Forest Regeneration: Links in the Chain and Key Bottlenecks

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Societal demands for renewable wood products and the ecosystem services provided by trees and forests—clean water and air, outdoor recreation, carbon sequestration, and climate adaptation—won't be met in 2080 without launching an aggressive and cohesive reforestation strategy. The strategy needs two prongs: (1) keep and better manage existing forests to stem losses to development; and (2) reforest areas where trees have been lost over the past 50 years.

Why Does the U.S. Need More Forests?

The United States has 823 million acres of forests and woodlands[2]. Forest land area alone occupies 766 million acres. Together, forest and woodlands comprise over one-third of the U.S. landscape. Private individuals, corporations, partnerships (e.g., hunting clubs), and tribes own 56 percent of the nation's forests. The rest are public forests--two-thirds in the West, most managed by federal agencies and one-third in the East, most managed by State agencies and local governments.

Although forest and woodland area totals have remained stable since 1910, U.S. population has more than tripled since then. Today, 331 million U.S. citizens consume 52.4 cubic feet of wood and paper products per capita each year This is 27 percent less than 20 years ago, largely due to the success of recycling programs and the reduction in paper use in the digital age. But annual consumption still totals 17.4 billion cubic feet or 434 million tons. Three-quarters of annual consumption is met by harvesting 4.25 million acres in the U.S. The rest is imported, often from countries with fewer or weaker environmental protections. That's neither self-sufficient nor sustainable.

Looking ahead, the U.S. Census Bureau projects the nation will have 531 million people in 2080—65 percent more than the 331 million people today. At current consumption rates, an additional 10.8 billion cubic feet from an additional 3 million acres of forest will need to be harvested—annually. To get ahead of the inexorable population growth rate, an additional 80 to 90 million acres of well-stocked, well-managed forests need to be created over the next 20 years, so they grow and mature to meet future population needs for clean water and air, outdoor recreation, and wood and paper products.

How Are New Forests Created?

The process of forest regeneration is a multi-step, multi-year process of creating a new forest that is healthy, productive, and resilient. Forest regeneration can be accomplished using silvicultural practices that encourage remaining trees to produce seeds that recolonize the site (i.e., natural regeneration) or by tree planting (i.e., artificial regeneration). The new forest may be replacing a forest previously harvested or one decimated by wildfires or pest outbreaks, called "reforestation," using either natural or artificial regeneration. In contrast, "afforestation" is creating a new forest on land previously used for some other purpose, such as crop production or grazing. Artificial regeneration is usually the only option for afforestation because there is no tree seed from trees remaining on, or adjacent to, the site.

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[2] Forests have more than 10 percent tree cover. Woodlands have less than 10 percent tree cover. Even at low tree cover percentages, land with trees provides many important ecological services.

Why Rely on Artificial Regeneration to Achieve New Policy Goals?

Now under consideration, a new policy goal of establishing 60 billion trees over the coming decade or two will require large areas of land—much more land than currently available in today's forests. Simply put, afforestation will be required more than reforestation. Further, although natural regeneration for reforestation may work in some areas, using natural regeneration won't help with assisted migration of tree species over the coming century when climate patterns are changing at an accelerating rate. Therefore, because afforestation would contribute the most to meeting the 60 billion tree goal, and artificial regeneration is the principal way to achieve afforestation, the assumption of this analysis is that all 60 billion trees will be established through tree planting (pertinent discussion about natural regeneration is, however, included as well). In order to meet the proposed goal, artificial regeneration will be needed at double or perhaps even triple the current rates.

How Many Forest Tree Seedlings are Grown and Planted Annually?

Data since 2012 illustrate that federal, state, and private nurseries are producing 1.24 billion tree seedlings annually for forestry and conservation purposes, enough to plant 2.35 million acres. Therefore, to achieve a goal of planting 60 billion seedlings, nursery production will need to grow substantially, Table 1.

1,200 public and private nurseries currently grow tree seedlings for forestry and conservation purposes. Public nurseries are a minor component of the 1,200—only six are USDA Forest Service nurseries and fewer than forty are state agency nurseries. Some of the 1,200 private nurseries also grow seedlings for the horticultural and landscaping sectors, as do many other private nurseries who don't produce any tree seedlings for forest and conservation purposes, but those production figures aren't included in the data, below.

Table 1.—Nursery production increases necessary to meet the policy goal of planting 60 billion trees over three different time periods

Time Period	Annual Planting Goal (seedlings/year)	Average Total Seedling Production, 2012-2018 (seedlings/year)	Percentage Increase Required by Goal	Additional Acres Needed Annually by Goal
10 years	6 billion	1.236 billion	**+ 385 percent**	**+ 9.1 million/year**
15 years	4 billion	1.236 billion	**+ 224 percent**	**+ 5.3 million/year**
20 years	3 billion	1.236 billion	**+ 143 percent**	**+ 3.4 million/year**

Source: Production data from articles published annually in Tree Planters' Notes (https://rngr.net/publications/tpn).

Key points:

- ***The recent successes of artificial forest regeneration in the U.S. are largely dependent on over 1,100 private nurseries producing seedlings for forestry and conservation purposes.***
- ***Any policy that calls for major increases in forest tree seedling production will necessarily rely most heavily on private forest tree nurseries for its success.***

Where are the Bottlenecks to Artificial Regeneration?

Bottlenecks in six areas of the forest regeneration process need to be resolved if policy goals to increase reforestation are to be achieved. The bottlenecks won't be overcome without deploying significant increases in the human capital and funding to accomplish the desired outcome of billions of new trees.

1. Land for planting trees
2. Seed availability
3. Nursery capacity
4. Site preparation capacity
5. Labor force for site preparation, nursery production, and tree planting
6. Monitoring seedling survival after four or five growing seasons and conducting early stand improvement activities

Bottleneck #1. Land for planting trees. In recent years, the 1.24 billion seedlings raised annually have been used to plant an average of 2.35 million acres each year. Most of the acreage planted was for reforestation. If planting 60 billion trees is the policy goal, then Table 1 illustrates how much additional land will be required beyond the 2.35 million acres currently planted each year. Where will the additional 67 million acres (20-year program) to 91 million acres (10-year program) land come from?

There is not a 67-to-91-million-acre backlog of forest land needing reforestation. To meet a policy objective of planting 60 billion new trees, non-forest land will need to be enticed into a new program aimed at afforestation in addition to reforestation.

The USDA Forest Service estimated that approximately 1.2 million acres of national forest land needs to be regenerated from an accumulation of recent disturbance events (mostly wildfire[3]), and about a quarter million new acres need reforestation annually. But many outside groups believe this national forest regeneration need is a significant underestimate; perhaps only one-quarter to one-half the real need. Still, even if the total cumulative regeneration need on national forests is 3 to 5 million acres, with another 2.5 million acres of new need developing during the next decade, that total is a relatively small proportion of the 67 to 91 million acres of land that will be needed to meet the 60-billion tree goal. The Department of Interior's unmet reforestation needs aren't known.

Corporate forest land is adequately fully regenerated by present planting levels. Therefore, to meet expanded forest regeneration goals, much privately-owned land and local government land will be needed. Private landowners include families, farmers and ranchers, and hunting clubs and other associations.[4] To achieve the forest regeneration policies envisioned, afforestation of additional private land will be essential. Afforestation acres will need to come from acres not currently well-stocked with trees. Examples include marginal crop land or pastureland; or unused, unmanaged land in developed areas; or land with trees that is so poorly stocked or in such poor health and vigor that whatever vegetation exists on site will need to be eliminated during site preparation.

The 2017 Census of Agriculture[5] reported that there were 900.2 million acres in farms and ranches, down 14.3 million acres since 2012. The total included 73.1 million acres of woodland, down 4 million acres since 2012. Permanent pasture and rangeland totaled 400.8 million acres, down 14.5 million acres since 2012. The fluctuations suggest opportunities for afforestation. Other sources of land sometimes mentioned are previously mined land needing reclamation. About 8.4 million acres were surface mined

[3] Over the past decade, wildfires have burned 7 million acres annually (range: 3.4 to 10.1 million acres). Although the proportions vary year-to-year, roughly one-quarter is Forest Service land, one-third is other federal land (e.g. Dept. of Interior), and the remainder is non-federal land (e.g. state or private). See https://crsreports.congress.gov/product/pdf/IF/IF10244.

[4] Investment organizations also own land, but those acres are included in the corporate landowner category.

[5] https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/

in the U.S. from the first half of the 20th century to today.[6] Currently, roughly 37,000 acres are surface mined each year. Since a new mine reclamation law was passed in 1977, acres reclaimed have risen, often using grasses and shrubs, although there is a "Forest Reclamation Approach" being used in the Appalachian region.[7] Abandoned citrus groves in Florida and California are sometimes mentioned. Again, recent estimates of losses are on the order of tens of thousands of acres annually, totaling perhaps 100,000 in recent years. Abandoned citrus groves often give way to development or other agricultural uses. Still, careful state and county analyses might identify strategic areas for targeting afforestation.

Lack of adequate, well-functioning markets is a key bottleneck to keeping existing private forests as working forests and to attracting new private land to forests.

Two kinds of well-functioning markets are needed: (1) the market for timber sold at final harvest; and (2) markets that pay regular annual or periodic returns to the private landowner during the forest's life.

Currently, markets for timber sold at final harvest are soft and stumpage prices are low. During the Great Recession of 2007-2008, over 1,000 mills closed. New housing starts—a prime driver of demand for softwood products—plummeted, and still haven't fully recovered to 2005-2006 levels.[8] What near-term to long-term effects the current Covid-19 pandemic will have on new housing starts and demand for solid wood products and pulp and paper products cannot yet be accurately foreseen. Yet many analysts believe the result will not be an acceleration of demand or a firming of stumpage prices.

Income from harvesting trees is the prime source of money to fund forest regeneration for many private landowners. Low stumpage prices cause some private landowners to question whether they should reinvest in forest regeneration or invest the money elsewhere and shift the land to some other use. This bottleneck can be overcome with policies that stimulate markets, leading to higher demand for wood products and increased stumpage prices for landowners.[9]

The second type of markets needed are ones that pay regular annual or periodic returns to private landowners. Currently, these are thin, fragmented, and don't exist everywhere. The classic example cited is hunting leases. Nationally, 3 percent of landowners lease their land for hunting. In the South, where hunting leases are more culturally acceptable than in some other regions, only 8 percent of landowners lease their land.[10] The major concerns of private landowners are liability and unwillingness to have outsiders on their property. Other types of markets that provide annual or periodic incomes are fragmented, of limited availability, or function poorly.

The nation's first experiment in carbon emissions cap and trade—the Chicago Climate Exchange—ended in 2010. Post-mortem analyses identified both positive and negative aspects of the exchange, which can help identify potential paths forward with greater likelihood of success. Since then, the California Air

[6] Office of Surface Mining.
[7] https://arri.osmre.gov/FRA/FRApproach.shtm
[8] A contributing factor to the lower per capital consumption of wood and paper products today compared to 2000.
[9] Examples include policies that expand markets for innovative uses of wood, such as engineered wood products (e.g., cross-laminated timber for high-rise buildings), or that encourage other sectors to used wood-based materials, such as the pharmaceuticals, plastics or high-performance fibers sectors.
[10] Hunting leases are more prevalent on corporate lands, where 84 percent of acres are leased to hunters.

Resources Board (CARB) has continued developing forest-based carbon offset programs.[11] Currently, CARB has contracts with landowners in roughly 40 States across the U.S. Much can be learned from how this program is organized and administered and how it's already benefitting participating forest landowners. Whether a new carbon market system can successfully emerge remains to be seen.

A major opportunity for improving markets paying annual income to private landowners is creating well-functioning, widely available, forest carbon markets that earn both investors' and landowners' trust.

Other policy tools exist that create incentives to plant trees. These include favorable income tax policies[12] and cost-sharing programs. Some impediments exist here too. For example, the Conservation Reserve Program has helped fund tree planting to take highly erodible land out of crop production. The 2018 Farm Bill raised the CRP cap, letting it grow to 27 million acres by 2023. It could be set even higher. Also, some incentive programs grade applications based on their ability to promote specific conservation activities, such as stream-bank erosion control, wetlands protection, or increasing habitat for wildlife species at risk. These filters are used by state agencies to allocate limited funding only to landowners whose activities will advance these other conservation objectives. The impediment seems mostly one of making the best use of limited funding rather than quibbling about what conservation objectives are more worthy than others. Programs like these illustrate workable paths forward, if their objectives can be broadened and funding increased.

Inescapably, a policy goal of planting 60 billion trees will need to draw agricultural land—either out of cropping or forage production entirely or into an agroforestry management system. The impacts of reducing land available for agricultural pursuits must be considered. In some cases, the impacts will be minimal while in others the impacts may be significant, particularly at the county or sub-state regional level. Policy advocates for expanding forest area and tree planting must be prepared to answer questions about the impacts on production and prices of farm commodities, just as ethanol advocates had to address these same issues in the 1990s.

Any policy that calls for major increases in forest area will need to address improvements in: (1) markets for timber harvested; (2) markets for forest carbon sequestration and other activities that pay annual or regular incomes to landowners; (3) existing laws, regulations, and funding for tree-planting incentive programs; and (4) impacts on the farm sector and commodity prices.

Bottleneck #2. Seed availability. Most tree species produce large quantities of seed every five to seven years and smaller amounts in other years. To overcome the irregular nature of seed production, seed collectors and nurseries collect and store seed in freezers ("seed banks") during years with bumper seed crops so adequate amounts of seed are available each year to maintain regular annual production of seedlings. This works for most, but not all, species. The amount of seed in storage depends on the nursery; the goal of many is to maintain a 10-year supply.

[11] See https://ww3.arb.ca.gov/cc/capandtrade/offsets/offsets.htm and https://ww3.arb.ca.gov/cc/capandtrade/protocols/usforest/resources/faq_102913_post.pdf.

[12] Reduced capital gains taxes on forest harvest income and the ability to expense forest regeneration activities instead of capitalizing them are two examples.

Seed in storage is labelled by "seed zone", defined by the geographic, topographic, and climatological conditions in the area where it was collected. The assumption is that seedlings grown from seed gathered in a zone will perform well anywhere within that zone. For the southern U.S., there are only five seed zones for major commercial tree species. Each zone has tons of seed in seed banks. For the western U.S., there are many more seed zones distinguished by local climatic conditions, elevation gradients, and differences among tree species. Smaller quantities of seed are in storage for each western zone.

While federal, state, and industrial land managers pay attention and strictly adhere to seed zones in their seed collection and outplanting, smaller organizations and private citizens, particularly those outside of the South, have less access to appropriate seed sources. State and private nurseries that speculate on consumer demands for reforestation seedlings must, out of economic necessity and to reduce risks, take a "middle of the road" approach, growing a single or limited number of seed sources focused on an average elevation, site, and/or geographic area. For example, the state nursery in Idaho acquires its Ponderosa pine (*Pinus ponderosa*) seed from a single source, and seedlings are distributed across the entire state as well as western Montana and eastern Washington. The subsequent mismatching of seed source to forest sites has potential to reduce forest productivity, and therefore, economic benefit to private landowners.

Developing appropriate seed source guidelines is on-going. For some species and locations, guidelines are often simplistic "rules of thumb." Obtaining the research data for intra-species variation in genetic traits to improve understanding of how tree seedlings adapt to specific site conditions (and thereby create or refine seed zones and seed-transfer guidelines) is difficult and requires appreciable time and effort. Therefore, most work to date has focused on the main commercial species, particularly in the South.

Most seed in storage is in the South, where 80 percent of current reforestation occurs. Further, most of the tree seed is for commercial species, collected in seed orchards where the genetic provenance and performance of the parent trees is well-known.[13] That knowledge is a good basis for making reforestation investment decisions. But in other parts of the U.S., seed orchards that once existed have been abandoned or cut down, often due to lack of funding to continue managing them. Where no seed orchards exist, seed collectors have reverted to what was done in the first half of the 20th century before tree improvement research and programs were created—collecting "wild" wind-pollinated seed wherever it can be found during occasional good-or-better seed production years. Also lacking are enough seed collectors and seed extractories to clean and properly prepare seed for storage.

A challenge facing reforestation specialists is that changing climate patterns are starting to affect the location of seed zone boundaries. Over the next 60 to 100 years, additional changes may dramatically affect seed zone boundaries in some areas, particularly in the West. Some zone boundaries may shift over a hundred miles. Following current seed zones means that seedlings planted today may mature in future conditions where they are poorly adapted—less resilient to the new-normal weather conditions; at more risk to pest outbreaks or premature death. This fear exists regardless of the number of seedlings planted annually.

[13] For example, lines that are resistant to fusiform rust (*Cronartium quercuum* f.sp. *fusiforme* (Hedgc. & N. Hunt))

Key points:

- ***While the current seed bank may seem quite large—measured in total tons stored regionally or nationally—there may be shortages for particular seed zones and/or species.***
- ***Any policy calling for major increases in seedling production may exhaust existing seed banks for certain zones and species before the next bumper crop of seed is produced.***
    - ***The initial implementation step to achieve any increase in seedling production must be to immediately increase seed collection and processing.***
    - ***Without increases in available seed, there can't be a sustained increase in the production of seedlings.***
- ***The best possible projections of future climate patterns—down-scaled to finer resolution than existing seed zone boundaries—are vitally important to revise seed zone boundaries, so seed collected in an area today can be used to replant areas where climate will be the same in the future—despite these two locations perhaps being far apart in latitude, longitude, and/or elevation.***

Bottleneck #3. Nursery capacity. Today, there are 1,200 nurseries that produce 1.24 billion forest tree seedlings annually, used to plant 2.35 million acres—the normal current business need. About 50 of these nurseries are publicly owned.

In 1979, the USDA Forest Service had 14 agency nurseries; one or more for each region. Today, six remain open. Where the agency once produced over 120 million seedlings annually (occasionally surging to nearly 140 million), production today hovers around 35 million seedlings annually; these are planted by the agency and other federal partners. With enough investments throughout the forest regeneration chain of activities, Forest Service nurseries could probably produce 70 million seedlings annually.

Similar reductions in the number of publicly owned nurseries occurred in many States. In 1975, there were 87 State nurseries; 35 remain open today. Louisiana, Mississippi, and California each had three state nurseries, all now closed. Georgia had five, now has one. Maine—the most heavily forested state in the U.S.—closed its only state nursery in 1988 and now relies on imports from Canadian provinces, private nurseries, and other New England states. Although firm numbers aren't available, a rough estimate is that Federal and State nurseries together produce less than 200 million seedlings annually; perhaps 15 percent of the national annual total.

Where could a big surge in forest tree nursery production come from? There are three possibilities:

- Create incentives for private bareroot nurseries to boost total production
    - Shift some of their production for the horticultural, landscaping, and Christmas tree sectors to reforestation. Shift some beds producing hardwoods to producing conifers.
    - Change use of certain practices, such as eliminating cover crops.
- Reopen "moth-balled" nurseries, retrofit their equipment, and bring them back into production. Getting old beds ready for new production and retrofitting equipment will likely take two years.
- Build new forest tree seedling nurseries. A current trend is to build new, large, container-seedling nurseries. An advantage is that large tracts of suitable soils for producing seedlings are not necessary. A disadvantage is that seedlings grown in containers can cost more (e.g., 18¢ versus 6¢).

In forest tree nurseries, conifer species are typically grown in bareroot nurseries at a density of 25/ft^2. Hardwood species, on the other hand, are grown at 6/ft^2. About 40 million hardwood seedlings are grown annually for forest planting. If hardwood production could be cut by 20 million, that bed space could grow 80 million bareroot conifer seedlings.[14] Similarly, temporarily shifting seedlings from one market, such as from the wholesaler nursery market for horticulture or landscaping to forest regeneration, could help initially to boost reforestation and afforestation effort, but at the expense of limiting seedlings supplied to other markets, such as Christmas trees or orchards. Incentives might be needed, because the horticultural or landscaping markets pay more per seedling.

Another way to boost production in the short-term is to eliminate cover crops. At some nurseries, a rotation is practiced of growing seedlings on two-thirds of the bed space and a cover crop on the other third. At the end of the growing season, the cover crop is plowed into the soil to add organic matter, which in finer-textured soils improves tilth and drainage. An added benefit of higher soil organic matter content is that when fumigation is needed, buffer zones can be smaller, which means more land can be kept in production. The cover crop could be skipped or an alternative organic material, like biochar, could be spread on the beds and plowed into the soil between growing seasons. Research has shown that biochar decomposes slower than a green cover crop, extending the time between needing to incorporate organic matter. Skipping a green cover crop could increase nursery production by one-third. Some nurseries on sandier soils have already stopped cover cropping because they don't need the benefit of organic matter improving drainage that's important on finer-textured soils. Applying fertilizer through the irrigation system offsets the slow release of nutrients from decaying organic matter. How big an impact this shift in nursery management would have on increasing bareroot seedling production hasn't been estimated beyond anecdotal accounts from individual nurseries.

An alternative to reopening a closed nursery as a bareroot nursery would be to reopen it as a container-seedling nursery. For example, one could install a center-pivot irrigation rig common to agriculture with a 204' arm, which would irrigate 3 acres (see photo). Instead of reworking the old beds, grow seedlings on metal benches. Conifer seedlings can be grown at higher density in containers (40 to 70/ft^2)—a second advantage over bareroot bed density. Twenty-five pivots installed on 100 acres could produce about 100 million seedlings.

In the western U.S. and Canadian provinces, smaller nurseries predominate. Some western nurseries have greenhouses,

[14] The decision to convert bed space from hardwood to conifer production would have both nursery implications—freeing bed space to produce conifers—and ecological consequences in the forest because fewer hardwood seedlings would be available for artificial regeneration. Is regenerating more acres of conifer forests a higher priority—perhaps because there would be a larger and faster carbon sequestration outcome—than the outcome of regenerating fewer hardwood forests during a surge?

others don't. Some produce container grown seedlings totally indoors. Others start seedlings in containers inside the greenhouse for a few months, then transplant them to outdoor beds to finish growing. Still others produce seedlings in containers like in the South, albeit on a smaller scale. What might be possible is to optimize production through partnerships among federal, state, and/or private nurseries, where some would start the seedlings in containers and then transfer the young seedlings to other bareroot nurseries to finish them off.

There are several factors to be considered in choosing among nursery types, Table 2.

Table 2. —Factors to consider in choosing among nursery types[15]

Factor	Container Nursery	Bare Root Nursery
Land Requirement	Less land needed	More land needed
Soil Quality	Not important because artificial growing media are used	Critical—sandy loams are preferred
Water Quality	Good water is desirable, but some problems can be chemically corrected	Good water is critical
Propagation Structures	Depends on location, size, and complexity of the nursery	None
Equipment	Depends on size and complexity of the nursery	Tractors and specialized equipment for sowing and harvesting
Duration of Crop Cycle	4 to 12 months to several years, depending on container size	1 to 3 years
Crop Storage and Transportation	Greater volume required	Lesser volume required
Plant Handling	Roots are protected in a plug	Roots are exposed and are often treated for additional protection
Season Seedlings can be Outplanted	Year-round if soil is unfrozen and soil moisture is good	Spring, or sometimes fall
Seedling Prices (fob the nursery)[16] • Southern pines • Western conifers	 $170 to $200/1000 $330 to $600/1000	 $80 to $110/1000 $220 to $400/1000

There are cost differences between bareroot and container seedlings. Southern pine (loblolly pine and shortleaf pine) container seedlings offered for sale today are roughly twice as expensive as bareroot seedlings. For western conifers, prices vary much more, depending on species, seed source, and the

[15] Dumroese, R.K., Landis, T.D., Luna, T. 2012. Raising native plants in nurseries: basic concepts. Gen. Tech. Rep. RMRS-GTR-274. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 84 p. With selected additions to update information and include price information.

[16] Prices are illustrative, highlighting the differences in seedling costs by type and region. The southern pine seedling price ranges were estimated from online order forms from five state-owned nurseries for loblolly pine (2nd generation improved, open-pollinated seed) and shortleaf pine—all one-year old. Western conifer seedlings prices were estimated from online order forms from five nurseries, some privately owned and some state-owned. Prices at the lower end of the range shown are for one-year old seedlings, while the prices at the upper end of the range are for two-year old seedlings. Western prices varied more widely among nurseries than for southern prices.

nursery, but container seedlings were roughly 50 percent more expensive than bareroot seedlings of the same age produced by the same nursery. Planting bareroot seedlings may also be slightly less costly.[17]

Key points:

- ***Existing nursery capacity in the U.S. cannot increase production enough to meet policy targets being discussed.***
- ***Major investments in building new nurseries will be required to achieve the goal of planting 60 billion seedlings over the coming decade or two.***
- ***Altering management practices at existing nurseries—skipping cover crops, shifting some hardwood growing space to conifers—would make marginal contributions, but still fall far short of achieving the annual production levels envisioned.***
- ***Creating new container nurseries in open areas and irrigating with a center-pivot irrigation rig is a cost-effective, proven approach—at least in the southern half of the country.***
- ***If new bareroot nurseries are created, pay special attention to choose sites on loamy sandy soils and with good water quality and quantity. This will help avoid issues of the past at nurseries on finer-textured soils that have been closed.***
- ***Planning for an orderly disposition of the enlarged nursery capacity after the program's objectives are achieved should be part of an overall plan.***

Bottleneck #4. Site preparation capacity. The two basic types of site preparation—both for artificial and natural regeneration—are mechanical methods and chemical methods. Preparing sites by hand is no longer widely practiced. However, timber stand improvement activities with hand tools is still common when applied several years after planting. Prescribed fire is also used in certain situations to control grass, forbs, and brush prior to planting or to open serotinous cones from a few species so they drop their seed for natural regeneration.

Mechanical methods rely on a crawler tractor or skidder whose horsepower requirements (and therefore capital costs to purchase and cost to operate) vary with the type of activity. Shearing, piling, and root-raking are common activities using modified front blades. Roller drum chopping, sub-soiling or ripping, bush-hogging, disking or scarifying, and bedding are common activities accomplished with towed equipment.

Chemical site preparation relies on spraying herbicides from helicopters or fixed-wing aircraft or sprayers mounted on tractors or skidders. Herbicide prescriptions are based on the nature of the undesirable vegetation (e.g., trees, shrubs, forbs, grasses), soil textures (e.g., from clayey to sandy), and other factors.

Expanding the capacity of both kinds of site preparation services require major capital investments. Both types also have limitations. Mechanical methods can be restricted somewhat by wet weather, poor drainage or extremes in topography. There may also be competing uses for the equipment—highway construction and site development work for crawler tractors, harvesting timber for skidders. Other problems include negative impacts on erodible or fragile soils and the potential for abundant hardwood sprout development. Aerial spraying doesn't work well on small tracts or places where

[17] Callaghan, D.W., Khanal, P.N., Straka, T.J., and Hagen, D.L. 2019. Influence of forestry practices cost on financial performance of forestry investments. Resources 8,28. 16 p. (http://dx.doi.org/10.3390/resources8010028).

sensitive areas or dwellings are nearby—better to use tractor-mounted equipment in those settings. Aircraft may be available regionally but demands for their services by the agricultural sector or others (e.g., public utilities managing right-of-way corridors) may not leave many windows for site preparation. While mechanical site preparation can be done during most any season, if the site isn't too wet, chemical treatments are best applied during the growing season. Herbicide application are more heavily regulated than mechanical methods.

Purchasing equipment to enter the site preparation market, or expand one's presence there, is moderately to highly expensive. Starting a new mechanical site preparation business will require $125,000 or more for equipment—even if purchased used. Creating or increasing an aircraft fleet and ground support staff costs even more. Typical current costs paid by landowners for mechanical site preparation are $75 to $125 per acre. Chemical application alone costs $20 to $40 per acre, plus the chemical costs (another $75 to $100 per acre). Will there be enough work at those prices to cover loan payments and operating costs for new firms entering the market to provide site preparation services?

Key points:

- ***Major increases in forest regeneration will require a substantial increase in site preparation services. Investments by established businesses in additional equipment will be needed, or creation of new businesses, will be required. Currently, little of this equipment sits idle for lack of work, especially in the South.***
- ***Demand for additional site preparation services in an area must be great enough to make it worthwhile for new entrants to secure bank loans for purchasing the necessary equipment. For a rapid increase in site preparation, policies may be needed that help guarantee loans or offer loans with below-market interest rates to encourage new businesses to enter the site preparation services market.***

Bottleneck #5. Labor force for site preparation, nursery production, and tree planting. A major issue afflicting the agriculture sector also impacts the forest sector—substance abuse in rural America. Although drug use trends and rates vary from year to year, recent data shows that substance abuse remains a persistent and pressing problem for many young adults.[18] In 2018, there were an estimated 34.1 million young adults (age 18 to 25) in the United States. According to the 2018 National Survey on Drug Use and Health,[19] more than one third of these young adults reported binge drinking (5 or more alcoholic drinks in a row) in the past month and about 2 in 5 young adults used an illicit drug in the past year. Other results indicating addiction rates among young adults on the order of 1 in 7 individuals.

Substance abuse typically renders an individual uninsurable for operating equipment—in the field, over-the-road, or in a manufacturing facility. McCrany[20] succinctly summarizes the issue and steps employers should take regarding substance abuse. Random testing for substance abuse often required by insurers as a condition of commercial insurance policies. Failed tests lead to interruptions in employment, disqualification for operating equipment or loss of jobs. While health insurance policies often provide some coverage for substance abuse treatment following failed tests, less than 30 percent of forestry

[18] https://americanaddictioncenters.org/rehab-guide/addiction-statistics/young-adults

[19] Substance Abuse and Mental Health Services Administration. 2019. Key substance use and mental health indicators in the United States: Results from the 2018 National Survey on Drug Use and Health.

[20] McCraney, J. 2017. Wood industry vs. substance abuse. Raleigh, NC: Forestry Mutual Insurance Co. Newsletter. June issue. p 3. (https://www.forestrymutual.com/wp-content/uploads/2020/01/Newsletters-ALL-2017.pdf)

workers are enrolled in employer health insurance programs. Policies that lead to high demand for jobs in rural areas might also need to consider funding expanded substance abuse education and treatment activities, as did the 2018 Farm Bill, to expand the eligible labor force.

Ten Job Corps centers nationwide have programs training young adults how to operate heavy equipment. Website descriptions of the program indicate that it is an 18+ month program and the skills taught seem aimed more at construction work, such as highway construction and paving, rather than mechanical site preparation activities. Several rural community colleges have similar programs. Many curricula include education about substance abuse. Graduates from these programs are likely to need less on-the-job training by site preparation contractors than new employees who haven't completed such programs. Policies to increase site preparation and tree planting might benefit from focused support for heavy equipment training programs through Job Corps or rural community colleges.

Since the 1990s, labor contractors for tree planting have had to rely on migrant workers. Labor contractors not only bid on tree-planting work, they also bid on work in the agricultural and horticultural sectors to provide continual, instead of intermittent, employment. But labor contractors still follow the seasons, finding work for a few months in one area, then moving to work in another State or another region. The result is an itinerant work life that is rejected by many in rural America. When labor shortages occur, crops don't get planted or harvested. For example, southern foresters would prefer to begin planting container-grown seedlings in early October—4 to 6 weeks before bareroot tree planting can begin. But during this window in time, many labor contractors still have their crews in more northern States, picking apples and other crops. Despite advertising in local newspapers and other media, few rural Americans are interested in doing this type of work.

Key points:

- ***Substance abuse is a well-recognized issue by employers and insurers in the forest industry. The 2018 Farm Bill expanded support for local substance abuse education and treatment programs because they can help increase the number of people in rural America who are eligible to be employed in agriculture and forestry activities. Therefore, policies and funding to support substance abused education and treatment should be considered as a component of forest regeneration.***
- ***Expanding seedling production and tree planting will require consistent migrant labor supplies at the right times of year. Historically, rural Americans haven't been willing to do that work.***
- ***Migrant worker policies may confound the implementation of expanded seedling nursery production and tree planting activities.***

Bottleneck #6. Monitoring seedling survival and early stand improvement needs. The two forest regeneration steps most likely to be unfunded and therefore unaccomplished are: (1) monitoring seedling survival and conditions after the fourth or fifth growing season; and (2) conducting early stand improvement activities. The latter include controlling competing vegetation, fertilization, and pest control. Most corporate landowners have post-planting monitoring programs. Less often do federal agencies and non-corporate private landowners. Some states have regulations that require landowners harvesting timber to meet specific requirements regarding seedling survival and stand treatments. One example is Oregon. It requires private landowners to: (1) replant harvested areas within two years; (2) monitor site conditions after the fourth or fifth growing season; and (3) complete any stand improvement activities before the end of the sixth season after harvest to ensure that the young trees

are vigorously growing and tall enough to out-compete grass and brush. Policies like this set clear targets and expectations that are essential to attaining the desired outcome of healthy, free-to-grow young forests. Without adequate commitments—and funding—to monitor and complete early stand improvement work, prior investments in all the previous steps in the regeneration process are threatened. Simply put, planting trees without doing anything more is no guarantee that the seedlings will survive or thrive to attain the desired outcome of healthy and productive forests.

A final point regarding natural regeneration. Monitoring and early stand improvement work are just as important for natural regeneration as for tree planting. There are two major challenges for natural regeneration—not enough seed falls to create a well-stocked new stand, and too much seed falls leading to drastic overstocking. Under-stocking due to lack of advance growth can't be easily remedied, other than by waiting a couple of more years for more seed to fall and sprout, or for shade-intolerant species, getting more light to the forest floor. Interplanting rarely occurs or works unless the desired species is tolerant of shade. Regarding over-stocking, I've witnessed shortleaf pine stands in Arkansas that regenerated naturally with great success—proverbially, "thick as the hair on a dog's back"—leading to over 10,000 seedlings per acre. Bush-hogging to reduce stocking to 400-500 seedlings per acre was the essential early stand treatment. Unless monitoring occurs, both of artificially and naturally regenerated stands, these situations won't be identified nor will appropriate stand improvement activities occur.

Key points:

- ***Monitoring the sapling stand four or five years after planting is critical to assess whether the surviving seedlings are "free to grow" from competing vegetation. If they aren't, competition control activities are needed.***
- ***The ultimate success of regeneration is not simply planting trees, it's whether the young stand is healthy, reasonably well-stocked, and free to grow from competing vegetation.***
    - ***Planting seedlings is an "output" measure of an activity.***
    - ***Monitoring a young stand four to six years after planting and applying the necessary TSI activities to results in a health, young stand is an "outcome" measure.***
- ***Success of policies is always best evaluated by outcome measures, not by output measures.***

Summary

People love to plant trees. They love having their pictures taken planting trees. But planting the tree is only one small, short, relatively inexpensive step in the entire forest regeneration process. The entire forest regeneration process is a set of links in a chain of events that must all be completed to successfully create a new forest. The entire chain is the total package that needs policymakers' attention and funding. Weak links—the wrong seed for the planting site, inadequate site preparation—and missing links—no post-planting monitoring, no stand improvement activities—threaten achievement of the ultimate goal—a healthy, vigorous, resilient forest providing the services and products that citizens need well into the future.

Where past forest regeneration programs have been successful, it took decades of persistent commitment and funding to attain the goals. Witnesses are the Yazoo-Little Tallahatchie restoration project (1947 to 1985 in Mississippi) and the Tillamook Burn (1933 to 1973 in Oregon). Where past forest regeneration programs have failed, much of the fault has been due to inadequate attention, lack

of continued commitment, and interruptions of funding for all the links in the chain of activities over the long term. Decades of commitment and resources are required to attain major forest regeneration goals.

Any new program to dramatically increase forest regeneration has to create and deploy a range of policies covering the entire chain and all its links—finding the land, collecting and storing enough seed, growing seedlings for the right zone conditions, preparing sites, planting seedlings, monitoring seedling survival and early growth, and implementing essential stand improvement activities to free seedlings from competing competition and other needs. Focusing only on one link in that chain—planting seedlings—will inevitably result, in the long run failure to achieve the ultimate policy goals.

What's needed is broad, deep, and ongoing support from the public and elected officials over decades to expand America's forests, enabling us all to enjoy the many benefits that more forest would provide.

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