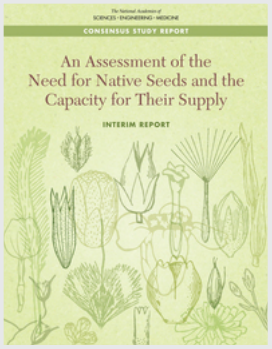

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An Assessment of the Need for Native Seeds and the Capacity for Their Supply

INTERIM REPORT

Committee on an Assessment of Native Seed Needs and Capacities

Board on Agriculture and Natural Resources
Division on Earth and Life Studies

Committee on National Statistics
Division of Behavioral and Social Sciences and Education

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This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by Peter Raven, Missouri Botanical Garden (emeritus) and Laurian J. Unnevehr, Economic Research Service (emerita). They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

Preface

This interim report represents the culmination of 9 months of exploration into the complex system by which seeds of native plants are produced and used in the United States. This system plays an essential but under-recognized role in the maintenance and restoration of the nation's natural and semi-natural areas, including national parks and forests, rangelands, roadsides, lands recovered after energy development, and many, many others. Our assessment committee—a group of diverse professionals from the public and private sector—is now at the end of this initial phase in its assessment of the demand for native seeds and the capacity of the supply chain to meet those demands. The goal remains deceptively simple: to understand who and what are parts of this system and how the system works.

To meet this goal we heard from federal agency representatives, city planners, restoration practitioners, seed suppliers, and other experts from across the system. The committee visited nurseries, restoration sites and seed cleaning facilities to understand the nuances of the many different paths through which native seed supplies are connected with the individuals and organizations who want to use them. In the course of this initial exploration, the committee developed a set of questions, the answers to which we hope to obtain in the next phase of the assessment. The ultimate aim will be to provide the essential information needed to delineate the existing system and suggest improvements to our nation's native seed supply.

I would like to thank all committee members and the experts who generously gave of their time and expertise. Additionally, on behalf of the committee I wish to thank the assessment staff from the National Academies of Sciences, Engineering, and Medicine for their efforts to forge a path for us to understand the native seed system, including Robin Schoen, the study director, and her team, Krisztina Marton, Jenna Briscoe and Sarah Kwon, who were indispensable in facilitating our inquiry.

Sincerely,

Susan P. Harrison, *Chair*
Committee on Assessment of Native Seed Needs and Capacities

Contents

Summary

This report describes the first phase of an examination of some of the nation's needs for native plant seeds (a shorthand term to include all forms of native propagative plant material) and of the capacity to meet those needs. Across the United States, millions of acres of land have been so disturbed by human activities or severe climate events that significant portions of their native plant communities have been lost and their ecosystems have been seriously compromised. Restoring impaired ecosystems requires a supply of diverse native plant seeds that are well suited to the climates, soils, and other living species of the system. Native seeds are also in demand for applications in urban land management, roadside maintenance, conservation agriculture, and other restorative activities that take into account the connection between native plant communities and the increasingly urgent need for resilient landscapes. Given the varied climatic and environmental niches of the more than 17,000 native plant species of the United States, supplying the desired seed types and species mixes for this wide range of activities is a challenge. There has never been a nationwide analysis of the full scope of needs for native plant seeds and how well they are being met. This report is an initial step in that direction.

In 2017 twelve federal agencies established the National Seed Strategy, an agreement to support ecological restoration by addressing the accessibility and use of native seed. Part of the motivation for the strategy came from Hurricane Sandy, which in 2012 struck the Eastern seaboard from Florida to Maine, leaving damaged coastal wetlands and forests for which the scarcity of native plant resources impeded restoration. Another impetus was the increasing destructiveness of wildfires, fueled by invasive cheatgrass (*Bromus tectorum*), in the sagebrush steppe of the intermountain West. The Department of Interior's Bureau of Land Management (BLM), which manages millions of acres of sagebrush steppe, has played a leadership role in the National Seed Strategy. In 2019 the BLM requested the National Academies of Sciences, Engineering, and Medicine to undertake an assessment of federal, state, tribal, and private sector needs for native plant seeds and to explore the seed industry's ability to supply those needs as well as public- and private-sector approaches to improving the supply. Focused primarily on the western United States, where frequent wildfire and other disturbances are important drivers of the demand for seed, but also introducing information about the rest of the country, the assessment will examine the frequency, scale, and diversity of uses of seeds of native plants, including native trees and shrubs. The assessment will identify entities that make up the native seed supply chain, describe how well native seed users and suppliers communicate their needs and offerings, respectively, and examine barriers to meeting user needs. In the course of its work, the committee will identify opportunities to increase the size and efficacy of the native seed supply.

A committee of experts appointed by the National Academies is conducting the assessment in two phases, as directed by the committee's statement of task (Chapter 1, Box 1-1). In this report of the first phase, the committee describes the participants in the native plant seed supply chain, makes preliminary observations, and proposes an information-gathering plan for the second phase of the assessment.

COMPONENTS OF THE NATIVE SEED SUPPLY CHAIN

Seed Buyers and Users

The largest buyers in the market for native plant seeds are public land and wildlife stewardship agencies, such as the BLM, U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), tribal nations, National Park Service (NPS), and U.S. Department of Defense, which collectively manage more than 640 million acres of land. The BLM buys hundreds of thousands to millions of pounds of seed annually, depending on the extent of wildland fires in a given year.

Federal agencies cooperate with each other by sharing research, small-scale seed cleaning and seed banking infrastructure, plant germplasm development, and related activities. Many are signatories to the National Seed Strategy and are represented on the federal liaison committee to the Plant Conservation Alliance, a public–private partnership whose goal is to ensure that native plant populations and their communities are maintained, enhanced, and restored.

The use of seeds from native plants is generally necessary for landscape restoration on federal land or else is, in the case of some multiple-use public lands agencies (e.g., BLM), strongly encouraged. Some agencies (e.g., USFS, NPS) further require or encourage that the native plant seeds used in restoration projects be derived from populations growing in natural environments similar to the locations where they will be used, reflecting the recognition that widespread native species often comprise a range of genetic variability adapted to different climates and soils.

Local governments (states, counties, and municipalities) use native seeds on their lands following disturbances (e.g., fires, hurricanes, floods), for roadside maintenance, for the creation of green infrastructure such as stormwater management, for the enhancement of wildlife habitat and pollinator resources, to control invasive species encroachment, and to improve urban ecosystems and parkland. These governments frequently work with developers and landscape designers in planning the use of native plants in their jurisdictions.

Private users of native seeds include ranchers and farmers, rural and urban home landscapers, homeowner associations, and companies involved in energy development and resource extraction. Many nonprofit groups use native seed in managing land for conservation, including The Nature Conservancy (TNC) and its collaborators, local and regional conservancies, and land trusts. Private restoration contractors conduct work for both the public and private sectors. Finally, there are public–private partnerships to reclaim abandoned industrial sites and farmland, create wildlife corridors, and restore other degraded landscapes.

One fundamental concern identified by the committee is that many practitioners of ecological restoration are interested in obtaining native seeds that meet certain specifications: first, representing as many species as possible of the plant community at a restoration site and, second, representing the internal genetic variation within each species, typically by being derived from seed stock that is collected either near the restored site or in the same climatic zone as the site. The National Seed Strategy refers to such seed as “genetically appropriate,” but for this report the more value-neutral term “provenance-specific” (where provenance means geographic seed source) is used. Provenance-specific seed is a product that is distinct from some cultivated varieties of native seed on the “manipulated track” (see below) which are intended to be usable over wide geographic areas. The demand for provenance-specific native seed is inherently harder

to meet than the demand for widespread cultivars since the supply of provenance-specific seeds must be more closely tailored to the end-user's specifications.

Seed Collectors, Developers, Growers, and Consolidators

Native seed finds its way to users through many different pathways and steps, but all native seed originates from collections of material taken from populations of wild-growing native plants. The protocol used in collecting the original material, the location in which it was collected, and how it is handled or manipulated afterwards are all determinants of the genetic identity of the seed product.

For most native grasses and forbs (i.e., herbaceous flowering plants that are not grasses), the purpose of wildland collections is to provide foundation seed "for increase" (that is, planted in cultivated fields in order to produce a larger quantity of seed) before their ultimate use. However, for some restoration projects the native seed used is obtained directly from wild-growing plants. This is the case when the amount of seed needed can be met from species capable of copious seed production in the wild. In addition, some native plants cannot be grown economically under cultivation, so collecting seeds from wild populations is the only way to obtain them. Large-scale (that is, covering hundreds to thousands of acres) and small-scale (a few acres) wildland seed collection is conducted by both public and private entities.

For most plant species the specimens that have been formally collected from the wild and made available to the native seed industry do not represent the full range of genetic diversity contained among wild populations of these plants. The Seeds of Success program is the largest coordinated effort to collect diverse native species and populations for seed banking, research, plant materials development, and ecological restoration. Established in 2001, Seeds of Success is led by BLM. At least 50 nonprofit institutions, mainly botanic gardens, collect seed directly for the program or identify contractors that collect seed for BLM. To date, over 25,000 accessions (unique samples of seed) have been collected from more than 43 states, with the focus of the collections being on the more common species that are likely to be the most useful in restoration.

Accessions of native plant seed have been collected for many years by the U.S. Department of Agriculture's (USDA) Agricultural Research Service (ARS), the plant materials centers of the Natural Resources Conservation Service (NRCS), the U.S. Forest Service, universities, extension programs, and private agronomists and horticulturalists. After characterization in test gardens, some accessions may be subjected to selection and breeding for desired traits, which places them on the "manipulated track" for seed certification and labeling purposes. Evaluation of those plants for notable characteristics—such as good establishment, vigor, and seed production—that are shown to be heritable and stable allows them to be named as (manipulated-track) cultivars and germplasm releases. The accessions grown in test gardens without any further manipulation are designated "natural track." Some natural-track accessions will have only the location of their collection and their species designation recorded. These will be certified and labeled as a source-identified germplasm release. Other accessions may be further studied and described and, if found to have characteristics that are heritable and stable, may also be released as (natural-track) cultivars and germplasm releases.

The NRCS plant materials centers have developed, produced, and stored foundation seed of conservation germplasm releases and cultivars that have resulted in seed production by commercial growers valued at more than $100 million annually, providing a major component of the native seed industry. These seeds are generally intended to be usable over broad geographic

areas, and many are widely used. However, they do not always match the preferences of practitioners of ecological restoration seeking provenance-specific seed that they anticipate will be better suited to establishment conditions and to maintaining biodiversity at a restoration site.

Large-scale field cultivation of native seeds is most common in the Western United States where seed demand by public land management agencies after wildfires drives the market. Field production also occurs in the Midwest, East, and South to meet regional needs. Seed suppliers in the native seed industry defy singular description and are specialized to some extent with respect to the particular species they grow, their production capacity, their relationships with collectors and growers, and their business models. Some collectors and producers have their own cleaning and bagging equipment and may market their seed directly to end users. Others deliver bulk or uncleaned seed on an ad hoc or contract basis to seed warehouses and vendors for cleaning, packaging, labeling, storing and shipping. Some vendors consolidate many different lots of seed from varied sources for larger wholesale and retail native seed markets.

Intermediaries: Permitting, Testing, Certification, Contracting, and Storage

Permits are required for collecting seed on public lands, and permitting procedures may vary among offices of the same land management agency. Permitting offices vary in their approaches to monitoring and facilitating seed collectors. Permission for collecting seed on private land is also required.

Federal and state laws require seed testing and labeling for all seed sold to an end user. Seed analysis is carried out by government and commercial laboratories following the rules of the Association of Official Seed Analysts; the analysis reports the percentage, by weight, of the pure seed units of the main species in a sample as well as their percent viability. The percentages of seed of other species (including weeds) and of inert matter are also reported. For buyers this information as reported on the seed label is essential for the proper use of the seed (e.g., seeding rates) as well as for providing accurate expectations concerning the germination of the seed. Test results play a role in the negotiations between buyer and seller on the price of the seed. For many native species testing techniques and rules have not yet been developed, and this lack of established testing procedures can lead to delays, increased costs, and inconsistencies between testing labs.

Seed analysis does not verify the identity of the seed. This is accomplished by a separate process—seed certification, which uses collection site and field inspections, cleaning, and other inspections and records to ensure that the seed in the container, as listed on a certification tag, is the species, variety, or germplasm claimed, whether it was collected from the wild for direct use or field produced. Labels may provide state, county, elevation and other geographic descriptions of the collection site. Seed certification is not required by law, but for many seed users the information provided is of central importance to decision making about the suitability of the seed for the restoration site.

The preference of certain seed users for certified seed of a specific origin or designation is frequently satisfied through procurement procedures and contracts, which connect users with suppliers and are an integral part of the supply chain. Purchases by agencies must follow government procedures (notably the U.S. Federal Acquisition Regulation) which typically require competitive bidding to meet specified contract terms.

Depending on how the seed is produced, contract terms for native seed typically dictate the species, quantities, and delivery timing, and they may also include specifications for the

degree of genetic diversity required, seed origin location, seed certification, and seed wild collection procedures. Contracts to purchase delivered seed place all the production risk on the supplier. In contrast, contracts to support a seed production process, typically on an ongoing basis, often contain provisions for risk sharing between the buyer and supplier. To ensure a continuous supply of native seeds, the BLM has recently begun to use an indefinite delivery/quantity contract; the USFS relies on a blanket purchase order available to all federal agencies. These contracts contain provisions for producers to receive fixed crop establishment fees, regardless of ultimate yields, reducing the burden of production risk on the supplier.

Seed for near-term use is frequently housed in warehouses under ambient conditions. Because seed longevity is enhanced by low temperatures and low humidity, parts of the arid western United States (e.g., Utah, Nevada, eastern Oregon) provide more effective ambient seed storage than warmer or more humid regions. Long-term storage requires conditions and special facilities not normally available to seed companies. The BLM has a total storage capacity for 2.6 million pounds of seed, with refrigerated storage at three warehouses with a total capacity of 135,000 pounds. The Utah Division of Wildlife Resources maintains a large seed warehouse with ambient and refrigerated storage capacity for about 1 million pounds. There appear to be no comparable native seed warehouses east of the Mississippi River.

Small amounts of seed of numerous species are kept in long-term storage in seed banks, or conservation collections. Seed can remain viable for many years under subzero conditions, either in mechanical freezers or liquid nitrogen containers, or at slightly higher temperatures; maintaining seed at these higher temperature facilitates its distribution and use and is more suited for active collections. Seed banking at the federal level is largely carried out by USDA's National Plant Germplasm System (NPGS), which has historically focused on safeguarding the genetic diversity of agriculturally important plants, including some native species and wild relatives of crops. Seed banking of wild plants for revegetation is relatively new and is growing in importance. Many accessions collected by Seeds of Success are stored and distributed in NPGS seed banks. Botanic gardens and similar institutions add some storage capacity to the federal system, often as a mix of long-term conservation collections and active collections for restoration and research.

Ancillary Influences: Funding, Policy, Research, Guidance, and Advocacy

Government agencies, policies, programs, land planners, landscape architects, university researchers, and seed associations affect the use of native seeds through various mechanisms, including (1) policies and funds that support the use of native plants, (2) guidance on which species to use, (3) basic and applied restoration research, and (4) tools to facilitate decision making. Examples of these ancillary influences include the National Seed Strategy and state and regional native plant materials development programs to support native seed use in restoration; the Burned Area Emergency Response Program and Burned Area Rehabilitation funds for post-fire assistance; the U.S. Department of Transportation's funds and guidance for state highway departments; the U.S. Environmental Protection Agency's clean water policies, funds, and guidance for seed transfer; the NRCS Conservation Technical Assistance Program for participants in USDA conservation programs; the USDA National Institute of Food and Agriculture' support of university researchers and the intramural research programs of USDA (including the ARS, USFS, and NRCS), and the U.S. Geological Survey. Finally, trade

associations such as the Western Seed Association and American Seed Trade Association advocate for the seed industry.

PRELIMINARY OBSERVATIONS

Discussions by the NASEM committee with participants in the native seed enterprise uncovered some of the factors that affect the performance of the seed supply chain. Preliminary observations about these factors are discussed below. They are called "preliminary" because additional information is needed to confirm or correct them. Refining an understanding of these and other issues related to the seed supply will be the goal of the next phase of the assessment and will be the basis for the conclusions and recommendations in the committee's final report.

Observation 1. Users have varied objectives and needs.

Some users of native seed are interested in restoring native ecosystems, focusing on biodiversity and function. Others have different functional goals, such as providing specific plants for pollinators or for production value, such as rangeland forage.

Given the diverse objectives and motivations for native seed use, the committee seeks to understand whether and how the needs are met by current supply channels. One specific question is how demand for provenance-specific seed and for more choices of seed from different seed zones and localities interacts with the market for native seed of other kinds, such as for seed of the same species but with origins outside the ecoregion in which it will be used or for the cultivars that are currently used in many applications.

Observation 2. The seed market in the western United States is strongly affected by decision making by the large land management agencies, such as the BLM and USFS.

Federal land management agencies strongly influence the market for native seeds. In the BLM, post-fire seeding has generally emphasized grass-dominated mixes for soil stabilization and for preventing the establishment of invasive species, rather than using the sorts of diverse mixes designed for longer-term ecological restoration. Records of BLM's consolidated seed buys (purchases made on behalf of BLM field offices) show an ongoing reliance on non-natives and cultivars and a limited, but increasing, use of provenance-specific natives.

The USFS has in recent years reduced its post-fire seeding, reflecting policy decisions to avoid non-native seeds and to not seed areas considered capable of regenerating naturally. Although expanded native seed restoration is recognized as a critical component of some USFS activities, there is no agency-wide native plant restoration program.

The committee is interested in understanding more about the determinants of seed choice and restoration decisions in these agencies, which vary among agencies and even within their different agency divisions (e.g., BLM field offices, USFS districts).

Observation 3. Timeframe, quantity, and quality strongly limit the overlap between what seed is available and what seed is desired.

Both the BLM and USFS policies emphasize the use of native seed, but substitutions are allowed and are common in the BLM. Much of these agencies' demand for native seed arises

suddenly in response to large 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. Given that wildland fires and other large-scale events will continue to be important drivers of seed demand, the committee will explore the problem of timeframe and urgency as they relate to the availability of native seed.

Observation 4. Seed choices do not always support restoration success, and outcomes do not always inform choices.

On public lands in the western United States, where many very large-scale seeding projects have taken place, it is common for many species to fail to become established, especially in hotter and drier locations. Seeds that are not well matched to the local climate contribute to seeding failure along with such factors as poor site preparation and planting methods, bad timing, unfavorable weather, weeds, and fire and drought cycles. This committee is interested in how seed choices influence the success of restoration and to what extent information on success feeds back into seed choices.

Grasses are often chosen for seeding after wildland fires. Many grasses tend to germinate readily, grow quickly, and compete strongly with other plants, and many cultivars and releases are selected for these characteristics. However, these attributes may lead seeded grasses, particularly exotic grass cultivars, to inhibit the establishment of seeded natives or slow the recovery of natives at the site. Grasses do not meet all of the needs of wildlife and pollinators, nor do they perform many of the essential ecological functions of shrubs and forbs. Although shrubs and forbs are increasingly added to seed mixes, large quantities of seed are available for only a few species.

Observation 5. The budgets and seed specifications of users vary greatly, as do the unit costs of suppliers.

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 (urban versus rural), project scale, project priority, and whether the project has legal requirements (for example, restoration following resource extraction). 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 specific restoration objectives to a low willingness for less well-funded projects with more flexible objectives. More information is needed about the range of factors that shape buyer willingness to pay for different seed types.

Observation 6. Seed procurement may be hampered by market volatility, risk, and contract structure.

More information is needed about the behaviors of buyers and sellers of native seed under different procurement scenarios. There are features of the native seed market that economic theory predicts will make it quite volatile. 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.

Market volatility is affected by the timing of the demand for seed. The interactions between the multi-year seed production cycles and the demand for seed, including the extent to which storage is used currently and the potential for its expansion, are essential in assessing market risks. However, many prospective and current growers are unwilling or unable to bear the risks of producing native seeds or of carrying inventories in the face of uncertain demand or the uncertain availability of funding for buyers in federal agencies.

One question regarding the market response to such risk is whether the urgent needs of buyers on the open market incentivize suppliers to choose species that have been historically seeded across a fairly large geographic area in order to increase the likelihood that they will be able to sell their inventories.

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 appropriate seed over large acreage, 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?

Observation 7. The seed market may be strongly affected by the limited capacity for seed banking and warehousing.

Because native seeds are frequently in short supply when they are needed to respond to a natural disaster, an obvious question to ask is whether it might be possible to stockpile seeds so that they are available when needed. Among other things, this approach would imply the need for predicting 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 the current storage capacity is, how much expanding storage 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.

Observation 8. Issues affecting urban and Eastern settings are somewhat distinct from those affecting public lands in the West.

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 addressing such issues as pollinator conservation, wildlife habitat, invasive species control, and farmland nutrient management in addition to basic ecological restoration. 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.

The supply chain for the eastern United States is also affected by several regional-scale constraints. First, because of the humid climate, seed warehousing is more challenging. There are no large public or private seed warehouses in the eastern United States. Second, there are only a

handful of institutions, such as New York City's Greenbelt Native Plant Center, the Mid-Atlantic Regional Seed Bank, and a few state-level programs, that conduct seed collection, processing, and banking in support of creating a sustainable supply of eco-regional native plant materials. Outside of these institutions, most seed collection is done on a short term, individual, or project basis, or it is done by commercial entities with no standardization, regulation, or use of available native seed collection or seed certification programs, as is true of much of nursery plant production.

INFORMATION-GATHERING STRATEGY

In the next phase of the committee's assessment, a systematic information-gathering effort will be employed to obtain a more complete picture of the native seed supply chain. Several mechanisms will be used to collect the needed information, with each approach fitted to the specific type, projected use, and availability of that information. Some information about seed purchases acquired for restoration purposes currently exists, for example, in the BLM consolidated seed buy and indefinite delivery/quantity contract records, USFS seed cleaning records, and Association of Official Seed Certifying Agencies seed certification records. These records will need to be analyzed by the committee. Additional information will be sought from other institutional datasets, such as for seed purchases by state highway administrations.

Other types of information may lend themselves to a statistical survey if an appropriate sampling frame with contact information can be assembled. For example, the buyer side of the native seed supply chain is dominated by a few large federal agencies which are relatively easy to identify as buyers, while there are numerous smaller buyers of different types (tribes, states, municipalities, nongovernmental organizations, etc.). To the extent that sampling frames can be constructed for different categories of buyers, it will be possible to gather information from them through a survey. It seems likely, however, that it will not be possible to target at least some of those in this manner, and qualitative data collection methods (such as individual interviews or focus groups) might be used instead of a survey. For the large agencies it will be necessary to understand their organizational structures to be able to know at which administrative and geographic levels (probably multiple levels) decisions regarding native seed buys are made.

Issues of interest for the assessment will include: buyer characteristics; the frequency, volume, types (species, germplasm designation), and purposes of native seed purchases; decision-making criteria concerning which species to buy and restoration project planning; the time horizon for purchases, and availability of the types and quality of seed sought. Questions also will be asked about the sources of information used to determine seed availability, the buyer's capacity to clean and store seed, the types of procurement and contracting mechanisms used, and institutional barriers to expanding the list of seeds purchased.

On the seed provider side, a list of companies and individuals that sell native seed or plants will be constructed from several sources, such as the USDA National Nursery and Seed Directory, BLM seed vendor lists, the American Seed Trade Association's Environmental and Conservation Seed Committee, the Native Seed Network, and other sources. If it is determined that it is possible to develop a sampling frame, the primary data collection method for this population will likely be a survey, possibly supplemented with individual interviews or focus groups.

Information needed on seed suppliers includes type of operation; species collected or cultivated; annual seed quantities sold and unsold inventories; capacity for growing, cleaning,

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and storing seed; customer base, intended uses, and geographical area served; types of contracting arrangements used; factors affecting production decisions and anticipating demand; and other challenges and potential solutions.

In preparation for the data collection the committee will (1) develop data collection instruments (survey questionnaires or interview guides), (2) develop formal data collection and analysis specifications for the surveys, and (3) identify a subcontractor to carry out the data collection. The committee will decide which specific tasks will be delegated to the data collection contractor, but it will maintain oversight of all activities, including sampling, instrument design, pretesting, and basic analyses.

Information will also be needed from other key players in the seed supply chain, including Seeds of Success and its collaborators, other seed collectors, collection permit issuers, seed cleaners and extractors, germplasm developers, seed analysts and certifiers, seed banks, seed warehouses, seed consolidators, and vendors. Input from these entities can further inform the committee's understanding of the seed supply chain and its limitations. Due to the large variation in the mission, activities, and characteristics of these entities, the committee will gather this input with individual interviews, focus groups, case studies, or other forms of qualitative information gathering. The committee will also attempt to collect existing administrative data relevant to these parts of the supply chain.

Finally, the committee will develop and publicize a process through which any interested party will be able to submit comments to the committee.

1

Introduction and Overview

BACKGROUND

In 2019, at the request of the Department of Interior's Bureau of Land Management (BLM), the National Academies of Sciences, Engineering, and Medicine established an ad hoc committee to assess federal, state, tribal, and private sector needs for native plant seeds and to assess seed industry capacities and public-sector solutions to supply those needs. Native plant seed[1] (a term used in this report to include all native plant propagative materials) is used for the ecological restoration of degraded wildlands and their biodiversity and for the enhancement of lands for conservation and for human and wildlife benefit.

The committee's statement of task (see Box 1-1) specifies that it should largely focus on the vast public land complex in the western continental United States where BLM and other agencies are continuously addressing the impacts of increasingly frequent, intense, wildland fire disturbances. Many of the landscapes affected are already extensively degraded. Some were previously seeded with an array of native and nonnative species. The statement of task also directs the committee to include information, as available, on native plant seed needs for other users and regions in an effort to begin constructing a national perspective of native seed use and supply. Millions of acres of land in settings that range from the most natural to the most urban are potentially in need of supplies of native seed to improve their resilience in the face of changing uses and climate change. A recognition of the connection between plant communities and the ecosystem goods and services on which human existence depends is driving the demand for native plant seeds.

The statement of task calls for the assessment to take place in two phases. This interim report describes the findings of the committee's phase 1 information-gathering activities which were undertaken in order to develop a framework for the additional data gathering that will take place in phase 2.

By elucidating the present status of native seed needs and capacities and recommending steps to ensure seed availability for ecological restoration, the completed assessment will take a major step towards fulfilling the first objective of the National Seed Strategy for Rehabilitation and Restoration 2015–2020 (PCA, 2015) to assess the nation's needs for and capacity to supply native seeds.

COMMITTEE ACTIVITIES TO DATE

Short biographies of the committee members appointed by National Academies to conduct the assessment are contained in Appendix A. The committee was initially constituted in

[1] The statement of task (see Box 1-1) specifically refers to "native plant seed," The report will use *native plant seed* to encompass not only seeds but other plant materials, such as containerized stock, bare root seedlings, cuttings, rhizomes, tissue culture callus material, and other plant propagules.

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August 2019 and was later expanded to include additional expertise in markets and contracts. The committee met four times in virtual meetings in closed session and held three in-person meetings, the first in Washington, D.C., on August 18–19, 2019. The topics explored included ecological restoration, seed source selection and seed collection, seed production, seed performance in restoration, seed certification, and marketing. The committee met with a BLM representative and listened to presentations on the roles of different federal agencies in the native seed enterprise, including the U.S. Department of Interior's Fish and Wildlife Service (USFWS), the U.S. Department of Agriculture's Forest Service (USFS), the Natural Resources Conservation Service (NRCS), and the National Institute of Food and Agriculture (NIFA). Several private and public sector seed producers provided their perspectives concerning the growing and marketing of native seeds.

BOX 1-1 Statement of Task

An ad hoc study committee appointed by the National Academies of Sciences, Engineering, and Medicine will assess federal, state, tribal, and private sector needs and capacity for supplying native plant seeds for ecological restoration and other purposes. The assessment will focus on the western continental United States and incorporate information from assessments of other U.S. regions, as available, towards the goal of a nationwide perspective. The assessment will be carried out in two phases. In phase one the committee will conduct fact-finding, develop a framework for information gathering for the assessment, and prepare an interim report describing the framework and implementation strategy. In the second phase the committee will oversee the data and information-gathering process, analyze the information obtained, and prepare a final report summarizing the committee's findings and conclusions. The final report will also provide recommendations for improving the reliability, predictability, and performance of the native seed supply.

The assessment may include information on:

- how native seeds are being used by public (federal, state, tribal) and private (land trusts, companies, nongovernmental) organizations in ecological restoration and other activities;
- the frequency and scale of the demand and the characteristics of the seeds pursued by users as well as the diversity of applications for which they are sought;
- how users find seeds that are appropriate for their intended purpose and how users communicate their needs for seeds to potential suppliers;
- how suppliers make known their capacity to potential users;
- the different kinds of entities and roles that compose the seed supply chain (from professionals and organizations involved in the identification of site-specific needs, to the collection, propagation, cleaning, storage, and supply of seed) and their respective capacities;
- the relationship of seed availability to other agricultural, land management, and conservation activities generally;
- procurement processes for native seeds and the cost, availability of funds, infrastructure, market, and other factors that influence decision making on the part of users and suppliers of native seeds;
- opportunities to increase the size and capacity of the native seed supply chain (and number of suppliers); and
- other relevant issues identified by native seed users and suppliers and other stakeholders.

The second in-person committee meeting was in Bend, Oregon, on October 10–11, 2019, at the Deschutes National Forest administration headquarters. The committee visited the Deschutes National Forest seed extractory (a facility that removes seed from plant material) and observed the diverse processes of native seed cleaning. The committee met again with representatives of the seed industry, listened to presentations on the USFS native seed needs, met remotely with a retired plant specialist from the Department of Transportation, and heard a presentation on the Oregon Seed Certification Service. The committee met remotely with representatives of the National Park Service and the Umatilla tribe to gather information on their respective uses of native seeds.

The third meeting was at the National Academy of Science's Beckman Center in Irvine, California, on January 28–29, 2020. Major topics included the best approaches to data gathering and interim report topics and organization. The committee also received information from representatives of various state departments of transportation and the Forest Service's Intertribal Nursery Program and again consulted with seed industry members. Field trips to seed-growing and ecological restoration sites in Irvine and Los Angeles provided firsthand insight into the scale of native seed needs in urban and semi-urban settings. Throughout this stage of the assessment, individual members of the committee sought information and insight from professionals in public and private organizations engaged in the native plant materials supply chain.

The remainder of this chapter provides a brief overview of some of the main concepts and issues the committee has investigated thus far, which are discussed in greater detail in other chapters of the report. Although the committee has focused mainly on the western United States to this point, it is mindful of differences in the seed supply in other regions of the country that will need elucidation as the assessment moves into its second phase.

OVERVIEW OF THE COMPOSITION AND STATUS OF THE NATIVE PLANT SEED SUPPLY CHAIN

Background on Native Plants and Their Supply and Use in Restorative Activities

For the purposes of this assessment, *native seed* is seed collected from native plants, including trees and shrubs, which are defined as "indigenous terrestrial and aquatic species that have evolved and occur naturally in a particular region, ecosystem, or habitat. Species native to North America are generally recognized as those occurring on the continent prior to European settlement" (PCA, 2015, p. 42). Native plants, therefore, are the foundation of our native ecosystems; they evolved with other species in a given area and context, resulting in a complex collection of ecological relationships.

Most plant species are represented by an array of genetically variable populations, reflecting different adaptations to varying soils, climates, and biotic factors across their geographic ranges. Long-term restoration success at a given site is dependent upon obtaining and establishing adapted plant seeds (Hereford, 2009; Johnson et al., 2010; Leimu and Fischer, 2008). Long-term ecosystem health is dependent on maintaining the adaptive variability found within and among local populations, and on maintaining critical ecological relationships among plants and animals. Along with other characteristics, (Byrne, 2011; Frankham et al., 2011; Breed et al., 2018) a plant's plasticity (i.e., its response to changing environments) can vary both among and within species and populations (Bradshaw, 1965). Plasticity can also vary from one specific plant trait to another (Espeland et al., 2018). Plant seeds that originate from the same site or from

environmentally similar locations are likely to have similar characteristics, and thus are more likely to establish and enhance ecological relationships than seeds from environmentally distant plants. Although there are exceptions, this basic pattern has generally been borne out by research (Baughman et al., 2019; Johnson et al., 2010; Leimu and Fischer, 2008).

In addition to considering whether native seeds have the appropriate genetic composition to become established and survive at a particular restoration site in the short- to medium term, other critical considerations include (1) whether the species that grow from the seeds will tend to coexist with, or to outcompete, other desirable native species at the site, (2) whether they will survive in the longer term under a changing climate, and (3) whether they, combined with the existing species at a site, represent the full array of species and functional types (grasses, forbs,[2] shrubs, trees) desired in an ecological restoration project (PCA, 2015). Meeting these criteria is inherently challenging since the seeds in question must be well-matched to particular restoration projects at specific recipient sites. Native seeds that are derived from specific known locations or climate zones in the wild are an important resource for fulfilling these criteria. In this report the committee refers to such native seeds as *provenance-specific* (where provenance means the geographic location of the original seed source), which are distinguished from native species that are genetically manipulated through intentional selection or breeding, as described later in the chapter.

The realities of seed production, both by plants in the wild and in cultivation, lead to different paths from the wild to native seed users. For species with copious seed production and large populations (e.g., sagebrush), wild-sourced native seed can supply a significant seed volume for direct sowing. For species that are difficult to grow economically under cultivation, including some shrubs (e.g., bitterbrush) and certain forbs and grasses, obtaining seeds for projects requires that they be collected from wildland plant stands. Ideally, those collections are made from areas that are ecologically similar to a planned or expected seeding site. For most species, seed is collected from the wild in limited quantities and then propagated in fields or nurseries to produce sufficient quantities for seeding projects. When obtaining seed from wild populations, collectors are encouraged or required to use particular sampling protocols designed to ensure that they capture the genetic diversity resident in the sampled populations (USDI BLM SOS, 2016; ENSCONET, 2009; Guerrant Jr. et al., 2014; Waters and Shaw, 2003).

The way in which a seed accession (a uniquely identified sample of seeds) is ultimately handled has significance to participants in the supply chain. The development of germplasm (living tissue that can produce new plants, such as seeds or rhizomes) can be as simple as increasing the numbers of seeds of wild collections in production fields, knowing only the provenance of the wild-growing parents, or it can involve evaluating an accession for its genotype and phenotypic expression and its potential for use in specific restoration projects, geographic areas, or seed zones (Box 1-2).

Germplasm development may also use plant breeding techniques such as selection for particular characteristics or crossing to create new genetic combinations (Johnson et al, 2010; Shaw and Jensen, 2014). One way to categorize native plant materials by describing their "natural" or "manipulated" status and their degree of development has been set forth by the Association of Official Seed Certification Agencies (AOSCA).[3] Seed accessions developed by public and private entities are in some cases offered as germplasm or as named cultivar releases

[2] A forb is an herbaceous flowering plant other than a grass.

[3] See https://www.aosca.org/about-aosca/programs-and-services/native-plant-restoration.

BOX 1-2 Seed Zones

The National Seed Strategy defines seed zones as "a mapped area with fixed boundaries in which seeds or plant materials can be transferred with minimal risk of maladaptation." *Empirical seed zones* differ by species and are developed from common garden studies using seeds collected from geographically diverse locations across a given region. The seed zones are based on correlation between genetic variation, identified in the common gardens, and the differing environments at seed source locations. This approach has been widely applied to tree species in the Western US, with recent focus in the last two decades on seed zone development for grasses, forbs, and shrubs. In the absence of empirical seed zones, which must be developed on a species by species basis*, provisional seed zones* are climate-based seed zones used as guidelines for seed deployment of the many species for which genetic data is lacking. Provisional seed zones are similar in concept to the USDA's general plant hardiness zones commonly used for gardening, while empirical seed zones are species-specific.

in accordance with AOSCA guidelines (Young et al., 2003). Supplies of some commonly available native germplasms and cultivars, most of them natural but some manipulated (through selection and breeding), have been greatly increased and applied across wide geographic ranges, especially in Western states. However, some restoration practitioners have questioned whether it is appropriate to use these native releases for ecological restoration so broadly outside of their areas of geographic provenance, and this practice runs counter to directives by the Forest Service and other agencies to be guided by seed zones in selecting seed (Breed et al., 2018; Leger and Baughman, 2015).

The committee's statement of task charges it to examine native seed needs and supply for "ecological restoration and other purposes." The committee has adopted the terminology of the Society for Ecological Restoration, which defines *ecological restoration* as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Gann et al., 2019, p. S7). The committee considered "other purposes" to include activities occurring within a restorative continuum (Figure 1-1) and involving a range of different objectives that take place in natural, semi-natural, agricultural, or urban areas. The restorative continuum encompasses a variety of seeding activities, from simple revegetation (attaining some degree of improvement in ecosystem function with the goal of, for instance, erosion control or fire mitigation) to ecological restoration with the aim of putting an ecological community on a trajectory to attain the species composition, structural diversity, genetic integrity, ecosystem function, and other conditions similar to those that would be present in an undisturbed reference ecosystem (Gann et al., 2019). The committee considers within its charge the use of native plants, including trees and shrubs, for activities along the restorative continuum.

One of the challenges in the native seed supply is aligning what is available on the market with the characteristics of seeds valued by different users, which are shaped, in part, by the objectives of their seeding projects and the characteristics of their project locations. In ecological restoration there is a high demand for provenance-specific native seeds. When used at sites that are geographically and ecologically similar to the source of the seeds, provenance-specific seeds are presumed to be locally adapted, i.e., to be capable of surviving at least in the short- to medium term and likely to coexist well with other native species. Provenance-specific seeds may be blended to create seed mixtures with the genetic variability believed to enhance the seeds' potential for adaptation within seed zones and to climate change (Etterson et al., 2020; Havens et al., 2015; Massatti, et al., 2020).

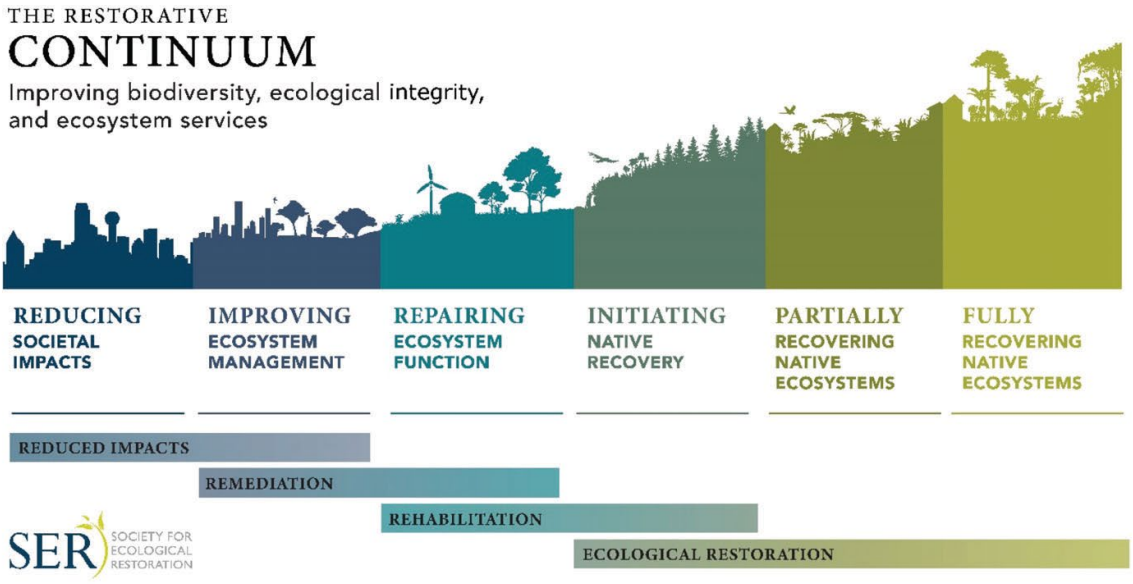

FIGURE 1-1 The restorative continuum. SOURCE: Gann et al. (2019). Reprinted with permission; copyright 2019, *Restoration Ecology*.

In other restorative activities, including revegetation with specific aims such as forage production or soil stabilization, there is generally greater acceptance of using widely adapted native seed from other seed zones or of genetically manipulated varieties of native species that have been bred for qualities such as fast growth, high biomass production, or wide climatic tolerance. Active and extensive debate continues about what mixtures of species and genotypes of native seeds are suitable for particular purposes and specific locations.

Drivers of Native Plant Restoration: Reactive versus Proactive Projects; Challenges of Scale, Geography, and Timing

Native plant restoration is conducted as a response either to the extreme degradation of native plant communities by any of a wide variety of human activities, such as unsustainable use and overdevelopment, or to large-scale losses of vegetative cover caused by such events as fires, hurricanes, encroachment by invasive weeds, and climate change. The primary impetus of native plant restoration is to help promote the reestablishment of landscapes in order to assist natural recovery. Although events such as wildfires and flooding have occurred throughout history and are not entirely human-caused, there is often a perception that some of today's very large and severe events—often combined with the loss of resilience due to previous degradation—may leave ecosystem recovery impaired in the absence of intervention (Oldfield et al., 2019).

Among the projects using the largest amounts of native seed are reactive projects following wildfires in Western U.S. forests and rangelands or those following storms and flooding in the coastal Eastern and Southern United States. One of the immediate goals of restoration following a disturbance such as fire is to prevent the spread and dominance of invasive plant species. Proactive restoration efforts, by contrast, are often smaller in size than reactive projects, and they usually have a lead-time for completion and are diverse in geographic location and scale. Examples of proactive projects include the creation of fuel breaks, the development of wildlife and pollinator habitat, the establishment of urban green infrastructure,

and federal and state cost share programs that require native plant establishment by private landowners. Other drivers of proactive seed use are various restoration projects that are required by regulation or policy following such intentional disturbances as utility corridors, mining, wind and solar power, or invasive plant removal.

Emergency reactive projects may encounter major difficulties in procuring large quantities of provenance-specific seed in the time frame needed (Shaw and Jensen, 2014). BLM procurement data show that even non-native species are frequently employed in those situations, perhaps because of the difficulty in acquiring the provenance-specific seed, although there appear to be many different factors that affect these purchasing decisions. The lead times for plant materials development and seed increase (field production to harvest more seed) can be anywhere from a few months to 5 or more years, making the acquisition of sufficient provenance-specific seed challenging even in proactive projects with longer lead times. The implication of the time frame of demand versus supply is a question raised for further exploration later in the report.

Supply Challenges

As indicated above, the outcomes of restoration or revegetation efforts vary greatly depending on whether the project is proactive or reactive, the size and urgency of the project, the availability of funding, and the project goals (e.g., where the project falls on the continuum of restorative activities). In the Western United States, native seed shortages appear largely driven by the need for large quantities of seeds following massive wildfires on public land combined with the limited diversity of seed available in large-scale production relative to what is desired, for reasons that will need additional exploration. Shortages also occur in other geographic regions for a variety of reasons, often due to the lack of a predictable market. As a result, growers often do not know or cannot anticipate future needs and thus focus on species that have sold well in the past. While the typical goal for ecological restoration is to use seeds from the same provenance or seed zone as the restoration site, the response to large unplanned disturbances such as fires often relies on the use of native seeds from adjacent seed zones, manipulated-track cultivars, or even non-native species (Camhi, et al., 2019; Peppin et al., 2010). With large disasters, restoration goals such as erosion control, exotic weed mitigation, the establishment of fire breaks, watershed protection, preparing for wildlife and livestock use, and endangered plant and wildlife recovery may all be compromised by the use of seed that is ill matched to the disturbance regime. With some exceptions (Ott et al., 2019), there have been no large-scale tests of these performance assumptions conducted within the post-fire seeding framework. However, as discussed in Chapter 3, research to date has found evidence for local adaptation in many geographically widespread species (Baughman et al., 2019).

An integral and related topic is the seed procurement methods of users of native plant seed. For small proactive projects, piecemeal buying from vendors is common, as is contracting for the collection of locally sourced seed for direct use or increase. For large reactive emergency needs, BLM and other land management agencies often purchase seed via consolidated purchases, and their options are often limited to buying seed that meet specific seed quality factors “off the shelf” at prices determined by the lowest bid within the certification category requested for the species (if available). In years of high demand this approach often falls short of meeting the greatly increased seed needs. Contracting with seed growers for production of a certain amount of seed has been proposed as an alternative way for seed users to obtain specific

native germplasms at specified quantities and prices, and some limited contracting efforts have recently been implemented by BLM and USFS.

DESCRIPTION OF REMAINING CHAPTERS IN THIS REPORT

Chapter 2 takes an in-depth look at the many different kinds of organizations that compose the native seed supply chain, including users and buyers, the entities that participate in supplying native seed, intermediaries that are part of the seed market infrastructure, and ancillary functions, technical assistance, policy, funding for restoration, and research. Chapter 2 provides support for the committee's final assessment by providing a comprehensive description of the components and participants in the U.S. supply chain for native seeds.

Chapter 3 describes the committee's initial observations, based on its investigations to date, of some of the realities and challenges that define and may constrain the native seed enterprise. These initial observations will serve as the foundation of the committee's analysis and final report on how to move the native seed industry forward.

Chapter 4 details the planned processes for gathering additional quantitative and qualitative data needed by the committee for its final assessment, conclusions, and recommendations.

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2

Supply Chain: Its Components and Flow

This chapter describes the organizations that participate in the native seed supply chain, beginning at the end of the chain with the purchasers (users) of native seed. It then discusses the pathways through which seed reaches users and describes what the committee has learned about the diversity of providers of native seed. The chapter next describes the intermediaries that provide various services to the supply chain such as contracting, seed testing and certification, and seed storage. Finally, the chapter discusses the agencies and organizations that provide ancillary support to the seed supply through research, policy, technical assistance, guidelines development, and funding that aids or informs the users and suppliers of native seed.

Assembling this at-large picture of the native seed supply chain is key to the next phase of the assessment, in which the committee will explore how actors in the supply chain make decisions, the functional quantitative and qualitative dimensions of seed use and supply, and opportunities for its expansion. Some of the subjects of interest to the committee are mentioned in this chapter and are expanded on in Chapter 3. This chapter is weighted toward describing the seed supply chain in the Western United States, because that is the larger focus of the assessment and reflects the committee's fact finding thus far. However, the committee anticipates that the data-gathering strategy planned for phase 2 will capture enough information about actors in the seed supply in other parts of the country to document, at a minimum, key similarities and differences in regional needs and capacity.

USERS OF NATIVE SEED

Native plant seed users are highly diverse; they vary according to their restoration objectives and funding sources and include both public and private entities. Some of the largest users of native plant materials are those with responsibility for managing public lands and their ecosystems, such as the Bureau of Land Management (BLM), U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), National Park Service (NPS), and U.S. military (Table 2-1).

States, counties, and municipalities also use native seeds on their lands following disturbances such as fires as well as for roadside plantings, urban ecosystems, parklands, green infrastructure management, wildlife areas, and pollinator habitat enhancement. Many large U.S. institutions and universities have sustainability initiatives that include the use of native plants for their campus landscapes. Groups such as The Nature Conservancy (TNC) and its cooperators use native seeds, as do other nongovernmental organizations (NGOs) that manage land for conservation purposes (e.g., local and regional conservancies, land trusts, homeowner associations). Private buyers and users of native seeds include ranchers and farmers, rural and urban home landscapers, and companies involved in mining and resource extraction. There are also many private restoration contractors who are frequently involved in the purchase of native seeds and who conduct work for both the public and private sectors. Finally, there are public–private partnerships of public agencies, NGOs, and private users who collaborate to plan and implement seeding projects.

This section addresses the diversity of users, providing short descriptions of the largest users and a listing of others. The largest user of all is the federal government, which manages approximately 640 million acres of land. Most of this land is managed by one of five major agencies (public land, Table 2-1).

In 2001, Congress directed the U.S. Department of the Interior (USDI) and the U.S. Department of Agriculture (USDA) to develop a long-term program to manage and supply native plant materials for land restoration and rehabilitation (USHR, 2001). Collaboration with several other public agencies resulted in the National Seed Strategy, discussed later in this chapter (PCA, 2015).

The BLM manages approximately a tenth of the land surface area of the United States, primarily in 13 western states: Alaska, Arizona, California Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. This public land is managed for multiple uses,[1] and BLM is charged with sustaining and using natural resources. Driven in part by the irregular occurrence of large wildfires, annual BLM seed purchases have been highly variable, ranging from a high of approximately 7.5 million pounds in 2007 to a low of approximately 300,000 pounds in 2009. BLM makes most of its seed purchases, which are based on requests from BLM field officers, through a centralized operation referred to as the "consolidated seed buy," which may be issued multiple times during a year (Olwell, 2019). At a much smaller scale, the BLM also proactively contracts with growers to produce specified native seed to supply its warehouses.

The USFS directly manages nearly 193 million acres of federal land (Table 2-1) and supports sustainable management on approximately 500 million acres of private, state, and tribal forests. As with the BLM, the USFS manages national forest lands for multiple uses.[2] Throughout the country, the USFS relies heavily on partnerships with other federal and state agencies and nonprofit groups as well as with private seed producers and nurseries. In the Western United States those managing national forests have access to four Forest Service nurseries and three seed extractories. The majority of restoration planning and purchasing of native seed and plant materials is directed from local district offices, with some special projects that involve larger geographic areas and multiple national forests conducted at the regional level (Carromero and Spurrier, 2019; Erickson, 2019).

TABLE 2-1 Land Managed by Five Major Federal Agencies (acres, 2018)

Bureau of Land Management	244,391,312
U. S. Forest Service	192,919,130
Fish and Wildlife Service	89,205,999
National Park Service	79,945,679
Department of Defense	8,845,476
Total for Five Agencies	615,311,596

SOURCE: Vincent et al. (2020).

[1] BLM follows a multiple-use management approach that encompasses "commercial, recreational, and conservation activities." https://www.blm.gov/about/how-we-manage (accessed September 29, 2020).

[2] Multiple-Use and Sustained Yield Act of 1960, Public Law 86-517, 86th Congress (June 12, 1960), § 4(a).

The USFS has an established policy[3] of being guided by seed zones in its collection and use of native germplasm (Box 1-2), but research-based or empirical seed zones are not available for most restoration species. As an alternative, Bower et al. (2014) developed comprehensive provisional seed zones based only on climate variables, and these provide one tool that is used when empirical seed zones are not available. The climatic zones are overlain by the Omernik level III ecoregion map, which includes details on local vegetation, soils, climate, and geology and can be used to, help distinguish among areas that are similar climatically yet different ecologically. Recently there has been an effort to update and modify Bower's provisional seed zones for the Eastern United States (Pike, et al., 2020). Other resources developed by USFS include the Climate-Smart Restoration Tool and the Seedlot Selection Tool (discussed later in this chapter) which provide information on seed collection and the transfer of native plants under future environmental scenarios.

The USFWS administers the National Wildlife Refuge System, a network of waters and lands where the focus is on resource management and conservation, including the restoration of fish, wildlife, and plant resources and their habitats. The USFWS also administers the Endangered Species Act of 1973[4] for terrestrial and freshwater organisms. Native seeds are used for promoting biodiversity through such actions as post-wildfire restoration, enhancing monarch butterfly habitat, and establishing native vegetation after the removal of invasive species.

The NPS manages land organized into 419 individual units, which are quite diverse and variable in size, type of land, and focus. They include national parks, national monuments, battlefield sites, recreation areas, seashores, and wild and scenic river systems. The NPS mission is to "conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same . . . as will leave them unimpaired for the enjoyment of future generations" (NPS, n.d.). NPS restoration policy is to use only plant materials that are closely related genetically and ecologically to existing park populations and that have been collected from within that park or nearby. The need for restoration arises from wildfires, invasive plant infestations, road construction or maintenance, and campground and trail maintenance (Eckert, 2019).

The Department of Defense (DOD) manages land on military reservations in support of DOD mission-related activities. Internal regulations state that the DOD "shall manage its natural resources to facilitate testing and training, mission readiness, and range sustainability in a long-term, comprehensive, coordinated, and cost-effective manner" (DOD, 2011). An important component of the DOD whose tasks are related to land restoration is the Army Corp of Engineers (USACE), which maintains, owns, or operates more than 600 dams, 12,000 miles of commercial inland navigation channels, and 926 coastal or inland harbors. It also manages many military construction projects and cleans up contaminated sites from past military activities. The USACE also partners with other agencies on large-scale ecosystem restoration projects in such areas as the Everglades and the Louisiana coastal area.

[3] See https://www.fs.fed.us/wildflowers/Native_Plant_Materials/documents/FSM_2070.pdf; https://www.fs.fed.us/wildflowers/Native_Plant_Materials/documents/NativePlantMaterialsPolicy_Sept2012.pdf.

[4] Endangered Species Act of 1973 (P.L. 93-205) as amended through the 108th Congress. See https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf (accessed September 29, 2020).

There are 566 federally recognized tribal nations, which hold 56 million acres of land in trust. Tribal communities often have the same interests and uses of native seed as do other land managers. Many tribes coordinate seed purchases with the Department of the Interior's Bureau of Indian Affairs, especially for rehabilitation after fires. Individual tribes that need seed for agriculture and range management programs are able to fund them using "638 contracts."[5] Other seed usages on tribal lands are related to the activities of power companies, pipelines, and phone companies, to maintain right-of-way projects. On a smaller scale, tribal ranchers will re-seed rangeland for erosion control projects with assistance from the USDA's Natural Resources Conservation Service (NRCS). A 2018 survey of the Navajo nation, which is the largest tribal reservation at 17.28 million acres, found that the primary objectives of native seed use are ecological restoration, education, range rehabilitation, wildlife habitat enhancement, and pollinator conservation (Mike et al., 2018).

Other federal and state agencies have critically important roles in maintaining and restoring land with native seeds. The Federal Highway Administration and state departments of transportation share responsibility for building and maintaining the roadsides in the United States. "Over 164,000 miles of highways in the National Highway System form the backbone of our 4-million-mile public road network" (FHA, 2011).

State government departments that use native plant materials include natural resources, wildlife agencies, and park authorities. Many states maintain native state tree nurseries. The methods vary among states, but most approach native tree production as a largely agronomic activity based more on experience than on researched standards for genetic diversity or geographic provenance. Counties and municipal governments, especially those of large municipalities, also have departments that maintain and restore their lands and may use native seed for these purposes.

Public–private partnerships are not uncommon. One notable effort is Utah's Watershed Restoration Initiative, sponsored by Utah Partners for Conservation and Development.[6] Since 2006 over 100,000 acres per year—spread over 150–200 projects annually—were planned, and the sites were prepared and seeded as appropriate, for a total cost per acre of about $100 (more in the case of the reestablishment of critical wildlife habitat). Over a million pounds of seed each year are procured through a bid process and then stored and planted; well over 1 million acres of proactive projects to improve watershed health and wildlife habitat have been completed thus far. Regional teams representing public and private interests annually rank and approve proposed projects, making possible timely site preparation and seed procurement. These geographically oriented projects effectively erase the boundaries of private, state, and federal lands through mutually beneficial planning and co-funding.

There is a wide array of private entities using substantial quantities of native seed. Farmers may employ native seed in areas adjacent to fields and in land that is set aside in the Conservation Reserve Program (CRP), although natives are not always required by the program. More than 23 million acres of farm and ranch land was enrolled in CRP in 2018 (Vincent et al., 2020). Livestock ranchers use native seed in efforts to improve livestock forage or for wildlife enhancement. Rural and urban landowners and homeowners use native seed for beautification,

[5] A "638 contract" or, more formally, a self-determination contract, is shorthand for a program under the Indian Self-Determination and Education Assistance Act (ISDEAA) of 1975 (Public Law 93-638), in which the operations of any federal program, function, service, or activity (and the funds needed to carry out those operations) must be transferred to tribes upon formal request for the benefit of the tribe.

[6] See http://wildlife.utah.gov/watersheds.

wildlife habitats, and green infrastructure. Recreation companies, such as the owners and managers of golf courses and ski areas, offer another example of private native plant and seed users.

In addition, utility companies and private contractors construct and maintain corridors, oil and gas pads, pipelines, and wind and solar-power footprints that are required to restore the areas they disturb on public land. U.S. nonprofit organizations, including conservation and wildlife groups, own and manage conservation land through trusts and conservation easements. These can be of significant size, when considered collectively. TNC, for example, holds easements on 3.1 million acres of lands in 49 states.

SOURCES OF SEED

The foundation of the native plant material supply chain is the seed that exists in local, wild populations. These wild seed resources must be conserved and properly managed if they are to remain the essential resource fueling the supply chain. From the wild origins of these seeds, there are multiple pathways by which that seed enters the seed supply and becomes a product that is available for use.

Commercial Wildland Collection

One source of native seed is collections made directly from native wildland populations. Seeds are collected, cleaned, and marketed for immediate use in restoration projects. A significant component of the national native seed supply is sourced in this way. Trees and shrubs in particular are often collected in commercial quantities from naturally occurring populations. For example, several hundred thousand pounds of sagebrush seed is collected annually from the Great Basin and directly marketed to consumers (Stevenson, 2016). Still, for most species of grasses and forbs, the purpose of wildland collections is to provide stock seed for cultivated production fields. Large- and small-scale wildland seed collection is conducted by both private and public entities.

Seed Collection for Seed Banking and Ecological Restoration

The Seeds of Success (SOS) program is the largest coordinated effort in the country to collect diverse native species and populations in order to strengthen the availability of germplasm for seed banking, research, plant materials development, and ecological restoration. Established in 2001, SOS is the national native seed collection and banking program led by BLM. At least 50 partners, including federal and state organizations and NGOs (mainly botanic gardens), also collect seed directly for the SOS program or oversee contractors that collect seed for BLM under SOS protocols.[7] To-date, over 25,000 collections have been conducted in over 43 states, focusing on collecting the more common "workhorse" species that, when used for restoration, form a plant community matrix into which additional plant species can be added.[8] Some of the seed collected by SOS has been increased and used in restoration projects in the Western states where BLM operates.

[7] See https://www.blm.gov/sites/blm.gov/files/uploads/SOS_Protocol_10.18.18.pdf.

[8] See https://www.blm.gov/programs/natural-resources/native-plant-communities/native-plant-and-seed-material-development/collection.

Seed collected by botanic garden partners in their own regions typically is cleaned at those gardens. Seed collections funded by BLM or its contractors are cleaned at the USFS Bend Seed Extractory in Oregon. After cleaning, some of SOS seed then goes to USDA's Western Regional Plant Introduction Station in Pullman, Washington, where it is divided into three pools—two for long-term conservation storage at separate locations and a third for the working collection from which small amounts are distributed. The remaining seed goes to various places, depending on who collected it and for what purpose it was collected. For example, botanic gardens typically bank their remaining seed. Remaining BLM seed is kept for shorter terms at USDA facilities in Pullman, Washington, and Bend, Oregon. This banked seed is available for BLM offices to request back or to use in providing material to growers to produce seed for BLM restoration projects (Greene et al., 2019).

Seed Collection and Plant Materials Development

Historically the NRCS plant materials centers (PMCs), USDA Agricultural Research Service (ARS), and USFS research units as well as universities, extension agents, and private agriculturalists have collected native seed from wild populations for evaluation and selection of the best performing accessions, leading to germplasm and cultivar releases of what are sometimes described as "improved plant materials." These releases typically provide seed to the marketplace with known levels of performance in traits such as forage yield and quality of benefit to both wildlife and livestock, seed production, stand establishment, drought resistance, persistence, and potential for wide geographic application. The evaluation of these plant materials over multiple generations ensures that the targeted traits are heritable over subsequent generations. This allows individual materials to be named and be described in release notices, with the goal of generating widespread recognition, demand, and production.

The committee learned that the 25 PMCs are plant evaluation and production farms (ranging in size from 40 to 300 acres) that evaluate plants in order to address natural resource challenges and support NRCS programs, public and private partners, and commercial growers. Each PMC has the facilities and equipment required for plant evaluation and seed production and is staffed with about 2.5 full-time-equivalents plus part-time and temporary employees. The PMC plant materials currently being released are typically natural populations chosen for characteristics important for use in conservation and wildland plantings (e.g., erosion control, range rehabilitation). Older plant materials were released as cultivars, including native cultivars that were propagated directly from wild populations as well as exotic, non-native selections developed for emergency rangeland stabilization and livestock forage.

The PMCs produce and store seed of cultivars and germplasm releases in sufficient quantity to supply commercial seed growers. About 570 releases are active (meaning that growers are able to access the seed for production), with more than 450, primarily grasses, being native. Commercial growers form the basis of the restoration and revegetation native seed industry and produce NRCS conservation germplasm releases and cultivars with an estimated value of $100 million annually, enough to plant over 2.5 million acres. These cultivars and germplasm releases constitute a large portion of commercially produced native seed.

A considerable number of additional native plant germplasms have been released or at least identified for restoration projects through programs sponsored individually or cooperatively by state, federal, NGO, or private entities throughout the United States.

The genetic material in these releases is typically sourced from a few specific geographic populations and represents only a small fraction of the genetic diversity of the species in question. These releases are often planted in environments that, while within the range of the species, may differ in various ways, such as in climate and elevation, from the original collection locations. Many ecological restorationists question the widespread use of native germplasm releases outside of their seed zones of origin because of concern that these plants might interact adversely with other flora and fauna in the new location. Such restorationists place a high value on the use of provenance-specific native genotypes from the same seed zone, for reasons that include their likelihood to be locally adapted, to establish and survive, to facilitate ecological recovery of the site, to retain historic genotypes and maintain diversity, and to increase future resilience.

Although NRCS, ARS, and other germplasm developers do make recommendations for areas of uses for each release based on test plots and similar floral regions, they do not generally use formal empirical or provisional seed zones in their plant material development. There are many participants in the seed supply chain, including collectors, growers, other developers, and users, who prefer the traditional method (collection, evaluation and selection of accessions based on desirable trait expression, and release) and who are concerned that a proliferation of seed zones would make it impractical to develop and maintain numerous seed lines for every species in the market.

SEED AND PLANT PRODUCTION

The bulk of the production of seed and plant material for restoration is done by commercial companies (Shaw and Jensen, 2014). These seed producers include commercial seed collectors as well as growers who plant wild-collected seed in an agricultural setting to produce slightly larger quantities of seed for direct use or for germplasm development (to evaluate seed traits, potentially for breeding purposes) prior to large-scale production. Many native seed producers, both those who collect large quantities of seed on wildland sites for direct marketing and those who grow seed in cultivated fields, have their own cleaning and bagging equipment and may market their seed directly to native seed markets. Other producers deliver un-cleaned or bulk seed on an ad hoc or contract basis to seed warehouses and vendors for cleaning, containerizing, labeling, storing, and shipping. Some vendors consolidate many different lots of seed for larger, more general seed markets.

There is limited detailed, published information on practices for producing and cleaning the seed of many native species in seed fields; many growers independently determine appropriate practices for the species they bring into cultivation, which requires time and adds to initial production costs. Many producers have limited production and cleaning equipment and cannot grow and process all species.[9]

A major component of native seed production is field cultivation. Large-scale production is most common and widespread in the western United States, where the seed is used to address the huge areas of degraded public and private land, including use in emergency wildfire rehabilitation. Significant production also occurs in the midwestern, eastern, and southern United States to meet local geographic restoration needs on degraded lands, for roadside revegetation, for riparian and wetland mitigation, for urban green infrastructure such as green roofs and bioswales, for prairie strips in agricultural areas, and for home landscaping.

[9] Jerry Benson, personal communication.

In the Western United States there is a wide range of specialization in the native seed industry with respect to particular species, production capacity, and business relationships and models. Companies that produce native plant seed are of varied sizes, some with only a few acres of wild-sourced collections, germplasm releases, and cultivars, and others with irrigated fields that are 100 acres or more in size. Some companies grow a combination of wild-sourced seed in plots of less than 0.1 acre, while others may grow native plant materials in larger fields of 10 acres or more that may contain many different native plant species. Some seed companies go beyond seed cultivation in their own fields and undertake land preparation and planting for restoration projects under contract with public land management and private landowners. There are a few large seed companies east of the Mississippi River that carry seed of native species, but their available seed lots include limited data on origin and may be marketed for use over broad areas. Nationally there are many small to midsize nurseries that focus on wild-sourced plant material from localized areas or seed zones and that sell to particular geographic regions.

Some public entities such as Midewin National Tallgrass Prairie[10] in Will County, Illinois, produce their own seed. The Forest Preserve District of Lake County[11] in Illinois operates its own native seed nursery. The Nature Conservancy's Kankakee Sands[12] in Indiana produce its own seed for use on its properties. Others such as Nachusa Grasslands[13] in Illinois, also with the Nature Conservancy, focus on collecting from prairie remnants to provide the seed needed for their restorations.

The Greenbelt Native Plant Center in New York City (NYC) has developed its own supply of seed stocks for 75 native species to use directly in seeding operations or as the basis for further commercial increase under contract to NYC. The center supports a staff of two seed collectors to make wildland seed collections in support of its own production. It maintains an average of 2,000 collections in its seed bank and over the past 25 years has produced 12 million wild-sourced plants that have been planted in NYC ecosystems.

INTERMEDIARIES

This section discusses processes and organizations that perform various essential functions within the supply chain, such as permitting, seed analysis, certification, contracting, and seed storage.

Permitting

Collecting seed on public and private lands requires permits or permission (BLM, 2013). Permitting procedures and requirements vary, sometimes even among permitting offices of the same land management agency, and permitting offices vary in terms of the availability of staff, staff training, and the resources that are available to monitor collectors. Collecting protocols differ depending on whether the seed is collected for direct use or gathered as stock seed for increase or for seed banking. Informal discussions that committee members had with various stakeholders revealed concerns about over-collection at certain locations, the population sizes of the target species, variation in annual seed production and collection during previous years, and

[10] See https://www.fs.usda.gov/midewin.
[11] See https://www.lcfpd.org/nursery.
[12] See https://www.nature.org/en-us/get-involved/how-to-help/places-we-protect/kankakee-sands.
[13] See https://www.nature.org/en-us/get-involved/how-to-help/places-we-protect/nachusa-grasslands.

the seed quality of collections. Commercial collectors report that difficulty in obtaining permits in places where legitimately collectable populations of many species are present means that much potential seed is not made available for restoration efforts. More information is needed to understand how the permitting process may be streamlined, and funds need to be provided to expand capacity while protecting wildland plant population resources.

Seed Analysis

The U. S. Federal Seed Act[14] and state seed laws mandate that seed cannot legally be sold to those who plant the seed—the end user—without a seed analysis label. The seed label is based on a seed analysis report, which is the written documentation of the tests performed on a sample in a seed testing laboratory and by a trained seed analyst. There are both government and commercial seed testing laboratories that follow seed testing rules published by the Association of Official Seed Analysts (AOSA).[15]

AOSA's seed testing rules[16] are followed in order to select representative working samples from the submitted seed sample, calculate the percentage by weight of the pure seed units of the main species, and determine the percentage of seeds that are viable. The percentages of seed of other species, of weed seeds (both identified by species and number/pound), and of inert matter are also calculated.

Recent conversations by committee members with seed analysts indicate that the AOSA testing rules for many native species are still in development or have not begun to be developed. Pure seed units may be difficult to define, and viability determinations may be complicated by seed dormancy. These difficulties lead to added costs and long wait times for analysis reports. For many species an inconsistency of results among seed labs often frustrates the determination of seed value for buyers and sellers alike. The committee plans to explore barriers related to testing capacity in the next phase of its work.

Notably, a seed testing laboratory does not verify the identity of a cultivar or germplasm unless costly chemical or DNA tests are specifically requested. When a seed analysis report lists a variety name or germplasm ID, it is noted only as "sender's information," and the report does not differentiate between subspecies, nor confirm the geographic area where the seed was collected or whether the seed has a specific germplasm identity, if it was field produced. This function is addressed by official seed certification, described in the following section.

Certification

Certification assures that the seed in the container, as listed on a certification tag, is from the source claimed for the collection, variety, or germplasm (Young et al., 2003). This applies both to field-produced seed and wild-collected seed for direct use. Labels may provide the state, county, and elevation or other geographic descriptions of the collection site, which may or may not aid in identifying the seed zone of the germplasm. The process for certifying seed is set by seed-certifying agencies that are members of Association of Official Seed Certifying Agencies (AOSCA). This is a third-party service provided in most U.S. states, Canada, and several other

[14] See https://www.ams.usda.gov/rules-regulations/fsa.
[15] A list of seed laboratories can be found at www.aosaseed.com and www.seedtechnology.net.
[16] See https://www.analyzeseeds.com/product-category/publications/aosa.

countries, including Australia and Argentina.[17] Seed certification is done by examining the records of the seed source (wildland site or field site), by inspecting generation and conditioning facilities, and by studying the results of formal seed sample analysis.

In contrast to seed analysis, the results of which are required to be provided on a seed analysis label, federal and state seed laws do not require that seed sold to users be certified. But for buyers concerned with ensuring the use of properly sourced seed in restoration projects, the verified germplasm identification provided by certification offers useful and trustworthy information.[18]

Government Procurement and Contracting

Procurement (purchasing) procedures and contracts connect users with suppliers and are an integral part of the supply chain. Procurement procedures define how native seed buyers must choose among the seed lots offered. Once desired seed is selected, contracts specify what, when, where, and how native seed is to be delivered. The effects of both procurement procedures and contracting are both direct (what the terms say) and indirect (how the terms affect producers' willingness to participate and whether buyers get what they want).

Because government agencies are the biggest buyers of native seed, their procurement rules play an outsize role in the seed market. Government agencies at all levels must follow procurement regulations, and many have procurement officers to ensure that the contract terms for native seed acquisition comply with those regulations.

Although procurement can be as simple as buying a product off the shelf at a store, government procedures (notably the U.S. Federal Acquisition Regulation)[19] typically require competitive bidding to meet specified contract terms. Seed providers must be registered as official vendors (e.g., with the federal System for Award Management)[20].

Contracts can stipulate requirements for native seed in a variety of ways. One important distinction is between contracts to buy delivered seed (e.g., BLM consolidated seed buys) and contracts to support a production process (e.g., indefinite delivery/quantity contracts). In the former, the seed producer bears all production risk and some marketing risk, whereas in the later both types of risk are shared. The contract terms for a native seed purchase typically dictate the species, quantities, and delivery timing, and they often include specifications for the degree of genetic diversity required, seed origin location, seed certification, and seed wild collection procedures.

Seed Warehouses

The storage of seed prior to its use is a critical piece of the seed supply. Large amounts of seed for restoration are often stored in warehouses under ambient conditions. Because seed longevity is enhanced by low temperatures and low humidity, locations in the arid western United States provide more effective ambient seed storage, from both a cost and a biological perspective, than more humid regions in the coastal Pacific Northwest, the Midwest, and the

[17] See www.aosca.org for a listing of agencies that provide certification services.

[18] See http://greatbasinfirescience.org/wp-content/uploads/2019/07/UtahCropImprovement_SeedConnoisseur.pdf.

[19] See https://www.acquisition.gov/browse/index/far.

[20] See https://sam.gov/sam.

East. Agencies and companies typically try to use warehoused seed within 1–2 years after production because the seed viability of many species decreases fairly quickly under ambient storage conditions, and space is needed for newly arriving seed lots. Agency seed warehouses in the United States include three managed by BLM located in Boise, Idaho; Ely, Nevada; and Twin Falls, Idaho, with a total combined capacity of 2.1 million pounds. The USFS does not appear to have such a large capacity for its seed storage under ambient, refrigerated, or frozen conditions. Storage is often located at nursery facilities with limited total space. The Bend, Oregon, seed extractory has significant storage but not at an industrial scale.

Some seed companies have limited access to cool or cold storage for short-term year-to-year storage of native seed, but long-term, multiple year storage requires conditions and special facilities that are not available to all companies. The BLM does have refrigerated storage at its Ely, Nevada, and Boise, Idaho, warehouses, with a capacity for 135,000 pounds of seed. There is also a large seed warehouse maintained by the Utah Division of Wildlife Resources in Ephraim, Utah, with ambient and refrigerated storage totaling about a million pounds of capacity. There appear to be no comparable native seed warehouses east of the Mississippi River.

Seed Banks

Seed banks, which often hold wild-collected seed, typically maintain much smaller amounts of seed than do seed warehouses, and many can maintain the seed for exceptionally long periods of time under subzero conditions, either in mechanical freezers or under cryogenic (liquid nitrogen) conditions. The banks with long-term storage are known as conservation seed banks or conservation collections. Other seed banks have active or working collections that are held for shorter periods at higher temperatures, just above freezing, to facilitate their distribution, particularly for research and development. At present relatively little is known about the "best practices" for the long-term seed storage of native plant species (Walters, 2015).

Seed banking at the federal level is largely carried out by USDA's National Plant Germplasm System (NPGS) within ARS and by non-USDA affiliated centers.[21] These centers are focused on safeguarding the genetic diversity of agriculturally important plants, including some native species, particularly crop wild relatives. The 19 USDA NPGS locations, including those is Pullman, Washington (Western Regional Plant Introduction Station), Fort Collins, Colorado (National Center for Genetic Resources Preservation; NCGRP), and Beltsville, Maryland (the National Germplasm Resources Laboratory), manage accessions of native plant seeds.

Seed banking of wild plants for restoration is relatively new and growing in importance. The USDA NCGRP in Fort Collins, Colorado, began banking seed of threatened plant species in the 1980s. Seeds of Success began banking seeds of common native plant restoration species in the early 2000s. Both programs use the NCGRP for long-term conservation storage for the relatively small quantity maintained for each seed collection (e.g., around 10,000 seeds per population) (Walters, 2015). Other agencies and entities—such as the University of Arizona's Desert Legume Program, the Boyce Thompson Arboretum in Arizona, and many NGOs—maintain dozens of smaller active seed banks or working collections, but the total storage capacity of these entities is unknown to the committee.

[21] See https://www.ars-grin.gov/Pages/Collections.

Botanic gardens and similar institutions provide additional storage capacity. For example, the Mid-Atlantic Regional Seed Bank (MARSB)[22] has taken steps to develop a regional working bank. In 2014 it solicited input from botanists throughout the mid-Atlantic region to develop a "regional prioritized collection list" (262 species out of a shared flora of 1,370 species and a comprehensive flora of 6,630 species). MARSB also offers seed storage to other groups in the region and holds seed collection workshops, mostly in New York State, both to teach other institutions how to make proper seed collections and to build a cadre of volunteers to help MARSB collection efforts.

Similarly, the Chicago Botanic Garden maintains a regional seed bank for the upper Midwest. From a regional flora of over 3,000 taxa, it prioritizes collections of 530 plant species that are most frequently used in restoration. The garden's Dixon National Tallgrass Prairie Seedbank uses volunteers to assist with cleaning and processing seed and relies on a network of contract collectors to collect seed throughout the Midwest. Storage at botanic garden seed banks is often a mix of long-term conservation collections and active collections used for restoration and research.

ANCILLARY INFLUENCES: FUNDING, POLICY, PROGRAMS, RESEARCH, AND ADVOCACY

Government agencies, policies, programs, university researchers, and seed associations affect native plant selection and use through various mechanisms, including (1) policies and funding that support the use of native plants, (2) guidance for which species to use, (3) basic and applied restoration research, and (4) tools to facilitate decision making. Several examples are provided below.

Burned Area Emergency Response Program

The Burned Area Emergency Response (BAER) Program[23] serves most of the federal land management agencies (Bureau of Indian Affairs, BLM, USFWS, NPS, USFS) and assists with the emergency stabilization measures required following fires when help is requested by local jurisdictional units. BAER teams are interagency and interdisciplinary (e.g., hydrologists, soil scientists, botanists, archaeologists) and work with local suppression teams, local unit personnel, and other affected public and private authorities to identify risks and develop emergency response plans. These plans prescribe the emergency treatments on federal and tribal trust lands that are required to mitigate risks to life and safety, infrastructure, and other natural and cultural resource values. BAER teams provide recommendations on where reseeding is needed and recommend seeding mix compositions; these recommendations can be changed at the local level. Funding is provided for the first post-fire year, with amounts depending on budgets and annual wildfire activity.

Although federal directives encourage that native plant materials be employed in any seeding, their use varies depending on the policies and guidance of different agencies. For fire-damaged lands that are not expected to recover naturally, USDI agencies can submit requests for

[22] See http://www.marsb.org.

[23] See https://www.nifc.gov/BAER/definitions.html.

competitive 3-year Burned Area Rehabilitation funds[24] that support treatments within 5 years of fire containment. The availability of these funds has declined in recent years, however. The costs of comparable projects on Forest Service lands must be covered by regularly appropriated funds.[25] For all agencies additional restoration treatments, such as wildlife habitat improvement, are covered by appropriated funds or pulled from other sources such as the BLM Greater Sage-Grouse Integrated Program of Work.[26]

National Seed Strategy for Rehabilitation and Restoration Progress Report

The 2015–2020 National Seed Strategy for Rehabilitation and Restoration (henceforth, "the Strategy"),[27] which was prepared by representatives of the 12 agencies of the federal committee of the Plant Conservation Alliance (PCA), provides a framework for improving collaboration among agencies and their many public and private collaborators in order to increase the availability of native plant materials and the technology required for their use in repairing damaged plant communities. The Strategy's 2018 progress report detailed accomplishments within each of its four goals (PCA, 2018). Some examples of major accomplishments include:

Goal 1: Identify seed needs and ensure the reliable availability of genetically appropriate seed. Accomplishments: commissioning the National Academy of Sciences Assessment of Seed Needs and Capacities; expansion of the Sagebrush in Prisons Program;[28] creation of databases for seed vendors, conservation experts, restoration species, and native plant policies; seed propagation; the development of plant propagation protocols; increases in seed banking.

Goal 2: Identify research needs and conduct research to provide genetically appropriate seed and improve technology for native seed production and ecosystem restoration. Accomplishments: the creation of additional empirical seed zones; development of guidelines for restoration that takes climate change into account; evaluation of long-term trends in land treatment practices.

Goal 3: Develop tools that enable managers to make timely, informed seeding decisions for ecological restoration. Accomplishments: Development of the Climate Smart Restoration Tool, the Seeding Probability Tool, and the Plant Demonstration Area database.

Goal 4: Develop strategies for internal and external communication. Accomplishments: Development of a toolkit for communicating the National Seed Strategy; the provision of numerous presentations and articles on the Strategy.

State- and Local-Level Seed Strategies

Developing collaborations among public and private partners to proactively conserve, collect, increase, and store native seed to meet long-term restoration needs is not only a national

[24] See https://www.doi.gov/sites/doi.gov/files/elips/documents/owf_policy_memo_2016-01_post_wildfire_recovery_program_policy_changes.pdf.

[25] Vicky Erickson and Cathy Farr, USFS R-6, personal communication.

[26] Anne Halford, BLM, personal communication.

[27] See https://www.blm.gov/programs/natural-resources/native-plant-communities/national-seed-strategy.

[28] See https://appliedeco.org/sagebrush-in-prisons-project-restoring-habitat-and-hope.

goal but is also a goal of many states and localities. For example, Iowa has a native seed program that pre-dates the National Seed Strategy. It began with a 1988 program to assist Iowa counties in using native plants in roadside vegetation management, which led to a plant materials program to develop Iowa source-identified stock seed for commercial production. In 1990 the creation of the Native Roadside Vegetation Center at the University of Northern Iowa, known today as the Tallgrass Prairie Center, began the development of a capacity to grow, clean, and store native seed, conduct research, and develop best practices—not only for roadsides, but for conservation plantings on farms and the restoration of natural areas, such as the Irvine Prairie.[29]

Other states and cities are also developing native seed strategies. For example, in 2016 Arkansas initiated the Arkansas Native Seed Program with the goal of creating "ample supplies of genetically appropriate native seed available when needed" following hurricanes and wildfires. The program has federal, state, and nonprofit partners for the collection and increase of native seeds.[30] Similarly, Nevada is working on a state-level native seed strategy with the goal of increasing the availability and use of native seed within the state. As with Arkansas, the Nevada Strategy, initiated in 2016 by the Nevada Native Seed Partnership, was inspired by the goals and structure of the National Seed Strategy. The Nevada Strategy currently partners with 12 federal and state agencies, nonprofits, and conservation districts as well as the University of Nevada, Reno. This state-level plan was finalized in spring 2020.

The city of Los Angeles (LA) also is coordinating with public and private groups to support a local seed strategy that includes collecting seeds and propagating plants within the LA region for projects in the LA area. Working with botanical gardens, volunteer-led nurseries, city parks, native plant associations, and other nongovernmental organizations, the effort serves as a laboratory in which to research topics related to urban ecology.

As noted earlier, in New York City the MARSB was established by the city's Department of Parks and Recreation in collaboration with Seeds of Success to "increase the availability of genetically appropriate native seed across the Mid-Atlantic" to meet the seed needs for region-wide, landscape-scale restoration. MARSB is unique in the eastern United States.

Department of Transportation Guidance and Technical Assistance

The U.S. Department of Transportation (USDOT) allots funds for the National Highway System through the Federal Highway Administration (FHWA) to state transportation departments based on proposals for interstate, state, municipal, and county highway construction or upgrades. Since 1987 several highway bills[31] have been passed that require or encourage state recipients of federal dollars to plant native plants in conjunction with road construction.

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[29] See https://tallgrassprairiecenter.org/irvine-prairie.

[30] See https://www.naturalheritage.com/blog/native-seed-program-takes-root.

[31] STURRA-1987: 23 USC §319 requires at least 0.25 percent of landscaping funds be allocated for planting native wildflowers on new projects and upgrades.

TEA-21-1998: Stipulates landscaping and scenic enhancement costs may be approved by the Secretary as part of federal-aid highway construction via transportation enhancement (TE) grants (replaced in 2015).

SAFETEA-LU-2006: Section 6006, 23 USC §329 makes control of noxious weeds and establishment of native species eligible for existing federal-aid funds.

FAST-2015 amends Section 23 USC 319 (Landscaping) to encourage pollinator habitat and forage on transportation rights-of-way through integrated vegetation management including reduced mowing and

USDOT is the primary contact for advice on pollinators and vegetation management for state recipients of federal highway funds. Guidance is provided to states in USDOT/FHWA-funded publications (e.g., *Roadside Use of Native Plants*, *Roadside Weed Management*, *Vegetation Management: An Ecoregional Approach*, and *Pollinators and Roadsides: Best Management Practices for Managers and Decision Makers*).[32]

Environmental Protection Agency Regulations and Grants

The Environmental Protection Agency (EPA) develops and enforces regulations to implement environmental laws and sets national standards that states and tribes enforce. The EPA generates and disseminates scientific information through grants, research, partnerships, education, and publications, and it includes restoration activities in pollution abatement programs, wetland mitigations, Superfund cleanup, and related programs. Stormwater construction project permits, for example, require that sites be restored with native vegetation to a uniform plant coverage of 70 percent of the site. EPA green infrastructure research focuses on the use of plants, soils, and landscaping to reduce polluted stormwater runoff. The Green Infrastructure Wizard[33] is a database with tools and resources developed from this research to aid in water management and community planning.

The Clean Water Act provides funding for stream and wetland restoration. The 1987 Section 319 Nonpoint Source Management Program (40 C.F.R. subchapters D, N, and O (parts 100–140, 401–471, and 501–503) provides for the distribution of grant money to states, territories, and tribes for technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and the monitoring of nonpoint source implementation projects. This addresses the need for greater federal leadership to help focus state and local nonpoint source efforts. In 2019 funding for stream and wetland restoration totaled $165.4 million.

Finally, the EPA's Omernik ecoregions[34] provide a spatial framework for ecosystem research, management, and monitoring across federal agencies and other jurisdictions with lands in similar geographic areas. These ecoregions subdivide U.S. lands using factors such as geology, dominant vegetation, climate, and soil data. The ecoregions are supplementary to the provisional seed zones developed by Bower et al. (2014), which incorporate Omernik Level III (Omernik and Griffith, 2014) ecoregions to guide seed transfer for areas without empirical or research-based seed zones.

USDA Natural Resources Conservation Service Guidance

The USDA Natural Resources Conservation Service's (NRCS) Conservation Technical Assistance Program (CTA) aids individuals or groups in developing plans for conserving natural resources and sustaining agricultural production on non-federal lands. CTA conservation plans

development of habitat and forage for Monarch butterflies, native pollinators, honeybees by planting native forbs (including native milkweeds) and grasses.

[32] See https://search.usa.gov/search?utf8=%26%23%23x2713%3B&affiliate=dot-fhwa&sitelimit=fhwa.dot.gov%2Fpublications%2Fresearch&query=plants&commit=GO.

[33] See https://www.epa.gov/sustainability/giwiz.

[34] See https://www.epa.gov/eco-research/ecoregions.

incorporate NRCS conservation practices and can be used to apply for federal assistance (e.g., through the Conservation Reserve Program, which incentivizes farmers to take marginal cropland out of production for 10–15 years, and other conservation programs of the Farm Bill)[35] as well as for state or private funding. The use of native species is not required, but an emphasis on native plants increases the likelihood of receiving funding. The species that are planted are selected from state conservation practices lists, and seed is purchased commercially by the user. Several presenters to the committee suggested that the conservation programs of the Farm Bill were a driver of seed demand—mostly developed cultivars and selected germplasm releases—by private landowners.

Plant materials specialists from the plant materials centers and the National Plant Data Team have produced 2,900 documents on conservation planting, with more than 1.5 million downloads annually. These documents include plant guides, technical notes, vendor lists, and the Plants Database, which contains extensive information on U.S. plants[36] (Englert, 2019).

USDA National Institute of Food and Agriculture Funding

The USDA National Institute of Food and Agriculture (NIFA) supports scientific research related to agriculture, food, the environment, and rural communities. NIFA is the extramural science funding source for USDA; funds are provided primarily to land grant universities, but also to other federal, state, and private entities. Competitive funding for natural resource programs is low (less than $25 million per year), but 36 native seed projects were actively supported in 2019 through grants programs on rangeland restoration and through the Agricultural Food and Research Initiative. These projects focused on techniques and strategies for improving the establishment of native plants for ecological restoration. The topics included seed enhancement, seed production practices to supply seed for current and future conditions, re-establishment of biological soil crusts, and the establishment of warm season grasses for forage and biofuel production[37] (Dobrowolski, 2019).

U.S. Geological Survey Collaboration and Research

The U.S. Geological Survey (USGS) plays an active role in providing research to support seed transfer guidance, native plant material development, and restoration strategies. Much of this work occurs through collaborative partnerships with the BLM's Mojave Desert and other ecoregional plant programs and with BLM state offices. Tools such as the USGS Land Treatment Digital Library,[38] which catalogs legacy data on BLM land treatments, aid managers in planning revegetation and adaptive management practices. Data from this particular repository have provided information for large-scale reviews of the success of seeding efforts to date.

USGS researchers conduct common garden and landscape genetic analyses, which provide information on traits that allow plants to survive, as well as studies of the distribution of adaptive genetic variation and natural patterns of genetic differentiation. Researchers also manipulate environmental conditions to investigate responses to potential future climate conditions. These studies use existing native plant materials and wildland collections to represent

[35] The Farm Bill is shorthand for the Agriculture Improvement Act of 2018, P.L. 115-334.
[36] See https://plants.usda.gov/java.
[37] Randi Johnson, USFS, personal communication.
[38] See https://ltdl.wr.usgs.gov.

the diversity of environmental conditions across a species distribution. Their approaches make it possible to understand how existing native plant materials may best be used, what new native plant materials are most critical to develop, and how to create accurate, species-specific seed transfer guidance for current and future climates. The knowledge gained is distilled into publicly available tools and data products to inform managers and practitioners. As the USGS research framework grows, an important challenge will be maintaining consistent funding to support ongoing investigations, as many of these research needs require long-term commitments. Ultimately, USGS investigations will improve restoration outcomes by facilitating the evidence-based development and use of native plant restoration materials.[39]

USDA Forest Service Research

The USDA Forest Service research arm has been a leader in genetic research and the development of seed transfer guidelines for conifer species since the early 1900s. Early research showed the importance of local adaptation, as the transfer of plants outside of their local environments resulted in poor performance or planting failures (Johnson et al., 2004). As a result of that research, seed zones for forest trees are now widely accepted and used. Local adaptation has also been documented for many other native species (Baughman et al., 2019). As the need for ecological restoration increased, the Forest Service and its partners have invested in genetic research and seed transfer development for numerous foundational native species occupying forests, shrublands, and grasslands. The return on these investments can be seen in improved ecological recovery, function, and resiliency. Climate change and an increasing frequency of disturbances has prompted the development of climate-smart ecological genetic models and decision support web platforms. These platforms use climate-associated genetic models and species distribution models to map seed transfer distances. Since these models are built using climate variables, the models can be projected for future climate scenarios. With the Climate Smart Restoration Tool[40] (for shrubs, grasses and forbs) or the Seedlot Selection Tool[41] (trees), users can develop seed transfer maps for their chosen species under contemporary or future climates. The Forest Service research arm, along with partners, has also been active in conducting research on seed technology (germination protocols, seed production, seed storage), plant materials development, the control of exotic species, and wildland seeding strategies, particularly for post-fire revegetation.

Universities

University researchers contribute basic and applied science to support the use of native seed, often working in tandem with state, federal, and NGO partners to answer the most pressing questions in such areas as seed zone development, seed dormancy investigations, seed coating technologies, genetic analyses, and identifying adaptive traits. University researchers also train the undergraduate and graduate students who engage in numerous parts of the native seed industry. With increasing focus and interest in restoration science, the number of programs preparing students to fill these positions is growing, and efforts are ongoing to increase the number of botanical training programs across the United States.

[39] Rob Massati, U.S. Geological Survey, personal communication.
[40] See https://climaterestorationtool.org/csrt.
[41] See https://seedlotselectiontool.org/sst.

Seed Associations

Many seed companies belong to state or national associations that work on their behalf to strengthen the seed industry. There are a few associations dedicated to native plant materials production, such as the Intermountain Native Plant Growers Association,[42] Western Seed Association,[43] Missouri Native Seed Association,[44] and Florida Association of Native Nurseries.[45] Statewide crop improvement associations such as the Iowa Crop Improvement Association and seed certification agencies in other states oversee programs of native seed certification as sponsored by the Association of Official Seed Certifying Agencies.

The American Seed Trade Association (ASTA) is a national seed industry organization. ASTA's Committee on Environmental and Conservation Seed consists of about 25 companies "who provide quality seed for land restoration, rehabilitation, and reclamation." The committee is focused on promoting "native seeds with introduced and released plant materials in projects on private and public lands" (ASTA, n.d.). ASTA has advocated for the use of germplasm releases and cultivars for BLM restoration projects and has developed a number of position papers regarding the use of local native seed, USDA NRCS national conservation practice standards, efficient native seed use by BLM, and best management practices for native seed production, which are published on its website.[46]

SUMMARY

Native seeds are needed for land restoration, and there is currently a system in place to supply those seeds. It starts with the collection of wild seed and the production of larger quantities of seed from existing seed supplies. Seed is cleaned, analyzed, certified, and stored during the process. The many users of native seed range from large federal agencies to local landowners. Seed needs are highly variable and are often driven by disasters such as wildfires and hurricanes, which periodically overloads native seed capacities. Furthermore, there are concerns that the current delivery system does not provide the quantity and diversity of native seed needed for ecological restoration.

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[42] See http://npj.uwpress.org/content/6/2/104.short.
[43] See https://www.westernseed.org.
[44] See http://monativeseed.org/index.html.
[45] See https://www.afnn.org.
[46] See https://www.betterseed.org/the-issues/environmental-and-conservation-seed.

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3

Preliminary Observations

INTRODUCTION

In this chapter the committee describes its preliminary observations about key dynamics of the native seed supply that came to light in discussions with experts and practitioners and around which the committee has a partial understanding. The observations are "preliminary" because additional information is needed to confirm or correct them. These preliminary observations provide the context for the additional study and data gathering that will take place in the next phase of the assessment.

OBSERVATIONS

At this point the committee offers the following observations about the native seed supply:

Observation 1. Users have varied objectives and needs.

The users of native seed have various objectives, which may include (1) restoring native ecosystems as completely as possible, (2) stabilizing land after a severe loss of vegetation, (3) providing specific ecosystem services (e.g., soil and water conservation, pollination, invasive species control), (4) providing commercial value such as rangeland forage, and (5) beautification and native plant awareness in designed landscapes. Depending on their objectives and budget, native seed users vary in their need for and the scale at which they use provenance-specific seed mixes that are likely to become established and to survive changing climate conditions and thus to facilitate ecosystem recovery and maintain biodiversity.

Urban parks, nongovernmental advocacy organizations, and the wildlife and habitat divisions of federal and state land management agencies often conduct ecological restoration in support of their missions. The disaster recovery divisions of the large federal land management agencies (e.g., the Bureau of Land Management's Emergency Stabilization and Rehabilitation program and the U.S. Forest Service's Burned Area Emergency Response program) concentrate on post-wildfire emergency stabilization of land and soils and on the prevention of invasive species. State agencies frequently seek native species for specific ecosystem services, such as the beautification of roadsides or to buffer rainwater flows in bio-swales (Armstrong et al., 2017). Farmers may seek native species that provide soil and water conservation, pollination, or habitat for natural enemies of crop pests (Jackson and Meissen, 2019). Ranchers may seek species that yield high-quality forage (Staub et al., 2016).

Given the diverse objectives, motivations, and purchasing behaviors of the various users of native seed, the committee seeks to understand if, how, and when user needs are met by the current native seed supply channels. One particular concern is how the supply of and demand for provenance-specific native seed interacts with the supply of and demand for the other types of native seed that are used in many applications.

Observation 2. The seed market in the western United States is strongly affected by decision making by the large land management agencies, such as the Bureau of Land Management (BLM) and United States Forest Service (USFS).

As some of the largest buyers of seed in the United States, and possibly in the western hemisphere (Mock et al., 2016), federal land management agencies strongly influence the market for native seeds. The committee is interested in understanding more about the determinants of seed choice and the decision-making processes concerning ecological restoration in these agencies, which vary both among the agencies themselves and even among different divisions within a single agency (e.g., BLM field offices, USFS districts).

In the USFS, post-fire seeding varies by region, but overall the practice has declined, reflecting policy decisions to avoid non-native seeds and to not seed areas considered capable of regenerating naturally (Erickson, 2019). The current emphases are wildfire mediation and control, timber sales, and fuel reduction. Although expanded native seed restoration is recognized as a critical component of forest management, and there is an official native seed policy, there is no agency-wide native plant restoration program.

In the BLM, post-fire seeding has generally emphasized grass-dominated mixes for stabilization rather than diverse mixes designed for longer-term ecological restoration. Seed mixes appear to be chosen by considering site conditions and historic vegetation and by consulting fire rehabilitation plans from nearby burn sites. The same mix is often applied on multiple sites for cost efficiencies. Seeds are procured through the consolidated seed buys, records of which show an ongoing reliance on non-natives, natives that are not specific to the local site, and limited but increasing requests for materials from specific seed zones.[1] The committee learned that the BLM seed selection process relies strongly on past practices; the contributing reasons include staff turnover, limited training, short timelines for project approval, and limited budgets. The monitoring of seeding projects is typically short-term (2–5 years), although the duration and intensity varies among projects. As a result, it is not always clear whether seeding has been successful or whether natural recovery has occurred. If a restoration project is unsuccessful, there is typically no further funding to continue the work. However, the success or failure of the project (and the practices employed) does not affect funding for future projects. A new database, TerrADat, is currently being used by some field offices to store monitoring results, which may provide an opportunity to use monitoring results to inform future decisions (BLM, 2020).

Large-scale, proactive restoration projects have not historically been the norm in either the BLM or the USFS, although the multimillion-dollar efforts to restore sage-grouse habitat and manage fire risks in the Great Basin are becoming important exceptions. The committee learned anecdotally that some federal agency practitioners have been able to succeed in carrying out proactive native seed-based restoration through collaborations with state wildlife agency partners (such as in Nevada and Utah) using a variety of ad-hoc funding sources, financial instruments (contracts, agreements), and applied science tools to assist in seed selection, collection, production, and procurement. As one example, in Idaho the BLM has used the Integrated Program of Work element of the fuels program to request additional support for particular seed mixes (BLM, 2019). Rather than changing traditional agency practices, it appears that a series of ad-hoc "work-arounds" are being developed, which may be effective for their purposes but are

[1] Unpublished reports from BLM consolidated seed buys are available upon request from the National Academies Public Access Records Office.

currently outside the main funding and planning streams. Whether these innovations could provide models for expanding proactive restoration work by the agencies, and how such an expansion might affect the native seed market, requires further exploration.

Observation 3. Timeframe, quantity, and quality strongly limit the overlap between what seed is available and what seed is desired.

Both the BLM and USFS have policies that emphasize the need to use native seed for restoration projects, but exceptions are allowed and indeed are common in the BLM. Much of the agency's demand for native seed arises suddenly in response to large wildfires or other large-scale events, and these large and reactive needs are much harder to meet than are proactively planned needs. Some of the seed demand may be met by the agency's own inventories, but large fires also create the need for rapid procurement of large quantities from commercial sources, and the scale and urgency of demand are likely to affect prices and availability. In this setting, BLM and USFS practitioners frequently lean on policies that allow the use of substitutes, including non-native species or native cultivars, when provenance-specific native seeds are not available (Camhi et al., 2019; Peppin et al., 2010). By contrast, proactive demand for provenance-specific native seed has a longer time horizon and thus allows more options for finding or developing sources of seed that meet agency preferences.

The availability and prices of provenance-specific seed are likely to be strongly affected by the balance between reactive and proactive demand. Given that wildland fires and other large-scale events will continue to be important drivers of seed demand, the committee will explore the problem of timeframe and urgency as it relates to the availability of all types of native seed. Although emergencies drive need, better advanced planning for emergencies may be possible using knowledge of the locations of fire-prone landscapes. Support for proactive restoration may also help create the supply needed for emergencies.

Observation 4. Seed choices do not always support restoration success, and outcomes do not always inform choices.

The committee is also interested in how seed choices influence the success of ecological restoration. Seeding for restoration may not meet all stated goals: the seeds may not germinate, or the plants may not persist, or the plants may persist but not fulfill the objective of recovery of biodiversity, failing at such specific tasks as controlling invasive species or reestablishing self-sustaining native plant populations.

On public lands in the western United States, where many very large-scale seeding projects have taken place, it is common for seeds to fail to become established, especially in warmer and drier locations (Arkle et al., 2014, Knutson et al., 2014, Pilliod et al., 2017). One of the major contributors to seeding failure is the use of seeds that are not well matched to the local climate (Baughman et al., 2016; Germino et al., 2019; Rowe and Leger, 2012); other factors in seeding failure include such things as site preparation and planting methods, timing, weather (including timely precipitation), and the presence of weeds, including those that might be present in the native seed lot used. For most species, local populations are usually better adapted to local environments than those from more distant environments (Baughman et al., 2019). Establishing plants in more extreme hot and dry environments is particularly difficult, but seed from populations adapted to such extreme environments are often scarce, which frequently leads to a

reliance on natives from dissimilar geographic origins or non-native plant seeds, which end up failing to meet restoration objectives.

Grasses, both native and non-native, have been heavily emphasized in seeding projects on western U.S. public lands (Olwell, 2019). Grasses are preferred on lands with active grazing allotments because of their forage value. Grass seeds are relatively easy to propagate in agricultural settings using equipment and techniques developed for exotic turf and forage crops. Grasses tend to germinate readily, grow quickly, and compete strongly with other plants. However, these same attributes may lead seeded grasses, particularly non-native grasses, to inhibit the recovery of other indigenous grasses, shrubs, and forbs that are naturally present in seeded sites (or are co-seeded with grasses). Grasses contribute substantially to, but do not meet all of the needs of, wildlife and pollinators, nor do they perform many of the essential ecological functions of shrubs and forbs. Although shrubs and forbs are increasingly being added to seeding mixes, only a few such species are available for seeding in large quantities (Pilliod et al., 2017). Cost, training needs, and the lack of seeding techniques for establishing mixtures of species are additional impediments to the ongoing effort to increase the use of shrubs and forbs for multiple restoration goals (Shaw et al., 2005).

Observation 5. The budgets and seed specifications of users vary greatly, as do the unit costs of suppliers.

Budget constraints often limit the ability of native seed users to meet their needs in the marketplace. Budgets available to native seed users appear to vary tremendously, as does the mix of native plant genetic attributes that buyers seek. Users' budgets may be affected by funding source, timeframe, project location (urban versus rural), project scale, project priority, and whether the project has legal requirements (for example, restoration following resource extraction).

Native seed buyers also vary in their goals for their planting projects and, hence, vary in the diversity of species and seed traits that they need. Some projects aim for the ecological restoration of ecosystems and may seek a broad set of natives species that show local adaptation and are likely to perform well in a given site. Other projects may have narrower goals, such as to plant native vegetation that supports pollinators or promotes soil conservation. More information is needed on the relationship between budgets and the desired seed specifications in shaping buyers' purchasing decisions. Across all native seed buyers, the willingness to pay for native seeds might be envisioned as a continuum, ranging from a high willingness for buyers with well-funded projects with specific restoration objectives to a low willingness in the case of less well-funded projects with more flexible objectives. The committee will investigate the range of factors that shape buyer willingness to pay for different types of seeds.

From conversations with seed producers, the committee understands that the commercial availability of native seeds is shaped by their costs of production. The costs of production vary by species and depend on factors such as how easily the species can be grown agronomically and commercially collected, how long it takes for plants to reach seed-bearing age, the seed yield for the species, and the costs of labor, equipment, and other inputs needed for seed production of a particular species. In addition, seed suppliers bear the costs of harvest, storage, marketing, and financing (Kleiner, 2019; Terrell, 2019). These costs appear to vary by geographic region, producer scale, and the species and native plant genetic attributes that suppliers are trying to produce. For example, it may be less costly to produce an agronomically successful cultivar of a

native species than to produce several genetically diverse local populations of the same species that have a more limited market.

The committee would like to understand better the costs per unit of native seed production for suppliers to meet different kinds of buyer specifications. The costs conceivably vary according to different production-related factors, with low-cost seeds being those that are easy to cultivate or collect, while higher-cost seeds are more difficult to cultivate or collect. The committee feels that it will be essential to carry out an empirical assessment of how production costs shape the willingness and abilities of producers to supply native seeds at different prices and buyer specifications.

Observation 6. Seed procurement may be hampered by market volatility, risk, and contract structure.

Seeds are procured through direct purchases and by contracts (Olwell, 2019). The committee plans to investigate the behaviors of buyers and sellers of native seed under different procurement scenarios. There are features of the native seed market that economic theory predicts should make it quite volatile. Some suppliers collect wildland seed or produce seed in cultivated fields speculatively, without a contract, in an attempt to predict highly uncertain future demand for specific species (Camhi et al., 2019; Peppin et al., 2010; Taylor et al., 2018).

Timing is a critical contributor to market volatility. The interactions between the multi-year seed production cycles and the demand for appropriate seed, including the extent to which storage is used currently and the potential for its expansion, are essential in assessing market risks. However, many prospective and current growers are unwilling or unable to bear the risks of both producing native seeds and of carrying inventories in the face of uncertain demand (Taylor et al., 2018).

The committee observed that buyers sometimes encounter difficulty in finding seed that meets their specifications (quantity, quality, genetic composition), especially when demand is urgent. It is possible that this urgency incentivizes suppliers to produce species and genotypes that can be grown across a broad geographic area in order to increase the likelihood that they will be able to sell their inventories. For some buyers, the costs for the preferred seed may be too high (Peppin et al., 2010). As noted above, how buyers with limited budgets respond to seed prices needs further exploration. Assuming that buyers know what they want to achieve and understand how the seed is likely to perform, do they, for example, decide to substitute less costly seed over a large acreage or use more expensive seed but on a smaller area? And do limited buyer budgets induce suppliers not to produce native seeds that would be too costly, particularly when some funds are released only under emergency conditions?

Native seeds are sometimes procured through contracts, including government purchases, as noted in the discussion of seed and plant production in Chapter 2 (Olwell, 2019). Economic theory predicts that market characteristics affect how well different types of contracts will work. Three such characteristics that appear to merit further investigation based on information collected to date: (1) the volatility of demand for native seeds and their associated quantities, as observed specifically for BLM purchases (Olwell, 2019); (2) the relationship, if any, between the diversity of species for which seed is needed (and the specificity of the seed zone) and the volume purchased; and (3) the importance of transaction costs and required contract provisions for designing a contract that both buyers and suppliers find attractive. Transaction costs include the efforts exerted by buyers and sellers to communicate needs and availability as well as to

agree upon terms of sale. In light of the importance of transaction costs, BLM identified communication tools as a challenge it would like the committee to address (Olwell, 2019).

A clearer understanding of the market conditions affecting contracts could help in designing contracts that would improve the responsiveness of native seed suppliers to seed needs. For example, the duration of a contract may influence its suitability for specific relationships. Risk sharing is another contract design decision that can influence its suitability. There are different ways of sharing risk. For example, sharing production costs is one way of sharing risks. Guaranteeing a purchasing "home" for all production (in which, for example, the buying agency takes the risk that some seed will never be used and have to be destroyed) is another. Perhaps agencies could facilitate the seed purchases of smaller public or private entities in order to smooth demand in years when natural disasters are not driving the need for seed. Thus one important question is, How can contract designs serve both buyers and sellers, and what kind of contracts work best under the range of market conditions that prevail for native seeds?

Observation 7. The seed market may be strongly affected by a limited capacity for seed banking and for adequate and appropriate storage conditions.

Because provenance-specific natives are frequently in short supply when they are needed to respond to a natural disaster, it might be useful to stockpile seeds so that they are available when needed. However, to stockpile seeds effectively would require adequate and economic seed storage capacity, the ability to forecast which areas are most likely to need seeds, and the ability to keep storage seeds viable long enough to respond to any need for prolonged periods.

Seed longevity depends on the species, initial seed quality, and storage conditions. Most plants (approximately 75–80 percent), including most western U.S. restoration species, produce seeds that can, with proper drying, withstand freezing that lengthens their viability (Walters et al., 2013). For these species, seed longevity can be approximately doubled for every 1 percent decrease in relative humidity and 5 °C decrease in temperature, within limits. Seeds stored at ambient conditions remain viable for a few months to about 10 years, but seed dried at low humidity and stored at -18 °C can last, on average, 200 years, and seed refrigerated at 4 °C falls in the middle of this wide range (Walters, 2004).

Seed companies have some limited cold storage for the short-term storage of native seed, but the long-term, multiple-year storage of seed requires the conditions noted above (low humidity and low temperature) at special facilities. Such facilities are currently limited in size and number. Furthermore, in many cases best practices for the long-term seed storage of native plant species are poorly understood.

The key questions for the committee in this are how much storage is available, how much expanding storage capacity could reduce the volatility of the seed market and the price of seeds, and what measures could be taken to expand storage capacity.

Observation 8. Issues affecting urban, Midwestern, and Eastern settings are somewhat distinct from those affecting public lands in the West.

Midwestern and Eastern U.S.

The committee has only begun to explore the nature of the seed supply outside of the Western states, but some fundamental differences are apparent. In contrast to the 11 western U.S.

states, where the federal government manages more than 40 percent of all land (Shaw, 2019), the largest users of native seeds in the midwestern and eastern United States are smaller entities: state, county, and municipal agencies; nonprofits; and public–private partnerships addressing such issues as pollinator conservation, wildlife habitat, invasive species control, and farmland nutrient management. For example, invasive species councils in each of New York State's seven subregions conduct state-funded programs for which they seek appropriate native plant seeds (NYS DEC, 2016). The potential may exist for these entities to expand the supply of native seeds through improved planning and coordination of their activities, such as by mitigating the barriers imposed by procurement policies. Extension programs in many states have master naturalist programs, and in Maryland the master naturalists have worked to produce native provenance-specific bulk seed.[2] These programs educate the public on the importance and need for native plants. The committee will explore opportunities and constraints for increasing locally adapted native plant seeds, particularly in the East.

In urban areas, project planning, design, and implementation are typically done by landscape architects and, to a lesser extent, by engineers. While these design professionals vary in their exposure to ecological principles, they are increasingly specifying provenance-specific plant materials. A survey of landscape architects, such as members of the American Society of Landscape Architects,[3] may be valuable for better understanding their uses of native species.

Hurricanes and flooding are creating an increasing demand for large-scale restoration in the eastern United States, analogous to the fire-driven demand for restoration on western U. S. public lands. The native plant material supply chain is generally inadequate to meet these large demands. New York City's municipal native plant nursery and seed bank were in place prior to Hurricane Sandy in 2012 and have been able to serve recovery efforts, but this case is an exception. Disaster recovery has also spurred resiliency planning aimed at making urban areas less vulnerable; the largest such initiative is the Mississippi Cities and Towns Initiative, which includes 64 cities located along the Mississippi River. Although rarely considered in the planning stage of these initiatives, native plant supply chains will be essential to their success. Thus it will be important to develop a better characterization of the potential future demand for native plant materials in the context of large climatic events and resilience planning.

The native plant material supply chain for the eastern United States is also affected by several regional-scale constraints. First, because of the humid climate seed warehousing is more challenging. There are no public sector seed warehouses in the eastern United States that are capable of storing significant quantities of bulk seed. Second, there are only a handful of institutions, such as the USFS and Mid-Atlantic Regional Seed Bank, that conduct seed collection, processing, and banking in support of creating a sustainable supply of ecoregional native plant seeds. Outside of these institutions, most seed collection is done on a short-term, individual, or project basis, or it is done by commercial entities with no standardization, regulation, or use of available native seed programs, as is also true of much of nursery plant production.

Urban Wildlands and Other Urban Issues

Natural and semi-natural areas in and around cities often support considerable biodiversity (Aronson et. al., 2017) which provides desirable services to humans. In addition to

[2] See https://extension.umd.edu/masternaturalist.

[3] See https://www.alsa.org/ecology.aspx.

the threats facing all wildlands (e.g., habitat loss, fragmentation, invasive species), these urban wildlands are subject to climatic disturbances, such as flooding and drought, that may be intensified by the surrounding expanses of impervious surfaces typical of urban landscapes.

Restoration in virtually every urban center depends on native plant materials from distant sources; a 2018 survey of eastern native plant materials users found average distances to suppliers of 375–415 miles, even though 74 percent of users expressed a preference for local ecotypes.[4] Urban centers rely much more heavily on live plant material than on bulk seed in managing urban ecosystems, but bulk seed use is on the increase, which may create a need to expand the supply.

Urban restoration often involves a network of regulatory and management entities at multiple levels of government (municipal, state, federal) as well as NGOs. For instance, in New York City at least 19 agencies from all levels of government may be involved in the funding or oversight of restoration projects. The complexity of these networks, each with its own set of planning rules and procurement policies, often leads to delays and difficulties in the native plant materials supply chain. The committee will explore what opportunities exist for improving the availability of native plant materials for urban wildland restoration projects.

Private residential uses of native plants are growing in urban and suburban areas as landscape professionals and homeowners are increasingly using native plant materials in their home landscaping. Popular literature as well as concerns for bird and pollinator decline are adding to this demand for ecoregional plant materials in the home landscape (Murray, 2019). There is also a growing market for native plants for green roofs in urban areas (DiNardo, 2019). Among other issues, an understanding is needed of the extent that these small-scale private uses can help move new species into the market and stabilize markets for larger scale uses.

SUMMARY

The market for native seeds reflects a diverse and distributed system of buyers and suppliers that operates in the face of multiple constraints. This chapter touched on many of those constraints and other features of the native seed enterprise that the committee seeks to explore further in the next phase of the assessment. In Chapter 4 the committee will describe the next steps it plans to take to obtain information needed for further analysis.

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[4] See http://www.marsb.org/sosmemberinfo/survey-native-plant-and-seed-use-in-the-eastern-u-s.

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4

Data Collection Approach

INTRODUCTION

Previous chapters discussed the native seed supply chain and the information gaps identified by the committee. This chapter describes the committee's data collection plans, based on the information already gathered and on the committee's deliberations to date.

The committee expects to use a variety of mechanisms to collect the needed information, fitting each approach to the specific type, projected use, and availability of that information. Some information currently exists, and we will attempt to access it directly. Other types of information may not have been collected before but could be gathered with standardized questionnaires. Some information may be more appropriately obtained through qualitative data collection such as focus groups or individual interviews.

The main components of the committee's data collection plan are listed below and are described in additional detail in the remainder of this chapter. They are:

- Obtain existing data that could inform the study;
- Collect data from seed suppliers, likely relying primarily on a standardized questionnaire
- Collect data from seed buyers, likely relying primarily on a standardized questionnaire; and
- Gather information about other parts of the supply chain, primarily in the form of interviews, focus groups, or presentations to the committee.

OBTAIN EXISTING DATA

To learn as much as possible about the native seed supply chain, the committee will attempt to obtain data that already exist in the form of administrative records at various agencies and other entities that are part of the supply chain. The committee is not aware of any existing data source that could provide a comprehensive picture of either the native seed supply or demand in the United States, but accessing this type of existing information can provide a granular view of some segments of the supply chain and enrich the committee's understanding of a few specific market players.

The main sources of existing data identified to date by the committee are the Bureau of Land Management (BLM) consolidated seed buy records and potentially information about seed purchases from the U.S. Forest Service (USFS). Additional data sources may be added as the committee learns more about what is available.

COLLECT DATA FROM SEED SUPPLIERS

This section discusses both the type of information that the committee plans to collect from seed suppliers and the process for collecting this information.

Questions for Seed Suppliers

Below is a preliminary list of key topic areas identified for the data collection from seed suppliers on the basis of the committee's deliberations to-date. These topic areas and the specific questions will continue to be refined by the committee over the course of the next few months and will be finalized in consultation with the data collection contractor selected to carry out the data collection. The final list will need to be determined (and very likely shortened) based on the appropriate questionnaire length to obtain maximum response rates and address any budget considerations. The key topic areas identified to date are:

- Operation type and demographic characteristics
- Species of native plants collected or cultivated
- Information about seed quantities sold, the inventories of unsold stock, and how long seed is held in inventory
- Information about the capacity for collecting seed
- Information about the capacity for growing seed
- Information about the capacity for storing seed
- Information about the capacity for cleaning seed
- Types of buyers, intended uses, and geographical area of use
- Types of contracting arrangements used
- Anticipating demand
- Factors considered in production decisions
- Other questions about challenges and potential solutions

Data Collection Approach

The committee will refine the data collection process based on additional research describing the population of seed suppliers and the feasibility of contacting them in a systematic way. This refining will be accomplished through the following steps.

Step 1: As described in previous chapters, there are multiple types of entities that are involved in supplying native seed in the United States. An important initial step will be to understand what types of entities are most relevant for the purposes of this study.

Step 2: It is unlikely that it will be possible to conduct a survey based on a sampling frame that accurately and completely represents the entire population of native seed suppliers in the United States. However, lists of subsets of this population exist and can be used to define target subpopulations. As part of this step, the committee will assess the availability, coverage, and overall quality of the available lists of seed suppliers with the goal of conducting a census of these populations—in other words, sending a questionnaire to everyone on the lists.

Some examples of sources with lists of seed suppliers that appear to meet the criteria of providing a reasonably accurate and complete representation of a specific subpopulation (even if not the entire population) appear below. The committee will continue to seek out and evaluate

additional lists of sources as it proceeds. Given that some suppliers will appear on more than one list, duplicates will be removed from the lists as much as possible before use. The potential sources of lists of seed suppliers include:

- U.S. Department of Agriculture (USDA) National Nursery and Seed Directory (Native Plants Journal list)
- BLM seed vendor lists
- USFS seed vendor list
- American Seed Trade Association's Environmental and Conservation Seed Committee
- Native Seed Network

Step 3: Based on the findings from steps 1 and 2, the committee will assess the need to create additional lists of seed suppliers or to enhance existing lists. These efforts will likely focus on obtaining adequate contact information for names on lists from existing sources.

Step 4: The committee will consider a variety of mechanisms to collect data from seed suppliers and will identify the most suitable approaches. If it is determined that it is possible to develop reasonably comprehensive lists that meet the committee's needs, the primary data collection method for this population will likely be a census. The potential quantitative data collection may be supplemented with qualitative data collection methods, such as individual interviews or focus groups, or qualitative methods might be used instead of the census if a list of acceptable quality cannot be developed.

Step 5: In preparation for fielding the data collection, the committee will: (1) develop a data collection instrument (questionnaire or interview guide), (2) develop formal data collection and analysis specifications for the data collection, and (3) identify a subcontractor to carry out the data collection. Work on some of these tasks (e.g., identifying a data collection contractor) will likely begin in parallel with the prior steps. The committee will decide which specific tasks will be delegated to the data collection contractor, but it will maintain oversight of all activities, including: instrument design, pretesting, and basic analyses.

COLLECT DATA FROM SEED BUYERS

This section discusses both the type of information the committee plans to collect from seed buyers and the process for collecting this information.

Questions for Seed Buyers

Below is a preliminary list of key topic areas for the data collection from seed buyers, as identified by the committee's deliberations to date. These topic areas and the specific questions will continue to be refined by the committee over the course of the next few months and will be finalized in consultation with the data collection contractor selected to carry out the data collection. As was the case for the seed supplier questions above, the final topics and questions are expected to be determined (and likely shortened) based on the appropriate questionnaire length to obtain maximum response rates and address budget considerations.

The key information to be collected from seed buyers includes:

- Buyer type and characteristics
- Frequency and volume of native seed purchases
- Purposes of native seed purchases
- Types of native seed purchased (species, whether source was identified, etc.)
- Decision-making criteria for what species or type to buy
- Availability of the types and quality of seed sought
- Sources of information about native seed availability
- Planning horizon; ways of communicating longer-term needs to potential suppliers
- Buyer's capacity for storing seed
- Buyer's capacity for cleaning seed
- Decision making in restoration project planning
- Types of contracting mechanisms used
- Institutional barriers to expanding the list of seeds purchased
- Other questions about challenges and potential solutions

Data Collection Approach

The committee will refine the data collection process based on additional research describing the population of seed buyers and the feasibility of contacting them in a systematic way. This will be accomplished by following the same steps as described for the seed suppliers above.

The buyer side of the native seed supply chain is dominated by a few large agencies that are relatively easy to identify as buyers, and they are joined by numerous smaller buyers of different types. To the extent that lists can be constructed for different categories of buyers, it may be possible to conduct a census and gather information from the buyers using a standardized questionnaire. For the large agencies it will be necessary to understand their organizational structures in order to know at which administrative and geographic levels (probably multiple levels) decisions regarding native seed buys are made and whether the data collection will need to be customized to capture differences in operations.

Below are some of the types of larger buyers that are likely to be included in the data collection:

- Federal agencies, including BLM, USFS, the National Park Service, the U.S. Fish and Wildlife Service, and the Department of Defense
- State public agencies such as state departments of transportation, state forest agencies, and state wildlife and conservation agencies such as the Utah Division of Wildlife Resources
- Tribes controlling large acreage of tribal lands such as the Navajo, Tohono O'odham, White Mountain Apache, San Carlos Apache, Hualapai, Mescalaro, Pine Ridge, Standing Rock, Cheyenne River, Fort Peck, Crow, Blackfeet, Flathead, Osage, Nez Pierce, Colville, Yakima, and Uintah/Ouray nations

Among the smaller buyers for which it will likely be difficult to construct lists, the committee identified city governments, energy development and utility companies and their contractors, farmers and ranchers enrolled in the Conservation Reserve Program,

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nongovernmental organizations such as The Nature Conservancy and wildlife advocacy organizations, and land trusts. For some smaller buyers, qualitative data collection methods (such as individual interviews or focus groups) might be used.

GATHER INFORMATION ABOUT OTHER PARTS OF THE SUPPLY CHAIN

As discussed in prior chapters, the seed supply chain includes other key players, such as permit issuers, seed developers, seed collectors (such as Seeds of Success), seed cleaners and extractories, seed certifiers (for example, individual state certification agencies that are members of the Association of Official Seed Certifying Agencies), seed analysts, seed banks, seed warehouses, seed consolidators and vendors, and procurement and contract agents. Additional information will be needed from those entities as well as from the agencies that make regulatory policy, provide technical advice or funding for restoration, and conduct or support research. Input from these entities can further inform the committee's understanding of the seed supply chain and its limitations. Due to the large variation in the missions, activities, and characteristics of these entities, the committee's approach to gathering this input will be in the form of individual interviews, focus groups, case studies, and other forms of qualitative information gathering to be customized over the coming months. The committee will also attempt to collect existing administrative data relevant to these parts of the supply chain, as described above.

Other Public Input

Because it will not be possible to design a data collection process that will include everyone who might want to provide input, a call for comments will be posted to the study page on the National Academies website, and the link to the input form will be circulated on relevant mailing lists. This will enable any interested party to submit comments to the committee before it completes its final report.

Appendix

Committee Member Biographies

Chair

Susan P. Harrison, University of California, Davis (NAS Member)

Dr. Susan P. Harrison is a Distinguished Professor in the Department of Environmental Science and Policy of the University of California, Davis. She was elected into the National Academy of Sciences in 2018 for her excellence in Environmental Science and Ecology. Harrison is a leader in the study of ecological diversity at different spatial and temporal scales, and of the mechanisms and processes that maintain diversity. Her work is of fundamental importance for understanding the impact of global change on ecological communities, and for conservation biology from local to global scales. Dr. Harrison received her B.S. in 1983 in Zoology and M.S. in 1986 in Ecology from University of California, Davis, and Ph.D. in 1989 in Biology from Stanford University.

Members

Delane Atcitty, Indian Nations Conservation Alliance

Delane Atcitty is Executive Director of the Indian Nations Conservation Alliance, an organization that connects underserved native ranchers and farmers to federal agencies and Tribal Leadership that share an interest in conservation and natural resource management. Mr. Atcitty also is the principal of Arrowhead Resource Management, LLC, which provides ranch management and agri-business consulting services to native communities. Previously, he was a Natural Resource Specialist at the Department of Interior's Bureau of Indian Affairs, a Rangeland Specialist with the Bureau of Land Management, and before that, a Rangeland Specialist for the Nature Conservancy SVR Ranch, overseeing management of cattle and bison on the ranch. Mr. Atcitty is a Board member of the Navajo Agricultural Products Industry (NAPI), Holistic Management International Board of Director, National Grazing Lands Coalition Advisory Board Member, and Past Chair of the Native American Rangeland Advisory Committee of the Society for Range Management. Mr. Atcitty received a Bachelor of Applied Science (B.A.Sc.) degree in Agribusiness in 2007 from Oklahoma Panhandle State University, and in 2009 a Masters in Ranch Management from Texas A&M University's King Ranch Institute.

Rob Fiegener, Institute of Applied Ecology

Rob Fiegener is an independent consultant who previously served as Director of Plant Materials at the Institute for Applied Ecology. Mr. Fiegener led the Institute's native seed collection, production, and distribution activities, including participation in Seeds of Success, the Willamette Valley Native Plant Partnership, and other regional plant materials efforts. He served as director of

the Native Seed Network from 2004 to 2020 and produced the series of National Native Seed Conferences from 2010-2017. Previously he worked for Oregon State University's Institute for Natural Resources, the US Forest Service, and the National Park Service. He currently serves as chair of the Society for Ecological Restoration's International Network for Seed-based Restoration and is a member of the IUCN Species Survival Commission Seed Conservation Specialist Group. He holds a BS in Natural Resources Management from Humboldt State University and a MS in Ecology from University of California, Davis.

Rachael E. Goodhue, University of California, Davis

Dr. Rachael Goodhue is Professor and Department Chair in Agricultural and Resource Economics at University of California, Davis. She earned her Ph.D. and M.S. from University of California, Berkeley and her B.A. from Swarthmore College. Her research interests include agricultural marketing and organization, agri-environmental policy, pest management, regulation, and contract design. She is on the editorial boards of Agricultural and Food Economics, California Agriculture, and Review of Industrial Organization. Currently she teaches intermediate microeconomic theory for undergraduates in the Managerial Economics major, and courses on agricultural markets and the economics of California agriculture for graduate students. Goodhue works regularly with the California Department of Food and Agriculture to assess the economic impact of proposed pesticide regulations.

Kayri Havens, Chicago Botanic Garden

Dr. Kayri Havens is the Director of Plant Science and Conservation and Senior Scientist at the Chicago Botanic Garden. She is also an Adjunct Professor of Biology at the University of Illinois-Chicago and at Northwestern University. Previously Dr. Havens was a Conservation Biologist at the Missouri Botanical Garden. Since 1999, she has been a member of the Conservation Committee of the American Public Gardens Association and served as Chair from 2006-2008. She is a board member and treasurer of Botanic Gardens Conservation International-US, co-director of the citizen science program Budburst, and a member of the IUCN Seed Conservation Specialist Group. Dr. Havens is also a past president of the Illinois Native Plant Society and founder of the Midwestern Rare Plant Task Force. She has received many awards including the American Horticultural Society Liberty Hyde Bailey Award in 2019 and the Secretary of the Interior's Partners in Conservation Award in 2010. Dr. Havens received her B.A. and M.S. in Botany from Southern Illinois University and Ph.D. in Biology from Indiana University.

Carol C. House, Independent Consultant

Ms. Carol House is an independent consultant who served as a senior program officer for the National Academies of Sciences, Engineering, and Medicine's Committee on National Statistics. Prior to the National Academies, she held several positions at the National Agricultural Statistics Service of the U.S. Department of Agriculture, including deputy administrator for programs and products, associate administrator, director of research and development, and director of survey management. She also served as chair of the Agricultural Statistics Board. She has provided statistical consulting on sample surveys in China, Colombia, the Dominican Republic, and Poland. She is a fellow of the American Statistical Association and an elected member of the International Statistical Institute. Her graduate training was in mathematics at the University of Maryland.

Richard C. Johnson, Washington State University

Dr. Richard C. Johnson is currently an adjunct professor at the Regional Plant Introduction Station, Washington State University. He is also a retired Research Agronomist from the U.S. Department of Agriculture – Agricultural Research Service where he worked for over 30 years on plant germplasm conservation and utilization. From 2005 to 2016, Johnson led a cooperative program between the National Plant Germplasm System (NPGS) and the BLM-Seeds of Success (SOS) program. As a result, more than 10,000 new native plant collections have been acquired for conservation, and thousands of native seed collections have been distributed to private and public entities for research and development. He has also worked extensively with the U.S. Forest Service, BLM, and the Great Basin Native Plant Project for enhancement and utilization of native plant materials. Dr. Johnson has published numerous scientific articles on adaptation of key native species and has developed seed zones to guide the use of germplasm for restoration projects. In 2010 Johnson was a recipient of the US Department of Interior "Partners in Conservation Award" through Ken Salazar, then Secretary of the Interior. In 2014, he chaired the Interagency Committee to "Identify Research Needs and Conduct Research to Provide Genetically Appropriate Seed, and to Improve Technology for Native Seed Production and Ecosystem Restoration." This contributed to the "Plant Conservation Alliance's National Seed Strategy for Rehabilitation and Restoration, 2015-2020." Dr. Johnson received B.S. degrees in Wildlife Biology (1974) and Agronomy (1976), and a M.S. in Agronomy in 1978, all from Washington State University. In 1981 he received a Ph.D. in Agronomy from Kansas State University.

Elizabeth Leger, University of Nevada, Reno

Dr. Elizabeth Leger is a Professor in the Department of Biology at the University of Nevada, Reno (UNR), where she has been faculty since 2006. She got her PhD in plant ecology from UC Davis, and did a post-doc focused on invasive plants at SUNY Stony Brook. Her current research focuses on native plant ecology and restoration in invaded areas of the Great Basin, and she has advised multiple post-docs, graduate students, and undergraduate students studying the plants of the Great Basin. Dr. Leger served on the UNR faculty senate as the representative for the College of Agriculture, Biotechnology, and Natural Resources for a three-year term, and served a three-year term as the associate director for the Ecology, Evolution and Conservation Biology graduate program. She serves the greater scientific community with review and editorial work, and has served on multiple grant review panels for federal organizations including the USDA and NSF. In addition to her work in plant ecology and restoration, Dr. Leger is the co-creator and director of the University of Nevada, Reno Museum of Natural History, which is a major research, teaching and outreach institution at UNR.

Virginia (Ginny) Lesser, Oregon State University

Dr. Virginia (Ginny) Lesser is Professor of Statistics and Director of the Survey Research Center at Oregon State University. She conducts research on survey methodology, applied statistics, environmental statistics, and ecological monitoring. Dr. Lesser currently works on survey research examining methods to improve response rates through using multiple contact modes, such as Web and mail, and other methods incorporated during administration of the surveys. She has designed and administered over 200 surveys conducted by the Survey Research Center at Oregon State University. She is a fellow of the American Statistical Association and an elected

member of the International Statistical Institute. She has served on several National Academies committees including: the Committee on Capitalizing on Science, Technology, and Innovation: An Assessment of the Small Business Innovation Research Program-Phase II; Panel on the Review of the Study Design of the National Children's Study Main Study; Panel on Survey Options for Estimating the Illegal Alien flow at the Southwest Border; Panel to Review the Occupational Information Network; Committee to Assess the Minerva Research Initiative and the Contribution of Social Science to Addressing Security Concerns; and Committee on the Review of the National Institute of Safety and Health/Bureau of Labor Statistics Respirator Use Survey Program. She has a Doctorate in Public Health in Biostatistics from the University of North Carolina, Chapel Hill.

Jean Opsomer, Westat

Dr. Jean Opsomer is a vice president at Westat in Rockville, Maryland. He was formerly a professor and department chair in the Department of Statistics at Colorado State University, as well as a faculty member at Iowa State University. His research focuses on shape-constrained and nonparametric methods in survey estimation and on several interdisciplinary projects with survey components on a range of topics. He is a member of Statistics Canada's Advisory Committee on Statistical Methods. He previously served on the Bureau of Labor Statistics' Technical Advisory Committee and the USDA's Advisory Committee on Agricultural Statistics. He has served on two National Academies' study committees, including the Panel to Review USDA's Agricultural Resource Management Survey, and the Panel on Improving Data Collection and Reporting about Agriculture with Increasingly Complex Farm Business Structures. Opsomer is an elected fellow of the Institute of Mathematical Statistics and the American Statistical Association, as well as an elected member of the International Statistical Institute. He holds a Ph.D. in statistics from Cornell University.

Nancy Shaw, U.S. Forest Service, Emerita

Dr. Nancy Shaw is currently an Emeritus Scientist with the US Forest Service's Rocky Mountain Research Station in Boise, Idaho. From 1985 until her retirement in 2013 she was a Research Botanist. Her research over the last 35 years has focused on native plant materials development and restoration of riparian and terrestrial systems in the Intermountain West. From 2003 to 2013, she was Team Leader for the Great Basin Native Plant Project, an interdisciplinary program to develop seed transfer guidelines, seed technology, seed production protocols, and improved methodology for re-establishing native plant communities. The project involved collaboration with 20 federal, state, and private cooperators, including researchers, academics, the native seed industry, practitioners, and students. She is currently a Board member of the Society for Ecological Restoration (SER) and Chair-elect for the International Network for Seed-based Restoration (INSR). She has served as an associate editor of the Native Plants Journal (2005-2014), a member of the Steering Committee for the National Seed Strategy (2014-2015), and is currently a contributor to the INSR's International Standards for Native Seeds – Supply, Storage and Use. Awards include the National Grasslands Research Award (USDA FS and NRCS, 2007), National Service First Award (USDA FS, co-awarded, 2007), National Rangeland Management Award for Research (USFS R&D, 2009), National Plant Materials Development Award (USDA FS, 2013), and the Asa Gray Career Achievement Award (USDA FS, 2013). Dr. Shaw holds a Ph.D. in Crop Science with a Seed Science emphasis from Oregon State University.

Douglas E. Soltis, University of Florida (NAS Member)

Dr. Douglas E. Soltis is a Distinguished Professor in the Florida Museum and the Department of Biology, University of Florida. Prior to moving to Florida in 2000, he was Professor of Botany at Washington State University. Research interests include building the tree of all life, flowering plant evolution, and genome doubling (polyploidy). He was born in Sewickley, Pennsylvania. He graduated from the College of William and Mary with a B.A. in Biology in 1975. He received his Ph.D. in 1980 from Indiana University. He was named a Distinguished Professor at the University of Florida in 2008. He was president of the Botanical Society of America (1999-2000). He has received the Centennial Award and the Distinguished Fellow Award from the Botanical Society of America. With Pam Soltis, he received the Dahlgren International Prize in Botany (2002) and the Asa Gray Award in Plant Systematics (2006) and Darwin-Wallace Medal (2016). With coauthors P. Soltis, P. Endress, M. Chase, he received the Stebbins Medal in 2006 (for Phylogeny and Evolution of Angiosperms). He was elected to the American Academy of Arts and Sciences and to the National Academy of Sciences in 2017.

Scott Swinton, Michigan State University

Dr. Scott Swinton is a University Distinguished Professor in the Department of Agricultural, Food, and Resource Economics at Michigan State University. His economic research looks at agriculture as a managed ecosystem, focusing on management and policy analysis for enhanced ecosystem services. He concentrates on problems involving crop pest, pollination, and nutrient management; precision agriculture; resource conservation; bioenergy crop production; and management of risks to human health and income. Besides his work on U.S. farming, he has extensive experience with agricultural and natural resource management in Latin America and Africa. He teaches undergraduate managerial economics and graduate research design and writing. He is a Fellow in the Agricultural and Applied Economics Association and served as its President in 2018-19. MSU granted him its William J. Beal Outstanding Faculty award in 2015. Dr. Swinton served on the NAS-IOM Committee on a Framework for Assessing the Health, Environmental, and Social Effects of the Food System and the NAS Committee on Status of Pollinators: Monitoring and Prevention of their Decline in North America. He holds a B.A. from Swarthmore College, a M.S. from Cornell University, and a Ph.D. from the University of Minnesota.

Edward Toth, Greenbelt Native Plant Center, New York City Department of Parks

Edward Toth is founder and director of New York City Parks' Greenbelt Native Plant Center (GNPC), one of the U.S.'s oldest and largest municipally owned native plant nurseries. The GNPC, through its programs and partnerships, works towards the conservation of the region's native flora. In 2012, he initiated the Mid-Atlantic Regional Seed Bank, a partner of the national Seeds of Success program, which promotes the use of ecorgegionally-based seed collection and banking in support of meeting the region's needs for genetically appropriate wild seed. He views seed as a critical natural resource and its wise management as essential to sustainable land management and mitigating climate change. Ed joined NYC Parks in the mid 1980's where he guided the transformation of the woodlands of Prospect Park from a degraded, denuded landscape into a thriving native ecosystem. In 2012, he received the Thomas Stofka award from NYC Parks. In 2018, he was awarded the Sloan Public Service Award from the Fund for the City of New York.

An Assessment of the Need for Native Seeds and the Capacity for Their Supply: Interim Report

Stanford A. Young, Utah State University

Dr. Stanford A. Young is Professor Emeritus of Plant Science at Utah State University (USU) in Logan, Utah. He led the seed certification and foundation seed program at USU, and was instrumental in developing native plant germplasm seed certification requirements and standards (both wildland collected and field produced) for the Association of Official Seed Certifying Agencies (AOSCA). He is an Honorary Member of AOSCA. Receiving B.S. and M.S. degrees from USU, Dr. Young attended Oregon State University in Corvallis, Oregon and earned a Ph.D. in Plant Pathology and Plant Breeding in 1977. He worked as a Biochemical Field Specialist for PPG Industries, Inc. based in Fresno, California and was part time faculty member at California State University, Fresno, before accepting the position as Seed Certification Specialist in the Plants, Soils, and Climate Department at USU in 1980. Dr. Young served as Chair of AOSCA National Variety Review Boards for Grass and Alfalfa. He was appointed to the Team for DOI-BLM Core Indicators for Monitoring, Plant Materials, and Data Standards in 2011. He is the author of many scholarly publications, newsletters, and bulletins regarding seed certification and seed quality for agronomic crops and native plants. He presently serves as Treasurer for the Great Basin Chapter of the Society for Ecological Restoration.