# Restoring Ethiopian drylands at scale

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## Introduction

Improving the productivity of drylands in Ethiopia supports government initiatives to increase livestock and crop production, increase food security, and enhance regulation of water flows. Many drylands in Ethiopia are moderately to severely degraded and require restoration, and the productivity of drylands in better condition can be maintained or improved. Some parts of the country have seen significant restoration success—including grazing exclosures and soil and water conservation—while other areas have seen few gains. There exists major potential for up-scaling restoration in Ethiopia (Tongul and Hobson 2013), however it is not often clear how likely various restoration options are to succeed in new areas. The biophysical and social context of a specific area significantly affects the success of restoration options, and the degree to which options require adaptation to fit local needs (Coe et al. 2014). The goals of this review are to: (i) identify options with proven success and high potential for up-scaling in Ethiopian drylands, (ii) analyze factors underlying relative success in different agro-ecologies and under different institutional conditions, and (iii) assess options that may have high potential in areas and systems without well proven successful options. Since it is difficult to disaggregate the specific effects of the multiple technical and institutional options that have successfully improved natural resource management in Ethiopia, restoration options are assessed from an integrated perspective. The review focuses especially on options currently being up-scaled by farmers, government programs, and civil society, synthesizing the evidence on options with the highest potential or feasibility for impact over large areas of Ethiopia.

## Grazing exclosures

*Option.* Grazing exclosures are created to improve year-round availability of forage, as well as to protect degraded communal lands from grazing-induced soil erosion and compaction. Often located on steep unproductive catchment slopes above croplands to increase infiltration and base flow to the croplands below, animals are excluded for all or portions of the year (especially the rainy season), with forage cut and removed from the exclosure during closure periods (Nedessa et al. 2005). Exclosure management regimes are primarily regulated by local institutions, including village councils and other informal institutions, which create by-laws for exclosure use and enforcement, often linked to the local government legal system (Yami et al. 2011). In Tigray, recurrent droughts and the need to improve land management to increase water supply to downslope cropping areas (Gebreyohannes and Hailemariam 2011) have driven exclosure establishment, aided at times by pre-existing organizational linkages from the military resistance to the Derg regime. In Hararghe in Oromia, drought and shortage of grazing land were the main factors behind widespread expansion of exclosures over recent decades (Gebreyohannes and Hailemariam 2011).

Exclosures have successfully improved production of forage as well as wood, yet have also generated a variety of other benefits, including soil conservation, improved soil fertility, C sequestration, and improved hydrological flows. Generally, exclosures reduce soil erosion and flood intensity, increase downstream water yield, and in some cases revive springs and increase the ground water table (Nedessa et al. 2005). Most detailed information on exclosure effects on soils and water comes from the highlands of Tigray Region.

In highland Tigray, exclosures increased ecosystem C stocks by 30-60 t $ha^{-1}$ (70-130% gains), largely due to soil C accretion (Mekuria et al. 2011a), sequestering 23 t C $ha^{-1}$ $yr^{-1}$ in the first 5 years and 11 t C $ha^{-1}$ $yr^{-1}$ over 15 years, and also substantially increased soil N and P stocks (Mekuria et al. 2011c). Consequently, the net present value (NPV) of ecosystem services provided by exclosures (grass production, C sequestration, buildup of soil N and P stocks) was estimated to be 28% (USD837) higher than alternative wheat production (Mekuria et al. 2011c). However, ecosystem services from older grass-dominated exclosures have not been rigorously assessed, yet could yield greater net benefits if synergy exists between forage production and C sequestration, or fewer net benefits if a trade-off prevails. Over 75% of highland farmers ranked effectiveness of exclosures for land restoration as high (52%) or medium (23%) with the remainder unsatisfied with extensive regeneration of less-preferable *Acacia* spp. (Mekuria et al. 2011c). Exclosures receive strong support from most communities and the Tigray regional government (Nedessa et al. 2005).

In the well-studied Degua Temben district of highland Tigray, exclosures had higher production and standing crop of leaf litter (Descheemaeker et al. 2006a), greater sediment depth and deposition rate (Descheemaeker et al. 2006c), and enhanced humus formation (Descheemaeker et al. 2009). Exclosures shed only 25-50% as much precipitation in runoff as compared to open grazing areas (Descheemaeker et al. 2006b), reduced soil erosion by ~50% (over and above pre-existing stone conservation structures), increased SOM by ~50% (to over 2%), and increased N and P stocks (Mekuria et al. 2007). Both farmers and extension officers reported higher yields in croplands below exclosures (Mekuria et al. 2009).

In more arid locations, exclosures have been less successful, though they are a reasonable option in many cases. In the drier, hotter lowlands of Tigray, gains were less impressive than in the highlands. Ecosystem C stocks increased by 18-40 t $ha^{-1}$ (60-100% gains), again largely due to increased soil C, sequestering 3.6 t C $ha^{-1}$ $yr^{-1}$ in the first 5 years and 2.7 t C $ha^{-1}$ $yr^{-1}$ over 15 years, and increased soil N and P stocks (Mekuria et al. 2011b). By 2004, exclosures remained virtually absent from the traditionally pastoral lowlands of East Shewa in the Rift Valley of Oromia Region, as compared to the 10-60% of available land in exclosure in 3 districts of highland Tigray (Nedessa et al. 2005, Descheemaeker et al. 2009).

*Context.* The history of *serit* local by-laws (Nedessa et al. 2005) and rainy season grazing restrictions in Tigray were significant precursors for the current use of exclosures, as was the decades-long history of zero-grazing exclosures in Hararghe (Gebreyohannes and Hailemariam 2011). In areas such as East Shewa that lack such a history, some old top-down, government reserves remain, but exclosures have not caught on (Nedessa et al. 2005).

The biophysical or ecological context of an area affects the success of exclosures. Older exclosures provide greater environmental benefits, but may not give the highest net livelihood benefits. In highland Tigray, litter production and standing crop increase with exclosure age (Descheemaeker et al. 2006a), and soils in older exclosures have more advanced humus formation (Descheemaeker et al. 2006c). Effects of exclosures on soils are strongest in the first 5 years and soil fertility did not differ between 5- and 15-year-old exclosures (Mekuria et al. 2007, Mekuria and Aynekulu 2011) although soil C, N, and P increased significantly between 5 and 20 years (Mekuria et al. 2011a) in highland sites. In lowland Tigray, soil C, N, and P increased between 5 and 15 years of exclosure (Mekuria 2013).

In both highland and lowland Tigray, older exclosures typically produce less forage due to woody competition, indicating a clear trade-off with wood production (Mekuria et al. 2011b, 2011c). If forage production exhibits a trade-off with C sequestration as well, C finance could be less feasible than reports indicate. Moreover, livelihood benefits can be greater from exclosures with more ground cover and fewer shrubs and trees that compete with forage grasses, as well as from exclosures with a faster rate of recovery—those in more productive sites, with pre-existing soil conservation measures, and enrichment planting (Nedessa et al. 2005, Yami et al. 2013).

Exclosure management depends on the existence and design of local by-laws and institutional mechanisms for enforcement (Nedessa et al. 2005, Yami et al. 2011, 2013). Exclosure success is generally improved by posting guards to enforce fines for breaking by-laws, and by linking village institutions to the government legal system (Yami et al. 2013). However, there is no clear or direct relation between exclosure success and the stringency of punishments. Low fines are often ignored, but high fines might weaken enforcement (Yami et al. 2011). Regardless, a sense of common responsibility is more effective than penalties or enforcement (Yami et al. 2013).

Inequitable distribution of benefits from exclosures (Nedessa et al. 2005, Gebreyohannes and Hailemariam 2011) and conflict among exclosure users (Yami et al. 2013) can limit the cohesion of collective action. In Tigray farmers rely on oxen for traction, and are therefore allowed to graze in some exclosures (Gebreyohannes and Hailemariam 2011, Yami et al. 2011). Since oxen are typically distributed unequally among residents, this situation can lead to inequity in benefits (Gebremedhin et al. 2004, Yami et al. 2011), potentially compromising exclosure management. Market access adds value to exclosure resources (Gebreyohannes and Hailemariam 2011) and can improve the economic potential of exclosures, but can also exacerbate theft (Nedessa et al. 2005, Yami et al. 2011, 2013).

Exclosures are generally more successful in areas that have seen greater intensification of cropping and farming systems (Gebreyohannes and Hailemariam 2011), and where exclosure establishment involves the active participation of exclosure users (Yami et al. 2013) rather than top-down government implementation (Yami et al. 2011). Other significant constraints arise from community expectations of high or rapid benefits (Nedessa et al. 2005, Yami et al. 2013), the labor requirements and possible gender implications of exclosures, for zero-grazing most particularly (Nedessa et al. 2005), land tenure arrangements, and the currently rapid individualization of communal lands (Nedessa et al. 2005, Yami et al. 2011).

*Synthesis.* Climate and soils play key roles in determining the rate of vegetation recovery and the potential of exclosures to produce benefits within an acceptable timeframe, which is strongly linked to their ultimate success. Exclosures are less successful and often not feasible in drier, hotter, lowland areas (where small ruminants dominate), unless water and alternative fodders are available (Gebreyohannes and Hailemariam 2011); similarly, zero-grazing is less feasible where grass production is lower (Yami et al. 2011). While forage scarcity and drought constrain exclosures and especially zero-grazing, they are sometimes a key motivation for collective action leading to improved management (Gebreyohannes and Hailemariam 2011, Yami et al. 2013). As such, multiple outcomes are possible for exclosures in a given climate. Institutional means of regulating exclosure use have been central to the successes achieved, in any ecological context. However, without more systematic study, substantial heterogeneity in the large set of relevant institutional and ecological factors (and collinearity among them) may limit clear identification of the full suite of factors critical to exclosure management.

Several next steps are available; first, it remains unclear how broad is the climatic range under which exclosures can produce benefits quickly enough to satisfy farmer expectations, and the climates under which exclosures are a feasible and sustainable option. How institutional instruments, such as the stringency of fines and enforcement, affect exclosure success have not been systematically reported among areas with widely varying conditions, such as climate and market access. As it remains unclear how the net economic benefits from exclosures vary with the dominance of woody versus grassy vegetation, synergies and trade-offs between C sequestration and other ecosystem services should be assessed in older, grassy exclosures before implementing payments for ecosystem services (PES), to ensure adequate harvest of forage under management in line with C payments. Finally, the target levels of woody biomass or cover to minimize the wood-forage trade-off remain largely undocumented, and synthesis of existing studies can provide a way forward.

**Integrated watershed management (IWSM)**

*Option.* Integrated watershed management (IWSM) in Ethiopia consists of a variety of soil and water conservation measures, often implemented in combination with one another under the guidance of local participatory watershed planning. The main soil and water conservation measures are terracing, planting of trees and grasses, and grazing exclosures, and IWSM can also include gully rehabilitation, changes to crop management (*e.g.*, mulching, crop rotation, broadbed maker tillage), and rain-water harvesting including diversions for small-scale or spate irrigation (Desta et al. 2005). Local institutions (both formal and informal) bear significant responsibility for planning in alignment with government directives and facilitation, often including a role for food-for-work (FFW) programs (Amede et al. 2007). Current approaches to IWSM follow in the wake of government promotion of terracing and tree planting under Derg government policies in the 1970s and 1980s (Admassie 1995, Amede et al. 2007), and policies of the current government have pursued soil and water conservation aggressively. Government promotion efforts have added to awareness of conservation measures beyond traditional techniques, but the highly centralized, top-down approach of the Derg government in particular generally led to widespread failures (Amede et al. 2007). Efforts in Tigray specifically benefitted from pre-existing organizational linkages from the former military resistance to the Derg regime, and were largely spurred by recurrent droughts and the need to improve the supply of water to downslope cropping areas (Gebreyohannes and Hailemariam 2011).

Returns on investment in ISWM have been significant yet can likely be improved. In Tigray Region stone bunds increased crop yields ~20%, and while no effect was apparent at regional scale in more humid Amhara Region (Kassie 2009), benefits in dry areas of Amhara probably compare more closely with Tigray. Across the Ethiopian highlands, returns on investment in terraces in dry highlands averaged 30-50%, as compared to 10% in humid areas (Yesuf and Pender 2007); regional benefits from stone bunds in Tigray amounted to ETB38-52M (Kassie 2009). Although stone terraces require substantial labor, the cost of construction was only slightly higher than value of the average annual yield increase (Nyssen et al. 2007) in highland Tigray. In sub-humid Alaba Zone, terracing and grazing exclosures under IWSM generated an additional ETB95,000 (USD11,000) in 2005 (Amede et al. 2007). Irrigation schemes can reduce drought vulnerability, increase crop production and incomes, and encourage crop intensification and restoration of rainfed areas through improved collective action (Amede 2014).

Programs under the current government such as MERET (Managing Environmental Resources to Enable Transitions) and PSNP (Productive Safety Net Program) have produced significant IWSM success at scale in the Ethiopian highlands (Tongul and Hobson 2013). These successes are partly attributable to their emphasis on participatory planning in smaller, more manageable sub-catchments, and success was stronger when by-laws for managing restored communal lands were housed within informal traditional systems yet bolstered by the legal bite of local government (Amede et al. 2007).

A well-known example of landscape-scale restoration success is the district of Atsbi Wenberta in highland Tigray. Stone bunds, grazing exclosures, and tree and grass planting under IWSM and small-scale irrigation increased crop yields by ~60 (wheat, barley) to 100% (teff), improved soil moisture and groundwater recharge (inferred from yield increases), reduced soil erosion, runoff, and sedimentation of waterways, and incentivized cropland intensification as well as restoration of upland catchment areas (Alemayehu et al. 2009). Modelling of a watershed in northeast Tigray indicates that where soil moisture limits crop growth, terraces increase crop production by extending the growing season; in contrast, mulching with crop residues barely increased crop yields (Hengsdijk et al. 2005). In highland Tigray, stone bunds decreased erosion by ~68% (USLE *P*-factor = 0.32), improved deep percolation for effective groundwater recharge (and enabling tree planting near bunds), increased crop yields by 12%, and improved runoff and flood control (Nyssen et al. 2007). In North Shewa, Amhara, planting *Rhamnus prenoides* trees strengthened unploughed strips, terraces, and spate diversions, generating an estimated mean net income gain of 57% (ETB200 $ha^{-1}yr^{-1}$) (Bekele-Tesemma 1997). There is clearly not a shortage of feasible and productive options available in dry highland areas.

However, ineffective approaches, such as geomembrane micro-ponds, are sometimes promoted where they are poorly suited (Adane 2015). Near Mekelle in Tigray, stone terraces and check dams reduced observed runoff to a third of model estimates, leaving poorly planned small reservoirs unfilled (Teka et al. 2013). Even well-designed water infrastructure may not be well maintained, due to inadequate participation in planning or inequitable access to irrigation; as a result, ineffective implementation may compromise benefits in terms of crop production, and may fail to successfully incentivize improved management of upslope catchment areas (Yami 2015). Though reforestation is widely viewed as an effective measure for reducing soil erosion, modelling indicates that in northern Tigray, reforestation with *Eucalyptus* spp. would require conversion of significant cropland areas to produce a non-trivial reduction in erosion (Hengsdijk et al. 2005), a move that would likely be unacceptable locally due to the negative impact on food security.

Farmers take measures such as soil bunds seriously and increasingly so, at times constructing them independently of government support (Adane 2015). In Degua Temben district of highland Tigray, 75% of farmers held a positive view on the effectiveness of stone bunds (Nyssen et al. 2007). Meanwhile in Atsbi Wenberta district, adoption of stone or soil bunds stands at 89% and increasing, tree planting at 75%, and composting at 50%, yet more remains to be done: only 60% of farmers were food secure for 5-8 months per year (Alemayehu et al. 2009).

*Context.* The traditional use of earthen canals, spate irrigation, and tillage patterns to channel water, especially in croplands with steep slopes above, remains common throughout mid-elevation to highland areas of Ethiopia (*e.g.*, Bekele-Tesemma 1997). This strong traditional knowledge base serves as a foundation for restoration efforts and should be capitalized upon.

The availability of land poses a constraint for terracing (Adane 2015), in part because terraces reduce cropping area (Hengsdijk et al. 2005, Nyssen et al. 2007). The reduction in cropping area is strongest on the steep slopes where terraces are most needed, implying that excessive terracing is possible. In communal grazing lands, terracing may not be the most efficient use of labor where unchecked livestock continue to prevent grazing lands from being rested. Terraces always require maintenance to be effective (Nyssen et al. 2007), and if farmers are not seeing sufficient economic benefits, the likelihood of terraces being maintained declines (Amede et al. 2007). Land tenure, labor costs, and assets (Yesuf and Pender 2007, Adane 2015) often restrict adoption of terraces and other soil and water conservation measures.

Measures supplementary to soil and water management can have negative side-effects or significant constraints, and should be assessed carefully prior to large-scale promotion. For example, using crop residues as mulch in croplands reduces dry season fodder availability (Hengsdijk et al. 2005), possibly causing a trade-off between crop and livestock production with negative implications for those whose livelihoods depend on livestock. In addition to seedling mortality from uncontrolled livestock, constraints facing agroforestry include land and tree tenure, government taxes, and farmer participation (Bekele-Tesemma 1997).

Access to markets and effective improvement of existing irrigation systems are important factors behind successful small-scale irrigation. Users of a scheme less than two hours' drive from the regional market of Mekelle, Tigray listed market access as the primary constraint to irrigated production, while users of a scheme near Mekelle ranked market access and input prices second after earthen (unimproved) canals—other constraints in both schemes included poor extension services and transport costs (Yami 2015). Technical quality remains a constraint for irrigation scheme design (Amede 2014), as well as for planning of micro-ponds, small reservoirs and other water infrastructure in agreement with terracing and other management applied to upslope catchment areas (Teka et al. 2013).

*Synthesis.* Market access helps enable farmers to switch to higher-value crops (Yesuf and Pender 2007) such as vegetables. Irrigation systems are often required to accomplish this switch, and economically productive irrigation systems in turn incentivize rehabilitation of upslope catchment areas due to their role in supplying water to downslope areas. This mechanism has proved significant in linking IWSM and intensification of cropping systems to robust adoption of terraces and other investments in soil and water conservation, as the strongest IWSM successes come from areas where market access enables irrigation schemes to be economically productive (Alemayehu et al. 2009, Amede 2014). For farmers engaged in irrigation in rural areas, market access may be a more of a concern than earthen canals (Yami 2015), pointing to the risk that infrastructure improvements may give slow returns in rural areas, potentially threatening maintenance of irrigation schemes. Effective participation and planning can significantly improve water and crop management, strengthen institutions and reduce competition among users, and improve overall returns from irrigation schemes (Amede 2014). Institutional effectiveness makes market success more likely, thereby increasing the feasibility of improved land management.

Terraces are a central technical option under IWSM, yet all terraces are not equally effective, and local climate and soils partly determine their effectiveness. For example, the effectiveness of terraces varies with soils and geology, producing more substantial yield improvement on basalt than on limestone lithologies (Nyssen et al. 2007). Terraces are clearly more effective in drier areas, improving crop yields by alleviating soil moisture limitations, while in humid areas terraces can cause waterlogging and other problems (Kassie 2009), or simply have no net effect on yields. On the steep slopes where terraces are needed most, the costs and benefits of terracing may warrant close attention.

Since IWSM approaches generally rely on a variety of technical options in combination with institutional strengthening, two key questions are which options to prioritize and in what sequence (Desta et al. 2005), and how to effectively integrate technical expertise (especially on water flows) with participatory, community-based planning in an iterative process of refinement. Answers to both of these questions will vary among watersheds with different institutional and ecological conditions. As the most successful examples of IWSM relate to market success, rural areas where market access is unlikely to improve rapidly may benefit more from low-cost options for land restoration.

**Participatory rangeland management (PRM)**

*Option.* Participatory rangeland management (PRM), the practice of community-based natural resource management in pastoral areas, refers to the process of (i) identifying and mapping rangeland resource use in space and time, (ii) facilitated negotiation of the rules and roles of local institutions in planning resource use, and finally (iii) implementation of the local rangeland management plan (Flintan and Cullis 2010, Dazé and Awgichew 2015). Traditional or customary institutions such as *gada* (Borana) and clan (Afar, Somali), pastoral associations (PAs; *kebele* level), and informal or formal local management committees are among those responsible for creating and implementing local rangeland management plans (Flintan and Cullis 2010). In recent decades pastoralist livelihoods have suffered from droughts, expansion of crops into rangelands, a government ban on burning, rapid population growth, and high livestock density (Angassa and Oba 2008). Rehabilitation of degraded pastoral areas would benefit from several available options. Range condition improvement can benefit from establishment of conducive land tenure security, control of invasive species (*e.g., Prosopis*) and bush encroachment, greater emphasis on camel and goat herding, re-seeding, maintaining mobility and restricting fragmentation (especially due to crops and other effectively 'privatized' lands), and perhaps most importantly, locating new water access points where they complement rather than conflict with grazing management systems (Solomon et al. 2007).

Successful restoration of pastoral rangelands is generally unlikely without the strengthening and at times creation of effective institutional arrangements overseeing rangeland management. For example, exclosures can either succeed or fail in the same area, or in different areas with similar climate (Angassa and Oba 2008, Beyene 2015, PRIME 2015), pointing to the central role of local institutions. Over recent decades in Borana Zone, Oromia Region, exclosures (*kallo*) began earlier in districts with larger towns, and now virtually 100% have access to exclosures (Angassa and Oba 2008), which now cover at least 10% of the land area (McCarthy et al. 2003), leaving little scope for expansion due to this impressive progress. Exclosures were sometimes successful in similarly semi-arid parts of eastern Oromia and Somali Regions, but the primary factor underlying variation in success was the relative strength of community institutions for implementing PRM: where local institutions were stronger, exclosures with soil conservation measures were better maintained over a longer period of time (Beyene 2015). In contrast, exclosures remained virtually absent from the traditionally pastoral lowlands of East Shewa in the Rift Valley of Oromia (Nedessa et al. 2005), where most pastoralists now cultivate maize, largely for fodder.

In pastoral systems, any technical option (re-seeding, bush clearing, etc.) is unlikely to be continued when not embedded within local institutions. Fire management is a good example of a promising technical option with significant organizational and climatic constraints (Solomon et al. 2007, Angassa and Oba 2008, LaMalfa et al. 2010). Burning is used in some pastoral areas of Ethiopia to control woody plants and improve forage quality (LaMalfa et al. 2008, 2010). Fire management was widely used traditionally (LaMalfa et al. 2008), with an average fire return interval of 3 years, though burning was effectively banned under the Derg government and has only recently re-emerged as a management option (Solomon et al. 2007). Currently, heavy grazing means that fine fuels, especially grasses, are often insufficient to carry a hot, effective fire. To build up the fuel load, degraded areas must be rested from grazing for a year or so before prescribed burning (Carbonari et al. 2012), and rested for some time afterwards to allow establishment of healthy grass cover (LaMalfa et al. 2010). Applying prescribed fire in *kallo* exclosures substantially reduced unfavorable bush species and improved forage quality (Carbonari et al. 2012). Eight years after combined bush clearing and prescribing burning, a formerly severely degraded area is now a *kallo* in excellent condition, and would not require repeat treatment for over 10 years (Sircely, *pers. obs.*), a potentially sustainable outcome. Pastoralists rated the effectiveness of prescribed burning highly, and planned to scale up independently (Carbonari et al. 2012). In less populated areas of Borana Zone where forage and fuel load limitations are less problematic, burning is increasingly prioritized for range management (J. Doyo, *pers. comm*, L. Robinson, *pers. comm.*).

*Context.* Pastoralists are exceptionally knowledgeable on the management of their land and resources (*e.g.*, Angassa and Oba 2008), and making use of communities' experience in rangeland management can enhance restoration success (Beyene 2015). For example, the expansion of exclosures in recent decades in Borana is pre-dated by a history of protected communal calf pastures (Angassa and Oba 2008). Rangeland restoration in pastoralism also depends partly on climate—for example, exclosures have succeeded in pastoral areas with intermediate rainfall, such as Borana. Climate significantly determines the severity of forage scarcity induced by protection from grazing during exclosure establishment (Solomon et al. 2007, Beyene 2015), and before and after prescribed burning (LaMalfa et al. 2010). During these periods, the opportunity costs of lost forage and milk production are significant (Solomon et al. 2007, LaMalfa et al. 2010, Beyene 2015). In semi-arid areas of Somali and eastern Oromia Regions, exclosures were more successful where exclosures recovered more quickly, and where diversified livelihoods allowed flexibility during exclosure establishment (Beyene 2015). Though important, climate is but one factor affecting forage scarcity, and both exclosures and fire management are likely more feasible in remote areas with surplus forage.

In all cases, local institutions involved in rangeland management must be strong—for example, strong enough to convince herders to protect new exclosures from grazing (Beyene 2015), or to protect areas to be burned (LaMalfa et al. 2010). The likelihood of institutional effectiveness increases when tenure arrangements legitimize communal ownership, and when customary institutions and herders from across all wealth strata (not solely poor households) are included as key stakeholders (Beyene 2015).

*Synthesis.* Any technical option—from farming fodder to soil bunds—will likely fail where the climate *or* institutions are poorly suited, causing poor returns on these investments. Bush clearing is an instructive example. Though it directly addresses bush encroachment, often a major problem in pastoral rangelands, bush clearing is labor intensive, is not cost-effective, and generally fails to transform large areas (Solomon et al. 2007). The climatic range under which exclosure is a viable option for pastoralists is not well known, yet in truly arid areas the returns may be modest or minimal. For other options, such as cut-and-carry grazing exclosures, the climate constraint is likely to be stronger. However, effective institutions may help ameliorate climatic constraints. If local institutions are strong, the climatic range within which options such as exclosures are feasible may be broader than otherwise.

Fire management may have great potential in pastoral systems due to its cost-effectiveness and history of widespread use by some pastoralists. Developing effective technical or institutional means of alleviating forage scarcity should increase opportunities for expansion of fire management. Exclosures are more prevalent in more populated districts (Angassa and Oba 2008, Beyene 2015), yet exclosures in these areas are less likely to be burned due to forage scarcity (Solomon et al. 2007). Exclosures are a key resource for residents of these areas, and applying fire management will often require alternative means of obtaining fodder. While availability of alternative livelihoods may ease forage scarcity constraints during exclosure establishment or prescribed burning, effective targeting to appropriate areas and years may improve success. Forage scarcity constraints on fire management may be avoided by targeting prescribed burning to wetter years, years following a drought, and to remote locations (LaMalfa et al. 2008). During exclosure establishment, the costs imposed by forage scarcity may be lessened by prioritizing degraded areas, potentially in combination with options such as fire management, re-seeding, and bush clearing under the guidance of effective local rangeland management institutions.

**Synthesis**

The confirmation of the strong potential for up-scaling dryland restoration with the support of Ethiopian farmers, government, and civil society indicates that restoration is a wise investment when technical and institutional options are targeted to appropriate contexts. Several key lessons from this analysis may assist the scaling of restoration in Ethiopia. First, institutional approaches and structures have played an important role in the most dramatic restoration successes in Ethiopia, and institutional effectiveness improves with the inclusion of traditional or customary institutions in understanding, negotiating, and implementing natural resource management plans. Communities with stronger institutions appear more capable of carrying out more intensive or costly restoration efforts, over longer periods of time. Climatic conditions are likely to significantly regulate restoration success through multiple mechanisms, including climate effects on forage scarcity and the rate of vegetation recovery. In mixed crop-livestock systems, the success of technical options is constrained by biophysical conditions, with institutional arrangements a key enabling factor. In pastoral areas institutional strengthening may generally produce the greatest gains, enabling technical options to be fitted to institutional and climatic demands. Over the longer term, market access and the realization of economic returns from restoration are strong determinants of the ultimate success of dryland restoration in Ethiopia.

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