regions that favor it, which mitigates some problems due to drought and shortages of fodder. However, grazing patterns have changed in recent years; population pressure, illegal fencing, and proliferation of boreholes have encouraged many pastoralists in the North to adopt more sedentary lifestyles. These factors have accelerated degradation of an already fragile ecosystem[7].

Within the seven administrative regions listed above, the CBRLM operated across 11 areas governed by Traditional Authorities (TAs)[3]. TAs allocate communal land, regulate communal land use, and formulate and enforce customary law[8]. Within each TA the GOPA implementation team mapped Rangeland Intervention Areas (RIAs) where CBRLM could be implemented. Wherever possible, RIAs conformed to the boundaries of pre-existing Communal Area Conservancies or Community Forests[3]. Where no Communal Area Conservancy or Community Forest existed, the implementation team worked with TAs to map appropriately sized intervention areas in their jurisdiction[9]. Each RIA contains five to 15 Grazing Areas (GAs). The GAs are communal rangeland parcels used by five to 50 cattle kraals; herd owners in each GA share forage and water resources. The cattle kraals are overnight holding pens for cattle herds owned by one to five households (usually extended family members). Households that share a kraal usually designate or hire a herd manager who is responsible for day-to-day management of cattle but does not generally make decisions with regards to buying, selling, or health treatments without the consent of the cattle owners. The size, makeup, and economic status of herding households varies greatly across Northern Namibia[6]. Most GAs have a local headman who is a member of the TA and is responsible for admission of new herd owners to the GA as well as the management of community disputes. In practice, the extent of the power of the local headman varies substantially among GAs.

CBRLM was intended to improve cattle raising by facilitating herd restructuring, animal husbandry, and cattle marketing. GOPA hoped that the intervention would improve the productivity and economic viability of cattle rearing in the NCAs[10]. Previous research points to low bull-to-cow ratios, low calving rates, and inadequate weaning practices as causes for poor productivity[11,12]. Others have argued that greater integration between small-scale communal pastoralism and livestock markets could also alleviate such problems. However, there are significant practical barriers to raising cattle for profit in northern Namibia; many cattle producers are absentee owners and marketing transaction costs can be a hindrance[13].

Such challenges are reflected in the broader literature on African pastoral development. Some critics of cattle commercialization projects argue that raising cattle for the formal market on communal land is not economically viable, and that development interventions should enhance herd productivity for its own sake[10]. There is also debate over factors that keep communal pastoralists from selling cattle in the formal economy. One argument is that for pastoralists the primary economic value of cattle comes not from income-generating potential but rather from their use as insurance[14]. In this view, cattle are a reliable store of wealth and animals are primarily sold during crisis. Others argue that reluctance to sell cattle comes from their value as social capital[15].

Water development is another key issue. The question of how to protect and sustainably maintain water resources is urgent in Namibia. Like many developing countries, the Namibian government has adopted a community-management approach to the maintenance of boreholes in rural areas[16,17]. However, water users often fail to pay their fees, especially in areas where governance is weak. Moreover, during times of drought water users often ignore externally imposed regulations in favor of traditional customs of reciprocity[16,17].

As will be described, the CBRLM project was conceived not only as a check on environmental degradation, but as a means of community self-help. New GA committees were created and incentivized to pool financial resources to fund cattle production inputs like vaccines, feed supplements, and herder salaries; CBRLM also invested in the development of local marketing cooperatives. As such, the CBRLM is an example of a partnership to create processes referred to as community-driven development (CDD). This is an increasingly popular concept in international development (see Main Text), but the literature on its efficacy is mixed[18]. Related evidence from recent randomized evaluations suggests that community-driven development can successfully deliver infrastructure and economic returns, but has less success sustainably affecting community governance and creation of social capital[19,20] and may even crowd-out pre-existing local institutions dependent on the beliefs of constituents with respect to local politics[21].

The Namibian government has previously pursued several projects meant to reduce rangeland degradation and improve livestock production in the NCAs. A project called the Northern Regions Livestock Development Project (NOLIDEP) took place from 1995-2003 and had a general focus on commercialization of livestock production, with specific attention to community capacity building and provision of strategic inputs such as rural veterinary clinics and water points[22]. Another effort, referred to as the Sustainable Animal and Rangeland Development Program (SARDEP), has existed in Namibia for over two decades with a focus on creating more sustainable linkages between rural producers and service institutions, as well as supporting dialogue to create national policies regarding sustainable use of natural resources[23].

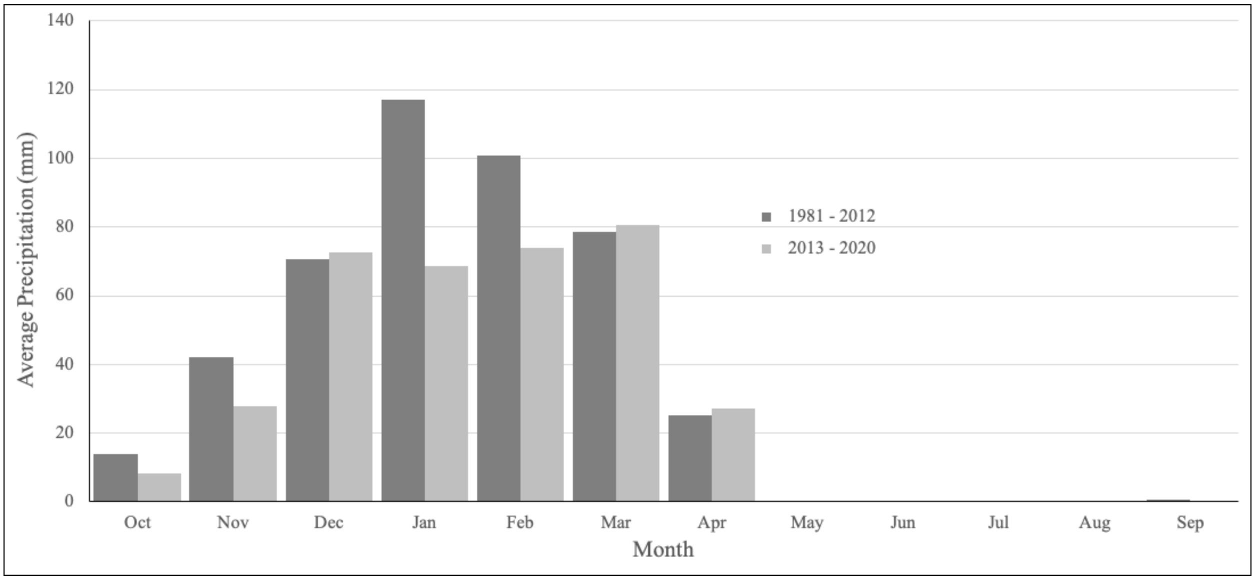
ii. Ecological context

In terms of ecological systems, the NCAs are diverse[2]. The topography is generally flat with only the extreme western region exhibiting topographic variation towards the Great Escarpment in Kunene (Supplementary Fig. 4). Precipitation has a distinct East to West gradient, with the West being drier than the East[2]. Across the entire study region, annual precipitation averages just under 400mm with high variability[2]. The main wet season occurs from January to March with precipitation steadily dropping after April. A distinct dry period occurs from May to September. During June through August the study region typically receives only scant precipitation[2].

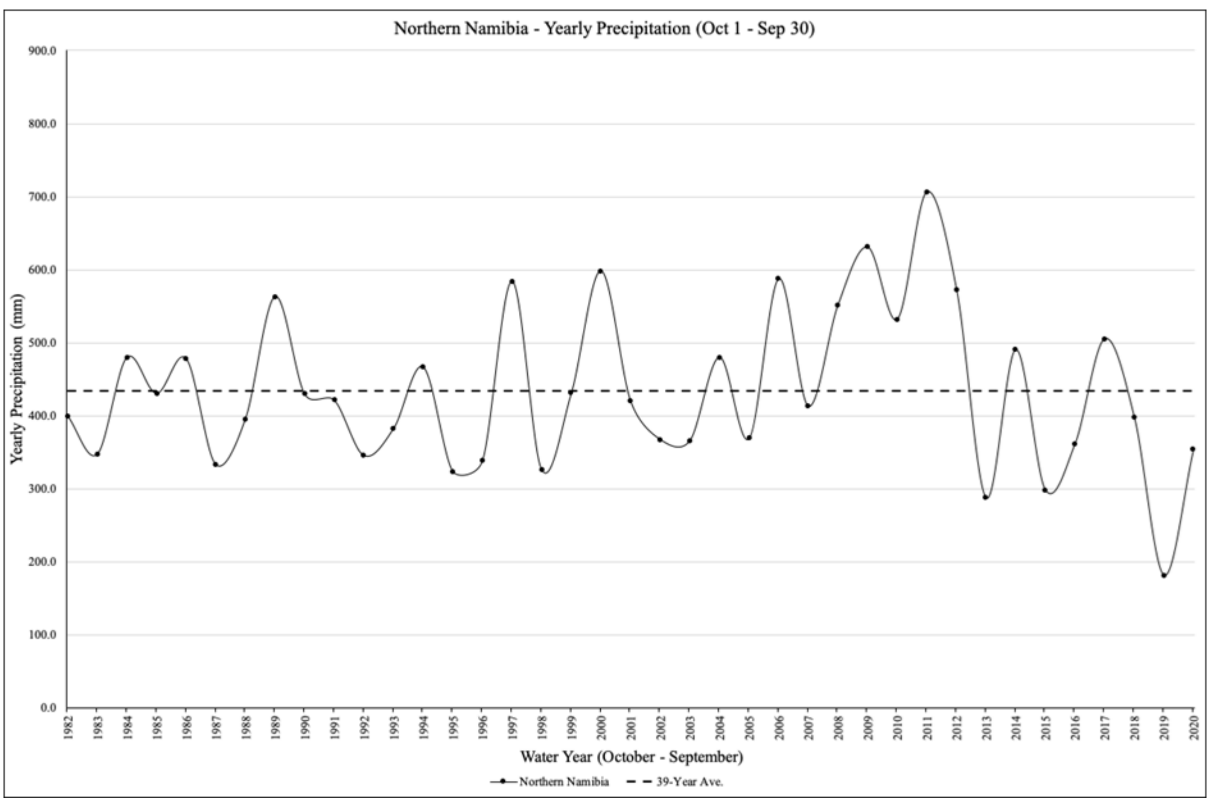
Soils are diverse and are dominated by sandy, silty, or clay substrates[2]. Vegetation community types include grasslands, shrublands, bushlands, and savannas[2]. Localized heavy livestock grazing over many years is associated with the sedentarization of human settlement and borehole development[7,24]. Woody encroachment and conversion of herbaceous perennial communities to annual plants are common ecological responses to overuse of these rangelands[7,24].

As with most drylands of the world, low and highly variable precipitation is the norm in northern Namibia. Drought, defined here as one or more years of below-average precipitation that negatively affect socioeconomic attributes, is common. Resource use systems such as pastoralism have evolved to cope with drought.

Our study region in northern Namibia has experienced a significant decline in rainfall in the past eight years (e.g., 2013 to 2020) when compared to the previous 31 years beginning in 1981. This is illustrated by superimposing the monthly rainfall distributions in Supplementary Fig. 5. Precipitation data are based on the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data set consisting of daily modeled precipitation from January 1981 to the present with a ground resolution of 5.5 km. The overall decline in precipitation is on the order of 36%, with notable decreases from the main wet season months of January, February, and March. Annual variation has been substantial over the past 39 years—and possibly increasing—as illustrated in Supplementary Fig. 6. These data suggest that CBRLM was implemented and evaluated during a particularly dynamic period. The project implementation phase of 2010 to 2014 may have been wetter than average, while the evaluation phase of 2014 to 2017 may have been drier than average. The implications of such dynamism for pastoral development outcomes from CBLRM are explored in subsequent sections.



Supplementary Fig. 5. Average monthly precipitation in northern Namibia for two periods, 1981 to 2012 and 2013 to 2020. Data are organized according to water year that commences October 1[25].



Supplementary Fig. 6. Annual precipitation patterns from 1981 to 2020 for northern Namibia[25].

b. Scientific rationale for planned grazing

Rotational grazing (often lumped into the category of 'planned grazing' or 'prescribed grazing') has become a popular resource management strategy for averting environmental degradation and increasing sustainable levels of forage and livestock production. The essential practice of rotational grazing consists of combining herds that would otherwise graze independently into one or more large herds. Herders then move these large herds around the landscape, spending a short period in one location before moving to a new location. Allan Savory[26,27] espoused the idea that this form of intensively managed grazing replicates co-evolved, sustainable relationships between grasses and large grazing animals, and that such interactions can be used to restore damaged rangelands.

The core idea is that grasses have evolved to withstand frequent herbivory and will be most productive when defoliated at a judicious frequency. Therefore, grasses in any given area should be subjected to intensive, short bursts of heavy defoliation and then allowed time to recover before subsequent waves of grazing. In a planned grazing rotation, livestock may occupy a grazing location for just a few days to a week or so—in some forms of rotational grazing the grazing period is just one day—and are herded together at high stocking density. This high-density grazing creates a 'herd effect' imposing concentrated disturbance to the soil that Savory believes is an important factor contributing to rangeland rehabilitation[26]. Savory has been one of the more high-profile advocates of rotational grazing since 1978 when he first presented his ideas, most of which were based on a book by French agronomist André Voisin[28] at the First International Rangeland Congress. Voisin pointed out that the concept of rotational grazing has been around since at least the late 18th century, but it has become common practice for ranchers and pastoralists on a global scale during only the last few decades.

Practitioners of rotational grazing see the benefits occurring more in terms of extended rest periods that allow the vegetation to recover from defoliation, rather than the impact of animal hooves disturbing the soil and breaking up dead plant material on the surface. They also observe changes in plant composition of the pasture or rangeland in which palatable species tend to increase at the expense of less palatable and weedy plants. In his review of relevant literature, Norton[29] noted that the rest periods protecting plants from grazing allow greater total forage production, and that increased above-ground photosynthetic biomass builds a larger root system penetrating deeper into the soil profile. However, Briske et al.[30] reported that while there has long been widespread concurrence among range scientists, federal land managers, and commercial ranchers regarding the efficacy of rotational grazing on US rangelands relative to continuous grazing, this distinction has not been supported by hard scientific evidence from grazing trials on research stations.

Many research trials comparing rotational grazing to continuous grazing have failed to find a consistent and significant benefit to either forage yield or livestock production[30,31]. Trials were conducted on research stations where the experimental paddocks were small and research herds likewise small, sometimes only 3-4 head of cattle. Another feature of research grazing trials is that the number of paddocks in the rotation was often as low as 3 (in deferred rotations) and rarely more than 14. Following the guidelines in Voisin[28], grazing periods should be limited to around seven days followed by a rest period of 30 days, which defines a rotation around just five paddocks. As the grazing period is reduced and the rest period increased, the number of paddocks required by the rotation rises. A grazing period of two days in a rotation of 60 paddocks means that livestock spend on average only six days grazing per year in each paddock, and the paddock is rested for almost 360 days per year, which can lead the biological mechanics of rotational grazing to cause a doubling of sustainable stocking rate and greater tolerance of low rainfall seasons or years[32]. Voisin[28] worked on dairy farms in temperate France; in a rangeland setting, on the other hand, for most of the year rest periods need to be much longer than 30 days to allow adequate time for recovery under the irregular and sparse rainfall patterns of a semi-arid environment. Similarly, herds need to consist of dozens of animals or more to achieve a grazing herd's natural cohesive social behavior.

A key factor of livestock management is missing from grazing research in small experimental units, namely, the spatial dimension: scientists could assume that both available forage and forage utilization by grazing animals were spatially homogeneous, which is untrue in a landscape context. When the distribution of grazing livestock across a spatially heterogenous landscape is entered into the discussion, rotational grazing is clearly superior to continuous grazing[33,34]. Even Briske et al. have admitted that research station results could not apply to a commercial-scale operation[35]. Livestock in a small paddock can explore the entire area of available pasture on a daily basis, and forage utilization is spatially more even than across a landscape where patch-grazing is usually the norm if animal movement is unconstrained. One would expect the simple factor of small paddocks to enhance livestock production, and it does. Norton[29] reported examples where he compared the experimental stocking rates to the stocking rates for livestock on commercial ranches near the station: rates approaching twice the recommended commercial rate could be sustained on the research station for many years without adverse ecological consequences to either the continuous or the rotation treatment. Alternatively, in a much larger paddock the livestock concentrate their grazing activity in preferred patches and much of the pasture is neglected. The stocking rate calculated for the entire paddock is much lower than the *de facto* stocking rate imposed on the preferred patches or zones where most of the grazing is taking place. A critical aspect of rotational grazing is to prevent patch grazing that opens up pastures to patch degradation (i.e., localized overgrazing), weed invasion, and erosion.

In a nutshell, the theory of rotational grazing has three elements: 1) Controlled defoliation frequency achieved by short grazing periods followed by long rest periods; 2) high-density grazing forcing even utilization by using combined herds for short grazing periods, with stocking rate calculated for the entire rotation area; and 3) even spatial distribution of grazing animals in a rotational sequence around landscape units. The outcomes comprise: 1) Greater forage production; 2) higher livestock productivity from bigger animals or higher fecundity or both; and 3) increased ecological health of the pasture in terms of biodiversity and drought tolerance. A good illustration of the benefits of rotational grazing that incorporates a number of dimensions of the livestock management/pasture interaction was published by Odadi et al. from work in Kenya.

Odadi et al.[36] describe an ecological assessment of rotational grazing conducted within a communal pastoral area in northern Kenya divided into unfenced 'paddocks'. The assessment followed five years of planned rotational grazing and employed an experimental approach with three pairs of sites. One of each site pair was subjected to rotational "planned grazing," while the other consisted of unplanned grazing (i.e., control). The planned system included bunched grazing of livestock, multiple unfenced paddocks, and a 50% recommended level of forage utilization prior to moving animals among paddocks. Overall, they concluded that the planned grazing system had positive effects on all plant and animal indicators[36].

In a later paper, Odadi et. al.[37] focused specifically on the effectiveness of bunched herds in a low-level rotation. Odadi and his colleagues compared herds that grazed in loose bunches managed by one herder with herds that grazed in tight bunches enforced by three herders. All other aspects of the grazing system were similar for both types of herding. The results were noteworthy. Cattle herded in tight bunches traveled shorter distances, had higher nutrient intake per unit of distance traveled, grazed less selectively consuming less of the preferred species with intake spread over a wider array of species, but had higher weight gain. The higher cattle live weights generated more income greater than the extra cost of herding. The benefits of herding in tight bunches were financial as well as ecological.

Herding for rotational grazing as practiced in the CBRLM GAs was much looser and often abandoned once the herd had been shepherded to a designated grazing site. In general, rotational grazing in the GAs lacked rigor of implementation and, not surprisingly, the results were unconvincing.

c. Comparing CBRLM and holistic management approaches

The approach to grazing management in the CBRLM proposal for the NCAs[10] was inspired by the Holistic Management (HM) model of Allan Savory[26,27]. In his 1988 textbook[27], Savory emphasizes the need to first identify community or household goals and then make detailed plans to achieve those goals, which should include financial and life-style goals as well as resource productivity, socio-economic sustainability, and household welfare. Furthermore, Savory stresses that resource managers should be flexible, monitoring performance and revising plans and activities on a regular basis. This flexibility and process of revising plans and actions is an essential component of the HM strategy.

In the case of CBRLM, although it adopted rotational grazing and socio-economic integration and household prosperity in project design[10], the overarching goals were largely imposed by external development agents instead of being generated by recipient communities, and revision of plans and activities was not possible within the short time-frame of project implementation, even if it had been accommodated in CBRLM design. Therefore, CBRLM did not employ the full HM template, although it followed some aspects of HM. For example, in a departure from the HM protocol, the measure of improvement in household conditions set by CBRLM is an increase in monetary assets, whereas household surveys conducted by the project revealed that increasing livestock numbers was a primary community goal, and so results from the marketing component of CBRLM were disappointing. It also transpired that communities were unable to strictly enforce grazing management protocols of combined herds and planned grazing; independent herder actions and trespassing by external herds that poached conserved forage compromised the recommended rotational grazing practice (see Main Text). Insofar as CBRLM is a test of rotational grazing at community and landscape scales, testing the efficacy of planned grazing management was frustrated and anticipated outcomes thwarted. CBRLM also failed as an example of HM because key features of HM were omitted, but even if CBRLM had faithfully followed HM, there was insufficient project time for adequate execution and evaluation of the full HM approach.

In general, CBRLM, however, can be lauded for pursuing a development effort that connected many elements of a complex social-ecological system (SES) in a core TOC (see previous section). The study of outcomes—very unusual in development programs—was thus a means to assess lessons learned. Our research has indicated that while persistent changes in many social features of this pastoral community occurred with respect to commons management planning, changes in the household economy, cattle production system, and rangeland condition were not observed. This is not surprising, however, given the relatively short time frame for assessment and bio-physical time lags in a setting strongly affected by variable rainfall and other perturbations (see Main Text).

How a complex SES responds to externally generated intervention has received little detailed study, particularly in the context of dryland settings. Rangeland management scholars note anecdotally that while practitioners (e.g., ranchers) adopting HM paradigms in the western US often perceive positive outcomes with regards to social or psychological aspects of their increased investments in resource planning, hard evidence of associated improvements in the natural environment as a result of treatment is often lacking[38]. A similar perspective is voiced by Gosnell et al. in their recent meta-analysis of global studies on HM[39]. Although they note the dearth of truly integrated SES research, their review points to a distinct dichotomy between the ecological and social domains of HM; namely, that while many controversies prevail over the pros and cons of ecological impacts arising from HM, far more consensus exists concerning the positive benefits in the social sphere including attention to goal setting, human capacity building, enhanced social networking, and creating social resilience. Our research findings generally conform to this perspective.

i. Community governance

One of the key assumptions of CBRLM was that community governance needed to be fortified to help combat environmental degradation as related to poor grazing management. There is a growing agreement among researchers and development practitioners that a weakening of traditional community governance is a major problem in the world's dry lands. Traditional governance in pastoral areas includes efforts to mitigate social disputes, allocate natural resources, and organize labor to address community challenges[15]. When these attributes are lost social cohesion can suffer and resource degradation occurs. Population growth, shifts in cultural norms, increases in resource-based conflicts, emergence of local, ultra-wealthy elites (who do as they please), expansion of absentee herd-ownership, and an undermining of local traditional authorities by regional or national governments are some of the major internal and external factors involved[40–43]. The problem is recognized by development agencies, who have increasingly focused on restoring aspects of traditional governance in local situations to improve natural resource management. Such processes include efforts to strengthen governance via participatory combinations of traditional and contemporary leadership that reflects differing knowledge bases and access to resources[42].

ii. Commercialization of livestock production

Another key assumption of CBRLM was that the communities would be responsive to efforts to boost cattle productivity via changes in animal husbandry, with an eye towards more marketed offtake and increased producer incomes. While this presumed process makes perfect sense to an outside expert trained in livestock development, there are false assumptions concerning cultural values and differing economic goals for traditional producers that undermine such plans in places like the NCAs of Namibia.

The struggles of pushing for more commercialized animal offtake from pastoral areas have been well known for decades, but largely ignored by project donors who follow top-down models of project design and implementation from a western perspective[42]. Cattle marketing is often pursued by governments seeking exports to boost foreign exchange coffers[42]. New projects based on false assumptions thus keep coming down the pipeline. The fundamental, inimical nature of subsistence pastoralism versus commercial livestock production is best depicted by Behnke[44]. Major differences occur in terms of inputs, outputs, goals, and even human demographics. While indeed pastoral systems are changing[40,45], it continues to be a truism that traditional herdowners (e.g., men) typically aspire to accumulate large stock such as cattle. More cattle may allow for a higher likelihood of surviving droughts or other crises, and there is little doubt that large herds can convey high social status to herd owners in many cultures[42]. The flip side is that large herds can dominate local resource consumption, thus exacerbating household wealth stratification[40]. Large herds can also suffer enormous death losses during droughts[15,40].

In contrast to cattle, however, small stock such as goats or sheep are more routinely sold by pastoralists to meet modest cash needs. Small stock are also more readily produced in more ecologically degraded environments[15]. Commercialization will thus tend to be more successful for small stock when compared to that for cattle, and this can have a gender dimension as women are then more likely to market these animals and use the proceeds to improve the livelihoods of themselves and their children[46]. Such processes are more aligned with the rural-development ambitions of project donors and development experts. Traditional pastoral systems are low-input, high-risk enterprises. For cattle, they are not "cow-calf" operations as seen in modern commercialized ranching. In pastoral systems, immature animals are typically retained and matures are sold at advanced ages when they have attained a maximum body size. And when mature cattle are sold the objective is often to use the proceeds to buy more immatures to meet herd-building goals[15].

Veterinary interventions for cattle are often embraced by producers because they facilitate herd-building goals, not commercialization or cash-generation goals. Alternative investments to large stock such as cattle are needed to diversify assets in support of household resilience and improvement in rangeland management, and this can include bank accounts, urban investments such as real estate or small businesses, and support for children who leave the traditional system and become formally educated. Such options become more attractive when "boom and bust" cycles for cattle productivity tilt the portfolio choices against more re-investment in livestock versus the relative stability of investments in non-pastoral options less connected to stocking rates or the weather[40]. A robust mix of different investments is the key for managing risk.

Besides socioeconomic barriers, the cattle producers of northern Namibia also face significant operational or structural barriers for marketing. These may include weak trading networks and low farm-gate prices[10]. The Veterinary Cordon Fence, imposed by colonial authorities and still enforced to manage the risks of epidemic diseases, limits access of producers in the NCAs to more lucrative markets in the southern parts of Namibia[4].

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4. Supplementary Tables 1 – 5 (following pages)

Supplementary Table 1: Randomization balance

Panel A: Data collected at RIA level	RIA-level statistics (pre-program)					
RIA characteristic	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*% missing*	*N*
Log of the number of CBRLM-eligible households *	4.47	4.61	0.445	0.307	0.00	38
RIA has good water source *	0.79	0.74	0.674	0.658	0.00	38
RIA has community-based organizations *	0.74	0.79	0.568	0.545	0.00	38
Forest present in RIA	0.42	0.42	1.000	0.870	0.00	38
Grassland present in RIA	0.11	0.11	1.000	0.980	0.00	38
Livestock density (kg/ha) *	16.79	16.88	0.939	0.953	0.00	38
Number of livestock *	17,380	16,497	0.903	0.824	0.00	38
RIA overlaps geographically with prior interventions *	0.37	0.42	0.530	0.456	0.00	38
	p-value, joint F-test:	0.998		p-value, joint F-test, RI:		>0.999

Panel B: Data collected at GA level	RIA-level statistics (pre-program)					
GA characteristic	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*% missing*	*N*
Community is willing to change	0.76	0.88	0.186	0.193	2.63	38
Traditional authority is ready for change	0.54	0.67	0.995	0.995	13.16	38
Community has social cohesion	0.63	0.67	0.756	0.721	0.00	38
Community is worried about spillover/grass poaching	0.49	0.65	0.166	0.094	2.63	38
Community perceives herder turnover as high	0.25	0.40	0.389	0.342	7.89	38
GA has cell phone reception	0.20	0.13	0.331	0.315	5.26	38
Community believes herders perform well	0.42	0.21	0.159	0.090	0.00	38
Cattle carrying capacity at or above regional norm	0.84	0.88	0.356	0.430	0.00	38
Proportion of HHs near water point made of mud/clay/brick	0.06	0.03	0.206	0.116	5.26	38
Full water point installed	0.72	0.66	0.754	0.771	7.89	38
Himba people live in community	0.25	0.36	0.454	0.381	5.26	38
Vegetation biomass production (1-9; 9 = extremely high production)	6.88	6.89	0.854	0.840	0.00	38
Non-cattle livestock density (mean #/square km)	1.12	1.27	0.874	0.834	0.00	38
Cattle density (mean #/square km)	7.63	8.01	0.925	0.904	0.00	38
Annual rainfall deficit (evaporation minus rainfall, in mm)	9.18	9.32	0.323	0.264	0.00	38
GA area (square km)	7,540.76	6,321.75	0.185	0.184	0.00	38
Ethnolinguistic fractionalization (inverted Herfindahl index)	0.00	0.01	0.380	0.247	0.00	38
Number of kraals per grazing area	25.25	22.84	0.452	0.326	0.00	38
Proportion plant cover of any kind	0.84	0.85	0.750	0.636	0.00	38
Rainfall (mm) in year ending in August 2016	353.30	355.33	0.753	0.698	0.00	38
	p-value, joint F-test:	0.662		p-value, joint F-test, RI:		>0.999

Panel C: Data collected from herd managers	Individual-level statistics (0 - 1 years after program end)					
Herd owner characteristic	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*% missing*	*N*
Herd owner age (years)	54.46	54.32	0.178	0.125	1.92	1,176
Herd owner completed primary education	0.39	0.44	0.804	0.773	0.00	1,199
	p-value, joint F-test:	0.396		p-value, joint F-test, RI:		0.557

Panel D: Data collected from heads of household	Individual-level statistics (3 years after program end)					
Household characteristic	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*% missing*	*N*
Household head is male	0.80	0.79	0.783	0.784	11.04	1,209
Household head age (years)	55.94	57.47	0.927	0.917	11.63	1,201
Household head education level (0 - 9 scale; 0=none)	2.13	2.42	0.555	0.549	11.04	1,209
Household speaks Rukwangli	0.17	0.19	0.120	0.125	11.04	1,209
Household speaks Herero	0.30	0.27	0.920	0.910	11.04	1,209
	p-value, joint F-test:	0.551		p-value, joint F-test, RI:		0.837

Notes: Treatment and control means are sample means for each subgroup. Each p-value is two-tailed and comes from an OLS regression of treatment on the associated balance variable, and indicates the probability of observing a test statistic as extreme or more extreme than the observed test statistic given a true null hypothesis of no treatment effect. In each joint F-test, treatment status is regressed on all the variables in the associated panel of the table. RI p-values are calculated using randomization inference. Standard errors are not clustered in Panels A and B because RIAs are the unit of observation and the unit of randomization, but in Panels C and D are clustered at the RIA level. Each regression in Panels A and B controls for a categorical variable for traditional authority (an administrative unit) that was used for block stratification. Panels C and D include as controls this categorical variable for traditional authority and the RIA-level variables used in re-randomization to ensure balance: vegetation type, number of livestock, livestock density, the log of the number of CBRLM-eligible households, and binary indicators for whether the RIA overlaps with prior intervention areas, has a quality water source, and has a community based organization. RIA-level regressions in Panels A and B do not include this full set of randomization controls to avoid having more predictors than observations. In Panel B, missing values are coded as 0. In Panels C and D, missing values are coded as zeros and regressions include a binary variable equal to 1 for observations in which the balance variable was missing and zero otherwise. Variables without description of units are binary. * indicates that a variable was used for re-randomization to ensure balance.

Supplementary Table 2: Program participation and attrition

Panel A: GA-level participation

Dependent variable	*Ctrl mean*	*Treat mean*	*p-val*	*RI p-val.*	*N*
GA formally enrolled in CBRLM	0.00	0.71	<0.001	<0.001	123

Panel B: GA manager-level participation

Dependent variable	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*N*
Manager has heard of CBRLM program	0.63	0.91	<0.001	0.002	1,234
Manager was offered chance to participate in CBRLM	0.13	0.67	<0.001	<0.001	1,208
Manager participated in CBRLM	0.05	0.56	<0.001	<0.001	1,222

Panel C: Attrition

Dependent variable	*Ctrl mean*	*Treat mean*	*p-val.*	*RI p-val.*	*N*
Attrited 0 - 1 years after end (behavioral survey 1)	0.03	0.04	0.336	0.407	1,241
Attrited 2 - 3 years after end (behavioral survey 2)	0.08	0.07	0.476	0.608	1,348
Attrited 2 - 3 years after end (cattle survey)	0.12	0.09	0.193	0.294	730
Attrited 3 years after end (household survey)	0.10	0.10	0.465	0.627	1,345

Notes: Each p-value is two-tailed and comes from an OLS regression of a variable measuring participation in the CBRLM program on treatment status, and indicates the probability of observing a test statistic as extreme or more extreme than the observed test statistic given a true null hypothesis of no treatment effect. RI p-values are calculated using randomization inference. Standard errors are clustered at the RIA level, i.e., the unit of randomization. Each regression includes as controls a categorical variable for traditional authority (an administrative unit) that was used for block stratification and the RIA-level variables used in re-randomization to ensure balance, which are: vegetation type, number of livestock, livestock density, the log of the number of CBRLM-eligible households, and binary indicators for whether the RIA overlaps with prior intervention areas, has a quality water source, and has a community based organization. Variables without description of units are binary.

Supplementary Table 3: Treatment effect on social indices, with inverse probability weighting

Panel A: Behaviors	**0 - 1 years after program end**						**2 - 3 years after program end**					
Dependent variable	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*
Grazing planning	1.36	0.23	<0.001	0.002	0.001	1,199	1.04	0.20	<0.001	0.002	0.001	1,218
Grazing plan adherence	0.38	0.08	<0.001	0.027	0.001	1,199	0.32	0.06	<0.001	0.002	0.001	1,240
Herding practices	0.40	0.12	0.001	0.014	0.002	1,199	0.31	0.08	<0.001	0.023	0.001	1,243
Herder management	0.17	0.08	0.044	0.101	0.045	1,199	0.43	0.14	0.003	0.058	0.004	1,243
Cattle husbandry *	0.38	0.11	<0.001	0.029	.	1,199	0.12	0.09	0.186	0.341	.	1,249
Herd restructuring *	-0.01	0.07	0.927	0.960	.	1,199	-0.02	0.04	0.506	0.746	.	1,243
Cattle marketing *	-0.05	0.06	0.378	0.649	.	1,199	0.07	0.05	0.210	0.484	.	1,245

Panel B: Community dynamics, knowledge, and attitudes	**0 - 1 years after program end**						**2 - 3 years after program end**					
Dependent variable	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*
Community governance	0.78	0.14	<0.001	0.008	0.001	1,199	0.55	0.11	<0.001	0.006	0.001	1,245
Collective action	1.59	0.24	<0.001	0.002	0.001	1,199	0.89	0.22	<0.001	0.002	0.001	1,245
Community disputes	0.07	0.07	0.303	0.444	0.418	1,140	-0.28	0.08	<0.001	0.088	0.002	1,243
Trust	-0.03	0.06	0.641	0.715	0.784	1,198	.	.	.	.	.	.
Knowledge	0.30	0.10	0.007	0.054	0.012	1,199	0.37	0.09	<0.001	0.009	0.001	1,248
Self & community efficacy	0.03	0.10	0.783	0.831	0.858	1,196	-0.01	0.07	0.857	0.916	0.858	1,009

Notes: Each β is the coefficient on the treatment variable in an OLS regression of a behavioral program outcome on treatment status. It is an intent-to-treat (ITT) estimate relative to the control group. Standard errors are clustered at the RIA level, i.e., the unit of randomization. Regressions are corrected for differences in probability of treatment assignment within stratification blocks using inverse probability weighting, and RI p-values are calculated using randomization inference; see Methods for explanations of these methods. Each regression includes as controls a categorical variable for traditional authority (an administrative unit) that was used for block stratification and the RIA-level variables used in re-randomization to ensure balance, which are: vegetation type, number of livestock, livestock density, the log of the number of CBRLM-eligible households, and binary indicators for whether the RIA overlaps with prior intervention areas, has a quality water source, and has a community based organization. Indices are the standardized (mean = 0 and sd = 1), unweighted average of standardized components. Variables for the "trust" index were not collected in the survey 2 - 3 years after program end. All p-values are two-tailed. * indicates variables for which multiple hypothesis correction was not specified in the pre-analysis plan.

Supplementary Table 4: Treatment effect on physical outcomes, with inverse probability weighting

Panel A: Primary outcomes (indices)	**2 - 3 years after program end**					
Dependent variable	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*
Herd value	0.00	0.10	0.984	0.994	0.984	653
Herd productivity	0.03	0.08	0.748	0.874	0.935	1,285
Weekly household income	0.10	0.07	0.163	0.353	0.408	1,210
Weekly household expenditure	0.03	0.05	0.567	0.506	0.935	1,210
Household livestock wealth	-0.07	0.05	0.121	0.423	0.408	1,210

Panel B: Secondary outcomes (indices)	**2 - 3 years after program end**					
Dependent variable	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*
Herd structure	-0.01	0.07	0.864	0.919	0.945	653
Time use	0.04	0.10	0.699	0.832	0.945	1,210
Resilience	-0.03	0.07	0.642	0.806	0.945	1,210
Female empowerment	-0.02	0.08	0.804	0.849	0.945	1,210
Meat and dairy consumption	0.00	0.04	0.945	0.965	0.945	1,210

Panel C: Rangeland outcomes (standardized)	**2 years after program end**					
Dependent variable	*β*	*SE*	*p-val.*	*RI p-val.*	*q-val.*	*N*
Erosion:						
Wet season site erosion (1 = no erosion, 0 = erosion)	-0.09	0.10	0.360	0.646	.	972
Ground cover:						
Wet season protected soil surface (%, logit-transformed)	-0.21	0.11	0.061	0.184	.	972
Wet season plant litter cover (%, logit-transformed)	-0.18	0.08	0.029	0.191	.	972
Dry season plant litter cover (%, logit-transformed)	-0.08	0.11	0.466	0.729	.	885
Herbaceous cover:						
Wet season herbaceous canopy cover (%, logit-transformed)	-0.23	0.13	0.092	0.303	.	972
Dry season herbaceous canopy cover (%, logit-transformed)	-0.23	0.07	0.002	0.076	.	885
Wet season fresh plant biomass (kg/ha, log-transformed)	-0.23	0.15	0.142	0.326	.	966
Dry season fresh plant biomass (kg/ha, log-transformed)	-0.21	0.07	0.004	0.116	.	792
Relative canopy cover of perennial and annual grasses:						
Wet season perennial to annual canopy ratio (log-transformed)	-0.06	0.07	0.389	0.710	.	972
Relative canopy cover of grasses and forbs:						
Wet season grass to forb canopy ratio (log-transformed)	-0.21	0.10	0.037	0.289	.	972
Weeds:						
Wet season % of shrubs that are not stinkbush (%, logit-transformed)	0.00	0.08	0.980	0.993	.	870
Wet season grass to Aristida canopy cover ratio (log-transformed) *	-0.12	0.13	0.358	0.554	.	752
Woody vegetation:						
Wet season shrub canopy cover (%, logit-transformed)	0.02	0.15	0.866	0.917	.	972
Dry season shrub canopy cover (%, logit-transformed)	-0.06	0.15	0.704	0.822	.	885

Notes: Each β is the coefficient on the treatment variable in an OLS regression of a program outcome on treatment status. It is an intent-to-treat (ITT) estimate relative to the control group. Data in Panels A and B were collected using surveys of heads of household and cattle managers, and data in Panel C were collected as described in the Methods. Standard errors are clustered at the RIA level, i.e., the unit of randomization. Regressions include corrections for differences in probability of treatment assignment within stratification blocks using inverse probability weighting, and RI p-values were calculated using randomization inference; see Methods for explanations of these methods. Each regression includes as controls a categorical variable for traditional authority (an administrative unit) that was used for block stratification and the RIA-level variables used in re-randomization to ensure balance, which are: vegetation type, number of livestock, livestock density, the log of the number of CBRLM-eligible households, and binary indicators for whether the RIA overlaps with prior intervention areas, has a quality water source, and has a community based organization. Indices are the standardized (mean = 0 and sd = 1), unweighted average of standardized components. Monetary variables have been scaled to weekly Namibian dollar (NAD) amounts. At the time of data collection (2017) the exchange rate was 13.3 NAD to 1 USD. Rangeland outcomes have been transformed (but not standardized as in Extended Data Table 2) as noted in parentheses to better meet assumptions of normality and homogeneity of variance, but treatment and control means are sample means computed from data on untransformed scales. Multiple hypothesis correction was not specified for rangeland outcomes in the pre-analysis plan. All p-values are two-tailed. * Aristida is a genus of grasses that are undesirable forage plants in this context.

Supplementary Table 5: Treatment effect heterogeneity by rainfall, social and cattle outcomes

Panel A: Community management (0 - 1 years)	Treatment			Low rainfall indicator			Treatment x low rainfall indicator				
Dependent variable	*β1*	*SE*	*p-val.*	*β2*	*SE*	*p-val.*	*β3*	*SE*	*p-val.*	*RI p-val.*	*N*
Grazing planning	1.70	0.32	<0.001	0.07	0.32	0.826	-0.75	0.42	0.086	0.409	1,199
Grazing plan adherence	0.42	0.08	<0.001	0.18	0.13	0.174	-0.14	0.15	0.331	0.560	1,199
Herding practices	0.36	0.12	0.004	0.12	0.23	0.596	0.02	0.18	0.928	0.954	1,199
Herder management	0.17	0.09	0.067	-0.01	0.19	0.944	-0.04	0.13	0.772	0.869	1,199
Cattle husbandry	0.51	0.12	<0.001	0.14	0.16	0.396	-0.27	0.17	0.113	0.470	1,199
Herd restructuring	0.07	0.11	0.503	0.03	0.12	0.795	-0.11	0.13	0.401	0.579	1,199
Cattle marketing	-0.01	0.08	0.920	0.15	0.14	0.301	-0.09	0.11	0.439	0.551	1,199
Community governance	0.92	0.19	<0.001	-0.02	0.24	0.943	-0.32	0.25	0.207	0.536	1,199
Collective action	1.65	0.27	<0.001	0.41	0.31	0.190	-0.25	0.45	0.585	0.771	1,199
Community disputes	0.13	0.07	0.065	0.01	0.12	0.912	-0.10	0.12	0.406	0.656	1,140
Trust	0.04	0.07	0.595	-0.01	0.14	0.927	-0.11	0.11	0.337	0.548	1,198
Knowledge	0.51	0.13	<0.001	0.42	0.18	0.029	-0.39	0.17	0.026	0.226	1,199
Self & community efficacy	0.04	0.12	0.725	0.02	0.19	0.930	-0.01	0.15	0.960	0.981	1,196

Panel B: Community management (2 - 3 years)	Treatment			Low rainfall indicator			Treatment x low rainfall indicator				
Dependent variable	*β1*	*SE*	*p-val.*	*β2*	*SE*	*p-val.*	*β3*	*SE*	*p-val.*	*RI p-val.*	*N*
Grazing planning	1.53	0.26	<0.001	0.80	0.27	0.006	-1.02	0.30	0.002	0.181	1,218
Grazing plan adherence	0.53	0.09	<0.001	0.21	0.15	0.173	-0.40	0.10	<0.001	0.156	1,240
Herding practices	0.46	0.12	<0.001	0.32	0.13	0.017	-0.32	0.16	0.057	0.214	1,243
Herder management	0.47	0.14	0.002	0.33	0.15	0.035	-0.10	0.20	0.641	0.834	1,243
Cattle husbandry	0.06	0.10	0.536	0.04	0.11	0.745	0.11	0.15	0.461	0.695	1,249
Herd restructuring	-0.01	0.06	0.822	0.21	0.08	0.014	-0.02	0.08	0.847	0.915	1,243
Cattle marketing	0.01	0.08	0.861	-0.17	0.10	0.096	0.12	0.12	0.343	0.606	1,245
Community governance	0.63	0.14	<0.001	0.16	0.18	0.385	-0.17	0.20	0.407	0.683	1,245
Collective action	1.07	0.20	<0.001	0.37	0.29	0.198	-0.37	0.40	0.353	0.602	1,245
Community disputes	-0.39	0.11	0.001	0.18	0.24	0.462	0.19	0.13	0.149	0.437	1,243
Knowledge	0.43	0.10	<0.001	-0.09	0.14	0.548	-0.16	0.15	0.297	0.538	1,248
Self & community efficacy	0.09	0.11	0.430	0.23	0.21	0.272	-0.20	0.18	0.298	0.473	1,009

Panel C: Physical outcomes (2 - 3 years)	Treatment			Low rainfall indicator			Treatment x low rainfall indicator				
Dependent variable	*β1*	*SE*	*p-val.*	*β2*	*SE*	*p-val.*	*β3*	*SE*	*p-val.*	*RI p-val.*	*N*
Herd value	0.17	0.12	0.153	-0.18	0.18	0.333	-0.26	0.17	0.138	0.341	653
Herd productivity	-0.15	0.13	0.274	-0.22	0.21	0.308	0.35	0.21	0.097	0.291	1,285
Weekly household income	58.22	38.66	0.141	40.78	52.69	0.444	-37.12	63.03	0.560	0.755	1,210
Weekly household expenditure	-33.96	74.49	0.651	-23.77	113.83	0.836	118.46	127.50	0.359	0.549	1,210
Household livestock wealth	-0.03	0.06	0.624	-0.03	0.16	0.841	-0.05	0.09	0.565	0.749	1,210
Herd structure	-0.12	0.09	0.204	-0.32	0.15	0.036	0.20	0.16	0.225	0.479	653
Time use	0.27	0.16	0.089	0.62	0.29	0.037	-0.48	0.26	0.068	0.168	1,210
Resilience	-0.17	0.09	0.076	0.00	0.13	0.969	0.28	0.12	0.028	0.177	1,210
Female empowerment	0.06	0.13	0.666	0.08	0.14	0.591	-0.14	0.14	0.347	0.521	1,210
Food consumption	0.03	0.07	0.662	-0.17	0.12	0.144	-0.05	0.07	0.505	0.659	1,210

Notes: Each row displays results from a separate regression in which the dependent variable is an index of behavioral, household, or cattle outcomes, and the independent variables are treatment status and an indicator variable for low rainfall. β1 indicates the coefficient on treatment, which is an intent-to-treat (ITT) estimate relative to control. β2 indicates the coefficient on an indicator variable for low rainfall, which is equal to 1 if a grazing area was below the median of all grazing areas in terms of percent difference in the grazing area's rainfall during the project period relative to the mean of the grazing area's rainfall over the 10 years prior to the program. β3 shows the interaction of the low-rainfall indicator with treatment. Standard errors are clustered at the RIA level, i.e., the unit of randomization. RI p-values are calculated using randomization inference. Each regression includes as controls a categorical variable for traditional authority (an administrative unit) that was used for block stratification and the RIA-level variables used in re-randomization to ensure balance, which are: vegetation type, number of livestock, livestock density, the log of the number of CBRLM-eligible households, and binary indicators for whether the RIA overlaps with prior intervention areas, has a quality water source, and has a community based organization. Indices are the standardized (mean = 0 and sd = 1), unweighted average of standardized components. Monetary variables are in Namibian dollar (NAD) amounts. 0 -1 years after program end (2014) the exchange rate was 10.8 NAD to 1 USD, and 2 - 3 years after program end was 14.7 NAD to 1 USD. See Methods and the Supplementary Information for additional details. All p-values are two-tailed.