Sourcing native plants to support ecosystem function in different planting contexts

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Current guidance on sourcing native plants to support ecosystem function focuses on the high risk of failure when unsuitable material is used in ecological restoration. However, there is growing recognition that risks may be lower and rewards higher at highly disturbed sites isolated from remnant populations, especially when considering support for pollinators, wildlife, and other ecosystem functions. We developed the first decision support tool using expert opinion to assess suitability of different native plant sources, including horticultural cultivars, in two different planting contexts. We assessed the suitability of 761 sources for 72 commonly sold native species in two different planting contexts (small, isolated, highly disturbed sites vs. large, undisturbed sites near remnant populations). Information on genetic and adaptive backgrounds of sources was strikingly lacking, forcing us to exclude one-third of sources from our assessment. While only 3% of cultivars received high suitability scores for use in large, undisturbed sites near remnant populations, 52% received high suitability scores in small, isolated, highly disturbed sites. However, nearly 25% of cultivars had floral or leaf traits that differed from wild plants in ways that may compromise their ability to support pollinators and other wildlife. Forbs and cultivars lacking genetic diversity and source information were most likely to have altered traits. We recommend that native plant breeders and sellers work together to ensure ecosystem function, adaptation, and diversity information is available to consumers, that consumers request this information to drive demand, and that researchers further investigate how context influences risks and benefits of different sources.

Key words: disturbed habitat, ecological restoration, horticultural cultivar, native plants supporting pollinators and wildlife, seed sourcing

Implications for Practice

- Most native plant sources available in the marketplace are cultivars that are typically unsuitable for ecological restoration efforts aimed at reestablishing diverse, self-sustaining populations. However, they may be appropriate in certain planting contexts, where the primary aim is to support pollinators, wildlife, and other ecosystem functions. Our structured decision-making tool is the first of its kind to allow users to assess benefits and risks of planting these sources in different contexts.
- Information on adaptation, genetic diversity, and ecosystem function is lacking for a majority of native plant sources in the marketplace, particularly for cultivars. Native plant breeders and sellers should work together to ensure this information is available and consumers should ask for this information to help drive demand.

Introduction

The replacement of native plant communities with non-native assemblages is a key threat to global biodiversity (Olden et al. 2004). One way to stem the loss of native species and the ecosystem functions they provide is to encourage the planting of native plants across all landscapes (Burghardt et al. 2009;...
Gámez-Virués et al. 2015). To this end, there is now extensive guidance to help expert (Meli et al. 2014) and nonexpert users (LBJWCI 2018) determine which native species to select for their specific planting situation, incorporating site factors like soil type, moisture, and shade, as well as planting goals such as the replacement of invasive species or providing specific pollinator host plants. However, less guidance is available to help nonexpert users make decisions about which sources (i.e., horticultural cultivars, wild-collected material, etc.) they should use once species are selected.

Available guidance about sourcing native plant material largely targets expert users (Rogers & Montalvo 2004). Empirical seed transfer zones, which delineate where sources should come from for any given planting site, have been developed for a growing number of restoration species (St. Clair et al. 2013), while provisional seed zones use climate data as a first approximation of potentially important adaptive variation among sources and planting sites for unstudied species (Bower et al. 2014). These sourcing guidelines minimize the risk that planting material will not be adapted to the planting site, as poorly adapted material may not survive (McKay et al. 2005) or provide desired ecosystem functions (Crutsinger 2016). Guidelines also minimize outbreeding depression risk to nearby remnant populations of the same species (Frankham et al. 2011) while maximizing the benefits of increasing connectivity among remnants (Frankham 2015). Other guidance incorporates risks of planting sources with limited genetic diversity, which may not be capable of responding to temporal change if the aim is to create self-sustaining populations (Basey et al. 2015; Havens et al. 2015). All of these guidelines assume that the planting goal is to restore high-quality habitat and ecosystem function over large areas (from one to thousands of acres) near remnant habitat where gene flow from the planting to remnant populations is possible, and that consumers have access to genetically diverse sources of known provenance needed to achieve these goals.

In contrast, there is a critical lack of guidance for nonexperts who want to plant native species at small sites (under an acre) in highly disturbed soils where gene flow into remnant populations is not a concern because there is no remnant habitat nearby. This scenario is particularly common in home gardens in highly urbanized areas, but may also be the case in rural areas with intensive agriculture. The lack of guidance for these contexts is a missed opportunity, as around one-quarter of urban areas have been found to consist of private gardens where nonexperts make decisions concerning what to plant (Van Heezik et al. 2012). The rewards and risks associated with planting different sources in small, highly disturbed sites far from remnant habitat are very different from those associated with large, undisturbed sites near remnant habitat. In small, isolated, and disturbed sites, the risks of planting the wrong source are low as long as it is able to survive, while the rewards can be substantial, particularly if the landscape is comprised predominantly of non-native species (Narango et al. 2017). Aesthetics and costs also influence decisions (Van Heezik et al. 2012). While sources recommended for use in high-quality restoration efforts may be available from specialized native plant nurseries, lower-priced horticultural sources are often more easily accessible from local nurseries or national retail chains. Nonexpert consumers wishing to plant native species can become overwhelmed when trying to navigate these choices. As a result, they may purchase plants that do not survive or provide desired ecosystem functions (Wilde et al. 2015). At the most extreme, consumers may forgo planting native plants entirely.

To begin to fill this gap in guidance, we developed a decision support tool for use by nonexperts that incorporates expert opinion on the risks, rewards, and realities involved in using different sources in different planting contexts. We explicitly address how the suitability of different sources changes in two extremely different planting contexts: (1) small, isolated, highly disturbed sites, and (2) large, undisturbed sites near remnant populations. We validate this tool with a dataset of 761 sources (primarily horticultural cultivars) of 72 commonly sold native species representing forbs, grasses, and woody plants in three geographic and climatic regions across the United States. We grouped different sources into common categories to facilitate generalization of results beyond our study species and sources. Results highlight steps needed to help consumers make informed decisions when selecting sources for planting in different contexts and to increase the availability of suitable material.

**Methods**

**Developing a Decision Support Tool**

To investigate the risks and rewards of selecting different plant materials in different planting contexts, a structured decision-making (SDM) workshop was convened. Workshop participants first clarified the problem statement following Hammond et al. (1999) that included four components: (1) Many sources of native plant materials are available to consumers, each with different attributes related to genetic diversity, adaptation, and ability to support ecosystem function, particularly pollinators and other insects. (2) Attributes of each source predict benefits and risks associated with its use. (3) Planting context (including size, proximity to natural populations, and disturbance) can moderate benefits and risks associated with using sources with different attributes. (4) Guidance for nonexperts currently lacks information on selecting sources with different attributes in different planting contexts.

With this problem statement, an objectives hierarchy was produced to organize the attributes of different source materials into two categories, with the aim of determining the suitability of each source (Fig. 1; full description in Appendix S1, Supporting Information). Genetics incorporated two attributes: (1) connectivity, the potential that genes move from planted material to neighboring conspecific populations, which is either beneficial (e.g., genetic rescue; Frankham 2015) or poses risks (e.g., outbreeding depression; Frankham et al. 2011) to other populations (Table S1); and (2) genetic diversity, the amount of diversity present in the source relative to that in large wild populations of the species. Adaptation also incorporated two attributes: (1) climate, the degree to which the hardness zone where the material was originally sourced from matches the planting location; and (2) ecoregion, the degree to which the Level III Ecoregion (Omernik 1987) of the source material matches that of
the planting site. While we initially incorporated a category for *ecosystem function* directly into our objectives hierarchy, we ultimately removed it due to uncertainty in how to assign weights relative to the other categories and in different contexts. In lieu of incorporating ecosystem function in the hierarchy, we decided to capture data on potential impacts that could be incorporated in decision-making based on the goals of the user, and expect that future research on this subject will provide additional information into our hierarchy.

Weights were elicited for each attribute by experts following Larkin et al. (2016) based on two planting contexts (Fig. 1): (1) small plantings in disturbed sites isolated from remnant populations (i.e. pollen and/or seeds of planted plants cannot travel to remnant populations); and (2) large plantings in undisturbed sites near remnant populations (pollen and/or seeds of introduced plants may travel to remnant populations). This weighting reflects the relative importance of each attribute and is used to calculate a suitability score for each source in each context. A tool was built that allowed each source to be assigned a suitability score for each context using R (R Development Core Team 2017). Suitability scores cannot be calculated for sources lacking data on one or more attributes.

**Testing the Tool and Assessing Scores of Commonly Available Sources**

To test the tool and begin to understand the suitability scores of available sources in different markets and planting contexts, we selected 30 native plant species commonly sold in each of three regions of the United States: (1) Chicago, Illinois; (2) Philadelphia, Pennsylvania; and (3) Los Angeles, California. To select species for each market, we used a dataset compiled of species lists from native plant vendors in the United States (White et al. 2018). We selected the top 10 species (ranked by number of vendors selling the species) with at least one named cultivar available for each of three life forms (forb, grass, woody) for each region, resulting in a total of 72 species (some species were sold by vendors in multiple regions). Only sources known to be sold in the region being assessed were included for that region (e.g. sources sold only by vendors in California were not included in the Pennsylvania dataset).

For all sources, online searches were performed to determine the wild origin of the source (including hardiness zone and ecoregion) and the approach used to breed or select plants (including details from patents wherever possible), as well the likely genetic diversity of the material based on its collection, selection, and/or cultivation history. We also searched the Plant Finder database (MOBOT 2017) for hardiness zone information and incorporated any data recorded by the Chicago Botanic Garden and Mt. Cuba Center plant evaluation programs (Smith 2015). Finally, we assessed whether specific plant traits that research has shown have the potential to influence insect/wildlife support and potentially other ecosystem functions were different from the wild type, including: (1) floral traits like flower shape, color, scent, and provision of nectar.
Sourcing native plants in different contexts

Table 1. Description of source types, including number of sources included in the model test, average number of vendors selling sources of each type in each region, and whether or not sufficient data were available to calculate a score for each planting context. aContext 1: small, disturbed sites where gene flow to remnant populations is not possible. bContext 2: large, undisturbed sites where gene flow to remnant populations is likely.

| Source Type                                      | Number of Sources | Average Number of Vendors per Source | Able to Calculate Context 1\(^a\) Score? | Able to Calculate Context 2\(^b\) Score? | Description                                                                 |
|--------------------------------------------------|-------------------|-------------------------------------|----------------------------------------|----------------------------------------|-----------------------------------------------------------------------------|
| Unnamed, all unknown                             | 72                | 40.9                                | No                                     | No                                     | Sources with no official cultivar name where no genetic or adaptation information is available. |
| Named, all unknown                               | 187               | 1.6                                 | No                                     | No                                     | Named cultivars for which no genetic or adaptation information is available. |
| Named, no genetic diversity, climate known       | 247               | 2.4                                 | Yes                                    | No                                     | Named cultivars with little-to-no genetic diversity for which only climate data are available. |
| Named, no genetic diversity, source known        | 118               | 3.1                                 | Yes                                    | Yes                                    | Named cultivars with little-to-no genetic diversity for which source location is available. |
| Named, medium genetic diversity, source known    | 65                | 1.6                                 | Yes                                    | Yes                                    | Named cultivars where source location is available and genetic diversity is not intentionally selected against. Includes selected or tested germplasm. |
| Unnamed, high genetic diversity, source known    | 72                | 6.0                                 | Yes                                    | Yes                                    | Sources sold by vendors that explicitly state sources are genetically diverse and source location is available. |

or pollen (White 2016); (2) leaf traits like color or variegation (Baisden et al. 2018); (3) seed production; or (4) traits altered due to hybridization with another species or ecotype not native to the region (Burghardt et al. 2010). Values of zero, low, medium, or high were assigned to each attribute for each source and region (Table S2).

Following data collection, each source was assigned to one of six groups, or source types, depending on whether it was named, the relative amount of genetic diversity it contained, and whether climate or source were known (Table 1). This was used in statistical analyses to understand how generalizable our results are beyond our study species and regions. We tested whether region or life form explained differences in (1) number of sources per species; (2) potential alteration of ecosystem function using generalized linear models; and (3) suitability scores for both contexts using linear models.

Results and Discussion

Source Availability

An average of 10 sources per species were available in each region (total of 761 sources). However, the number of sources per species varied widely. More than half of all species had fewer than five named cultivars available in a single region, while at the most extreme, Phlox paniculata had 90 named cultivars available (61 in the Philadelphia region). Neither life form nor region significantly explained variation in the number of sources per species, indicating that plant breeding efforts are relatively equally distributed across urban areas in the United States, and across different life forms.

Information Availability

One-third of all sources (255) had both genetic and adaptation information available, allowing suitability scores to be calculated for both contexts (Table 1). No information was available for more than one-third (259) of the sources, categorized as “unnamed, all unknown” or “named, all unknown” source types, and these were excluded from all tests. The “unnamed, all unknown” source type was by far the most commonly sold in our dataset (average of 40.9 vendors/species in each region). Only climate information was available for one-third (247) of sources (“named, no genetic diversity, climate known” source type), allowing suitability scores to be calculated only for context 1 (small, disturbed, no gene flow to remnant). Information availability varied by location, with more information available for sources sold in Chicago and Philadelphia compared to Los Angeles. This was driven in part by data collected by plant evaluation programs at the Chicago Botanic Garden and Mt. Cuba Center, which allowed 89 sources to be evaluated that would have otherwise been excluded.

Potentially Altered Ecosystem Function

Nearly 25% of our 761 sources had altered leaf color, flower color, or morphology relative to the wild species, or were interspecies hybrids with a species not native to the region, all of which may impact the ability of the source to provide the desired ecosystem function (Burghardt & Tallamy 2015; White 2016; Baisden et al. 2018). Forbs were more likely to have potentially altered ecosystem function than grasses or woody plants (38% vs. 17 and 12% of sources, respectively; \( p < 0.001 \)). Finally, source type significantly predicted the potential for altered ecosystem function, with two source types
Sourcing native plants in different contexts

Figure 2. Percent of sources with potentially altered ecosystem function (i.e. insect/wildlife support) (A) for each source type, and (B) the average suitability score for context 1 (dark gray) and context 2 (light gray). Standard errors of the mean on raw data are shown. Note that for “unnamed, high GD, source known” source types in both contexts, standard error is 0 because all sources have the same value (99.99). GD, genetic diversity.

(named, all unknown; named, no genetic diversity, climate known) less likely to support insects and other wildlife (Fig. 2; \( p = 0.001 \)).

Suitability Scores in Each Planting Context

Large differences in suitability scores were significantly explained by source type for contexts 1 and 2 \( (F = 106.2, \ p < 0.001; \ F = 493.3, \ p < 0.001, \) respectively; Fig. 2). This indicates our categorization of source types effectively captured variation in sources available to consumers and may be a useful approach for evaluating native plant sources beyond our study regions.

Our decision support tool identified sources with very low suitability scores in context 2 (large, undisturbed, with gene flow to remnant populations), but high suitability scores in context 1 (small, disturbed, no gene flow to remnant). For example, only 10% of sources with sufficient data to run through our tool received a low suitability score in context 1, largely because they were either from plant hardiness zones unlikely to be able to survive long at the planting site, or had died when evaluated by the local plant evaluation program. The remaining sources had high suitability scores because they either came from the same or similar hardiness zones as the planting site or had performed well in the local plant evaluation program. However, 24% of the sources that received high suitability scores in context 1 had potentially altered ecosystem function.

While all sources sold by nurseries offering high genetic diversity plants with known sources (unnamed, high genetic diversity, source known) were identified as potentially appropriate for planting in context 2, only a few named sources received high suitability scores in this context. The highest scoring named source was located in the Los Angeles region and was categorized as “named, medium genetic diversity, source known.” More sources from this source type could have scored higher, but because development of this type of material has traditionally focused on the intermountain region of the western United States (Waters & Shaw 2003) and not within our study regions, “named, medium genetic diversity, source known” sources as a whole were rarely adapted to the climate in our planting regions. This meant they often scored lower than sources with no genetic diversity but known source locations from the region (Fig. 2).

Conclusions and Recommendations

The context of the planting site affects the choice of native materials suitable for planting. For example, plants used
in small, disturbed sites with no gene flow to remnant populations (context 1) may have low genetic diversity yet still provide ecosystem functions and pose few risks. Aesthetics are often incorporated into decisions when selecting materials for planting in context 1, and our results indicate that there should be greater support for these types of materials in this context, with the caveat that many materials may be so substantially altered that they do not provide desired ecosystem functions. On the other hand, at large, undisturbed sites where gene flow to remnant populations may occur (context 2), large differences in suitability scores and potentially altered ecosystem functions among source types support current guidance on selecting sources with high diversity, appropriate adaptation, and absence of altered traits.

Our decision support tool is a first step toward a formal decision-making tool for helping the general public and practitioners make informed decisions about the plant materials they select. More information is needed to improve the tool and incorporate additional landscape contexts (e.g. small sites in disturbed habitat where gene flow to remnant populations is likely, etc.) faced by users that do not easily fit into the two extreme contexts tested here. Even so, our results make it clear that not all sources available to consumers are equivalent, and consumers often lack important details about sources that impact their performance and potential to support ecosystem functions.

Specific Recommendations

(1) Expand research on how specific trait changes impact ecosystem function: More rigorous trials with more species and types of trait selection are needed to better understand which trait changes affect different ecosystem functions provided by a plant, including pollinator attraction and support, as well as palatability to wildlife.

(2) Conduct plant breeding with ecosystem function in mind: As described in Wilde et al. (2015), the use of molecular breeding tools and a more interdisciplinary approach to evaluating ornamental plants for ecological functions may help overcome the challenges of developing native plants for a commercial market that are economically viable and that possess ornamental traits that satisfy consumer demand while also supporting ecological function.

(3) Ensure relevant information follows plants through the supply chain from source to breeding to sales: At a minimum, information on the climate from which the source originated, as well as the climate in which it was selected and, if it has been evaluated, which climates were tested, should be easily accessible to consumers.

(4) Encourage buyers to ask for this information to help drive demand: Consistent demand is necessary for native plant nurseries to offer sources with high suitability scores (Handel 2017). Consumers can help drive demand by requesting information about their plant materials, and then making decisions based on their survivability and ecosystem function.

(5) Expand plant evaluation programs: Without current plant evaluation programs at Chicago Botanic Garden and Mt. Cuba Center (Smith 2015), many fewer sources would have been evaluated. These programs provide meaningful information on sources that is region-specific, and can be invaluable to individuals trying to make informed decisions when selecting material for planting in context 1 (small, disturbed sites with no gene flow to remnant populations). Having a similar program based in Los Angeles would have greatly improved our dataset. Some data for named cultivars in the Los Angeles region were available through the USDA Natural Resource Conservation Service’s Plant Materials Program, which “selects conservation plants and develops innovative planting technology to address today’s natural resource challenges and maintain healthy and productive farms and ranches” (USDA-NRCS 2019). Indeed, some of the cultivars were developed and released through one of the 25 Plant Materials Centers operated by this program. However, because of their historically rural focus, many of the releases and evaluations did not pertain to the climate in Los Angeles. Expansion of this program to more explicitly include urban areas will be valuable.

To better inform decision-making, we recommend that these programs perform evaluations on a wide range of potential soil types in the region (particularly highly disturbed soils) that could help inform planting choices. Finally, we recommend more formally incorporating the provision of ecosystem function, especially pollinator support, into the evaluation process. A citizen science effort called “Budburst:Nativars” is currently underway to do this at numerous botanic gardens, nature centers, and schools across the United States via the online program Budburst (www.budburst.org).

(6) Consider climate change: In many planting contexts users aim to plant sources that will survive well into the future. For restoration, the traditional rule of thumb has been to source material locally, with the assumption that plant material originating nearby is best adapted to the climate, soils, and other conditions at the planting site (McKay et al. 2005). However, in this era of rapid climate change, the “local is best” assumption is increasingly being questioned (Havens et al. 2015; Breed et al. 2018). Two basic approaches are being taken regarding sourcing plant materials with climate change in mind. First, “predictive provenancing” involves sourcing material from regions with climates similar to what is predicted for the planting site in the future. This depends on being able to accurately predict future climates, which is improving but still far from perfect. The other approach (regional admixture provenancing) involves sourcing materials from multiple locations to increase genetic diversity and allowing natural selection to act, with better adapted plants presumably surviving and reproducing over time (Bucharova et al. 2018).

Sourcing decisions related to climate change are most important in plantings where establishing diverse, self-sustaining populations is the goal. However, it is also important for long-lived woody plants in any planting context, where the cost of replanting trees no longer adapted to current climates can be prohibitive.
Acknowledgments

We thank Mt. Cuba Center and the U.S. Botanic Garden for funding support, R. Hawke at Chicago Botanic Garden and G. Coombs at Mt. Cuba Center for plant evaluation data, and Dana Dudle and the Kramer-Havens lab for thoughtful feedback on previous versions of this article.

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Supporting Information

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

Appendix S1. Structured decision-making workshop details.

Appendix S2. Structured decision-making tool — model code.

Table S1. Value function for connectivity score based on ecotype match.

Table S2. Species, source name, assigned source type, life form, and number of vendors listing each source in that region for all sources run through the model, shown by location of assessment.

Received: 18 September, 2018; First decision: 27 December, 2018; Revised: 15 January, 2019; Accepted: 4 February, 2019; First published online: 7 March, 2019