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Restoring species diversity: assessing capacity in the U.S. native plant industry

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Large quantities of diverse and appropriately adapted native plant germplasm are required to facilitate restoration globally, yet shortages can prevent restorations from attaining desired species diversity and structure. An extensive native plant industry has developed in the United States to help meet these demands, yet very little is known about its capacity to support germplasm needs. To better understand current capacity and germplasm availability, we report results of the first comprehensive and quantitative assessment of the native plant industry in the United States, which includes at least 841 vendors nationwide and the species they make available for restoration. We synthesized lists of commercially available species from native plant vendors across the United States and identified gaps in species availability to inform germplasm research, development, and production. Of the approximately 25,000 vascular plant taxa native to the United States, 26% are sold commercially, with growth form, conservation status, distribution, and taxonomy significantly predicting availability. In contrast, only 0.07% of approximately 3,000 native nonvascular taxa are sold commercially. We also investigated how demand for germplasm to support high-quality restoration efforts is met by vendors in the Midwestern tallgrass prairie region, which has been targeted extensively by restoration efforts for decades. In this well-developed native plant market, 74% of more than 1,000 target species are commercially available, often from vendors that advertise genetically diverse, locally sourced germplasm. We make recommendations to build on the successes of regional markets like the tallgrass prairie region, and to fill identified gaps, including investing in research to support production, ensuring more consistent and clear demand, and fostering regional collaboration.

Key words: ecological restoration, germplasm, national gap analysis, native plant materials production, native plant vendors, tallgrass prairie

Implications for Practice

- More than 6,500 native plant taxa can be purchased from commercial nurseries across the United States, yet 74% of the nation's native vascular flora is unavailable for restoration efforts unless material is acquired from wild populations. Vulnerable and geographically restricted taxa are most often missing.
- The reverse is true for vascular taxa needed to restore high-quality Midwestern tallgrass prairie habitat: 74% are commercially available from regional nurseries. This region can serve as a model for efforts to fill gaps in availability.
- To increase taxonomic diversity of commercially available germplasm, we recommend (1) species-specific research to support new species production, (2) education and outreach to increase demand for native plant materials, and (3) continued investment in public–private collaborations to increase native plant supply.

Introduction

To assist the recovery of degraded, damaged, or destroyed ecosystems on the scale that current global initiatives require, large amounts of diverse and appropriately adapted germplasm are needed (McDonald et al. 2016; Miller et al. 2016). However, critical germplasm shortages can limit the scale and quality of ecological restoration efforts in the United States and globally (USDI & USDA 2002; Waters & Shaw 2003; Merritt & Dixon 2011; Ladouceur et al. 2017). Restorations often aim to recover ecosystems with diversity that matches remnant sites, but this is rarely the case (Polley et al. 2005; Barak et al. 2017; Jones et al. 2018). Although many factors may contribute to a lack of species diversity in restorations (e.g. management and site history; Grman et al. 2013), understanding and addressing limitations in germplasm availability are critical steps in supporting the restoration of diverse habitats.

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Several factors contribute to a mismatch between supply and demand for native plant germplasm, including storage limitations and the unpredictability of disturbance (Oldfield & Olwell 2015). The methods used to acquire foundation material may also exacerbate this mismatch. To maximize the likelihood that plants are adapted to a site, germplasm is often collected from nearby native stands (Johnson et al. 2010), but this approach is not always feasible, and overharvesting can negatively affect those stands (Meissen et al. 2015). To meet growing demand for native plant germplasm, restoration practitioners in the United States and elsewhere increasingly rely on the native plant industry (Oldfield & Olwell 2015; Ladouceur et al. 2017). This large, diverse, and growing billion-dollar commercial industry is well established across the United States and strongly supports ecological restoration. However, the capacity of this industry to meet current and future demand, even at the species level, is largely unknown.

The most recent efforts to characterize the native plant industry were completed in the early 2000s (Potts et al. 2002; Dunne & Dunne 2003; Hooper 2003; Smith et al. 2007; Peppin et al. 2010). These studies highlighted challenges suppliers face as they navigate a market with largely unstable demand and limited resources. However, these evaluations were narrowly focused on the western United States and based on survey responses from a small number of vendors. Critically, the U.S. native plant industry has expanded at a rapid pace since the 2000s, and will need to continue this growth to meet increasing restoration demands (Oldfield & Olwell 2015).

Here we report results of the first comprehensive and quantitative assessment of the commercial native plant industry in the United States, focusing on species availability. We identify gaps in species coverage explained by life history, conservation status, distribution, and taxonomy, and begin to understand the availability of genetically diverse material from known sources. We also investigate how demand for germplasm to support high-quality restoration efforts is met by vendors in the Midwestern tallgrass prairie region, which has been the target of extensive restoration efforts for decades. Results provide a baseline for collaborative action between restoration practitioners, the native plant industry, and researchers to meet restoration germplasm needs across the country.

Methods

Assembling Vendor and Species Lists

In 2015, we compiled information on all known commercial vendors in the United States that currently sell native plant germplasm using publically available directories and other online resources (Table S1, Supporting Information). In 2016, retail and wholesale lists of available species were obtained from all possible vendor websites or requested via email. Reported species, as well as cultivar names, were recorded. If provided, seed collection methods and source were noted.

Assigning Metadata to Species

Once species lists were digitized, they were corrected for synonymy and spelling errors using the USDA PLANTS database (hereafter “PLANTS”; USDA, 18 February 2017). Additional metadata from PLANTS were appended, including state distribution data and fields pertaining to taxonomy, ecology, and legal status. Finally, NatureServe’s Global Conservation Status Ranks were matched to taxa in three categories: G1-critically imperiled, G2-imperiled, and G3-vulnerable (NatureServe 2016). Remaining native taxa were assigned the status of G4/G5-secure.

Syntheses and Analyses

Native Plant Vendors. We summarized vendor information as follows: number of vendors currently operating in the United States, the proportion of those vendors making different types of collections (e.g. wild collection, local sourcing), and geographic coverage across states and level III ecoregions (Omernik 1987). Spatial data were added to each vendor using an online city/county/state database geocoded with Google Maps (Yin 2013), and then visualized and analyzed using ArcGIS 10.3.1 (ESRI, Redlands, California, USA).

Commercial Availability of Native Plants. We assessed representation of commercially available taxa compared to all accepted U.S. native taxa in the PLANTS database (vascular and nonvascular). We accounted for synonymy across datasets by matching on the accepted symbol provided by PLANTS. We conducted a species-level gap analysis based on PLANTS and NatureServe metadata in order to identify missing or under-represented groups. For this, each native taxon from the PLANTS database was assigned a binomial variable of commercially available (1) or unavailable (0). A generalized linear model (GLM) was fitted to determine whether variation in commercial availability in vascular taxa could be explained by (1) growth form (forb, graminoid, shrub, tree, vine), (2) conservation status (G1, G2, G3, G4/5), (3) distribution (categorized as: widespread [found in >25 states], limited [found in 6−25 states], restricted [found in 2−5 states], and endemic [found in 1 state]), and (4) taxonomy (plant family). All analyses were performed in R version 3.3.2 (R Development Core Team 2016).

Availability of Tallgrass Prairie Species in the Midwest

To assess whether commercial production matches species-level demand for high-quality restoration efforts in an ecoregion with a well-developed native seed market, we assembled a master list of 1,103 vascular taxa used in wild-collected seed mixes for tallgrass prairie restorations across the Midwestern United States (IL, IN, MN, MO, and NE) by nine member organizations within the Grassland Restoration Network (GRN). This represents slightly more than the 988 vascular taxa identified by Ladd (1997) as native to the Midwestern tallgrass prairie. The GRN conducts large, collaborative tallgrass prairie restoration projects, and uses long-term planning and experimentation with species composition to ensure high species diversity, including species that are uncommon or difficult to collect (Dolan et al. 2008; Goldblum et al. 2013). We corrected for synonymy and

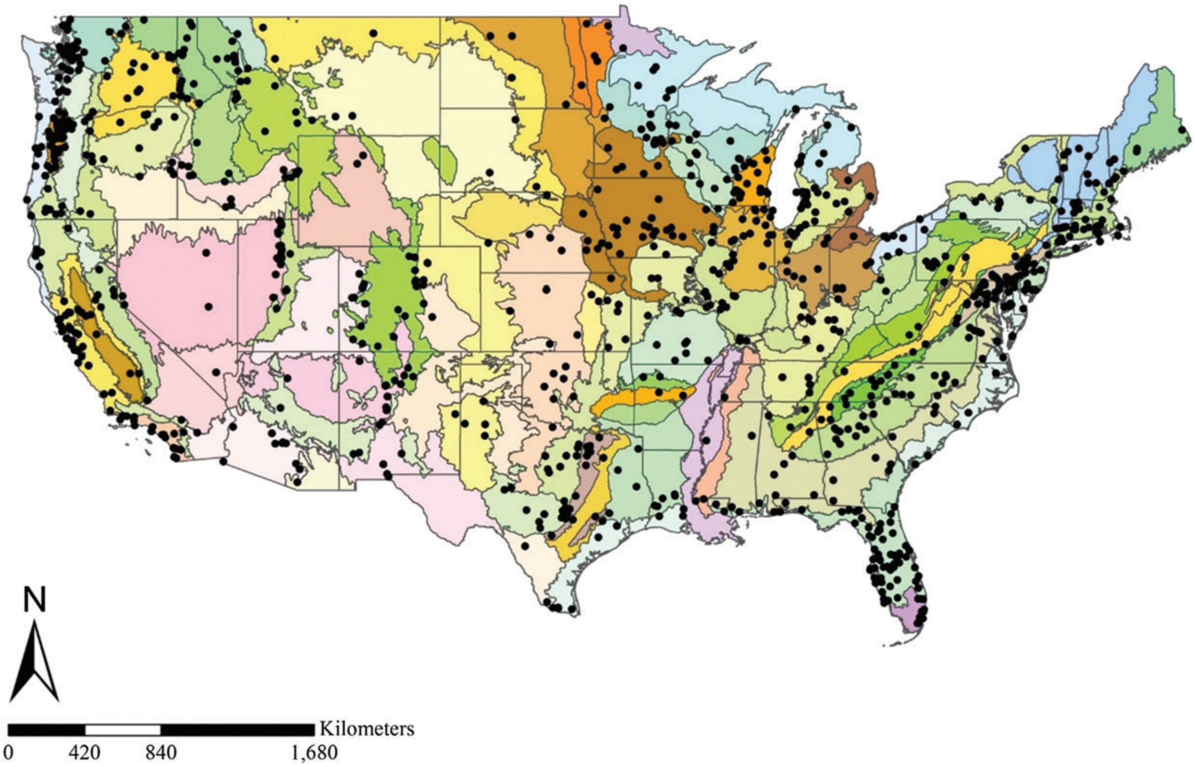

Figure 1. Spatial distribution of vendors within level III ecoregions.

compared this sample of high-quality prairie taxa to the full list of commercially available taxa from vendors in those states using GLMs, as above.

Results and Discussion

Native Plant Vendors

We compiled a list of 1,257 commercial vendors currently selling native plants germplasm, but were only able confirm the active status of 841 vendors via email or online presence. We obtained species lists from 601 of these active vendors, either online ($n = 553$) or via email ($n = 48$; 14 without a website). Vendors range substantially in size, with some facilities selling over 1,000 taxa, whereas others specialize in a few taxa. In general, small, local vendors form the core of the industry. The geographic distribution of vendors varies considerably ($n = 3-130$ vendors/state), with five states serving as "hotspots" of commercial production (CA, FL, OR, TX, and WA; Fig. 1). Of note, the flora in these states have some of the highest levels of endemism nationwide. Vendors are generally clustered near major cities, creating potential gaps in coverage for large tracts of land and ecoregions, especially in the western United States (e.g. the Wyoming Basin; Fig. 1).

Commercial Availability of Native Plants

We compiled 105,346 records of taxa available at native plant vendors across the country, with 91% successfully matched to the PLANTS database. In most cases, unmatched records were neither native nor naturalized to the United States, and were excluded from subsequent analyses. Of the matched records, 70% represented native taxa, while the remainders were introduced taxa or taxa listed as genera with no species details, and therefore no associated information on native status. In total, we identified only 26% ($n = 6{,}443$) of the 25,264 native vascular plant taxa represented in PLANTS as being available via at least one vendor. Of 2,915 nonvascular taxa native to North America, only two taxa (0.07%) were available.

Within vascular plant taxa, commercial availability varied significantly by growth form ($\chi^2 = 683.9$, $p < 0.001$), conservation status ($\chi^2 = 1114.6$, $p < 0.001$), and distribution ($\chi^2 = 2351.2$, $p < 0.0001$; Fig. 2). In particular, trees were at least three times more likely to be available than other growth forms. Secure (G4/G5) taxa and widely distributed taxa (found in more than 25 states) were also more likely to be available, while vulnerable (G3) taxa that may benefit the most from being included in restoration efforts are often missing. Commercial availability also differed significantly by taxonomic group ($\chi^2 = 2600.1$, $p < 0.0001$; Table S2). A few major plant families were more common, particularly the Asteraceae and Poaceae which comprised 24% of our dataset. A recent study found that these families also dominated restored prairies in northeastern Illinois, leading to lower phylogenetic diversity compared to remnant sites (Barak et al. 2017). The over-representation of some families in restored ecosystems is consistent with the high demand and large production volumes of these groups in this study.

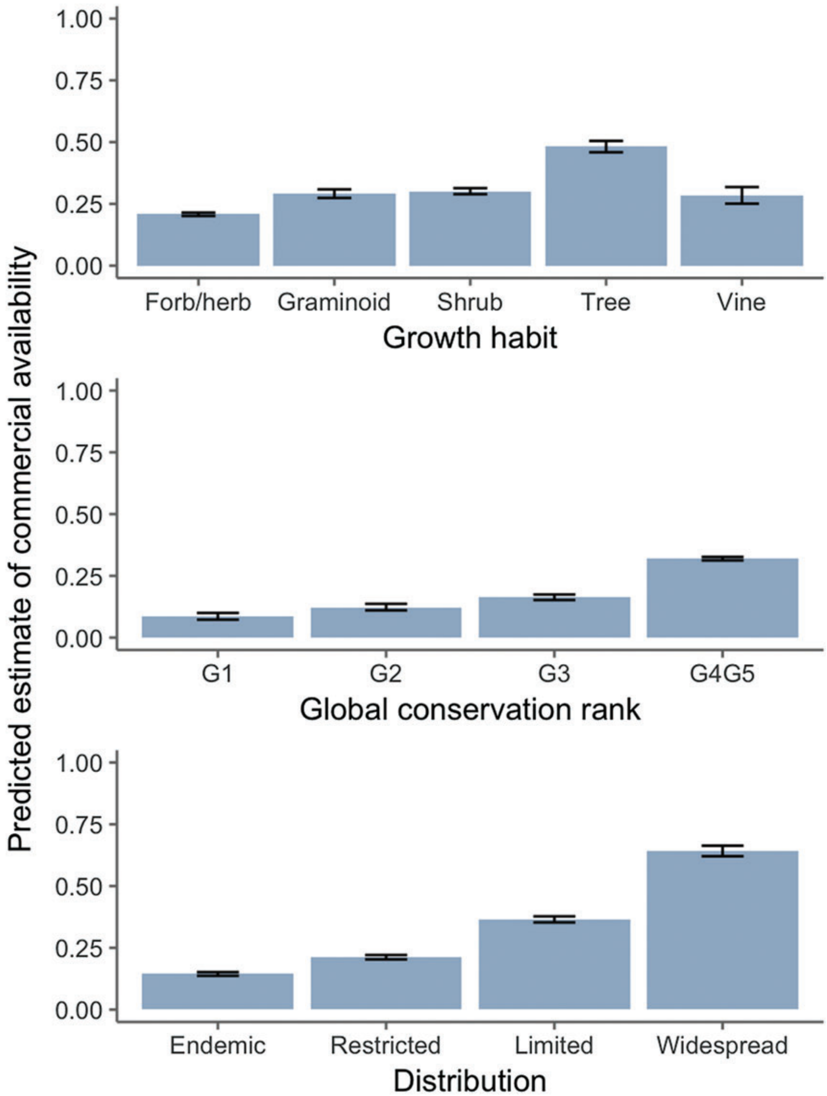

Figure 2. Predicted commercial availability of species groups: (A) growth habit, (B) global conservation rank, and (3) distribution. Probability was estimated using GLM fitted to the commercial availability data of each taxon. Bars represent the probability of that group being commercially available and error bars are the upper and lower limits of that estimate.

These results illustrate where the greatest capacity and most significant gaps in commercial availability are within the U.S. native plant industry. Incorporating more species into production is an important goal going forward, and this gap analysis can be used to help target priority species and groups of species for future research and development.

Availability of Tallgrass Prairie Species in the Midwest

We found that 74% of the 1,103 vascular taxa used for high-quality prairie restorations by the GRN were available from at least one of 64 regional nurseries. While we were not able to quantify how many of these taxa and sources are genetically appropriate for restoration use at sites across the region, nearly half of the nurseries that sell these prairie taxa specifically report providing diverse, locally sourced materials. In this region, growth form ($\chi^2 = 14.1$, $p = 0.007$) and distribution ($\chi^2 = 6.05$, $p = 0.048$) were still significant predictors of species availability but, unlike our nationwide analyses, conservation status, and taxonomy were not. Forbs and shrubs were most likely to be available, while species with a restricted distribution (2–5 states) were less likely to be available (no state-endemic species were included in the dataset).

A number of factors likely contribute to greater commercial availability of tallgrass prairie taxa relative to the United States as a whole. The tallgrass prairie is one of the world's most threatened ecosystems due to large-scale conversion to agriculture, and is also one of the most highly studied (Samson & Knopf 1994; Samson et al. 2004). Relative to other ecosystems in the country, it has a long history of public and private engagement in preservation and restoration efforts, which began as early as the 1930s (Anderson 2009). As a result, by the early 1970s a number of commercial nurseries specializing in the production of prairie taxa were established to support these efforts.

Conclusions and Recommendations

The native plant industry in the United States is comprised of more than 800 active vendors making more than 26% of the country's native vascular flora (nearly 6,500 taxa) available for restoration. While we are not aware of similar nationwide assessments in other countries, available data suggest that the United States is a global leader in producing germplasm for restoration. For example, recent surveys of the European market found that only 39% of 1,122 target restoration species are available, supplied by 100 growers in 21 countries (De Vitis et al. 2017; Ladouceur et al. 2017). While many factors contribute to the United States's leadership in this industry, much of it can be attributed to a long-standing history of government support and private partnership to restore and revegetate public and private lands (Houseal & Smith 2000; Waters & Shaw 2003). This includes nearly a century of federal investment to develop and test grass varieties for rangeland revegetation (initially non-native species, but increasingly shifting to native species), which were then given to commercial growers to produce in large quantities for revegetation efforts (Alderson & Sharp 1994; Davis et al. 2002). Other more-recent collaborative efforts between the government and commercial growers have focused on building consistent demand and developing habitat- and region-specific materials, including on public lands in the western United States (Johnson et al. 2010) and in the tallgrass prairie (Houseal & Smith 2000).

Understanding how many different sources of each species are available, including how they represent the distribution and genetic diversity of each species, requires additional research. Many vendors report selling locally sourced germplasm of known origin, but we were not able to quantify this for all vendors in our dataset. The Association of Official Seed Certifying Agencies (AOSCA) provides a framework and standards for source-identified seed, but not all growers use it. Having source-level information is necessary for practitioners seeking genetically appropriate material for their site. While determining which sources are genetically appropriate for a restoration site is a source of ongoing research, numerous guidelines exist to help circumscribe which sources may be best suited to different sites, including Provisional Seed Transfer Zones in the United States (Bower et al. 2014). To understand the extent to which source-level details for germplasm of native species are available within the United States to support the use of seed transfer zones, further investigation is needed.

Our study also identified a diversity of practices used by vendors to maintain genetic diversity, with some wild-collecting germplasm from native stands and supplementing nursery stock to increase genetic diversity. However, further work is also needed here to quantify the scale and scope of these different practices across the country. This is particularly important because genetic diversity can be easily lost or altered depending on production techniques (Basey et al. 2015).

Based on our results, we make three specific recommendations to help increase availability of native germplasm for restorations. Many of these are similar to the goals of the National Seed Strategy (NSS) for Rehabilitation and Restoration, developed in 2015 and currently being implemented by a coalition of government, nonprofit, and private sector businesses across the country (Oldfield & Olwell 2015). This strategy sets out 50-specific actions to ensure the availability of genetically appropriate seed to restore viable and productive plant communities and sustainable ecosystems. The first goal spells out the need to identify and inventory public and private sector seed collections, nurseries, and storage capacity, and this assessment is a first deliverable toward that action. Recommendations include:

1. *Research to support production:* Publicly available research on seed and reproductive biology is needed to reliably and affordably produce larger and more diverse quantities of seed for restoration (NSS Goal Two). Other studies have shown that species with published germination protocols are more likely to be commercially available (Ladouceur et al. 2017). However, seed germination requirements are unknown for many native species, limiting their use in greenhouses or in the field. Species-specific research is also needed to adapt traditional agronomic approaches to production of new species. For example, species with wind-dispersed seeds may defy conventional mechanical harvest techniques and species with a long-fruiting period may not be suited to traditional one-time harvesting. Other components of the production process, including disease and weed management, pollinator biology, and soil science, also require investigation and testing in production trials.

Public funding is needed to support this research and ensure results are widely available, promoting free exchange of best practices among nursery professionals. In the United States, Plant Materials Centers operated by the Department of Agriculture's Natural Resources Conservation Service contribute to necessary research and outreach with private growers, and are well-positioned to increase those contributions. Numerous botanic gardens and universities around the country are conducting relevant research, often as part of ecoregional native plant material development programs like the Great Basin Native Plant Program (Table S3), and have the potential to extend this work through continued partnerships. The U.S. Forest Service Reforestation, Nurseries and Genetic Resources (RNGR) program and Southern Regional Extension Forestry conduct research and sponsor the online Native Plant Propagation database, devoted to making propagation information freely available (https://npn.rngr.net/npn/propagation/protocols/). Finally, the *Native Plants Journal* provides a platform for making the results of production research on native North American plants widely available to the native plant industry and land managers.

2. *Mechanisms to drive consistent demand:* The majority of native plant providers are small businesses, and without consistent demand, many are reluctant to propagate novel

species for fear of wasted time and money if production fails or if those seeds or plants do not sell (Potts et al. 2002; Peppin et al. 2010; Shaw et al. 2012). Species not currently in production are often produced via contracted grow-outs at the request of a buyer. This approach is generally expensive, as it requires sufficient time, knowledge, and resources to locate source material and successfully increase it to the quantities needed (Shaw et al. 2005). As a result, budget- or time-limited consumers may substitute less desirable but inexpensive and readily available species when formulating their seed mixes (Shaw et al. 2012), thereby driving the current U.S. market to produce large quantities of a limited number of common, easy-to-grow species. An increase in demand for a wider range of taxa could incentivize the industry to deliver increased species diversity.

Government policy, guidance, and procurement practices are important drivers of demand for native plant germplasm. A number of federal agencies have preference policies for the use of native plants on federal lands, and a new bill introduced in 2017 aims to expand this policy (Native Plant Materials Research, Restoration, and Promotion Act; H.R.1054, 115th U.S. Congress). Demand for regionally adapted native species in the Intermountain West increased following a 2015 order issued by the secretary of the Department of Interior, which called for action to suppress and prevent rangeland fire, and to restore habitat damaged by fire using appropriately adapted native plant material (Oldfield & Olwell 2015). However, because fire cycles are often unpredictable and rarely consistent from year to year, demand for native seed can also change significantly on an annual basis, making it difficult for growers to meet supply and keep costs manageable. To address this challenge, the NSS calls for increased seed storage capacity among federal land management agencies so a consistent amount of seed can be purchased every year regardless of postfire restoration needs, thus ensuring consistent supply and demand for seed growers as well as seed users. Furthermore, research on predicted fire risk and severity is being used to help direct seed collection and increase efforts, focusing on seed zones where the probability of large and intense fires is greatest (V. Erickson 2018, US Forest Service, PNW Region, personal communication). As described in Goal Three of the NSS, producing germplasm efficiently and economically using forward planning will help maximize restoration success.

Education and communication about the key role native plants play in supporting wildlife and people is also an important driver of demand for native plant material. For example, the Federal Highways Administration is producing a technical report and resource library in collaboration with multiple partners that explains the use of native species in roadside revegetation projects and provides an online native species selection utility (USDOT & FHWA 2017). When utilized by practitioners, these educational products should further facilitate the use of native plants in restoration. Another example of education driving demand comes from recent monarch butterfly conservation efforts. With increasing awareness that habitat loss is contributing to dramatic declines in the monarch population (Pleasants & Oberhauser 2013), demand has grown for native plant materials (particularly milkweed and nectar plants) to restore habitat (Houseal 2015). This is illustrated by the Monarch Butterfly and Pollinators Conservation Fund, which has awarded \$11.1 million dollars in grant funding since its 2015 establishment, supporting the propagation of 730,000 milkweed or nectar plant seedlings to restore 127,000 acres of habitat (NFWF 2018).

3. *Public–private collaboration*: Collaboration among native plant growers, scientists, policy-makers, and land managers (NSS Goal Four) is essential for building native plant supply, demand, and funding. Informal and formal collaborations at regional scales can make more species available, as illustrated by relative success in the tallgrass prairie region where nearly 75 % of species needed for high-quality restoration are commercially available. Collaboration continues even in this region to ensure that more species and regionally appropriate sources are made available. For example, Chicago Botanic Garden is working with stewards at Nachusa Grassland to study the basic seed biology and ecology of *Comandra umbellata* (bastard toadflax), an important prairie species that, despite decades of attempts by numerous growers, has stymied all efforts to produce seed for large-scale restoration use.

There are numerous other regional public–private collaborations currently underway across the United States that aim to support research and production of more species while promoting their use and implementing policies to ensure consistent demand. This includes native plant programs in states and regions ranging from South Texas to Georgia, the Mid-Atlantic, Great Basin, Colorado Plateau, and Mojave Desert. There are also examples of U.S. government agencies working cooperatively with seed suppliers to increase the availability of native species, particularly those that are difficult to produce (Oldfield & Olwell 2015).

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Supporting Information

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

Table S1. Directories used to compile a master list of vendors selling native plant materials in the United States.
Table S2. Proportion of commercially available native vascular taxa compared to total number of taxa in plants within each plant family.
Table S3. Ecoregional Native Plant Programs in the United States, including background details, the goals of the program, region of focus, and website for additional information.

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