PERSPECTIVE

Preparing for the Need for a Supply of Native Seed

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In mid-September 2020, millions of hectares in the western U.S. were on fire and the year's second wave of seasonal hurricanes and tropical storms were queueing up to batter the states along the Gulf of Mexico. As members of a National Academies of Sciences, Engineering, and Medicine committee tasked with assessing the need for and supply of native seed in the Western United States and other regions of the country, we viewed the unfolding natural disasters as an appropriate, if troubling, backdrop for our work. The assessment of the seed supply was requested by the U.S. Bureau of Land Management (BLM), which uses native seed on a continuing basis for restoration projects on the public lands it manages, and in large quantities after major wildland fires and disasters. Like other federal agencies, BLM turned to the independent, Congressionally chartered National Academies in search of impartial scientific advice. Ultimately, our committee will recommend steps that could help to expand the quantity and diversity of native plant seeds available from commercial seed markets.

As we finalized our interim report (NASEM 2020), describing the structure of the supply chain, the drivers of the need for native seed, and a plan for additional information gathering in the next phase of our work, the assessment felt especially timely. The spectacle of habitat destruction from so many different directions at once seemed to portend a new normal, one that climate scientists have long warned about, with its costly and potentially long-lasting effects on both manmade structures and natural ecosystems.

Hurricanes and wildfires occur naturally, but global warming in tandem with other anthropogenic impacts such as invasive species, fire suppression, and habitat fragmentation have intensified their impacts to the point where natural regeneration may be impaired or impossible. The most recent U.S. catastrophes have been striking in their severity and scale, but more gradual alterations to the natural environment, from the impervious surfaces of urban sprawl that alter hydrological systems to the unsustainable use of natural resources on vast areas of public and private land, eventually cause their own slow-moving disasters that erode the resilience of ecosystems. The impacts of cataclysmic and chronic destruction of vegetated landscapes reveal a potentially large-scale need for plant material (here, "seed" for simplicity) to assist in the recovery and restoration of plant communities in diverse settings, from natural and seminatural areas to cities and other highly-managed spaces.

All of this raises the question "Will the necessary types and quantities of native plant seed be available when land managers are ready to deploy them?" The answer appears to depend partly on whether the current volatility of demand, created by the unpredictability of funding cycles coupled with the erratic timing of major disturbances, proves to be too challenging to maintain a reliable native seed industry responsive to the needs of users.

As a previous perspective in this journal noted, the proposition for restorative activities is not to recreate the past but to enable an ecosystem to endure into the future (Clewell 2009). Native plant seeds are essential to accomplish that goal and fulfill other objectives along the restorative continuum (Gann et al. 2019). The committee learned that, for most plant species, the germplasm collected from the wild and made available to the native seed industry do not represent an adequate range of the genetic diversity contained among the wild populations of these plants in different environments. Consequently, whether seeds with genetic characteristics suitable for a wide diversity of projects are even available is a question that needs further examination. Except in cases where enough seed is collected from the wild to be used directly in projects, seed collection and seed banking are the first steps in a pathway of seed increase, development, cultivation, certification, and analysis before seeds reach end users.

Each step in the native seed pathway also defines some part of the capacity of the seed supply. There is a physical infrastructure of equipment and facilities required for seed gathering, seed banking, cultivated seed production, seed

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cleaning, seed storage, seed testing, bagging, and labeling. Some of this capacity exists in the public sector, such as the U.S. Department of Agriculture's long-term germplasm storage and distribution facilities, the US Forest Service's seed extractory, and the BLM's seed warehouses. But most of the capacity for wildland seed collection, field production, seed cleaning, storage, and banking resides in the private commercial and not-for-profit sectors. A critical mass of equipment and facilities is necessary to support a viable seed industry.

There also is a longstanding regulatory infrastructure, part of which was created to control the spread of weeds in seed stocks for sale. It now includes permitting procedures for collecting seed from the wild, rules for seed analysis, reporting requirements for seed viability, and protocols for seed labelling, certification, and species and source identification. The market infrastructure includes procurement regulations for federal, state, and municipal agencies to buy seed, and rules that shape contracting arrangements that link seed producers with users. Like the physical infrastructure, the market, contracting, and regulatory apparatus may need to adapt and develop to meet the needs of the native seed supply. For example, guidelines for when and how to collect seed of different species from the wild are still evolving or undeveloped, as are the ways to properly grow and clean seed and then test seed viability for many native species.

Complementary to the physical, regulatory, and market structures is a knowledge infrastructure that includes the scientific insights from the fields of botany, agronomy, plant selection and breeding, genetics and the practical expertise in cultivation and harvesting that supported the foundation of agriculture. To achieve the same kind of success in managing a nation's natural vegetation as it has had in crop production, this infrastructure must expand to integrate more disciplines, such as ecology, evolution, genecology, genomics, population biology, and expertise in site preparation. Of course, in every aspect of the seed supply, individual people are the warehouses of knowledge that make the system work. The conclusion is that a broad foundation exists to support an expanded native seed supply, assuming there is flexibility to adapt to the specific needs of an industry that is small by comparison to agricultural crop seed production, but with potentially high impact.

While the physical, market, regulatory, and knowledge infrastructures play essential roles in supporting the seed supply, other major factors also influence how the native seed market functions. Based on its initial investigations, the committee made several preliminary observations about these factors. They are "preliminary" because additional information is needed to confirm or correct them.

Observation 1. Native seed users have varied objectives and needs.

Buyers seek native seeds for a wide range of objectives that may influence preferences for seed of a specific type or designation (e.g., a particular germplasm release), which may affect the availability of seed of other types or designations. In trying to better understand this important dynamic, we find that even the language used to describe different kinds of native seed may be complicated and somewhat opaque. For example, there is a clear distinction between highly bred, selected cultivars of native species on one hand, and native genotypes representing known wild source populations on the other. However, there is disagreement about the practical meaning of the term "genetically appropriate" seed—the standard for ecological restoration, implying genetic matching between the source material and its destination location. While this term makes sense from the reference point of a given restoration site and the objectives of a project, it is not a fixed attribute of any particular seed product. Although this term has relevance for the restoration community (even if definitions vary), suppliers need more precise reference points, such as "provenance-specific" to denote seed of a discrete geographic and/or climatic origin.

Observation 2. Decisions by large land agencies, such as BLM and the USFS, greatly shape the native seed market in large regions of the United States.

The large semi-annual purchases by the BLM after fires, especially in the sagebrush steppe of the Intermountain West, might be expected to bring a steady source of funding into the market. However, the agency's purchases vary tremendously from year to year and include non-native grasses, native cultivars, and provenance-specific native seed. We seek to better understand the rationale behind large seed purchases by agencies. Greater consistency may be advantageous both to the suppliers and to the other seed buyers who would benefit from a robust native seed supply chain.

Observation 3. Demand for native seeds is often urgent and unpredictable.

Both the BLM and USFS policies emphasize the use of native seed, but non-native substitutions are allowed and common for the BLM. Much of these agencies' demands for native seed arises suddenly in response to wildfires or other large-scale events, and these large and reactive needs are harder to meet than proactively planned needs. Some of the seed demand may be met by the agencies' own inventories, but large fires create the need for rapid procurement of large quantities from commercial sources, and the scale and urgency of the demand are likely to affect prices and availability. We seek to identify possible ways in which more proactive planning and funding, based perhaps on predictions about the frequency and scale of

large disturbances, might reduce the volatility of the seed market and expand the availability of seeds.

Observation 4. Seed choices may not be well linked to evidence of restoration success.
On public lands in the western United States, where many very large-scale seeding projects take place, the failure of seedlings to establish is not uncommon, especially in hotter and drier locations. Seeds that are ill-matched to the local climate, along with such factors as poor site preparation and planting methods, unfavorable weather during seeding, weeds outcompeting the planted seeds, and fire and drought cycles that inhibit plant growth, contribute to seeding failure. We want to know how seed choices influence the success of restoration, and the extent to which information on success or failure informs subsequent seed choices.

Observation 5. Many seed users operate on very limited budgets.
The budgets available to native seed users appear to vary tremendously, as does the mix of native plant attributes that buyers seek. Users' budgets may be affected by their funding source, timeframe, project location, project scale, project priority, and the regulatory mandates governing the project. Across all native seed buyers with their range of budget levels and purchase objectives, the willingness to pay for native seeds ranges from a high willingness for buyers with well-funded projects with ecological restoration objectives, to a low willingness for less well-funded projects with more flexible objectives.

We need more information about the range of factors that shape the willingness of buyers to pay for different seed types. For some buyers, for example, the costs for a preferred seed type may be too high, even if its use would increase restoration success. Do buyers decide to substitute more affordable, but less locally adapted seed or even nonnative seed over large acreages, or use the more expensive seed on a smaller area? Furthermore, do limited buyer budgets induce suppliers to not produce native seeds that would be too costly, particularly given that some funds are released only under emergency conditions? Conversely, if there is a large unmet demand for high quality, provenance-specific seeds even though they are costly, why is this demand not being met?

Observation 6. Seed suppliers face a volatile and risky market.
The native seed market has some features that economic theory predicts will make it quite volatile, most notably the strong influences of unpredictable natural disasters and almost equally unpredictable agency budgets. Some suppliers collect wildland seed or produce seed in cultivated fields speculatively, without a contract, in an attempt to anticipate highly uncertain future demand for specific species. However, many suppliers may respond to volatility and risk by preferentially specializing in species that have been historically seeded across fairly large geographic areas to increase the likelihood that they will be able to sell their inventories. In turn, this risk-averse strategy may be one factor that limits the diversity of seeds available on the open market.

Alternatives to purchasing seed on the open market are being explored to reduce uncertainty for growers and share the risk that comes with producing seeds of native plants, for which yields are unpredictable, especially in harsh environments. Contracting with seed growers on an ongoing basis to produce specific germplasms, for which time and inputs are compensated along with the seed product, has been proposed as one way to reduce volatility in the seed supply and get buyers more of what they want. BLM and other land management agencies have recently implemented "indefinite delivery–indefinite quantity" contracts of this nature.

Observation 7. Seed banking and warehousing are critical parts of the supply chain.
Seed banking refers to the collection and storage of small quantities of seeds from wild populations for future uses that may include cultivation for use in restoration; it can be viewed as an insurance policy to secure the availability of wild seed germplasm for future uses. Seed warehousing refers to the storage of larger quantities that can be harvested immediately. Because native seeds are frequently in short supply when needed to respond to natural disasters, an obvious question is whether it might be possible to stockpile seeds in warehouses so that they are available. Among other things, this approach would imply an ability to predict which areas are most likely to need seed, for adequate and economic seed storage capacity, and for seeds that remain viable long enough to respond to any need over prolonged storage periods.

Key questions for the committee are what is the current storage capacity nationally and regionally, how much expanding warehouse capacity would reduce the volatility of the seed market and the price of seeds, whether accurate forecasting capabilities are available, and what measures could be taken to expand storage capacity. In addition, the committee needs to consider the security and sustainability of wild seed sources, which may be under pressure from over-collecting as well as from habitat loss and degradation.

Observation 8. Urban and eastern U.S. settings face somewhat different issues than Western U.S. public lands.
In contrast to the 11 western U.S. states where the federal government manages more than 40 percent of all land, the largest users of native seeds in the Midwest and eastern United States are smaller entities: state, county, and municipal agencies; nonprofits; and public–private partnerships. In addition to ecological restoration, they address issues such as pollinator conservation, wildlife habitat, invasive species control, and nutrient management

on farms. Hurricanes and flooding are creating a demand for large-scale restoration and resiliency planning in the eastern United States, analogous to the fire-driven demand on western U.S. public lands. The native plant seed supply chain is generally inadequate to meet these large demands and future demands are projected to be even greater (Tangren and Toth 2020). There are no large public or private seed warehouses in the eastern United States. Only a handful of institutions, such as New York City's Greenbelt Native Plant Center, the Mid-Atlantic Regional Seed Bank, the Chicago Botanic Garden's Dixon National Tallgrass Prairie Seed Bank, and a few state-level programs conduct seed collection, processing, and banking in support of creating a sustainable supply of eco-regional native plant materials.

The next phase of the committee's work is to collect systematic, survey-style information from federal, state, tribal, and private sector users and suppliers of native seed, and analyze these data to develop a more thorough picture of the native seed supply and the factors that shape it. Our final report, due out in late summer 2021, will offer recommendations to strengthen and expand the native seed supply. A similar assessment was recently completed in Australia (Hancock et al. 2020), but this will be the first such assessment of native seed needs and capacities in the United States.

Strassburg et al. (2020) recently suggested that restoring 15% of global lands that were converted to croplands or pastures back to native vegetation would sequester 30% of the total CO2 increase since the start of the Industrial Revolution and prevent 60% of the anticipated extinctions of plant and animal species. (An estimated 40% of plant species globally are threatened with extinction; Antonelli et al. 2020). If a 'green carbon' strategy to mitigate climate change were pursued in the U.S., and if it included a strong mandate to restore natural and semi-natural lands using native species because of their additional ecological benefits, the demand for native plant seeds would expand enormously, adding to an already growing need. Now is the time to take stock of our natural resources and build a native seed supply for the future.

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