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Developing and supporting quality nursery facilities and staff are necessary to meet global forest and landscape restoration needs

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Abstract

Seedlings are the foundation for many terrestrial ecosystems and are a critical consideration and investment for implementing global forest and landscape restoration programs. Global leaders have pledged to restore millions of hectares during the next decade, necessitating many millions of established plants. Although natural regeneration and direct seeding will likely meet a portion of that need, large quantities of high-quality, nursery-grown seedlings are also required. Insufficient plant quantities or poor-quality plants result in unsuccessful outplanting programs. Such failures have considerable economic and environmental consequences and will result in an inability to meet restoration goals. Nonetheless, the importance of restoration nurseries is often overlooked when making large-scale restoration commitments. Technology already exists to produce high-quality plants to meet a variety of goals. This technology cannot be applied, however, unless adequate resources and training are made available by overcoming political and socioeconomic barriers. In this article, we discuss the important role of nurseries to meet global restoration commitments and review three case studies where increased support to nursery programs resulted in improved restoration success.

Keywords

High-quality seedling; Target Plant Concept; Bonn Challenge; Reforestation

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1 Introduction – The worldwide need for tree nurseries

With few exceptions, tree, shrub, forb, and grass seedlings are the foundation of all healthy forest and terrestrial ecosystems. Forest and land degradation is a worldwide crisis and requires multiple approaches to mitigate (Chazdon 2008; Halme et al. 2013; Laestadius et al. 2015; Lamb et al. 2005; Sabogal et al. 2015; Stanturf et al. 2014a; 2014b), nearly all of which call for some level of plant establishment. Anticipated effects of global climate change suggest the future need for restoration will increase (Stanturf et al. 2014a) as site conditions become harsher (Oliet and Jacobs 2012), incidence of megafires increase (Williams 2013), and assisted migration is implemented (Williams and Dumroese 2013). In recent years, international leaders have pledged to restore millions of hectares of deforested and degraded lands (Table 1). To help meet these unprecedented and ambitious commitments to forest and landscape restoration, availability of quality nursery seedlings is a crucial consideration (Gregorio et al. 2015; Harrison et al. 2008).

High-quality, nursery-grown plants are often a critical requirement for successfully implementing forest and landscape restoration programs to create healthy, functional, sustainable, and resilient ecosystems. In turn, these forests and landscapes provide multiple ecological, social, and economic benefits. These benefits include: human wellbeing and sustainable livelihoods; wildlife and pollinator habitat; food security and nutrition; carbon sequestration; shelterbelts and windbreaks; agroforestry production; biodiversity and gene conservation; urban beautification; reestablishment of native, rare, and endangered species; cooling and shade; soil stabilization and rehabilitation; watershed and fisheries protection; air quality; wood products and fuelwood; medicinal and cultural plant availability; recreation, tourism, and aesthetic values; and more. In an examination of 20 conservation, restoration, and improved land management actions as pathways to achieve the Paris Climate Agreement goal of holding warming to below 2°C, reforestation ranked highest in climate mitigation potential (Griscom et al. 2017). Stopping deforestation and restoring forests could effectively remove as much carbon dioxide as eliminating all cars in the world (Minnemeyer et al. 2017). In an economic analysis of large-scale ecosystem restoration, Verdone and Seidl (2017) estimate that achieving the Bonn Challenge would generate a net benefit of between US$0.7 and US$9 trillion.

By examining some simplified calculations, the need for nurseries is obvious. For example, meeting the expanded Bonn Challenge of 350 x 10^6 (million) hectares restored by 2030 at a target density of 500 plants per hectare would require establishment of 175 x 10^9 (billion) plants. Assuming a relatively high survival rate of 80% means that nearly 220 x 10^9 plants would need to be outplanted (roughly 18.3 x 10^9 seedlings per year during the 12 years until 2030). Land-use objectives and restoration strategies will vary greatly, but these generalized calculations illustrate the enormous quantity of established plants needed to meet ambitious targets currently set forth. While natural regeneration and direct seeding will likely meet a significant portion of that need, the demand for high-quality, nursery-grown seedlings is still staggering. Although many large, industrial nurseries in the world can produce up to 50 million plants annually, most of these nurseries are already at capacity and do not necessarily contribute to global restoration objectives described in Table 1.

Table 1. Many national and multi-national programs have established commitments for restoration, conservation, sustainability, and biodiversity. This table is by no means exhaustive but illustrates the global community's recognition of the critical need for wide-scale ecological restoration.

Program	Objectives	Details
Bonn Challenge	Restore 150 million hectares of deforested and degraded land around the world by 2020 and 350 million hectares by 2030 using a landscape approach	A global effort launched in 2011 to restore ecological integrity and improve human wellbeing. As of late 2017, 45 commitments have pledged a total of 156 million hectares for restoration. http://www.bonnchallenge.org/
New York Declaration on Forests	Endorsed and extended the Bonn Challenge and strives to cut forest loss in half by 2020 and to end it by 2030	The NYDF is a voluntary international declaration and was first endorsed at the UN Climate Summit in 2014. http://forestdeclaration.org/
Agenda for Sustainable Development	Achieve 17 Sustainable Development Goals (SDG) to end poverty, promote prosperity, and protect the planet by 2030	Adopted in 2015 by world leaders at a UN Summit. SDG 15 is to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. http://www.un.org/sustainabledevelopment/
REDD+ (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries)	Provide guidelines to encourage developing countries to reduce emissions through forest management options	Negotiated under the UN Framework Convention on Climate Change since 2005. Provides a web platform to publish information about REDD+ activities. http://redd.unfccc.int/
Micronesia Challenge	Preserve 30% of near-shore marine resources and 20% of terrestrial resources by 2020	Multi-jurisdiction commitment by the Federated States of Micronesia, the Republic of the Marshall Islands, the Republic of Palau, Guam, and the Commonwealth of the Northern Mariana Islands. http://themicronesiachallenge.blogspot.com/
Initiative 20x20	Restore 20 million hectares of land in Latin America and the Caribbean by 2020	This initiative is in support of the Bonn Challenge. http://www.wri.org/our-work/project/initiative-20x20
AFR100 (African Forest Landscape Restoration Initiative)	Restore 100 million hectares of deforested and degraded land in Africa by 2030	This project supports the Bonn Challenge, the NY Declaration, and the African Resilient Landscapes Initiative. http://www.wri.org/our-work/project/AFR100
The Atlantic Forest Restoration Pact	Restore 15 million hectares of forest in Brazil by 2050	Launched in 2009, the Pact involves a coalition of 260+ stakeholders, including governmental agencies, private sector, NGOs and research institutions. http://www.pactomataatlantica.org.br/
Aichi Biodiversity Targets	Conserve biological diversity by implementing the twenty targets by 2020	Developed by the Convention on Biological Diversity as part of the Strategic Plan for Biodiversity. https://www.cbd.int/
Plant for the Planet	Plant 1 x 10^{12} trees	Launched by the United Nations Environment Programme in 2006. https://www.plant-for-the-planet.org/
Plant a Billion Trees	Plant one billion trees by 2025	Worldwide campaign organized by the Nature Conservancy. http://www.plantabillion.org/
APEC Sustainable Forest Product Trade	Increase forest cover by at least 20 million hectares by 2020 across APEC	Established by ministers from Asia-Pacific Economic Cooperation members through the October 2017 "Seoul Statement" https://www.apec.org/Meeting-Papers/Sectoral-Ministerial-Meetings/Forestry/2017_forestry

In spite of their obvious role in forest and landscape restoration, nurseries are regularly "off the radar." For example, a recent international forestry conference used the image of a seedling for all its materials, yet very few presentations focused on seed, seedlings, or nurseries were included. In another example, a publication on international standards for restoration had an image of a seedling on the front cover but did not include any standards for seedling production or quality. Governments and other entities often consider nursery establishment and/or support to be a low priority. Established nurseries, especially those that are publicly funded and/or grow non-commercial crops, can be viewed as expendable and must regularly justify their existence and need for continued support and maintenance (e.g., Beogo et al. 2017; Iowa DNR 2016). Managers of restoration nurseries often express frustration that they are seemingly invisible when it comes to planning, funding, training, and other resources and that there is an overall lack of recognition and understanding regarding their contribution to restoration success (personal observations). Obtaining quality seedlings from a nursery can be one of the last aspects that a restoration project manager considers (if at all). In fact, seedling and nursery specifications should be one of the first considerations. This oversight can result in nurseries being excluded in the planning stages or allocation of resources for restoration projects and can have far-reaching and long-term economic and environmental consequences. These examples, along with dozens of others, are indicative of the pervasive absence of attention to the integral role of nurseries in restoration programs.

Failure to support and value nurseries occurs in developing and developed countries. In the U.S., several states have closed their nurseries, resulting in seedling shortages for small landowners to reforest following harvest, wildfire, or other disturbances (IFA 2016; NASF 2016; Riddle 1988; Zippay 2008). Additionally, the U.S. Forest Service once had dozens of forest nurseries across the country but most have closed (Dumroese et al. 2005). Similarly, most government nurseries in Canada have been closed or privatized (Van Eerden 2002). Policy and regulations can result in inefficient production of government-run nurseries. In many instances, private nurseries can meet local demands. Nonetheless, government nurseries fill an important role that cannot always be met by private nurseries such as education, smaller scale production of a variety of species, and sales to smallholders.

Lack of support or attention to the importance of nurseries is not the case in all instances. Companies that grow seedlings for profitable crops such as timber, cacao, biomass, ginseng, and ornamental landscape plants (to name a few) recognize the critical importance of high-quality plants and the necessary investment into nurseries to meet their goals (Figure 1). Although continued research into seedling physiology and production practices is always needed, an abundance of science-based nursery technology has already been developed for producing both bareroot and container plants at small or large scales for a variety of circumstances and with high-tech or low-tech approaches (Dumroese et al. 2012; Duryea and Landis 1984; Gregorio et al. 2010; Haase 2008; Haase et al. 2011; Jaenicke 1999; Landis et al. 1989-2010, Liegel and Venator 1987; Longman 2002; Munjuga et al. 2013; Wilkinson et al. 2014). When nurseries are not considered a high priority, however, they do not receive this technology or the resources to function adequately.

Figure 1. Nurseries that produce seedlings for profitable commodities, such as these eucalyptus seedlings in Chile (left) or conifer seedlings in the northwestern USA (right), often have more investment into infrastructure, supplies, and training for optimum application of nursery technology than do nurseries that produce plants for restoration purposes.

2 Role of quality nurseries to meet restoration needs

The misconception that growing plants is easy is widespread, perhaps partly due to the common practice of agricultural production. In reality, however, plant production requires specialized knowledge and attention to many important factors to be able to deliver adequate quantities of high-quality plants from appropriate genetic seed sources to the land manger in a timely manner. This process relies on the Target Plant Concept (Dumroese et al. 2016b; Landis 2011) which starts with a partnership between the client and the nursery manager to focus on putting the best plant materials on specific project sites. Answers to important questions about the project and the site define the target plant material needed to meet project objectives. The nursery produces the plant material and the client monitors outplanting performance. The client and nursery manager assess successes and failures and use that information to improve future plant production (Figure 2).

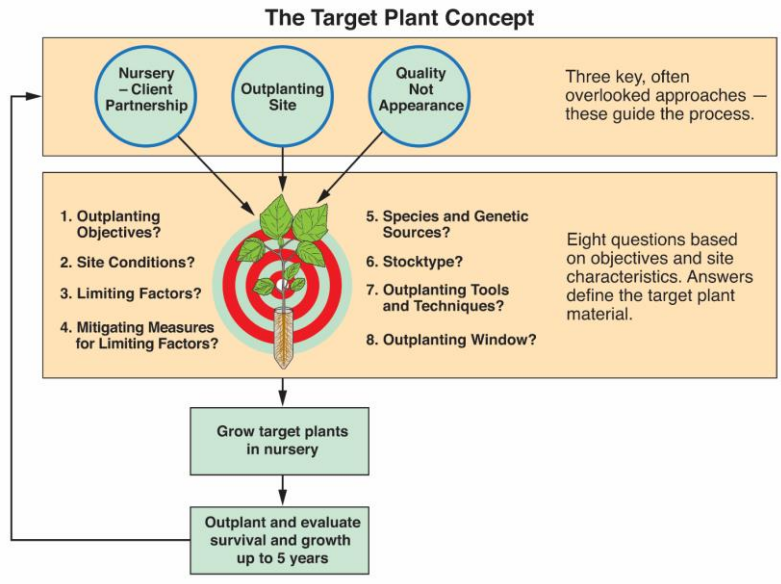


Figure 2. The Target Plant Concept is used to define specific plant characteristics and guide nursery production based on project objectives and site conditions (from Wilkinson et al. 2014).

When propagating quality seedlings, nursery personnel must be knowledgeable in the physiology, morphology, phenology, genetics, and ecotype of each species through its nursery stages of germination, active growth, and hardening. Based on those characteristics, they can choose to propagate from seeds or from vegetative material and apply specific culturing techniques (e.g. irrigation, fertilization, pest management, etc.) accordingly to achieve target specifications based on conditions at the outplanting site (Haase et al. 2016; Dumroese et al. 2016a; Dumroese et al. 2016b; Landis et al. 1989-2010). The nursery environment (e.g., annual temperature and precipitation patterns, and water quantity and quality), supplies, and equipment for effective culturing are also key factors to consider for successful nursery production. For container nurseries, growing structures and available growing medium must also be considered and for bareroot nurseries, good soil characteristics for plant production are critical.

Many nurseries also serve as a seed bank, providing storage for multiple species and seed provenances within a given region (Figure 3). Seed shortages are problematic for restoration (Burley 1980; Carandang et al. 2006; Gregorio et al. 2015; Nyoka et al. 2015), especially for seeds of tropical species that cannot be stored (Hong and Ellis 2002). In addition to seed storage, some nurseries establish and maintain seed orchards, stooling beds, and other sources of propagative material. For each species, knowledge of seed maturity patterns, collection techniques, cleaning and storage procedures, and treatments to break seed dormancy are required (Bonner and Karrfalt 2008; Dumroese et al. 2016a; Vozzo 2002). These activities and expertise not only function to maintain adequate seed supplies for nursery production, but also to conserve genetic resources and diversity, and to establish seed inventories that can be used for direct seeding.

Figure 3. Many nurseries specialize in seed collection, processing, and storage, thereby serving as a regional seedbank for nursery production and direct seeding needs. Expert nursery staff can also ensure that genetically appropriate seed are used for specific restoration sites. The seeds in this photo are kept at controlled temperature and humidity conditions and are part of a seedbank to provide several species and provenances for reforestation and restoration in New Mexico, USA.

Successful nurseries can also provide extension services to educate landowners and land managers on selecting appropriate species and provenances, establishing target plant characteristics, ensuring genetic diversity, maintaining seedling quality, and using proper planting techniques to optimize long-term outplanting success. In addition, nurseries can provide educational programs to local schools, universities, and communities regarding plant biology, restoration, and conservation. Some nurseries

include demonstration plots for a variety of species (Figure 4). Many nurseries are also instrumental in developing new propagation technology for specific species in their region to improve production, quality, and field performance.

Figure 4. Demonstration plots, such as this one adjacent to a nursery in Guam, are useful for increased understanding of species' growth rates and patterns. The exhibition of mature plants can also help the land manager choose which species are most appropriate to plant for a given project.

A high-functioning nursery can contribute significantly to the economic well-being of the local and regional community by providing employment to nursery workers and income to the farmers and land managers who establish the plants on their land. In Cameroon, a program to establish village nurseries in poor rural communities resulted in improved livelihoods, diet, health, and income generation (Tchoundjeu et al. 2010). In South Africa, nurseries are recognized as contributors to rural environmental knowledge but face challenges in becoming financially independent (Botha et al. 2006). Well-developed nursery networks can provide gainful employment to local citizens as well as high-quality seedlings for outplanting projects (e.g. Schnepf and Davis 2013).

3 Alternatives to nursery-produced plants

Reluctance to establish or support plant nurseries can occur when land managers focus solely on natural regeneration or direct seeding strategies to achieve plant establishment. These approaches can be effective and offer the advantage of rapidly covering large, sometimes difficult-to-access, areas at relatively low costs (Chazdon and Guariguata 2016; Grossnickle and Ivetić 2017; Palmerlee and Young 2010).

Seed efficiency can be low with these approaches, thereby requiring an abundant seed supply to compensate for low germination and high seed predation. In a review of 75 direct-seeding trials of tropical, temperate hardwood, and conifer species, overall germination was 44% and survival after at least one growing season was 21% (Grossnickle and Ivetić 2017). If seed availability is limited, nurseries have a much higher seedling-to-seed ratio. A review of 120 publications reporting on experiments using seeds or seedlings in a range of ecosystems found that direct seeding had significantly lower survivorship than planting seedlings (Palma and Laurance 2015). Similarly, a meta-analysis of nearly 250 plant species reintroductions worldwide found that the use of seedlings resulted in higher survival rates compared with seeds in the first year after reintroduction (Godefroid et al. 2011).

When relying on direct seeding or natural regeneration, land managers have little control over density, distribution, and species composition of the established seedlings. For successful natural regeneration, seed trees must be within a reasonable distance for seedfall and animal dispersal to adequately seed the area. Natural seed sources can be unreliable, however, due to unpredictable seed production from year to year. If restoration goals include the use of new seed sources to implement assisted migration to address climate change (Williams and Dumroese 2013) or to use genetically selected seed to improve tree characteristics or pest resistance (Dumroese et al. 2015b), then natural regeneration is not an option. When natural seed sources are too far away or seed availability is low, seedlings produced in nurseries can be the most effective and efficient means for ensuring the right plants are planted in the right place and will survive and thrive after planting.

4 Economic and environmental consequences of inadequate nursery facilities and inexpert staff

Nurseries without proper facilities, supplies, or skilled staff tend to produce poor-quality plants (Edralin and Mercado 2010; Gregorio et al. 2017; Harrison et al. 2008), particularly without a corresponding investment in level-appropriate training. Untrained nursery staff are usually well meaning but lack the knowledge for growing plants that meet morphological and physiological quality targets. Common issues are low germination, deformed roots (Cedamon et al. 2005; Takoutsing et al. 2014) (Figure 5), undesirable shoot-to-root ratios (Takoutsing et al. 2014) (Figure 6), insect, weed, or disease infestations (Figure 7), and overall poor vigor (Figure 8). These issues, combined with insufficient resources (Figure 9) and poor management, can lead to high staff turnover, loss of customers, and nursery closure.

Figure 5. Deformed root systems are one of the most common problems that occur when nurseries lack appropriate staff training and when timing is not well coordinated with outplanting activities. These deformations can persist for many years after planting and can result in problems such as reduced vigor, increased susceptibility to toppling, and poor access to soil water and nutrients.

Figure 6. Without proper culturing, the root-to-shoot ratio of nursery-grown seedlings can become very unbalanced. After outplanting, the root system will be unlikely to support the large shoot, especially in the absence of irrigation and fertilization that may have sustained it while at the nursery.

Figure 7. Poor nursery management due to insufficient staffing or training can lead to numerous issues. At this nursery, these plants have become choked with weeds. The undesirable species will compete for water and nutrients and reduce growth and vigor of nursery plants.

Figure 8. This nursery uses a low-quality growing medium resulting in poor drainage as well as nutrient deficiencies. In turn, seedlings are chlorotic, slow growing, and vulnerable to insect and pest infestations.

Restoration projects that need nursery plants are negatively affected by insufficient plant quantities, few species choices, and/or low-vigor plants that do not survive or grow well after outplanting. Analysis of a rural nursery program in Cameroon cited several factors for nurseries growing below capacity including lack of technical skill (poor water management, insufficient maintenance of stock plants, etc.), lack of motivation or perspective, declining participation in group activities, and inadequate marketing knowledge or opportunity (Degrande et al. 2006). Beogo et al. (2017) noted the potential for private nurseries to provide jobs and contribute to conservation of plant diversity, but found that lack of public support and technical training hindered this sector. In South Africa, a study of 65 outreach nurseries identified several problems hindering nursery success including markets, business skills, pricing, institutional and community support, transportation, and more (Botha et al. 2006).

Figure 9. When funding was lacking for containers at this nursery, staff resorted to buying Styrofoam cups at the local grocery store. These cups can create issues with spiraled roots and can contribute to environmental pollution.

In many cases, invasive species or seedlings from inappropriate seed sources are produced when nursery expertise and resources are insufficient (Dedefo et al. 2017; Gregorio et al. 2005; Harrison et al. 2008; Nyoka et al. 2015). Knowledge of genetic source and diversity and integrating that knowledge is a determining factor in restoration success (Godefroid et al. 2011; Thomas et al. 2015). If the geographic origin of the plants is inappropriate, project failures may not be evident for several years until the maladaptation becomes known. When sites are understocked, establishment and spread of invasive, competing vegetation can occur. When poor-quality plants are used, land managers will likely need to replant the site, thereby incurring additional costs.

5 Overcoming barriers to address nursery priorities

To run efficiently and effectively, a nursery requires skilled, knowledgeable, and enthusiastic staff, well-maintained and secure facilities, tools and supplies, and sustainable local sources of good-quality water, growing medium (or land with nutrient-rich, well-draining soil for bareroot production), and genetically appropriate germplasm. A consistent demand for seedlings and the ability to transport and market seedlings are also key factors (Gregorio et al. 2015; Harrison et al. 2008). In addition, staff need opportunities for continued educational development through classes, workshops, and technical exchanges. Lack of technical or business skills and inadequate extension services are common constraints to nursery establishment and success (Carandang et al. 2006; Gregorio et al. 2005; Takoutsing et al. 2014). All training must be appropriate for the staff's existing skills and resources, the local culture, and the target plant species and restoration sites.

Nursery technical and financial support must be consistent and constant priorities. It is not enough to set up a nursery, purchase some supplies, and have a one-week training course delivered by foreigners. Follow-up support and training are imperative to successfully implement technology, troubleshoot problems as they arise, replenish supplies, and empower staff to attain adequate knowledge, leadership, and independence. Roshetko et al. (2008) evaluated several nurseries in Indonesia and observed that steps to achieve successful nursery enterprises are: awareness and interest in the importance of quality seedlings; technical capacity to establish and operate nurseries; establishment of the nursery and related infrastructure; linkage with

sources of quality germplasm and extension support; and networking to strengthen access to seedling markets. Similarly, Gregorio et al. (2017) evaluated several nurseries in the Philippines and provided insights into necessary improvements for seedling production such as: establishing quality standards; promoting and identifying sources of high-quality germplasm from a range of species for nurseries to access; capacity-building support; adequate planning of forest restoration activities including appropriate seedling production schedules; and not undermining seedling quality to keep costs low.

Financial support is often a primary barrier for establishing or maintaining nurseries, especially when the plants are grown for ecological restoration rather than commodities and therefore generate minimal revenue for the nursery. Nurseries that grow plants for restoration purposes, especially in developing countries, must keep their seedling prices low (and, in fact, some nurseries do not charge anything) to encourage and enable farmers and other land managers to invest in the plants (Degrande et al. 2013). Although the value of goods and services from tree planting can be high over time (Verdone and Seidl 2017), farmers and other land managers may be reluctant to invest time, money, and effort into seedlings when little or no short-term financial gain is anticipated (Degrande et al. 2006; Lamb et al. 2005). In addition, restoration nurseries usually grow their stock speculatively based on anticipated demand rather than contract-based production. This system requires the nursery to do some guesswork and to take on significant risk if demands decrease before the nursery growing cycle has completed. Therefore, expecting publicly funded restoration nurseries to be self-supporting or profitable (especially in the first few years of operation) is short-sighted and defeats the long-term objectives. At the same time, private nurseries must be able to become profitable so they can remain in operation if government funding for seedling production declines. Coordination and balance between government and private nurseries needs to occur (Gregorio et al. 2010). It must be recognized at both the government and community levels that investment into nurseries and seedlings results in significant economic and ecologic returns.

Nursery funding tends to be more politically than ecologically motivated and can be described in the context of the “issue-attention cycle” (Downs 1972, Peters and Hogwood 1985). The cycle (Figure 10) occurs as follows: 1) an undesirable problem exists but has not yet captured public attention (pre-problem stage); 2) the public becomes aware of the situation and optimism is generated to fix the problem (alarmed discovery and euphoric enthusiasm); 3) a gradual realization of the monetary cost and potential sacrifices required to fix the problem occurs (realizing the cost of significant progress); 4) interest wanes as people become discouraged, threatened, or bored with the problem or shift their attention to a different problem (gradual decline of intense public interest); and 5) the problem moves into prolonged limbo with lesser attention and sporadic resurgences of interest (post-problem stage). Many nurseries, especially those supported with public funding, experience this cycle. The initial excitement and attention to forest and landscape restoration in a given area results in establishment of the nursery, purchase of supplies, and recruitment of staff. But as attention wanes or shifts to another issue, resources and staff training become scarce and seedling quality and quantity decline. To overcome this waning attention, the “enthusiasm gap” (Figure 10) needs to be filled with effective and long-term policy, government, and community support.

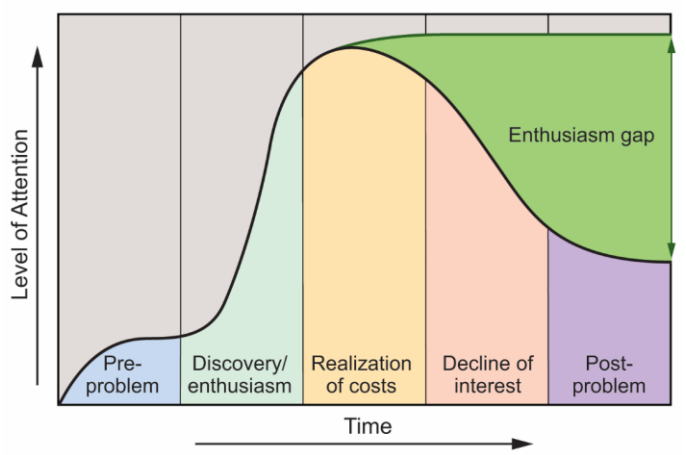


Figure 10. Nursery support often follows the "issue-attention cycle." Filling the enthusiasm gap to maintain attention, along with the associated funding, policy, staffing, and other resources, is crucial. (Adapted from Downs 1972).

Other social, economic, and cultural barriers can inhibit nursery success and may be particularly challenging to overcome. Engaging rural landowners and land managers to implement restoration can be difficult due to uncertain, communal, or nomadic land tenure; a persistent need for grazing, fuelwood, or annual crops; and a delay in financial benefits (Burley 1980; Lamb et al. 2005; Tschinkel 1987). In some cultures, wealth is represented by the quantity of domestic animals owned, a contributor to land degradation. In other cultures, individuals base their self-worth and derive their motivation from the approval of community elders or leaders. If those elders or leaders do not favor a strong work ethic or do not value long-term restoration objectives, there can be inertia and even sabotage to achieve meaningful progress. Nurseries operating under these circumstances often produce poor quality stock unfit for successful restoration (Figure 11). Furthermore, corruption or unskilled management leads to ineffective or inefficient use of funding and other resources. Integrating community involvement (including elders, cultural leaders, and decision makers) can give the nursery visibility and garner local pride and suport.

Sustained nursery support requires a range of stakeholders, including communities, policymakers, government agencies, and individual land users to be actively and consistently engaged and inspired (Botha et al. 2005; Harrison et al. 2008; Roshetko et al. 2008; Shah 1987; Tschinkel 1987). Successful nurseries need integrated support including: 1) community-based planning and decision making, 2) cooperation and coordination among national, subnational, and local government agencies, 3) improved local resources, facilities, technology, and expertise, 4) effective policies, regulations, and laws that recognize and support the integral role of nurseries to achieve forest and landscape restoration goals, and 5) financial loans, incentives, or other assistance to enable nursery managers to produce quality seedlings and landowners to restore their land. Success of restoration nurseries could be evaluated using the same themes – motivate, enable, and implement – and many of the key success factors identified in the World Resources Institute's *Restoration Diagnostic* (Hanson et al. 2015). Recognizing and addressing gaps will increase the probability for sustained success.

While many examples of the connection between availability of quality seedlings and restoration success exist, following are three case studies from

developing countries that describe potential activities to develop and support successful nurseries with an aim to increase restoration success while also providing a foundation for broader impacts including gender empowerment, science education, and rural community governance. Beyond these case studies, it is equally important to note that increased support and attention for restoration nurseries is also much needed in many developed countries (e.g. NASF 2016).

Figure 11. Poor staffing, disinterest by management, and overall neglect are evident at this nursery. Fallen seedling were never righted and have developed bowed stems. Additionally, leaves are chlorotic and infested with insects. These seedlings are likely to perform poorly after outplanting.

5.1 Case study – Lebanon reforestation initiative

The Lebanon Reforestation Initiative (LRI), a project funded by USAID and developed by the USDA Forest Service International Programs is a large-scale project aimed to increase restoration success. This small, Mediterranean country has long-standing deforestation issues, resulting in a present condition of approximately 13% forest cover (Mitri and Hajj 2007). Recent efforts to maintain and increase forest cover have focused on arresting deforestation, controlling wildfires, and improving outplanting success. The primary components of the LRI were to address low seedling quality and poor outplanting survival.

Estimated first-year survival of outplanted seedlings has been less than 20% (pers. communication). Seedlings were typically produced in large (often > 1 L) polybags

filled with relatively poor-quality growing medium (largely soil from nearby sources) and grown for several years in an effort to develop adequate height and root systems, despite inadequate irrigation and nutrition practices (Figure 12, left photo). These seedlings were largely dependent on nursery irrigation to survive, often having roots extending into the ground beneath the polybags, and thus were poorly suited for the dry, often shallow and rocky soils into which they were outplanted. Seedlings were often imported without concern for provenance.

The LRI program opted to apply the Target Plant Concept (Dumroese et al. 2016b) to its reforestation approach by collecting seed from appropriate zones, coordinating site preparation practices with stocktype selection, and using monitoring and evaluation to better determine nursery and outplanting practices. Using a broad, research-driven process, seedling production practices were refined by modifying seed treatment protocols, and introducing new nursery cultural practices and materials (including nursery and irrigation design, fertilization, sow date, improved growing medium, container selection, and more). To address the lack of coordination between seedling production, outplanting, and post-planting care, LRI conducted a series of training workshops, provided materials developed for the specific environmental and administrative challenges faced, and offered regular technical support to nine nurseries (e.g. Davis et al. 2013) resulting in significant improvements to seedling quality and quantity (Figure 12, right photo).

Figure 12. Seedling nursery in Yachouch, Lebanon using traditional practices without technical support in July 2011 (left) and after receiving new materials and technical training based on the Target Plant Concept in November 2013 (right).

Enhanced decision-making was also an important component of the LRI project (e.g. Aghai et al. 2017; Bouzza et al. 2017) that led to development of a decision support process for ensuring that all elements of seedling production and outplanting were considered at the appropriate time (Figure 13). Through the subsequent years, acceptance, implementation, and revision of nursery and field practices resulted in an increase in average first-year survival to more than 60% (K. Bouazza, personal communication). The success of these practices, and the connection between outplanting and the nursery components of reforestation programs, has led to the formation of the Cooperative of Native Tree Producers of Lebanon, a group of nine nurseries that refine and share best practices with the aim of continuous improvement

of reforestation in Lebanon. Closer attention to detail regarding provenance and seedling quality, higher yield from the nursery, and more educated partners in reforestation should result in longer term increases in the number of hectares effectively planted with locally produced plant material.

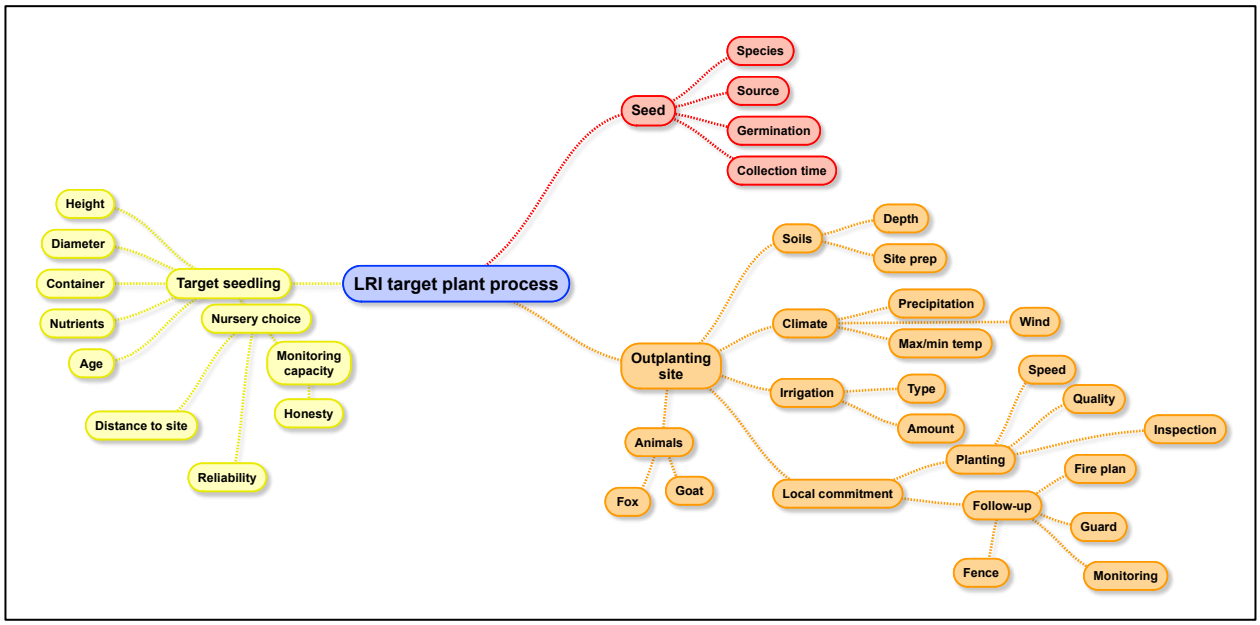


Figure 13. The Lebanon Reforestation Initiative model for developing target plants identified core areas and expanded on those to guide resource allocation for overcoming challenges as they emerged.

5.2 Case study – Haiti

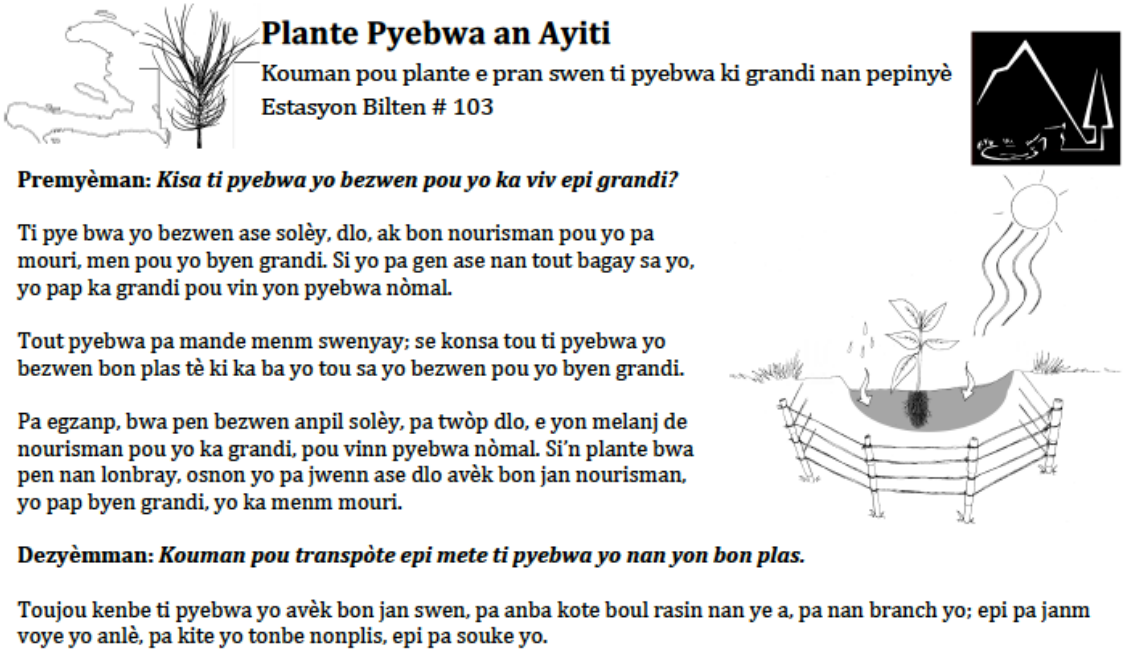
Haiti is one of the most deforested countries in the world. In addition to the loss of habitat and rural economic opportunities generated from forests, this severe deforestation is a critical threat to the country's water sources and slopes due to instability and erosion potential, both driven by routine weather patterns as well as catastrophic events such as hurricanes and earthquakes.

Successful tree planting projects in Haiti have primarily focused on species that yield agricultural products, given the relatively short turnaround between establishment and financial yield. While of critical importance, these species do not serve to restore the degraded ecosystems of this island nation. Native tree seedlings that are produced are typically not of high enough quality to survive the variable climate (Fiondella 2010), with limited root system development due to poor growing medium, limited irrigation, and generally unspecified nursery growing protocols (Figure 14).

Using Hispaniolan pine (*Pinus occidentalis*) as a model species, a combination of research and training has been developed to inform local partners interested in restoration planting of potential best practices. Workshops held in Kenscoff, a small mountain suburb of Port-au-Prince, have been well attended. Materials are typically available in English or French, the languages of the educated, but not always those of rural community members who are likely to complete the needed work on the ground. Additional materials are being developed in Creole and in graphic format for those with limited literacy (Figure 15). These workshops and training programs have led to

establishment of the proof-of-concept Bryan S. Turner Nursery in Kenscoff, Haiti (Figure 16), which uses the Target Plant Concept in guiding seed selection, nursery cultural practices, and delivery of seedlings to engaged partners. Growing medium used in the nursery consists primarily of a locally produced organic product derived from composting toilets (Kompost Lakay, SOIL-Haiti, Port-au-Prince, HT).

Figure 14. Traditional seedling production in the mountains of Haiti. Seedling quality is relatively poor, with roots emerging from polybags into the soil below resulting in even poorer quality after lifting. Containers are filled with locally collected topsoil and irrigated on a relatively random basis.



Plante Pyebwa an Ayiti

Kouman pou plante e pran swen ti pyebwa ki grandi nan pepinyè

Estasyon Bilten # 103

Premyèman: ***Kisa ti pyebwa yo bezwen pou yo ka viv epi grandi?***

Ti pye bwa yo bezwen ase solèy, dlo, ak bon nourisman pou yo pa mouri, men pou yo byen grandi. Si yo pa gen ase nan tout bagay sa yo, yo pap ka grandi pou vin yon pyebwa nòmal.

Tout pyebwa pa mande menm swenyay; se konsa tou ti pyebwa yo bezwen bon plas tè ki ka ba yo tou sa yo bezwen pou yo byen grandi.

Pa egzanp, bwa pen bezwen anpil solèy, pa twòp dlo, e yon melanj de nourisman pou yo ka grandi, pou vinn pyebwa nòmal. Si'n plante bwa pen nan lonbray, osnon yo pa jwenn ase dlo avèk bon jan nourisman, yo pap byen grandi, yo ka menm mouri.

Dezyèmman: ***Kouman pou transpòte epi mete ti pyebwa yo nan yon bon plas.***

Toujou kenbe ti pyebwa yo avèk bon jan swen, pa anba kote boul rasin nan ye a, pa nan branch yo; epi pa janm voye yo anlè, pa kite yo tonbe nonplis, epi pa souke yo.

Figure 15. Tree Planting in Haiti: How to Plant and Care for Nursery Grown Seedlings (Hubbel et al. 2016) was the first in a developing series of education materials on the science-based approaches necessary for tree planting to be successful. These materials were translated into Creole and French.

Figure 16. Training activity at the Bryan S Turner Nursery in Haiti. In the background, Hispaniola pine seedlings are being grown using locally adapted versions of best practices for pine production derived from growing protocols from the Native Plant Network (https://npn.rngr.net/npn/propagation).

5.3 Case study – Jordan

Jordan is in need of major improvements in restoration planting success with an estimated < 20 % first-year survival of outplanted rangeland species. To address this need, the USDA Forest Service International Programs implemented the USAID funded Sustainable Economic and Environmental Development (SEED) project in 2016 to focus on the degraded Badia region (dry rangelands that compose more than 80% of Jordan's land area).

Previously, seedlings were grown in soil-filled polybags with little regard for the chemical or physical properties that are needed to promote quality seedling development. Coordination between the nursery and outplanting sites has been nearly non-existent. Seedlings have been poorly matched to the outplanting conditions. For example, seed may be collected from a wide range of areas without attention to geographic origin, seedlings often have high leaf area despite low-rainfall conditions, and outplanting timing does not always align with available soil moisture. With the SEED project, the goal is to improve production techniques such that seedlings are grown for a single growing season in the nursery and then outplanted at the beginning of the rainy season in the fall or early winter. One technique is the gravimetric irrigation method (Dumroese et al. 2015a) to provide irrigation aligned with seedling growth phases, including a well-monitored hardening regime. Container selection is based on soil depth and seedling rooting habit, and shoot pruning is conducted to limit foliar area and reduce transpirational demands. Growing media pH and EC are measured to ensure that fertilization is applied in the appropriate quantities and to avoid accidental over-salinization due to the combination of fertilization and naturally high salts in irrigation water.

Producing Mediterranean saltbush (*Atriplex halimus*) as a model species using the new methods resulted in ≥ 79% first-year survival on each of three test sites (Bouazza et al. 2017). As the SEED project enters a second year, the plan is to expand from an annual production of 65,000 seedlings at a single nursery to more than 200,000 seedlings across multiple nurseries. At this scale, the hope is that other seedling

producers (including government, NGO, and private sector) will see the feasibility of this approach. One of the greatest challenges facing acceptance of this program is the higher production cost of SEED-based seedlings. The Ministry of Agriculture regularly offers seedlings at little or no cost (average approximately USD$0.25), giving the mistaken impression that seedlings for restoration projects are inexpensive. SEED seedlings are estimated to cost closer to USD$1.00 and the cost of planting and maintenance is roughly an additional USD$2.50 per seedling. A successful first planting with high-quality seedlings is more financially viable than one that requires multiple efforts in the same place, particularly when considering the dramatic difference in first-year survival that has been observed to date. With increased discussion across partners, the intent is to drive a shift from cost per seedling as the determining factor for choosing a stocktype to cost per established plant at the restoration site, a much more important economic consideration.

Figure 17. Nursery growers at the Sabha Nursery in Mafraq, Jordan, explain the relationship between nursery cultural practices and seedling quality. Seedlings are thriving under the current methods in the nursery and after outplanting.

One interesting attribute of this project is the focus on engaging women from the local community in the production of native plant seedlings (Figure 17). Recruitment of a motivated team of women provided a platform for training specifically around the attributes needed to grow high-quality seedlings for restoration. This training program allowed for development of more than just a team of well-trained nursery growers, but also for the introduction of natural resource stewardship and conservation as an

important role in community engagement. These program participants are far more environmentally literate now than before and show potential to become champions for rangeland stewardship in their communities. When asked to rank their current agricultural knowledge on a Likert scale, women consistently gave high values for current technical knowledge (8.92/10), while citing consistently low knowledge before beginning the project (1.58/10) (Engbring et al. 2017). This self-growth and environmental empowerment corresponds with a similar effect reported in forest nurseries in India (Verma 1988). In addition, the nursery has become a "safe space" for local women to learn about and discuss environmental stewardship, science, and community building.

6 Conclusions

The aforementioned three case studies highlight how increasing support to nursery programs and sharing best practices across a range of environmental, geopolitical, and economic conditions can lead to increased restoration success. These successes were achieved by applying the Target Plant Concept in a way that allows for local innovation and experimentation and progressive improvement of plant establishment success. The building of human capacity across these networks, through international conferences and virtual networks, provides a dual pathway for sharing of relevant results and experiences. For example, the methods developed in Lebanon have been shared with potential partners in Armenia and Morocco (as well as being a launching point for the SEED program in Jordan), while the Jordan program has a natural partner in the West Bank, considering the shared ecological conditions in the region. Furthermore, the training of nursery growers at the pilot site in Jordan was conducted by members of the team from Lebanon, and those same nursery growers in Jordan are now helping to train others in improved nursery techniques.

Nurseries can be centers of extension services, providing the transfer of science to local communities through engagement with planting campaigns, visits by schools and other groups, and hosting demonstrations of how plants grow and how they can be used. Nurseries are hubs of restoration expertise and activities and provide the opportunity for professionals and laypersons to learn about the role of plants in functional ecosystems at the local, watershed, and even national levels.

Instead of being "off the radar", nurseries need to be recognized as an integral component of forest and land restoration goals and a priority investment to ensure those goals are achieved. Nurseries are an essential gateway from ecologically degraded landscapes to ecologically functional landscapes. If society aims to meet the lofty and necessary restoration goals made through worldwide commitments (Table 1), supporting nurseries is a critical step. This support is a key investment toward ensuring that the stewardship of resources from genetic origin (e.g. seed) to value provision (e.g. habitat, fuelwood, slope stability, etc.) is done in an economically and ecologically viable manner.

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