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RESEARCH ARTICLE

# Community participation and ecological criteria for selecting species and restoring natural capital with native species in the Sahel

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**Combining community needs and preferences with dryland plant expertise in order to select suitable native species for large-scale natural capital restoration is the approach that has been successful in the Sahel as part of Africa's Great Green Wall program. In order to increase plant diversity and restore degraded land, we investigated four cross-border regions of Mali, Burkina Faso, and Niger, all located in dryland ecosystems of the Sahel. In 120 beneficiary village communities, with a total population of over 50,000 farmers, including 51% women, participatory diagnostic meetings were conducted, leading to the selection of 193 plant species, most of which were mainly used for food, medicine, fodder, and fuel. Of these, 170 were native and considered suitable for enriching and restoring those village lands. The most environmentally well-adapted and economically relevant species were prioritized, quality seeds were collected, and nursery seedlings produced under technical supervision of villages. From 2013 to 2015, 55 woody and herbaceous species were planted to initiate restoration of 2,235 ha of degraded land. On average, 60% of seedlings survived and grew well in the field after three rainy seasons. Due to its multiple uses, including gum arabic production, *Acacia senegal* was preferred by local people in most cases, accounting for 30% of seedlings planted. Such promising results, in an effort to restore degraded land for and with the help of thousands of farmers, could not have been achieved without the combination of scientific plant expertise and efficient rural capacity development, underpinned by high levels of community engagement.**

**Key words:** **Africa dryland, Burkina Faso, Great Green Wall, Mali, Niger, restoration, rural communities**

### Implications for Practice

- Africa's Great Green Wall is developing into a mosaic of interventions and activities that consider benefits to the vicinity communities, bringing success to large-scale restoration and improving socio ecological resilience to climate change.
- Restoring large-scale agrosylvopastoral systems in the Sahel has been a successful operations model, through mobilization of committed communities, the planting and maintenance of useful native woody and herbaceous species.
- This success is grounded in restoration activities, which are in-line with the communities' preferences and needs.
- This approach is planned for dryland countries in Africa, the Carribean (Haiti), and Pacific (Fiji) through "Action Against Desertification" project funded by EU/ACP, keeping communities at the heart of the restoration initiatives and thereby helping to ensure sustainable future.

## Introduction

Dryland forests and agro-sylvo-pastoral systems in the Sahel are a source of a wide range of ecosystem services on which local communities depend for their living. With increasing demand, natural resources are being overexploited leading to land degradation and desertification, putting at risk these most vulnerable people in the drylands. The Sahel is affected by desertification in many places, a process that is due to combined effects of climatic and anthropogenic factors (UNCCD 1994). Although a simplification, the vicious cycle of land degradation holds true in many cases where inappropriate use of land lead to a decrease in productivity and thus increasing poverty. Thus, the costs of the environmental crisis and subsequent degradation are most strongly borne by the poor, further contributing to their poverty and malnutrition (Stern 2006; Bremner et al. 2010; IPCC 2014).

Sub-Saharan Africa is believed to remain one of the global regions most vulnerable to climate change (Fingar 2008; Nakhooda et al. 2011). Warming temperatures and changing

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precipitation regimes are projected to exacerbate natural hazards, accelerate desertification, increase exposure to infectious diseases, compromise food and water security, and accelerate the degradation of ecosystem services (IPCC 2014). Given the inevitability of some degree of climate change and already observed impacts, the Great Green Wall (GGW) for the Sahara and the Sahel initiative is one of the responses for a large-scale adaptation and resilience of natural and human systems. Endorsed in 2007 by the African Union and facilitated and delivered through a large number of partners, this program aims to incorporate environment and development issues, by adopting a series of different sustainable land management across the countries involved both south and north of the Sahara. As a large mosaic of sustainable land use approaches, actions are tailored to national plans and contexts of the local communities and local environments. Restoration of agro-sylvo-pastoral landscapes and degraded lands is one of the priority interventions acknowledged by member countries of the Africa's GGW (AUC/PAGGW 2012; Berrahmouni et al. 2014).

For a large-scale restoration such as the GGW program to succeed, it is crucial not only to audit the ecological types of landscapes before adapting suitable interventions but also to consider community participation and their lifestyles (Wortley et al. 2013; Meli et al. 2014). In the Sahel, desertification is exacerbated by unsustainable over-exploitation and mismanagement of natural resources, without replacement and/or without leaving sufficient time for these resources to regenerate naturally, in combination with drought and climate change. Within similar dryland ecological and ecosystem contexts, countries such as Burkina Faso, Mali, and Niger are facing similar environmental challenges in getting the balance right. Planting is only one possible strategy of restoration intervention and sustainable land management, but remains one of the most powerful tools for communication with and mobilization of rural communities. Many local initiatives on reforestation and agro-forestry have been developed in the Sahel and North Africa over the years, often using traditional ecological knowledge and multipurpose plant species of known benefits for the inhabitants of these regions (Berkes et al. 2000). However, much of this knowledge has not been formally disseminated to the wider world and remains in the gray literature.

The ambition of the restoration efforts within the GGW initiative is huge. For its success, it is critical that we learn from past mistakes and capitalize on current advancements in science and technology. The Food and Agriculture Organization of the United Nations (2015) is taking the lead role in turning this ambition into reality by supporting the African Union and other organizations, governments, and stakeholders on the ground. As part of this collaboration, the Royal Botanic Gardens, Kew is coordinating and providing technical assistance on selected suitable native species for this large-scale restoration. Using its unique botanical knowledge, long-standing partnerships in the region and information resources, as well as engaging with in-country partner specialists and local communities, Kew is helping to identify and propagate well-adapted native species that meet the needs of the involved communities.

In this project, we combine community needs and preferences with ecological criteria in selecting native species suitable for the restoration of natural capital in the Sahel in the framework of the GGW program. The restoration approach is focussed on community participation and engagement in four cross-border regions of Mali, Burkina Faso, and Niger. Targeting both an increase in multipurpose plant diversity and land cover, this large-scale restoration of agro-sylvo-pastoral systems in the Sahel includes propagating tree, shrub, and herbaceous fodder species useful to these communities and their livestock.

## Methods

### Selection of Intervention Areas

In the framework of the GGW restoration program in the Sahel, national plans of action (FAO 2015) were used to locate intervention areas in the cross-borders between Burkina Faso, Mali, and Niger. Partner communities were selected to take part in the project according to criteria commonly agreed on by the facilitating organizations, the national tree seed centers and representatives of non-governmental organizations (NGO), and the community-based organizations. These criteria included (1) availability of degraded land to restore in the villages; (2) possibility to improve agro-sylvo-pastoral and landscape systems; (3) motivation and commitment of villages to participate in restoration activities, including their in-kind contributions with land and labor; (4) social diversity of village beneficiaries (gender, age, and profession) and community-based structure and organization; (5) availability of facilities such as water sources for installing village nursery; and/or (6) availability of opportunities to work with other ongoing programs or projects in the villages and the region.

### Botanical Information and Prioritization of Restoration Species

Consultation with communities was organized to collect information on plant species known and used in the localities and their conservation status, and on communities' priorities and their objectives for restoration. With all communities involved, this process enabled recording and understanding local needs and preferences for species, the collation of local uses of plant species and products, and agreement on restoration objectives from community perspectives. Such consultation was a critical initial step of collaboration as the communities had to contribute and commit their land and labor for implementing the planned activities.

Communities' criteria for selecting and prioritizing species were made according to their lifestyles, well-being aspirations, and opportunities to extract value from their environments. Preferred species were then matched according to the needs and activities of communities, analyzed, and prioritized according to their known adaptability to local environmental conditions. Research on species properties included their seed germination and handling requirements, and seedling propagation in nursery. Some of these preferred species required botanical verification and authentication prior to any action. Others needed further research on dormancy breaking or germination protocol in nurseries. In this article, seed samples and herbarium specimens for species authentication were analyzed in the laboratory in-country and/or at Kew.

### Implementation on the Ground and Monitoring

**Quality Seed Collection and Seedling Production.** All prioritized species were subjected to seed collections and seedling production in villages close to the planting sites. Seeds from herbaceous species were collected in bulk and from the best known provenances. Those of woody species were collected in selected natural seed stands defined in seed zones, usually determined by the national tree seed center, based on the similarity of ecological conditions. In order to ensure a sufficient genetic variation in the seed lots, bulk samples were made of collections from 20 to 25 different trees, separated by about 50–100 m (OECD 2014). Seed characteristics were studied according to the International Seed Testing Association (ISTA) seed testing rules (2010) to determine their germination response and thousand seed weight. These parameters allowed the estimation of the amount of seeds to collect per species, which were appropriate to cover the surface areas to be restored.

Nursery techniques were used for seedling production in villages and in institutional nurseries. Two types of seedlings are generally produced. Seedlings of fast-growing native species are readily planted out within a year, while those of slow-growing native species are planted in the second year of nursery growth.

**Soil Preparation for Planting.** Soil preparation for planting is a determining factor in drylands where moisture retention is critical to restoration success. To allow maintenance of maximum moisture from limited rainfalls and moist soil for the longest possible periods of time, the traditional techniques of "half-moon" or "zai" cultivation were used to prepare planting sites. These stopped water run-off and allowed water harvesting by creating multiple small dams in the field, improving seedling establishment. Land scarification was also applied in wider inter-village areas. Planting seeds and seedlings occurred at the onset of and during the rainy seasons, generally in June–July, ending in September, in the intervention areas, so that the plants benefit maximally from the first year rainfalls.

**Monitoring and Evaluation of Field Performance of Species.** Field data were collected on survival and growth of seedlings, and on frequency of maintenance and management of planted areas (these data are in preparation for a separate publication). Monitoring was conducted by trained village technicians and in full cooperation with the communities involved. The technicians cared for the seedlings and plants, and collected information and data on growth and establishment.

A technical and management team was set up consisting of representatives of all stakeholder groups, including recipient beneficiaries, the local communities, local environmental NGOs, technical facilitators, and sponsors. The whole team met once a year to evaluate, compile lessons learnt, and plan restoration activities. This was a valuable way to communicate, and was a forum where progress was assessed and roles, responsibilities, accountabilities, and reporting were defined.

### Capacity Development of Village Technicians

Technical training was provided to villages in formal modules on how to collect good quality seed in defined seed zones by the national forest seed centers, on seedling production and participatory forest management. This also included training on added-value and the development of plant (non-timber forest) products, marketing and local business management in order to support income generation. Other important needs being addressed included improving adult literacy and family health and nutrition standards in conjunction with other specialized rural development sectors.

## Results

### Village Community Consultation

The process of engaging with villages was conducted through participatory diagnostic meetings for restoration planning and activities. This included introductory community workshops, group discussions, individual in-depth interviews through structured questionnaires, field visits of lands to invest in, and workshops for agreement on plans with all the selected villages. Applying the criteria set for selecting villages and communities to take part in the restoration program allowed the work to be extended to 120 villages of the four cross-border regions in 3 years, including 85 in Burkina Faso, 13 in Mali, and 22 in Niger (Fig. 1). The number of communities increased markedly over the 3 years of the project, expanding from 21 villages in 2013 to 96 in 2014 and 120 in 2015. Total individual contributors and beneficiaries were just over 50,000 people, including 25,170 women (51%). Age groups varied from 15- to 70-years old, with formal thematic professions of farmers, herders, traditional healers, and herbalists (detailed data not published but are available in the project reports and GGW restoration database).

### Prioritized Native Species for Restoration

An initial list of 193 plant species was provided by, and listed as useful to, the 120 communities during consultations. Plant use data given by respondent farmers in the communities were classified according to the economic botany data collection standard (Cook 1995). These species were usually preferred for their multipurpose social utility and according to the community semi-nomadic lifestyle in the regions. The largest proportions of given uses accounted for their importance in human (74%–143 species) and veterinary medicine (13%–25 species), and as food (58%–112 species) and livestock feed accounting for 105 species (54%) (Fig. 2). A large number of species were reported to have two or more uses, including *Acacia senegal* (also called *Senegalia senegal*, by some specialists), *Balanites aegyptiaca*, *Cymbopogon giganteus*, and *Khaya senegalenis*. Among them, multipurpose species with great potential market

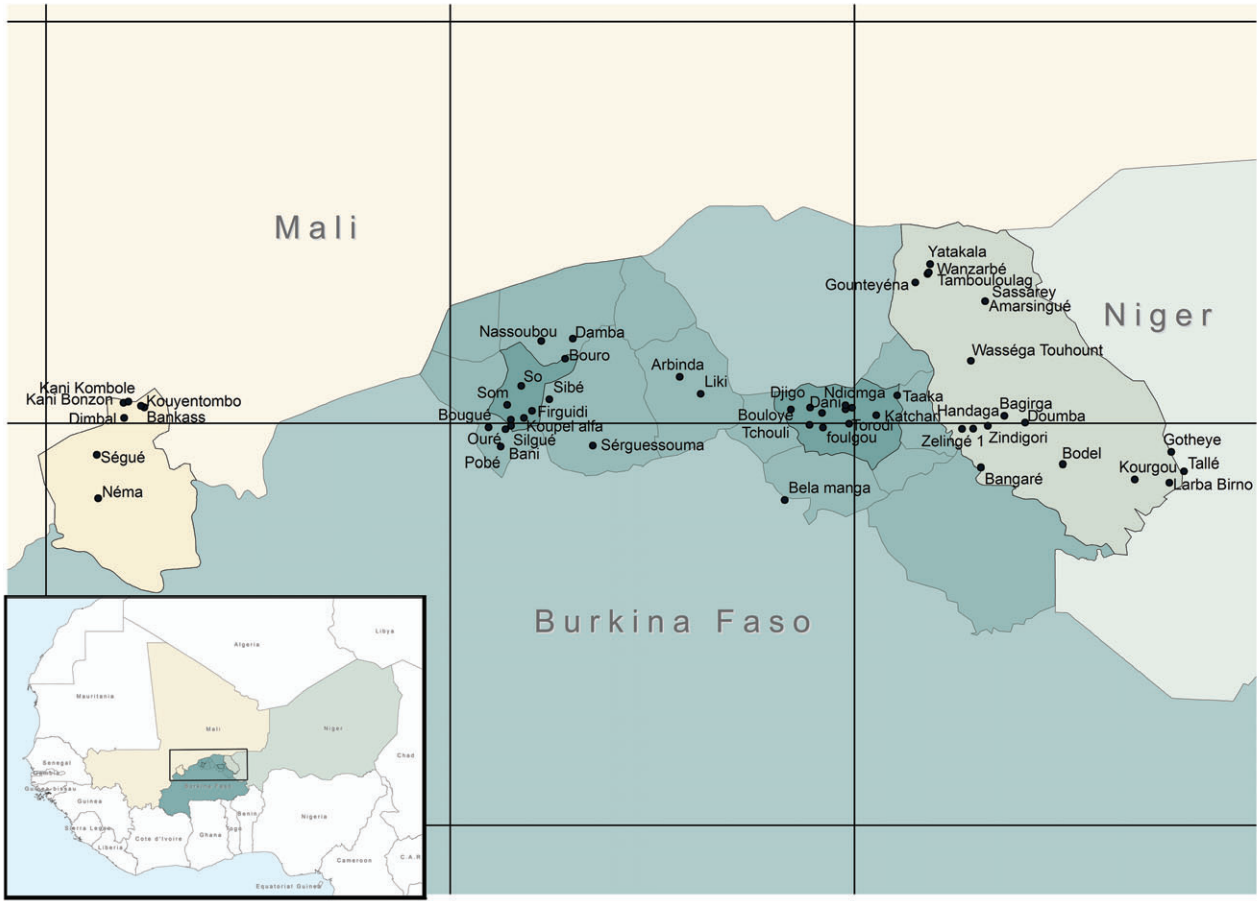


Figure 1. Distribution map showing 52 georeferenced villages out of 120 total villages involved in restoration activities for the GGW program across four regions of East Mali (seven villages), West and East Burkina Faso (27 villages), and West Niger (18 villages). These villages are located between longitudes −3.74 and 1.07° and latitudes 14.02 and 14.72°.

values of saleable products such as gums and resins or fodder, had highest priority and were in huge demand with communities. Often all parts of the plants are used and most species have more than one use. For example, *A. senegal* is mainly exploited and planted to produce gum arabic for income generation, but it is also used as a source of food and fodder, and for the production of honey. Some of the preferred species are both fodder and food plants, e.g. *Digitaria horizontalis* (locally known as fonio) and *Panicum laetum*.

Botanical analyses of results using several Kew databases such as the Survey of economic plants for arid and semiarid lands (SEPASAL) and the Plant Resources of Tropical Africa (PROTA), showed that 170 (73%) of these species were suitable and appropriate for dryland ecosystem restoration. The remainder of the species, which were not used for restoration activities, were listed based on farmers' personal knowledge, or aspiration for uses. In some cases, the species were either exotics, e.g. *Azadirachta indica* or suitable for slightly more humid environments (e.g. *Vitellaria paradoxa*). A detailed implementation plan of actions and timetable was presented to the communities and following discussion and modification, was agreed on by all stakeholders, including prioritization of species and activities for restoration.

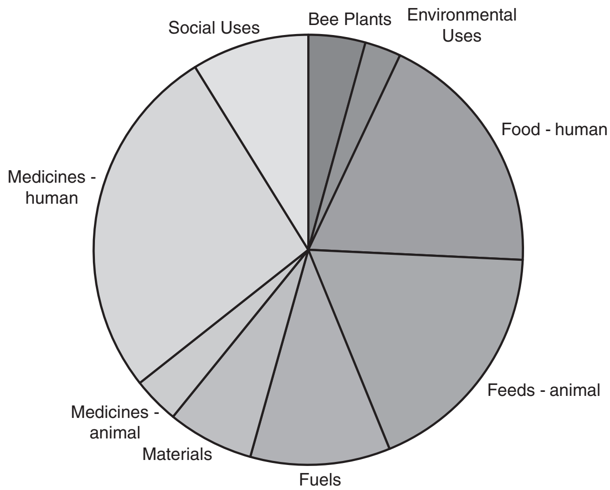


Figure 2. All categories and proportions of native species selected and preferred by local communities, including higher proportions for medicinal-human species (24%), animal feeds (19%), food species (18%), and fuelwood (11%). These choices also illustrated people's needs and priorities in this part of the Sahel, where natural plant resources are very limited.

**Table 1.** Forest seed mobilization capacity of countries with established seed systems assessed through Kew's Millennium Seed Bank partnership in sub-Saharan Africa. The seed banks in Burkina Faso, Mali, and Niger contributed substantially to supplying quality seeds and seedlings for the GGW restoration program.

| *Country* | *Institution* | *Capacity per year (kg)* | *Species (Trees, Shrubs, and Grasses)* |
|---|---|---|---|
| Burkina Faso | Centre National de Semences Forestières—CNSF, Burkina (registered OECD forestry Scheme) | 3,000 | 50 |
| Ethiopia | Forestry Research Centre (EIAR-FRC) | 8,000 | 20 |
| Kenya | National Tree Seed Centre, Kenya Forestry Research Institute (KEFRI—registered OECD forestry Scheme) | 10,000 | 40 |
| Mali | Unité de Semences Forestières—USF (IER) | 1,000 | 50 |
| Niger | Centre National de Semences Forestières (CNSF, Niger) | 1,000 | 20 |
| Senegal | Projet National de Semences Forestières (ProNaSef) | 2,500 | 20 |
| Total | | 25,500 | 200 |

### On-Ground Operational Processes

**Seed Collection and Seedling Production.** Among other technical considerations, we looked at Kew's country-focused taxonomy connections and at the global seed mobilization capacity of Kew's Millennium Seed Bank partnership countries in Africa. Recently, the GGW countries can supply about 25,000 kg of seeds per annum of about 200 species of trees, shrubs, and grasses (Table 1). The total forest seed mobilization capacity of the three national forest seed centers involved in the restoration project are about 3 tons across 50 species per annum for Burkina Faso and 1 ton for both Mali and Niger across 50 and 20 species, respectively (Table 1). The proportions of selected species for the GGW were far less than the amount available annually. Importantly, two national forest seed centers, CNSF in Burkina Faso and KEFRI in Kenya, are registered under the OECD Forestry Scheme, which allows independent checks on the physiological quality of seeds and seedlings provided to users and their traceability. Quality seed collections and seedling production of woody species in selected village nurseries with training in local administrative nurseries were undertaken. In total, 55 species were prioritized for planting in 2013, 2014, and 2015. Of those, 25 were preferentially and concomitantly selected by communities in the four cross-border regions, including 75% woody species and 25% of multipurpose grasses, which are mainly used as animal feeds and/or food (Table S1; Fig. 2). Seed characteristics such as 1,000 seed weight and germination responses of seed lots were determined for all the collections (ISTA 2010). This information was used to estimate the quantities of seeds needed to be produced for each species.

Seed-collecting and seedling production of the selected and prioritized species started in 2013. A vigorous normal seedling that has reached 40 to 80 cm generally has an increased chance of survival when planted out. This stage of development occurs about 3–6 months for fast-growing native species such as most of the *Acacia* species. Due to slow growth in the nursery, seedlings of species such as *B. aegyptiaca*, *Faidherbia albida*, or *Tamarindus indica* were maintained for 14–18 months before being planted out in the second year. Seedling growth rate is an important factor to consider in restoration projects with native species, as often short term (e.g. 3 years) projects only permit the use of slow-growing seedlings toward the third year, and thus limiting impacts on the ground.

### Soil Prepared for Planting

Seedlings produced in nurseries were planted out in hand-dug holes prepared by the communities as subsidized paid labor. Land prepared for the planting greatly reduced rainwater run-off and benefitted the young plants (Fig. 3). About 300 half-moons were dug in a hectare of land. This ratio was used at some sites to estimate the areas planted in the villages. Animal ploughing and mechanized scarification of soil were applied for larger land areas in communal forests and between villages, which were mostly used for livestock grazing. In those sites, seeds were directly sown, specifically of fodder and edible grass species and in conjunction with some of the woody species as well.

All 120 villages involved in the project contributed planting, sowing and maintaining natural regeneration and were committed to organize the maintenance and surveillance systems for better protection and management of planted areas (Figs. 4 & 5). On sites where it was appropriate, assisted natural regeneration was applied alongside the enrichment of the plots with planted species. In open land, at least 10 species were planted per hectare, combining woody seedlings, and herbaceous seed sowing usually in a ratio of 7:3 or 8:2 per station. Over 1 million seeds and seedlings were produced in 2013, 2014, and 2015, composed of 957,000 nursery seedlings and 5,548 kg of seeds. The quality of the seed material was reflected in their germination levels, being 60–100% for most species (Table S1). All seed collections were made by the national forest seed centers and by the trained village technicians. For maximum plant diversity and land cover in village woodlots, over 1,000 woody seedlings/ha were planted ($3 \times 3$–m spacings), equivalent to three seedlings per half-moon. Where intermediate diversity or lower was required, woodlots were planted with seedlings ($4 \times 4$–m or $5 \times 5$–m spacings), resulting in more than 625 but less than 1,000 seedlings/ha. This design follows the usual forestry or agro-forestry procedure that farmers apply in the Sahel. In low diversity conditions, usually applied for the inter-village land that is mostly scarified grazing area, between 100 and 625

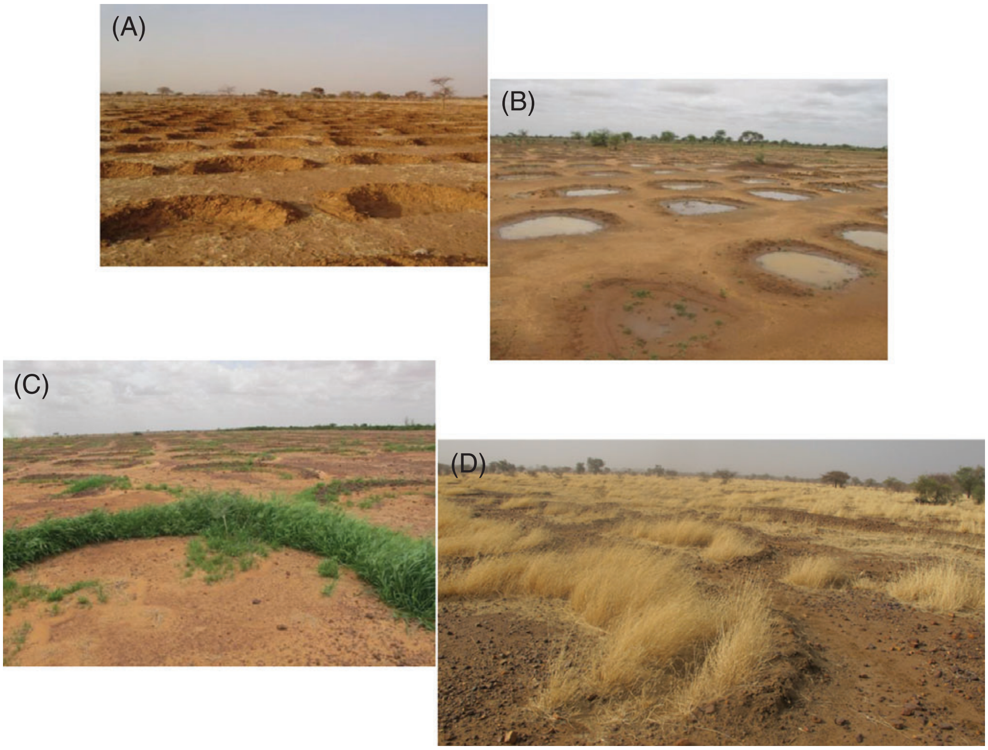


Figure 3. Hand-dug "half-moon" planting holes prepared and planted in 2013 by GGW communities of Dori, Burkina Faso: (A) before the rainy season (top left), which (B) successfully trap rainwater (top right). This technique enables (C) newly planted woody and herbaceous seedlings to achieve rapid growth in wet season (bottom left). The assessment shows (D) seedlings established and herbaceous cover of initial bare land in the dry season in 2015 (bottom right). Photo can be credited: M. Sacande.

seedlings were planted per hectare in woodlots ($10 \times 10$–m spacings). On average, 200–500 seedlings were planted per hectare to enrich farmer-managed village lands. On average, there was a 60% survival, across all planted seeds and seedlings.

The preferred woody species planted were: *Acacia nilotica*, *A. tortilis*, *A. senegal*, *Adansonia digitata*, *B. aegyptiaca*, *Bauhinia rufescens*, *F. albida*, *Khaya senegalensis*, *Lannea microcarpa*, *Prosopis africana*, and *Ziziphus mauritiana* (Table S1; Fig. 5). Gum- and resin-producing species such as *A. nilotica* and *A. senegal* by far outnumbered other species due to their multipurpose uses and potentials for income generation for farmers. Both acacias comprised 50% of all plantings, with *A. senegal* alone accounting for 30% of seedlings planted (Fig. 5). Five important fodder grass species were planted, representing greater than 3,000 kg of seed at a seeding rate of about 5–10 kg seeds per hectare. These included *Alysicarpus ovalifolius*, *Andropogon gayanus*, *C. giganteus*, *P. laetum*, and *Pennisetum pedicellatum*. These herbaceous species were planted either singly or in mixtures of low spreading species, such as *A. ovalifolius*, which only reaches 0.5 m high, combined with much taller grasses, e.g. *A. gayanus* (up to 2.5 m high), so that they could still be harvested separately. The total area planted by 120 partner villages across the four transborder regions has increased from 300 ha in 2013 to 1,150 ha in 2014 and 2,235 ha in 2015 for this GGW restoration intervention (Figs. 1, 4, & 5).

### Capacity Development of GGW Communities

Village farmers participated in locally run training programs in 2013 and 2014, with the first such workshop taking place in Burkina Faso, involving national partners and new partners from Niger, enabling enhanced capacity and collaboration across borders. Over 100 village technicians have been trained and supervised to collect seeds and produce seedlings in village nurseries near the planting sites. In 2015, another 45 farmers from Burkina Faso and Niger were trained in beekeeping and honey production, this time in Niger.

Village communities involved in the planting of their land participated in the regular monitoring and evaluation of the plots, which included assessing seedling suvival and growth and planted surface areas (Fig. 4). In its first two years, the project trained about 70 administrative technicians who were familiarized with this restoration approach and were committed to the activities on the ground. Trainees were always mixed groups of women and men, and of different ages, who go on being supervised native seed collectors, seedling producers, and/or woodland managers.

## Discussion

The intrinsic and complex link between people and the landscapes in which they live is of critical importance when developing a restoration program. Incorporating the needs of

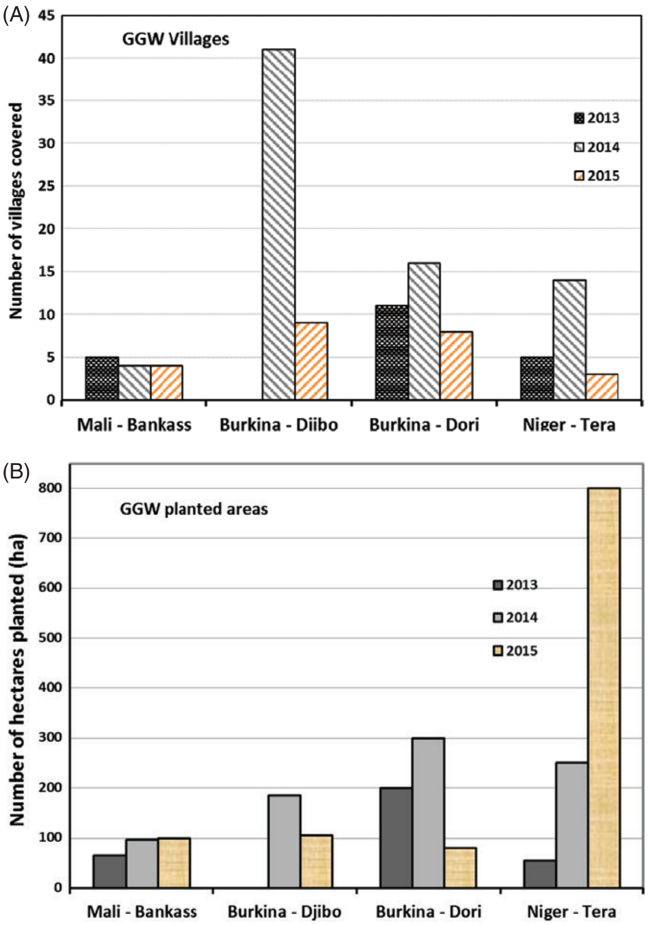


Figure 4. (A) Increase in partner villages covered by the project and (B) farmer-managed areas and sites planted by 120 communities across the four Sahelian regions from 2013 to 2015 for GGW restoration. These were the very first plantings of the GGW program for Burkina Faso and Mali.

local communities and other stakeholders is of vital importance in achieving success in both environmental goals and the promotion of human well-being. Projects aiming to achieve both poverty alleviation and conservation are a commendable, but complex task (McShane et al. 2011; Turner et al. 2012). With humans continuing to be the major driving force in dryland ecosystems (Aronson et al. 1993) any planning of restoration projects must address the needs and contexts of the people who live in the area to ensure success.

### Ecological Context

Sub-Saharan Africa is believed to remain one of the most vulnerable regions globally to climate change (Fingar 2008; Nakhooda et al. 2011). Warming temperatures and changing precipitation regimes are projected to exacerbate natural hazards, accelerate desertification, increase exposure to infectious diseases, compromise food and water security, and accelerate the degradation of ecosystem services (Aronson & Alexander 2013; IPCC 2014). Dryland regions of the Sahel, in particular, are vulnerable in terms of the capacity to adapt to the predicted effects of climate change (OECD/SWAC 2014). This reflects the already marginal environment, high dependence on rain-fed agriculture, ongoing desertification challenges, and limited adaptive capacity of socioeconomic systems (World Bank 2010). There are already considerable consequences of climate change and already observed impacts. Restoration of forest landscapes and degraded lands has been identified in countries' strategies in the GGW priority intervention areas (Conedera et al. 2010; Berrahmouni et al. 2014). The GGW for the Sahara and the Sahel initiative is a significant response to these threats, promoting direct action to increase adaptation and resilience of natural and human systems.

### Technical Aspects

Large-scale restoration and plant reintroductions must be underpinned by the effective use of seeds of wild species, which in turn requires sufficient biological and technical knowledge of a large number of species to enable the collection, storage, and germination of seeds and establishment of seedlings (Merritt & Dixon 2011). However, despite the critical importance of a reliable supply of seeds to achieve restoration goals, constraints surrounding the quantity and quality of native seed required are not always recognized. Our model approach relies on established forest tree seed centers with which RBG Kew has long-standing research partnerships for over a decade (Sacande & Pritchard 2004). In addition, the global program of GGW in Africa is relying on two major forest seed centers in Burkina Faso and Kenya that are managed according to international forest seed standards (OECD 2014). Both countries have defined national formal seed zones (Yoda & Gamene 2003) that guide their seed collection. Seed supply systems in other GGW countries are also improving, as stressed by the Strategic Priority 6 of the FAO Global Plan of Action for ex situ conservation of forest genetic resources (FAO 2014). Adoption of all these frameworks and the associated guidelines and protocols requires and allows an independent quality control of forest seed material mobilized and used, not only ensuring systematic record-keeping but also guaranteeing the traceability of planted material, from initial seed source to mature restored areas. Such data are being captured in RBG Kew's GGW species database, including seed provenance and physiological quality, seedling performances over time in the field, and so on. These types of databases are crucially lacking for many plant reintroduction projects particularly in Africa (Godefroid & Vanderborght 2011). Availability of these data sets a baseline, which provides reference and targets against which efforts and impacts are monitored.

Insufficient and uncoordinated seed supply can be a significant limiting factor in restoration programs. The amount of seed required for the current GGW restoration program can be calculated to be in the hundreds of tons per annum, far exceeding the seed-collecting capacities of government agencies. For example, we used greater than 1,500 kg of seeds in Niger in 2014, whereas its national tree seed center produces only 1,000 kg per annum in total. Quality seed availability is thus one of the most significant challenges to this large-scale restoration. RBG Kew through its partnerships in the GGW

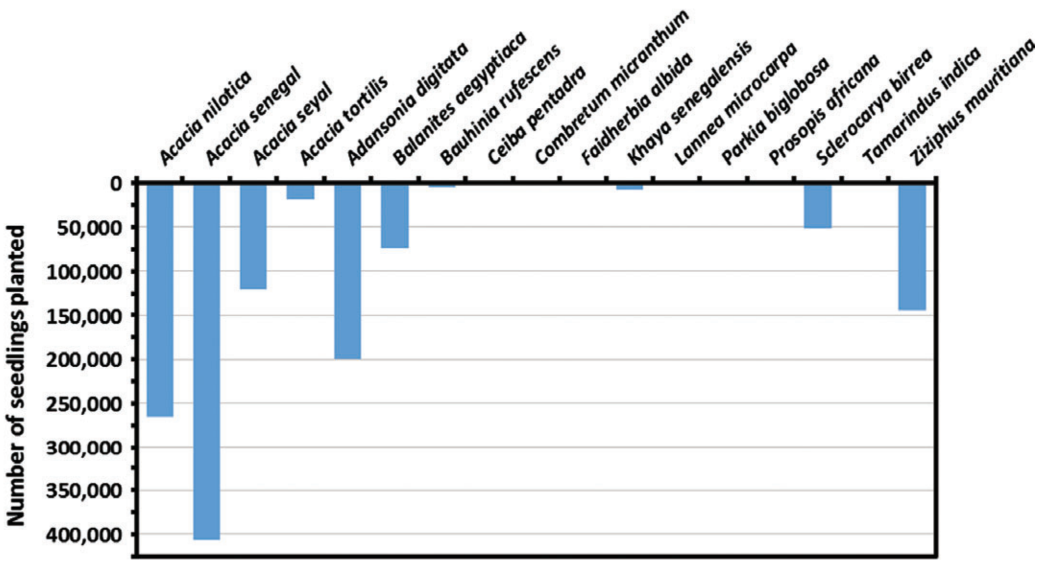


Figure 5. Number of seedlings planted for the top 17 out of 25 preferred species commonly planted in 2013, 2014, and 2015 in Burkina Faso, Mali, and Niger for the GGW restoration program in the Sahel. For seven species, more than 50,000 seedlings were planted, led by *Acacia senegal*, which accounted for 30% of the total seedlings planted.

countries is addressing such constraints to seed supply through local capacity development. Seed banks can have a major role to play in habitat restoration, both as a source of material and in solving research problems related to reintroducing species back into the landscape (Sacande & Pritchard 2004; Elliott et al. 2013). The combined science-based seed knowledge with the infrastructure to support large-scale seed management and the development of effective working relationships between seed scientists and the local communities are ensuring seeds are used to their full potential and guaranteeing restoration success in this GGW program. These relationships are extended to capacity development through training of village technicians as certified seed collectors, forest seedling producers, and plantation managers.

The long-term success of these large-scale restoration actions is in the return on investment in reversing desertification. Although it is difficult to predict the specific way in which the climate will change in these regions, several studies have reported that investing and acting strongly now will help mitigate potential irreversible impacts (Stern 2006; IPCC 2014). With potential increased frequency of extreme environmental events (IPCC 2014), for example more rainfall, some areas might see increased vegetation. Through land cover and soil development, there will be increased opportunities to provide communities with food security and income generation for their livelihoods. Poverty and a high demand for food, fodder, and fuel wood, high depletion rates of and pressure on natural forest resources are all severe in the Sahel region (OECD/SWAC 2014). Combining planting of slow-growing woody plants with fast-growing edible herbaceous and fodder species for livestock (www.feedipedia.org) has been a great success with all the communities involved, and is in high demand by other neighboring communities.

The restoration model also includes and considers a solution for improving livestock grazing as part of the Sahelian landscape in open pasture land. This is a crucial component for most of these pastoralist communities of the Sahel and their lifestyle, as previously suggested (Weber & Horst 2011). Such inclusive planning processes might even improve arid and semiarid rangeland ecosystems as livestock management is part of the solution to the problem of land degradation. Already the benefits from year 1 are the harvesting of edible grass seeds and the collecting of fodder from the plots (quantitative data not shown). These results are in contrast to several previous concepts of a "line of trees" and emphasize the need to also plant shrubs and grass as an alternative, while complementing the current focus on trees (Escadafal et al. 2011; O'Connor & Ford 2014). Our interventions aim to improve plant biodiversity and increase community involvement. In contrast to using large numbers of native species, Senegal's GGW Agency is planting six important priority species for major land reclamation, selected for their ecological adaptations, and economical importance in local uses: *Acacia nilotica*, *A. senegal*, *A. tortilis* ssp. *raddiana* (synonym *Acacia raddiana* (Sacande et al. 2012), *Balanites aegyptiaca*, *Tamarindus indica*, and *Ziziphus mauritiana* (Boetsch 2013). These species were identified in the Ferlo region of Senegal as potential species for the GGW landscapes (Niang et al. 2014) and have also been prioritized in the four regions. Evidently these two projects can benefit from collaborating.

### Societal Considerations

The recent increased interest in the GGW as a program for rural development reflects concerns over desertification in the context of climate change, its significant implications for food security and biodiversity loss, and the growing recognition that past efforts have not met their objectives (Pagnutti et al.

2013; OECD/SWAC 2014). The GGW program itself is already being implemented, but in a piecemeal fashion, depending on countries' priorities and mobilization of funds for projects. To date, there has been major land restoration within Senegal and Niger through the program (FAO 2015), but the current project is the very first restoration action on the ground in Burkina Faso and Mali. Work in other GGW countries has not even started yet. In all cases, there is an emphasis on environmental protection, societal well-being and economic gain. This combination of objectives recognizes that it is only through ecosystem protection that current livelihoods can be maintained (Rockström & Falkenmark 2015).

One essential component of the GGW program is to ensure, through consultation, local involvement and local community ownership of all restoration investments. The reason for this inclusive model approach is that all the community groups, village technicians, and individuals involved are seeing direct improvements in the environment from this program and are thus far more motivated to maintain their commitment over the medium- to longer-term. This approach generates strong community buy-in and support for this restoration program. The rapid establishment and maturation of herbaceous species are ensuring that investment into these areas will be sufficient to maintain current lifestyles and could result in significant improvements in the agricultural, economic, and environmental impacts of the GGW. In addition, the capacity development provided to these transborder communities will bring more understanding to each other efforts and subsequently ease potential tensions between farmers and livestock keepers across borders (Hussein et al. 1999; Turner 2004). Moreover, farmers and herders live in the same communities and interact on a day-to-day level through multiple economic relationships including those that exist between sellers and buyers of milk, manure, or grains or livestock owner, trader and herder. Since the droughts of the 1970s in the Sahel, the livelihoods of "farmers" and "herders" have blurred with both involved in farming and both committed to owning livestock (Toulmin 1983). There are, however, several assessments and management interventions that must be completed collectively at the local level to ensure such success is sustainable. Therefore, continuous inclusion of local people in every step of the process is important to create local ownership and ensure sustainability.

We believe that the success of the GGW initiative so far not only reflects the application of better science and technology, e.g. choice of local species likely to survive in difficult drier bio-climatic conditions, but also the commitment by communities and a shared vision of protecting and restoring natural capital. Dryland communities have traditional ecological knowledge and land management skills, illustrated through the half-moon techniques used in the Sahel for rainwater harvesting that improves seedling and crop establishment. However, this seems insufficient in the face of rapid climate change; hence the need of external and additional inputs into the ecosystems, such as the GGW project. The state of well-being for all is paramount and should be taken into account (Boetsch 2013) so as to avoid repeating the failures or limited successes of previous large-scale restoration projects (Bensaid 1995; Zhang 1996; Wang et al. 2010; Tan & Li 2015). Although the GGW has been proposed as an adaptive strategy to climate change, it has also been promoted as important for mitigation through the provision of substantial carbon sequestration through large-scale planting (Thiam et al. 2014). This would also potentially allow for the countries involved in the GGW to sell carbon credits through international climate instruments.

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## Supporting Information

The following information may be found in the online version of this article:

**Table S1.** Great Green Wall restoration species prioritized and planted with communities in 2013–2015 in Burkina, Mali, and Niger.

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