Chapter 18
Genetic Resources of Herbaceous Ornamentals in North America

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Abstract Herbaceous ornamental plants represent a crop category that includes hundreds of species used in diverse ways. Such plants have been an important component of constructed landscapes and represent a significant economic activity. There are many North American native species that are used as herbaceous ornamentals although worldwide trade tends to be dominated by species native elsewhere. While there are some North American herbaceous ornamentals that fit conventional definitions of a crop, and would thus benefit from availability of crop wild relatives for enhancement through breeding, many more are basically nearly wild utilized species that are readily propagated and fit the demands of the marketplace. The study and preservation of herbaceous ornamentals genetic resources significantly lags that of food and industrial crops as evidenced by scant germplasm collections and very limited representations in the collections that do exist. This chapter highlights general issues associated with crop wild relatives and wild utilized species of herbaceous ornamentals and provides examples of current status of and work with three genera: *Coreopsis* L., *Rudbeckia* L., and *Phlox* L. These are three priority genera for germplasm development and conservation at the Ornamental Plant Germplasm Center in Columbus, Ohio. The prospects for utilization of genetic resources of native herbaceous taxa are very good, but the limited resources and relatively low priority of this group of plants present considerable challenges to comprehensive conservation.

Keywords Ornamentals · Germplasm · Conservation · *Coreopsis* · *Phlox* · *Rudbeckia*

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S. L. Greene et al. (eds.), *North American Crop Wild Relatives, Volume 2*,
https://doi.org/10.1007/978-3-319-97121-6_18

18.1 Overview of Herbaceous Ornamentals

18.1.1 Introduction

18.1.1.1 Origin and History of Use Worldwide

Plants that are described as ornamental play a significant role in daily life and are arguably essential for the health and well-being of people in the twenty-first century. Although the term ornamental implies "decoration," the plants are much more than just decorative. Ornamental plants enhance our surroundings and are central to cultural landscapes. As more than half of the world population now lives in urban areas (UN 2014), the use of plants in designed/constructed landscapes will likely play an increasingly significant role in providing environmental benefits and ecological services (Wilde et al. 2015). Addressing challenges of climate change in urban areas will require creative, functional, and aesthetic use of plants to, for example, ameliorate anticipated higher temperatures through shading, reduction in glare, and moisture retention to manage storm water runoff.

Herbaceous ornamental plants represent a crop *category*, rather than a single crop, that includes many species from all over the world, with a significant representation of species native to North America. Approximately 2000 genera that include 15,000 taxa of both woody and herbaceous plants, native and nonnative, have been described for cultivation as ornamentals in the diverse climatic zones of North America (Brickell 2004). The majority of these taxa are herbaceous plants. The species within this crop category are defined not only by the type of usage but also by botanical and horticultural traits such as life cycle, habit, flowering response (seasonality, flower abundance, color), management requirements, and overall aesthetic appeal.

18.1.1.2 Modern Day Use

The primary uses of herbaceous ornamentals parallel the classification followed by the United States Department of Agriculture (USDA) of the crop category, where annual bedding/garden plants, potted flowering plants, and herbaceous perennials are grown primarily outdoors either in containers or in the ground. Indoor uses include foliage plants and indoor/patio, cut flowers, and cut cultivated greens (USDA 2016). Herbaceous ornamentals are used as part of modern urban/suburban life in small-scale residential contexts (balcony or patio plants in pots), in larger-scale residential settings with a wide range of formal and informal gardens, in commercial/industrial settings where constructed landscapes are used to enhance the image of an organization, and in much larger-scale plantings that may be components of restoration projects, highway beautifications, and even primarily functional plantings such as rain gardens and retention catchments (Fig. 18.1). Within the last couple of decades, there has also been an expansion of intense urban-setting plantings, such as green roofs and green walls, both for aesthetic and functional purposes (Rowe 2011).

Fig. 18.1 Examples of herbaceous ornamental plantings used in different landscape contexts. (**a**) Winter-tender herbaceous plants grown in containers. (**b**) Enhancement of an urban setting with a combination of herbaceous perennials and woody plants. (**c**) Native North American herbaceous perennials that include the genera *Coreopsis* L., *Echinacea* Moench, *Phlox* L., and *Rudbeckia* L.

Fig. 18.1 (continued)

Herbaceous ornamentals are the defining crops of the floriculture industry and a significant component of the nursery industry, which also includes woody plants. Worldwide trade in ornamental plants accounts for approximately US$16 billion (UN Comtrade 2016), but overall use outside of trade doubles the value to nearly US$35 billion; the USA and Canada account for only 15–20% of this worldwide activity (Hanks 2016). The majority of the international trade is based on only a couple of hundred species; and for cut flowers, a few genera predominate, such as tulips, gerberas, chrysanthemums, and carnations (Table 18.1).

Current activities in breeding and cultivar development are naturally focused on the largest segments of the floriculture/nursery industry: annual bedding and garden plants, potted flowering plants, herbaceous perennials, and cut flowers. An example of the range of genera of bedding plants that have active breeding programs can be seen in the entries for new cultivars at the Annuals Trials of the Ohio State University (https://ohiofloriculture.osu.edu/cultivar-trials; Table 18.2). Similar trials are held

Table 18.1 Major crops of herbaceous plant genera based on sales volume in the USA (USDA 2016)

Potted plants	Cut flowers
Begonia L.	*Alstroemeria* L.
Petunia Juss.	*Dianthus* L. (carnations)
Tagetes L. (marigold)	*Chrysanthemum* L.
Viola L. (pansy)	*Delphinium* L. (larkspurs)
Impatiens L.	*Gerbera* L. (daisies)
Pelargonium L'Hér. (geranium)	*Gladiolus* L.
Lilium L. (Easter lilies)	*Iris* L.
Euphorbia L. (poinsettias)	*Lilium* L.
Chrysanthemum L. (mums)	*Eustoma* Salisb. (lisianthus)
Hosta Tratt.	*Rosa* L. (roses)
Orchids	*Antirrhinum* L. (snapdragons)
Ferns	*Tulipa* L. (tulips)

Table 18.2 Genera of herbaceous ornamentals entered into the OSU Annuals Trials in 2015[a]

Agapanthus L'Hér.	***Cosmos*** Cav.[b]	***Melampodium*** L.[b]
Agastache J. Clayton ex Gronov.[b]	***Dahlia*** Cav.[c]	*Nemesia* Vent.
Angelonia Humb. and Bonpl.[c]	*Dianthus* L.	*Nepeta* L.
Antirrhinum L.	*Diascia* Link & Otto	*Petunia* Juss.
Argyranthemum Webb ex Sch. Bip.	***Euphorbia*** L.[b]	***Phlox*** L.[b]
Begonia L.	***Fuchsia*** L.[c]	*Portulaca* L.
Bidens L.[b]	***Gaura*** (*Oenothera* L.)[b]	***Salvia*** L.[c]
Bracteantha (Xerochrysum Tzvelev*)*	***Geranium*** L.[b]	*Scaevola* L.
Caladium Vent.	*Gerbera* L.	*Stachys* L.
Calibrachoa Cerv.	*Hibiscus* L.	***Tagetes*** L.[b] (marigold)
Capsicum L.[c] (orn. pepper)	***Impatiens*** L.[b]	*Verbena (Glandularia* J. F. Gmel.*)*
Canna L.[b]	*Ipomoea* L.	*Vinca* L.
Celosia L.[c]	*Lobelia* L.	***Zinnia*** L.[b]
Coleus Lour. *(Plectranthus* L'Hér.*)*	*Lobularia* Desv.	
Coreopsis L.[b]	***Mandevilla*** Lindl.[b]	

[a]Genera in bold include species native to North America
[b]Genus consists of species native in parts of North America that include USA
[c]Genus consists of species native primarily in Mexico

throughout the USA and Canada with an equivalent range of genera. Genera native to North America are identified in the table, where they constitute slightly less than half of the total.

Another example of the extent of breeding activity in herbaceous ornamentals can be seen in the annual Spring Trials held in California every year (http://www.springtrials.org). This week-long event showcases newly introduced cultivars and provides a broad perspective on the most economically important herbaceous ornamentals. Thousands of cultivars have been introduced in the past 5 years alone; the greatest numbers of new introductions are found in petunia, poinsettia, geranium (*Pelargonium* L'Hér.), begonia, calibrachoa, pansy (*Viola* L.), verbena (*Glandularia* J. F. Gmel.), chrysanthemum, impatiens, and gerbera.

Whereas worldwide trade in herbaceous ornamentals is dominated by non-US native species, there is significant commerce in the native genera such as *Agastache* J. Clayton ex Gronov., *Coreopsis* L., *Gaillardia* Foug., *Gaura (Oenothera* L.*)*, *Lobelia* L., *Penstemon* Schmidel, *Phlox* L., and *Rudbeckia* L., as evidenced by the offerings in many of the larger floriculture and nursery catalogs. A popular nursery lists 13 *Heuchera* L., 4 *Echinacea* Moench, and 3 ×*Heucherella* H. R. Wehrh. cultivars among its top 25 sellers; all these originate from native North American species (Terra Nova Nurseries 2016). Of the major herbaceous ornamentals in the trade, marigolds (*Tagetes* L.) and poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) are native to Mexico, a country also rich in genetic resources for other ornamentals such as *Salvia* L., *Zinnia* L., *Dahlia* Cav., *Capsicum* L. (ornamental peppers), *Begonia* L., *Plectranthus* L'Hér., *Agave* L., *Yucca* L., etc. (USDA, ARS 2017b).

There are more than 170 genera of North American native herbaceous ornamental plants (wildflowers, grasses, ferns, and orchids) that can be used in American gardens (Table 18.3), although the list is dominated by woodland species (Armitage 2006; Borland 2006). Armitage's compendium only lists plants available in the marketplace; thus, there are likely more species of herbaceous ornamentals that could be used for landscapes but that have not yet found their place in commerce.

18.1.1.3 Challenges in Cultivation and Use

The challenges to cultivation of herbaceous ornamentals vary by species, although there are issues in common with the production of any plant in controlled environments and with the use of plants in constructed landscapes. The high diversity of herbaceous ornamentals precludes any reasonable assessment of cultivation challenges that may be faced by each species. However, as with most crops, there are some common challenges during the production phase, such as diseases and pests. There are also challenges during the utilization phase of these plants since herbaceous perennials are grown for long periods in constructed landscapes; such challenges are associated with overall performance, resilience, drought tolerance, diseases, and occasional pests. The more typical production challenges lie in managing diseases and pests. Among the various diseases that can affect production are

Table 18.3 Genera of herbaceous ornamentals with species native to North America; including crops and WUS (Armitage 2006)

Aconitum L.	*Coreopsis* L.	*Hydrophyllum* L.	*Salvia* L.
Actaea L.	*Cornus* L.	*Hymenocallis* Salisb.	*Sanguinaria* L.
Adiantum L.	*Corydalis* DC.	*Hypoxis* L.	*Sanguisorba* L.
Adlumia Raf. ex DC.	*Crinum* L.	*Hyssopus* L.	*Saururus* L.
Agastache J. Clayton ex Gronov.	*Cynoglossum* L.	*Hystrix* (*Leymus* Hochst.)	*Schizachyrium* Nees
Ageratina Spach	*Cypripedium* L.	*Impatiens* L.	*Scutellaria* L.
Amsonia Walter	*Darmera* Voss	*Iris* L.	*Sedum* L.
Andropogon L.	*Delphinium* L.	*Isopyrum* L.	*Senecio* L.
Anemone L.	*Deschampsia* P. Beauv.	*Jeffersonia* Barton	*Shortia* Torr. & A. Gray
Antennaria Gaerth.	*Dicentra* Bernh.	*Liatris* Gaertn. ex Schreb.	*Silene* L.
Ampelaster G. L. Nesom	*Diphylleia* Michx.	*Lilium* L.	*Silphium* L.
Aquilegia L.	*Disporum* Salisb.	*Lobelia* L.	*Sisyrinchium* L.
Arisaema Mart.	*Doellingeria* Nees.	*Lupinus* L.	*Solidago* L.
Aruncus L.	*Dodecatheon* L. (*Primula* L.)	*Lysichiton* Schott	*Spigelia* L.
Asarum L.	*Dryopteris* Adans.	*Maianthemum* F. H. Wigg.	*Spiranthes* Rich.
Asclepias L.	*Echinacea* Moench	*Marshallia* Schreb.	*Sporobolus* R. Br.
Astilbe Buch.-Ham. ex D. Don	*Elymus* L.	*Mertensia* Roth	*Stipa* L.
Athyrium Roth	*Enemion* Raf.	*Mitella* L.	*Stokesia* L'Hér.
Baptisia Vent.	*Epilobium* L.	*Monarda* L.	*Streptopus* Michx.
Berlandiera DC.	*Equisetum* L.	*Muhlenbergia* Schreb.	*Stylophorum* Nutt.
Bidens L.	*Eragrostis* Wolf	*Nassella* (Trin.) É. Desv.	*Symphyotrichum* Nees
Blephilia Raf.	*Eryngium* L.	*Nemophila* Nutt.	*Symplocarpus* Salisb. ex W. P. C. Barton
Boltonia L'Hér.	*Erythronium* L.	*Oenothera* L.	*Tagetes* L.
Bothriochloa Kuntze	*Eupatorium* L.	*Onoclea* L.	*Talinum* Adans.
Bouteloua Lag.	*Euphorbia* L.	*Osmunda* L.	*Thalia* L.
Callirhoe Nutt.	*Eurybia* (Cass.) Cass.	*Pachysandra* Michx.	*Thalictrum* L.
Callisia Loefl.	*Filipendula* Mill.	*Packera* Á. Löve & D. Löve	*Thermopsis* R. Br.
Camassia Lindl.	*Gaillardia* Foug.	*Panicum* L.	*Tiarella* L.
Campanula L.	*Galax* Sims	*Parthenium* L.	*Tradescantia* L.
Cardamine L.	*Gentiana* L.	*Penstemon* Schmidel	*Trillium* L.
Caulophyllum Michx.	*Gentianopsis* Ma	*Phacelia* Juss.	*Trollius* L.
Centaurea L.	*Geranium* L.	*Phlox* L.	*Uvularia* L.

(continued)

Table 18.3 (continued)

Chamaelirium Willd.	*Geum* L.	*Physostegia* Benth.	*Veratrum* L.
Chasmanthium Link	*Gillenia* Moench	*Pityopsis* Nutt.	*Verbena* L.
Chelone L.	*Glandularia* J.F. Gmel.	*Podophyllum* L.	*Vernonia* Schreb.
Chrysogonum L.	*Helenium* L.	*Polemonium* L.	*Veronicastrum* Heist. ex Fabr.
Chrysopsis (Nutt.) Elliott	*Helianthus* L.	*Polygonatum* Mill.	*Viola* L.
Cimicifuga Wernisch. (*Actaea* L.)	*Heliopsis* Pers.	*Porteranthus* Britton (*Gillenia* Moench)	*Woodwardia* Sm.
Claytonia L.	*Heterotheca* Cass.	*Pycnanthemum* Michx.	*Yucca* L.
Clematis L.	*Heuchera* L.	*Ratibida* Raf.	*Zephyranthes* Herb.
Clintonia Raf.	*Hibiscus* L.	*Rudbeckia* L.	*Zinnia* L.
Conoclinium DC.	*Hydrastis* J. Ellis	*Ruellia* L.	

powdery mildew, botrytis blight, root rot diseases (*Rhizoctonia* D.C., *Phytophthora* de Bary, *Pythium* Pringsh., *Thielaviopsis* Went), damping off, and bacterial blight of geranium, verticillium wilt, and viruses (Daughtrey and Benson 2005). The challenges in the utilization of herbaceous ornamentals vary by the type of use in constructed landscapes, but in general, reliable performance with minimal maintenance, absence of diseases and pests, and adaptability to environmental extremes are the principal factors that influence plant quality.

18.1.2 Crop Wild Relatives and Wild Utilized Species

18.1.2.1 Genepool Classifications and Wild Species

Crop wild relatives (CWR) are defined in relation to the domesticated crops. In most food and industrial crops, there is a fully domesticated species that can benefit from traits that may be introduced from relatives. In the case of many herbaceous ornamentals, there is a less-defined demarcation between a wild and a domesticated form. Thus, both CWR and wild utilized species (WUS) will be treated together in this chapter. In the context of this chapter, WUS refers to species that are grown as ornamentals in their unimproved form, rather than those that are collected from the wild and used immediately, as is common for plants used as food and medicine. As stated by Meilleur and Hodgkin (2004): “Ambiguity remains on the status as ‘crops’ of many forestry, forage, medicinal and ornamental species, especially those recently domesticated or potentially ‘domesticable’, and thus on the status of their wild relatives as CWR.” The genepool concept of Harlan and de Wet (1971) is based on interspecific sexual compatibility between a crop and its wild relatives. Studies to delineate such compatibility have not been undertaken for most herbaceous ornamental species. The alternative genepool categories of Maxted et al. (2006), and expanded by Wiersema et al. (2012), are based on taxonomic and evolutionary relationships, and these may be of greater applicability to herbaceous ornamentals.

North America includes many species that currently are, or could be, considered herbaceous ornamentals. There are approximately 16,000 vascular plant species in 1900 genera native to the USA and Canada (Qian 1999) and more continue to be discovered (Flora of North America 2016). Mexico alone has approximately 26,000 species of flowering plants (Rhoda and Burton 2010; SciDevNet 2016). Among these thousands of North American native species are many genetic resources important for agriculture in general, such as for food and industrial crops, but the largest group of CWR and WUS from the USA is primarily used for ornamental, restoration, and medicinal purposes (Khoury et al. 2013). Regardless of the distinction between CWR and WUS, the genetic resources available in North America, as determined in the most recent survey (Khoury et al. 2013), include ten families (Asteraceae, Ericaceae, Fabaceae, Oleaceae, Papaveraceae, Plantaginaceae, Poaceae, Ranunculaceae, Rosaceae, and Salicaceae) and over 800 taxa. A representative sample of herbaceous ornamentals native to USA, presented in Table 18.4, provides a sense of the diversity of native genera that contribute to constructed landscapes. This list was selected by the author based on personal experience with the plants found in the trade and includes 29 genera and 1031 taxa.

There is no systematic or comprehensive assessment of the CWR or WUS for nearly all of the genera listed in Table 18.4. The diversity of native herbaceous ornamentals provides ample opportunity for introduction of new crops and development of new ornamental forms. The genus *Penstemon*, for example, is the third most speciose genus of native North American taxa (Kartesz 2015), representing a large reservoir of genetic diversity that has been exploited only to a very limited extent. The Ornamental Plant Germplasm Center (OPGC), a genebank at The Ohio State University that is part of the National Plant Germplasm System (NPGS), has been developing genetic resources for herbaceous ornamentals. The collection includes over 5000 accessions of more than 1000 species in over 200 genera. Some of these genera are native to North America. Among the six genera selected as priority for germplasm development, there are four with species native to North America: *Coreopsis*, *Lilium* L., *Phlox*, and *Rudbeckia*. The scope of this treatise does not allow for a detailed assessment of each native herbaceous ornamental genus. Instead, three genera, *Coreopsis*, *Rudbeckia*, and *Phlox*, will be used to illustrate the type of information being gathered to build the genetic resources for conservation and utilization.

18.1.2.2 Utilization and Potential for Expanded Use

A driving force in the use of herbaceous ornamentals is novelty. The commercial life of any new bedding plant cultivar is estimated to be only 3–5 years, so there is intense effort to develop novel flower/foliage colors or habits within established and well-known crops such as petunia and begonia. There are different breeding

Table 18.4 Genetic resources and commercially available cultivars of selected North American native herbaceous ornamentals[a]

Genus	Number of taxa	Threatened or endangered taxa Federal	State	Number of OPGC active accessions	Commercially available cultivars
Agastache J. Clayton ex Gronov.	15	0	3	92	3
Asclepias L.	46	2	19	111	29
Baptisia Vent.	24	1	8	68	25
Bidens L.	20	2	10	14	20
Coreopsis **L.**	**41**	**0**	**7**	**133**	**140**
Echinacea Moench	13	2	5	188	165
Euphorbia L.	76	2	7	53	1
Gaillardia Foug.	12	0	0	29	69
Glandularia J. F. Gmel.**	21	0	1	11	150+
Helenium L.	15	1	2	18	27
Heliopsis Pers.	2	0	0	12	18
Heuchera L.	20	0	3	14	228
Iris L.	32	1	7	1	30
Liatris Gaertn. ex Schreb.	32	2	11	100	13
Lilium L.	32	2	10	7	1
Lobelia L.	17	4	14	20	6
Monarda L.	14	0	5	76	65
Oenothera L.*	93	3	19	440	71*
Panicum L.	12	2	11	717	33
Penstemon Schmidel	199	3	20	312	124
Phlox **L.**	**114**	**2**	**15**	**378**	**247**
Rudbeckia **L.**	**42**	**0**	**10**	**267**	**62**
Salvia L.	51	0	3	129	30
Schizachyrium Nees	3	0	2	391	17
Silene L.	43	6	13	30	8
Tagetes L.	17	0	0	160	200
Tiarella L.	3	0	1	3	27
Vernonia Schreb.	10	1	4	21	7
Zinnia L.	12	0	0	141	150
Total (29)	1031		210	3936	905

[a]Included in this table are the total number of taxa for North America; the accessions also represent those that could be identified as originating in the USA, though not all of these may be native taxa. The three genera in **bold** are discussed in this chapter

[b]Data from USDA, ARS (2017b)

[c]Threatened taxa obtained from ECOS (2016)

[d]Data from USDA, ARS (2017a)

[e]Data from Ball Horticulture (2016)

approaches and strategies, ranging from sophisticated systems for many of the annual bedding plants to simple selection of unique forms in the wild for many herbaceous perennials. Some herbaceous ornamentals have been studied thoroughly as exemplified by petunia (Bombarely et al. 2016), snapdragon (Hudson et al. 2016; Schwarz-Sommer et al. 2003), geraniums, and lilies (Craig 2003). Arguably the most significant breeding tool has been interspecific hybridization. A premier example of such hybrids has been the development of the zonal geranium, *Pelargonium* x *hortorum* L. H Bailey, a hybrid of *P. zonale* (L.) L'Hér. and *P. inquinans* (L.) L'Hér. (USDA, ARS 2017b), and also the regal geranium, *P.* x *domesticum* L. H. Bailey, a complex hybrid involving *P. grandiflorum* (Andrews) Willd., *P. cucullatum* (L.) L'Hér., and others.

New germplasm, especially from wild species, is desired as a source of variation in traits of interest, including flower color, altered growth habit (e.g., trailing instead of upright, for use in hanging baskets), and disease resistance, mainly because much of the current breeding uses existing cultivars for incremental changes in the crop. In addition, clonal cultivars have little of the desirable variation. A significant challenge is the development of new ornamental plants essentially through domestication of wild species that requires some breeding so the plants meet market expectations and can be produced with relative ease. For example, many of the North American prairie forbs, such as species of *Helenium* L., *Rudbeckia*, *Silphium* L., *Sorghastrum* Nash, and *Vernonia* Schreb., tend to be tall plants that do not fit the more compact habit desirable for mass market and would need to be bred for more marketable characteristics.

The increasing interest and desire for enhanced biodiversity in landscapes and plants that provide ecological services as well as aesthetics indicates that native species are likely to play a more significant role in gardens (Tallamy 2009; Wilde et al. 2015). As recommended by McKinney (2002) and Parker et al. (2014), native plant species should be cultivated in order to maintain native biodiversity in increasingly urbanized communities. Thus, expanded use of native North American species is very possible, and greater availability and selection of such species is desirable.

In parallel with the diverse use of herbaceous ornamentals, breeding goals also vary, but there are common threads. Aesthetic value of a plant is central, and it includes traits such as flower color, number of flowers, altered flower morphology (e.g., double flowers), blooming period, and repeat blooming, as well as flower vase life. Overall habit and branching pattern are also critical; some uses emphasize a more upright habit and others a more trailing habit. General adaptability, as reflected in disease resistance, drought tolerance, and efficient nutrient uptake are also highly desirable performance traits. However, all of these aesthetic and growth attributes must be matched by ease of propagation, environmentally friendly production, minimal post-production "shrinkage" (a loss in quality in the time between the crops is produced and purchased by the end user), and high marketability (Horn 2004; Wilde et al. 2015).

A general challenge to greater use of either CWR or WUS of native herbaceous ornamentals is lack of availability of diverse and well-characterized genetic resources. Conservation of CWR and WUS of herbaceous ornamentals significantly lags the conservation of food crops; these plants are poorly represented in genebanks worldwide (Heywood 2003; Jaenicke 2013). There is only one genebank focused on herbaceous ornamentals, the OPGC, mentioned previously (Tay 2003, 2007). This relative dearth of available wild germplasm, with some notable exceptions, such as *Echinacea*, limits their more widespread use in breeding.

A second challenge to the increased use of wild species is the lack of relevant information about them. Very little is known about the potential for hybridization between these species. There is likely to be wide variation in the ability of different species to hybridize. Some appear to be relatively easy (e.g., *Coreopsis*, *Heuchera*), but others are likely to be much more challenging (e.g., *Rudbeckia*). There is also limited knowledge of ploidy and its variation within populations. For many species, such as the perennial forms of *Phlox*, there are no reliable seed germination protocols and even less knowledge about dormancy mechanisms. In addition, culture requirements have not been defined. However, increased availability of germplasm will likely lead to more studies that can provide insights into many of these issues.

A third challenge has been limited marketing of the native herbaceous ornamentals. There is a link between marketing and availability; the more demand there is for a species, the more likely is its availability. The limited use of some native species may be related to insufficient availability, but their marketing has also been very limited. A few programs exist, such as the American Beauties Native Plants® label (http://www.abnativeplants.com), that are making inroads into the market and popularizing native species.

18.1.3 Conservation Status of Herbaceous Ornamental CWR and WUS in North America

18.1.3.1 In Situ Conservation

Of the native North American genera listed in Table 18.4, about half (16 of 29) have at least one taxon on the US Fish and Wildlife Service (USFWS) list of endangered and threatened plants (ECOS 2016), and 25 of the genera have species with threatened/endangered designation in at least one state in the USA. Approximately 16% of the taxa within these listed genera are at risk in some regions of the country. A review of these taxa in NatureServe (2017) shows that 20 of the 29 genera have one or more species as either critically imperiled (G1) or imperiled (G2). Species endemic to Hawaii such as *Bidens*, *Euphorbia*, *Panicum*, and *Silene* are, not surprisingly, among the most imperiled. Information on the federally listed threatened and endangered species in Mexico can be found on the official list for the country (SEGOB 2015). Nevertheless, although it is likely that the majority of currently used or potential herbaceous ornamental taxa are not threatened or endangered in their native habitats, a thorough assessment of their conservation statuses is needed and requires detailed ecogeographical information (distribution, population size, and possible threats).

While in situ conservation is an important complement to ex situ conservation for CWR, there are very few examples of the use of this approach, even for food crops (Maxted et al. 2016). It is not surprising that in situ conservation activities related to ornamental plants are minimal. At present, the major effort lies in establishing priorities, setting targets, identifying challenges (BGCI 2016; Kramer et al. 2011; NatureServe 2017), and the summaries and gap analysis generated by Khoury et al. (2013) point the way forward. There is passive conservation of many potential herbaceous ornamental plants in protected areas and such sites can be one of the best sources of germplasm for ex situ conservation, but focused in situ conservation efforts for specific herbaceous ornamentals are rare.

The large diversity of taxa that fall under the herbaceous ornamental category makes it impossible to summarize species-specific needs and opportunities, but strategies and activities that lead to diverse habitat conservation are likely to contribute to conservation of many desired taxa. A key need is to develop an ecogeographic inventory of the herbaceous ornamental taxa at risk; this effort depends strongly on prioritizing the genera that should be surveyed to identify taxa that need protection (Meilleur and Hodgkin 2004). A good starting point would be the selection of the important genera among those listed in Table 18.3. The North American Botanic Garden Strategy for Plant Conservation includes relevant objectives for ornamental plants. For example, objective B4 pertaining to conserving plant diversity states that “Botanic gardens will contribute to the conservation and preservation of economically and culturally important plants, including crop wild relatives.” Two targets associated with this objective include the following: (1) “Botanic gardens will increase efforts to identify priorities, set targets and take action for preserving economically and culturally important plants in North America and other regions where they work.” (2) “Conservation programs for ornamental plant varieties will be developed, especially heirloom plants and plants of historical or cultural importance including those derived from non-native species” (BGCI 2016).

In situ preservation of herbaceous ornamental CWR and WUS is challenged on many fronts, most of which are no different from those of any other species. These include limited financial resources, differences in mission and objectives between organizations, and insufficient coordination between conservation activities. A specific challenge is that public perception of ornamental plants as not “critical” likely will limit funding to study and evaluate conservation needs of plants that have a primarily nonconsumptive value, regardless of the many other important benefits they provide. Herbaceous ornamentals are likely to be protected in a more passive way as part of a landscape ecology strategy that preserves critical natural habitats. There are threatened species that require targeted conservation actions, but diverse genotypes of the many species used as ornamentals will be best preserved in overall healthy natural habitats. The sheer diversity of native herbaceous species with potential for ornamental use also presents a challenge for conservation, emphasizing the need for establishing priorities based on criteria that are relevant to the use of such plants in landscapes.

18.1.3.2 Ex Situ Conservation

Genebanks with ornamental taxa in their collections are very few and primarily include the NPGS in the USA, the Leibniz-Institut für Pflanzengenetik und Kulturpflanzenforschung (IPK-Gatersleben) in Germany, the Center for Genetic Resources in the Netherlands, the National Agriculture and Food Research Organization (NARO) genebank in Japan, and the National GeneBank of China. However, botanical gardens and arboreta play a critical role in conservation of native North American taxa, including many ornamental plants. The Plant Collections Network (formerly NAPCC) is a national group of public gardens that promotes strategies for germplasm conservation and management; its major collections are of trees and shrubs, but valuable herbaceous plant collections exist at a few institutions (Plant Collections Network 2016). Examples include *Penstemon* at the Arboretum at Flagstaff and the Idaho Botanical Garden, alpine plants at the Denver Botanical Garden, *Geranium* L. at the Chicago Botanical Garden, *Sarracenia* L. at the Atlanta Botanical Garden, and ornamental grasses at the Minnesota Landscape Arboretum. Significant seed collections are stored at the Rancho Santa Ana Botanic Garden in California, the R. S. Berry Seed Bank at Portland State University in Oregon, and the Desert Botanical Garden in Arizona (Kramer et al. 2011). The Center for Plant Conservation focuses on 700 endangered species, the majority herbaceous plants, which are conserved by participating institutions (Center for Plant Conservation 2016). These are endangered species, not necessarily plants with potential use as ornamentals. On an international level, the Millennium Seed Bank of Kew Gardens in Great Britain also houses a large seed collection of native herbaceous North American species.

The OPGC conserves approximately 200 genera of herbaceous ornamentals and nearly 60% of these include species native to North America. However, many of these genera are represented by a single accession. Table 18.4 lists approximately 2400 accessions of native herbaceous taxa within 25 genera in the NPGS, but the representation of these accessions varies widely. None of the genera can be said to have a comprehensive coverage, although the most extensive collections (number in parenthesis) can be found in *Coreopsis* (133), *Penstemon* (320), *Phlox* (382), and *Rudbeckia* (267). There are collections of genetic resources that have use both as ornamentals and as medicinals (e.g., *Echinacea*, *Calendula* L.), or as industrial crops (e.g., *Salvia*). Tropical ornamentals have limited representation within the NPGS, where the Subtropical Horticulture Research Station in Florida and the Daniel K. Inouye US Pacific Basin Agricultural Research Center in Hawaii conserve some (mainly woody) ornamental plants.

As part of its mission, the OPGC actively explores and collects relevant germplasm of its priority genera in the USA including *Phlox*, *Rudbeckia*, and *Coreopsis*. Since 2006, there has been a concerted effort to develop genetic resources for these three genera, but other genera have been collected as well. Regeneration activities have also been ongoing and include work with the aforementioned genera as well as *Penstemon*, *Stokesia* L'Hér., *Tradescantia* L., and *Ratibida* Raf. The Seeds of Success program of the Bureau of Land Management (SOS 2016) has been a major contributor of new accessions of principally western USA taxa. Botanic gardens, such as Mt. Cuba Center in Delaware, have contributed germplasm of *Baptisia* Vent., *Clematis* L., *Coreopsis*, *Lilium*, *Monarda* L., and *Rudbeckia*.

There is a need for more comprehensive sampling of the priority genera at the OPGC and to expand the list of native genera targeted for conservation. Developing further collaboration with different botanic gardens in exploration and exchange is also desirable. From a technical standpoint, studies on the seed quality, dormancy, germination, and longevity of many of the native genera are of utmost importance. Limited information is available on seed management of many wild species, and this creates an opportunity for research and development, which is hampered by scant financial resources. An important tool that requires further development is the establishment of in vitro preservation protocols for selected genera because such tools are essential for the generation of disease-free material that can then be used for seed production under controlled conditions.

18.1.3.3 Suggestions on Ways to Improve Conservation

Conservation efforts may be enhanced with greater collaboration between germplasm centers and organizations, such as botanical gardens and arboreta, that have regional collections of herbaceous ornamentals. The perception that utilization of germplasm for commercial purposes is inconsistent with conservation efforts sometimes limits opportunities for collaboration. Some of this concern arises from situations where unscrupulous collectors, often with economic incentives, have decimated native populations or rare plants. However, as some have indicated, propagation may be a powerful tool for conservation; making desirable plants more readily available could be a strategy to minimize their loss in natural areas.

18.2 Examples of Herbaceous Ornamental Crop Wild Relatives and Wild Utilized Species in North America

18.2.1 Coreopsis L.

18.2.1.1 Introduction

Coreopsis is a long-standing, popular, and generally reliable garden plant grown for bright flower colors, long-blooming period, and ease of cultivation. *Coreopsis* species and cultivars are versatile: they can be used in mixed or herbaceous borders, as bedding, in containers, in naturalistic landscapes, and as components of green roofs. Of the 28 species of *Coreopsis* in North America, fewer than half have been used to any extent in constructed landscapes. The principal cultivated species (with a representative number of named cultivars in parentheses) include *C. auriculata* L. (2), *C. grandiflora* Hogg ex Sweet (10), *C. lanceolata* L. (1), *C. major* Walter, *C. palmata* Nutt., *C. pubescens* Elliott (1), *C. rosea* Nutt. (4), *C. tripteris* L., *C. tinctoria* Nutt. (2), and *C. verticillata* L. (5). However, in addition to these 25 or so cultivars of individual species, there are probably 30 or more other cultivars that are interspecific hybrids, most of mixed parentage (Armitage 2011; Padhye and Cameron 2005). There has been continuous introduction of new *Coreopsis* cultivars, most of them interspecific hybrids, developed by breeders in the USA, Europe, and Israel. One nursery (Darwin Perennials) offers 18 selections of *Coreopsis*, whereas another (Terra Nova) offers 26.

18.2.1.2 Crop Wild Relatives and Wild Utilized Species in North America

18.2.1.2.1 Genepool Classifications

Coreopsis taxonomy is organized into an eastern and a western clade (Table 18.5), although some treatments have transferred the western clade into the genus *Leptosyne* (Jepson Flora Project 2016). The extensive development of interspecific hybrids in *Coreopsis* is a consequence of the broad sexual compatibility that appears to exist within members of the eastern clade. Studies by Archibald et al. (2005) demonstrated

Table 18.5 Germplasm accessions of *Coreopsis* L. in the OPGC[a]

Region	Section	Taxon	Number of accessions	Number of cultivars
Eastern NA	*Silphidium*	*C. latifolia* Michx.	0	
	Gyrophyllum	*C. delphiniifolia* Lam.	2	
		C. major Walter	12	
		C. palmata Nutt.	7	
		C. pulchra F. E. Boynton	2	
		C. triperis L.	13	1
		C. tripteris x *C. verticillata*	1	
		C. verticillata L.	10	7
	Calliopsis	*C. leavenworthii* Torr. & A. Gray	3	
		C. paludosa M. E. Jones	0	
		C. tinctoria Nutt.	6	1
	Eublepharis	*C. falcata* F. E. Boynton	1	
		C. floridana E. B. Sm	0	
		C. gladiata Walter	3	
		C. integrifolia Poir.	1	
		C. linifolia Nutt.	0	
		C. nudata Nutt.	0	
		C. rosea Nutt.	5	5
	Coreopsis	*C. auriculata* L.	6	5
		C. basalis (A. Dietr.) S. F. Blake	1	
		C. grandiflora Hogg ex Sweet	18	17
		C. intermedia Sherff	0	
		C. lanceolata L.	12	2
		C. nuecensis A. Heller	2	
		C. nuecensoides E. B. Sm.	0	
		C. pubescens Elliott	4	1
		C. wrightii (A. Gray) H. M. Parker	4	
	Unknown	*Coreopsis* sp.	22	17

(continued)

Table 18.5 (continued)

Region	Section	Taxon	Number of accessions	Number of cultivars
Western NA	*Electra*	*C. cuneifolia* Greenm.	0	
Mexico		*C. mutica* DC.	0	
	Anathysana	*C. cyclocarpa* S. F. Blake	0	
	Tuckermannia	*C. gigantea* (Kellogg) H. M. Hall	1	
		C. maritima (Nutt.) Hook. f.	0	
	Pugiopappus	*C. bigelovii* (A. Gray) Voss	2	
		C. calliopsidea (DC.) A. Gray	0	
		C. hamiltonii (Elmer) H. Sharsm.	0	
	Leptosyne	*C. californica* (Nutt.) H. Scharsm.	0	
		C. douglasii (DC.) H. M. Hall	0	
		C. stillmanii (A. Gray) S. F. Blake	0	
	Pseudoagarista	*C. mcvaughii* D. J. Crawford	0	
		C. petrophila A. Gray	0	
		C. petrophiloides B. L. Rob. & Greenm.	0	
		C. rudis (Benth.) Hemsl.	0	
		Total	133	56

[a]Data from USDA, ARS (2017a)

the successful production of interspecific hybrids between most species of the eastern clade, although pollen viability in the hybrids ranged from 0 to 100%. Thus, there are possible limitations to the production of fertile hybrids in some crosses, but the entire clade can potentially be considered as part of GP1 or GP2 (Harlan and de Wet 1971). The barriers to interspecific hybridization that do exist have yet to be carefully delineated. The potential for crop improvement and development of new forms within the economically important *Coreopsis* is relatively high.

18.2.1.2.2 Distribution/Habitat/Abundance

Coreopsis is found throughout the continental USA (Fig. 18.2), but the eastern clade is most abundant in the southeastern region (Kartesz 2015). Only *C. palmata*, *C. intermedia* Sherff, *C. nuecensis* A. Heller, and *C. nuecensoides* E. B. Sm. are generally absent from much of this region. The most widely distributed species are *C. tinctoria*, *C. grandiflora*, *C. lanceolata*, and *C. tripteris*. The western clade species are mostly restricted to southern California. The different species occur in a wide range of soil types (heavy loams, moist clay soils, sandy or rocky soils, moist sands, alkaline flats, granite and sandstone outcrops, shale, and serpentine slopes) and habitats (prairies, open woods, pine barrens, swamps, marsh edges, peaty bogs, coastal bluffs, dunes, alkaline playas, ditches, low woodlands, flood plains, disturbed sites, roadsides, and various oak woodlands).

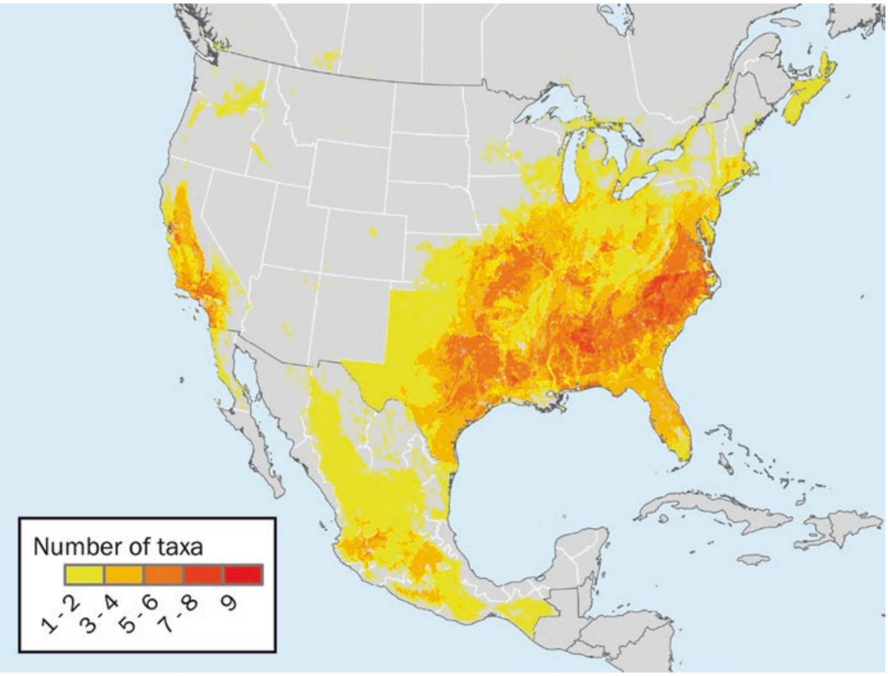

Fig. 18.2 Species richness of modeled potential distributions of North American *Coreopsis* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

18.2.1.2.3 Utilization and Potential for Expanded Use

Breeding of *Coreopsis* cultivars is relatively active, as indicated by the many new cultivars introduced within the last 15 years. The salient feature of the majority of new cultivars is new combinations of flower colors; another feature is more compact and dense habit. Cultivars with yellow foliage have also been introduced. The diversity in inflorescence colors arose from a concerted effort to combine traits from wild forms of different species with the cultivated forms. A plant patent granted in 2012 for the cultivar *Coreopsis* 'Star Cluster' states: "The inventor collected seed in the wild from five different species that are not commercialized and made six generations of crosses to produce interspecific hybrids to utilize in his breeding work" (Probst 2012). While the species are not mentioned, they likely include the colorful annual *C. tinctoria*, the white and pink-flowered forms of *C. rosea*, and other species.

The characters that are typically sought in *Coreopsis* cultivars include compact habit, alternative growth forms (prostrate, upright), variable foliage textures, variable inflorescence colors, long flowering period, lack of seed production, winter hardiness to at least USDA Plant Hardiness Zone 5, and disease resistance. The most common diseases for which resistances are sought are *Alternaria* Nees, *Botrytis* P. Micheli ex Haller, *Cercospora* Fresen. ex Fuckel, downy mildew, powdery mildew, and *Verticillium* Nees; of these, powdery mildew is the most prevalent (Daughtrey and Benson 2005), although it can be managed to a certain extent by cultural practices and fungicide treatments.

The most likely challenge to increased use of *Coreopsis* germplasm is availability of a comprehensive and well-documented collection that can expedite the introduction of new traits. Availability of such germplasm would allow other breeders to explore new combinations of traits for the crop. Many breeding programs do not have the option of extensive exploration for new germplasm in the plants' native habitats. The potential for expanded use rests with the market for *Coreopsis* in general. Superior plants with good performance, robust winter hardiness, and variable flower colors are likely to find successful placement within a range of contexts, including the native plants market.

18.2.1.3 Conservation Status of *Coreopsis* Crop Wild Relatives and Wild Utilized Species in North America

18.2.1.3.1 In Situ Conservation

The USFWS does not list any *Coreopsis* taxa as federally threatened or endangered (ECOS 2016). However, *C. latifolia* Michx. is in the Center for Plant Conservation's National Collection of Endangered Plants (Center for Plant Conservation 2016). NatureServe (2017) includes *C. hamiltonii* (Elmer) H. Sharsm., *C. integrifolia* Poir., and *C. pulchra* F. E. Boynton as either critically imperiled or imperiled at both a global and state level. *Coreopsis rosea* is listed as endangered in Canada (COSEWIC 2012) and is protected in the Pine Barrens of New Jersey (New Jersey Pinelands Commission 2012). It is listed as vulnerable by NatureServe (2017). *Coreopsis nudata* Nutt., while not uncommon in northern Florida, is considered critically imperiled in Alabama and rare or threatened in other southern states (NatureServe 2017). *Coreopsis integrifolia*, *C. pulchra*, and *C. rosea* are generally considered rare plants wherever they occur (Cosner and Crawford 1994).

The author is not aware of any in situ conservation programs that include taxa of *Coreopsis* as a specific conservation goal. For *C. rosea*, there are efforts in Canada and Massachusetts to protect habitats where the plants occur. For example, the Domero Cortelli Reserve near Plymouth, Massachusetts, includes habitat ideal for *C. rosea*; a healthy population of this species was noted at this site during a visit by the author in 2015.

In situ conservation for the rare species may benefit from a more up-to-date assessment of current efforts. Collaboration between local organizations that protect habitats and organizations, such as the OPGC, that seek to conserve the germplasm ex situ, may yield mutually beneficial outcomes. There remains resistance on the part of some in the conservation community to working with germplasm centers that provide materials to the horticulture industry; unfortunately, the industry is sometimes viewed as contributing to the decline of some rare species.

18.2.1.3.2 Ex Situ Conservation

Ex situ preservation of *Coreopsis* can be very successful since seeds of most species tend to be relatively easy to obtain and display normal, desiccation-tolerant behavior. The only genebank in North America with significant numbers of accessions of native taxa of *Coreopsis* is the OPGC, which has approximately 80 accessions of wild germplasm for 21 of the 43 taxa listed for the genus in Table 18.5. Of these, 11 have three or fewer accessions. Five taxa have ten or more accessions, but the extent of coverage within the native distribution of these species is not comprehensive. Since 2008, the OPGC has conducted four exploration/collection trips for *Coreopsis* and more are planned for the future, targeting both more comprehensive coverage of the major taxa but also aiming to include representation of all species.

Characterization of the collection is a continuous process. In a survey of 99 accessions of 18 of the 27 known eastern clade species of *Coreopsis* (67 wild accessions and 32 cultivars), it was found that the majority had DNA content equivalent to diploid chromosome numbers (Jourdan et al. 2015). In addition to the natural tetraploid *C. delphinifolia* Lam. (Smith 1975), probable tetraploids were found in cultivars of *C. rosea*, *C. verticillata*, and *C. grandiflora*.

There is a need for expansion of the ex situ collection by additional exploration, particularly for the species that are underrepresented in the collection. Sampling germplasm along the perimeter of the distribution range for the more widely distributed species, such as the northernmost range, may provide material with desirable attributes, such as cold hardiness. There is also an urgent need to obtain wild germplasm of all the western species and of the more rare species, such as *C. hamiltonii*, *C. integrifolia*, *C. nudata*, and *C. pulchra*. The use of some species in highway seed mixes and the potential for escape from cultivation makes it critical to ensure that collections are of truly wild local germplasm. The major challenge is one of limited resources primarily because of the broad mandate in the conservation of many herbaceous ornamental plants.

18.2.2 Rudbeckia L.

18.2.2.1 Introduction

Widely known as black-eyed Susan or coneflower, *Rudbeckia* species can be found throughout the USA growing along roadsides, forest and stream edges, and in open fields. For many in North America, the black-eyed Susan (*R. fulgida* Aiton) may be the quintessential wildflower species (Harkess and Lyons 1994). The cultivated forms are easy to grow, have showy inflorescences in shades of yellow and orange, are tolerant of a wide range of constructed landscape conditions, have few insect or disease problems, and require only minimal care for a show of color from summer through autumn.

The taxonomy of *Rudbeckia* is relatively well established (Urbatsch et al. 2000), although there has been reassessment of the status of some subspecific taxa, particularly for the widely distributed *R. fulgida* (Campbell and Seymour 2013). There are 23 species organized into three sections (Table 18.6). The two principal species that have important cultivars are *R. hirta* L. and *R. fulgida*. The former is grown as an annual and is widely used in beddings and containers and as a cut flower. There are both diploid and tetraploid cultivars (Palmer et al. 2009). The latter species is the most commonly grown of the perennial *Rudbeckia* species, principally the long-popular cultivar 'Goldsturm.' However, selections and cultivars exist of *R. maxima* Nutt., *R. laciniata* L., *R. nitida* Nutt., *R. subtomentosa* Pursh, and *R. triloba* L. There are both diploid and tetraploid cytotypes of *R. hirta* and *R. fulgida*, although

Table 18.6 Germplasm accessions of *Rudbeckia* in the OPGC[a]

Section	Species	Total number of accessions	Number of cultivars
Dracopis	*R. amplexicaulis* Vahl	1	
Macrocline	*R. alpicola* Piper	1	
	R. auriculata (Perdue) Kral	2	
	R. californica A. Gray	1	
	R. glaucescens Eastw.	3	
	R. klamathensis P. B. Cox & Urbatsch	0	
	R. laciniata L.	24	3
	R. maxima Nutt.	6	1
	R. mohrii A. Gray	4	
	R. montana A. Gray	0	
	R. nitida Nutt.	3	1
	R. occidentalis Nutt.	13	2
	R. scabrifolia L. E. Br.	1	
	R. texana (Perdue) P. B. Cox & Urbatsch	3	
Rudbeckia	*R. fulgida* Aiton	52	5
	R. graminifolia (Torr. & A. Gray) C. L. Boyonton & Beadle	1	
	R. grandiflora (Sweet) C. C. Gmel. ex DC.	6	1
	R. heliopsidis Torr. & A. Gray	1	
	R. hirta L.	88	24
	R. missouriensis Engelm. ex C. L. Boynton & Beadle	3	
	R. mollis Elliott	2	
	R. subtomentosa Pursh	7	1
	R. triloba L.	30	1
Unknown	*Rudbeckia* sp.	15	3
	Total	267	41

[a]Data from USDA, ARS (2017a)

tetraploids of *R. fulgida* seem to be most common (Jourdan et al. 2015; Palmer et al. 2009). *Rudbeckia* inflorescences, particularly those of *R. hirta*, are found in colors ranging from lemon yellow to gold, chestnut, mahogany, and bronze, and flowers come in single and double forms; some cultivars have quill-shaped rolled ligules.

18.2.2.2 Crop Wild Relatives and Wild Utilized Species in North America

18.2.2.2.1 Genepool Classifications

The primary genepool (GP-1) for both *R. hirta* and *R. fulgida* is the wild accessions of the same species. Both are widely distributed throughout the Eastern USA and have also become naturalized in most regions of the country where growing conditions are suitable (Urbatsch et al. 2000). The potential for the other species to be within GP-2 and GP-3 is limited by low sexual compatibility. Some interspecific hybrids appear possible, albeit with great difficulty (Palmer et al. 2009); however, attempts at such hybridization have thus far been few, so the extent to which interspecific combinations are possible needs more careful evaluation. There is one report of a somatic hybrid between *R. hirta* and *R. laciniata* (Al-Atabee et al. 1990).

18.2.2.2.2 Distribution/Habitat/Abundance

The species of *Rudbeckia* include annuals, biennials, and perennials. Four of the species (*R. fulgida, R. hirta, R. laciniata*, and *R. triloba*) are widely distributed in the continental USA, especially in the eastern half; the rest tend to have more restricted distributions in southeastern or western states (Fig. 18.3). Native stands of *R. hirta* have been found in virtually every state in the continental USA. The soil types and habitats where the different species occur vary, but moist to wet sites are preferred. Habitats include open meadows, old fields, mesic pastures, edges of woods, thickets, wet prairies, along streams, wet pine savannahs, bogs, seeps, serpentines, rocky prairies, limestone glades, and sandy soils (Flora of North America 2016).

18.2.2.2.3 Utilization and Potential for Expanded Use

The most extensive breeding effort has been made with *R. hirta*, which became an important annual crop after introduction of improved cultivars by Goldsmith Seeds in the 1960s (M. Miller, personal communication). There are tetraploid cultivars that are vegetatively propagated and diploid cultivars that are seed propagated. In contrast to the relative ease of hybridization between species in *Coreopsis*, significant barriers to interspecific hybridization occur in *Rudbeckia* (Oates et al. 2012; Palmer et al. 2009). For example, only one hybrid between *R. subtomentosa* and *R. hirta* was identified among 844 seedlings obtained from the cross. The genus has

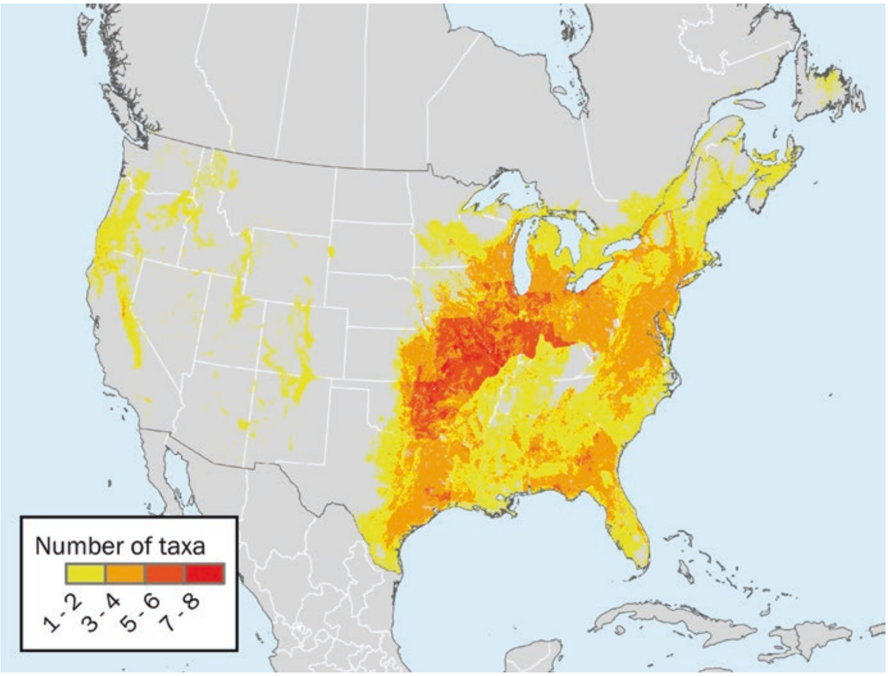

Fig. 18.3 Species richness of modeled potential distributions of North American *Rudbeckia* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

strong self-incompatibility and pseudogamy, a form of apomixis, that appears to be a common reproductive pathway (Palmer et al. 2009).

The typical traits previously described for ornamental plants are relevant for *Rudbeckia*. Novelty in flower color continues to be desirable. For some of the species (*R. laciniata*, *R. nitida*, *R. maxima*, *R. triloba*), compact habit is of great interest as this would broaden the options for use in more confined urban settings. Disease resistance in *R. fulgida* is also desirable as occasional problems occur with *Septoria* Sacc. and *Ramularia* Unger leaf spot, as well as powdery mildew and aster yellows (Daughtrey and Benson 2005).

> Increased use of *Rudbeckia* in constructed landscapes will depend on more intense domestication of species other than *R. hirta* and *R. fulgida*. Expansion of the available germplasm as well as more intensive screening for desirable traits is needed. Some compact forms have been found among the tall species, but the stability of the trait and ease of growth is still undetermined (S. Stieve, personal communication). Additional efforts at interspecific hybridization, even by protoplast fusion, could be beneficial, although prior attempts have encountered limited success. Similarly, ploidy manipulation may open possibilities that have not yet been fully examined.

18.2.2.3 Conservation Status of *Rudbeckia* Crop Wild Relatives and Wild Utilized Species in North America

18.2.2.3.1 In Situ Conservation

Some taxa are abundant throughout their native range (e.g., *R. hirta*), whereas others have a restricted distribution and lower abundance (e.g., *R. klamathensis* P. B. Cox and Urbatsch) (Kartesz 2015). *Rudbeckia auriculata* (Perdue) Kral is a rare and threatened plant restricted to the coastal plain (Diamond and Boyd 2004). NatureServe (2017) lists its conservation status as critically imperiled (S1) in Florida and Georgia and imperiled (S2) in Alabama. *Rudbeckia heliopsidis* Torr. & A. Gray and *R. auriculata* are currently under review by the USFWS for possible threatened/endangered listing (ECOS 2016). The Flora of North America (2016) describes conservation concern also for *R. alpicola* Piper, *R. klamathensis*, and *R. nitida*, as well as indicating that *R. scabrifolia* L. E. Br. is in the Center for Plant Conservation's National Collection of Endangered Plants. However, none of these species have a formal in situ conservation programs. The Nature Conservancy protects habitats of some rare species, like *R. scabrifolia* in Texas (Poole 2007). Conservation management plans for even the more abundant *R. fulgida* var. *sullivantii* have been proposed to ensure persistence of healthy populations of the species (USDA Forest Service 2003). A more comprehensive and updated study of the status of the threatened taxa is clearly needed. Making the genus a priority for conservation and identifying clear targets for conservation are necessary in order to encourage in situ conservation efforts.

18.2.2.3.2 Ex Situ Conservation

The OPGC collection of *Rudbeckia* consists of approximately 270 accessions, with about 15% of them as cultivars (Table 18.6). There is a reasonably good numerical representation of wild accessions in *R. hirta*, *R. fulgida*, *R. triloba*, and *R. laciniata*, but the geographic coverage is still limited, considering the extent of distribution of the taxa. In contrast, eight taxa have only one or two accessions, and there are no accessions of two other taxa; these accessions were not collected from the wild and represent a minimal sampling of the genetic diversity that may be available. The overall collection consists primarily of seeds, but one quarter of the taxa are represented by a single plant, obtained from commercial sources.

Exploration for *Rudbeckia* germplasm by OPGC personnel has been ongoing since 2008; three collection trips have been conducted in the USA. Additional explorations are needed both for more comprehensive coverage of the distribution of species and for more complete representation of genetic diversity within all taxa. Characterization efforts have included genome size measurements (Jourdan et al. 2015); there are both diploid and polyploid forms of some species, but polyploids were more frequent among the cultivars. The widely distributed *R. fulgida* displayed a nearly continuous variation in genome size, indicating a complexity that needs further examination to assess its significance. To be fully comprehensive, the collection must have additional representation of germplasm from diverse habitats of the widely distributed species. In addition, more sampling of the western USA taxa, including *R. alpicola, R. californica* A. Gray, *R. klamathensis*, and *R. occidentalis* Nutt., is needed. The same holds true for some of the eastern species, such as *R. auriculata*, *R. heliopsidis*, *R. mollis* Elliott, and *R. scabrifolia*. Greater availability of diverse germplasm for these species may permit a more thorough analysis of interspecific compatibilities between them.

18.2.3 Phlox L.

18.2.3.1 Introduction

The genus *Phlox* provides another example of a native North American herbaceous ornamental with current diverse utility and potential for further development and use (Locklear 2011). There are approximately 65 species that have two broad centers of distribution in the eastern and western USA (Wherry 1955). All of the important cultivated taxa are from the eastern group. The species *P. drummondii* Hook., an annual, as well as *P. subulata* L. and *P. paniculata* L., both long-lived perennials, can be considered the principal crops and are some of the most easily recognized and widely cultivated flowering plants in temperate regions of the world (Locklear 2011). There are numerous cultivars of the three principal crop species. In fact, the garden phlox, *P. paniculata*, is reported to have over 500 cultivars (Bendtsen 2009), although only a fraction of them are in the general trade; however, a specialty nursery lists 136 cultivars for sale (Perennial Pleasures 2016). Most major nursery catalogs list only a dozen or so cultivars. Both *P. subulata* and *P. drummondii* also have approximately a dozen cultivars regularly available in commerce. Other species straddle the line between a crop and a WUS; these include *P. divaricata* L., *P. carolina* L., *P. glaberrima* L., *P. maculata* L., and *P. stolonifera* Sims. *Phlox pilosa* L. is sometimes used in wildflower mixes. A popular cultivar of a perennial phlox is 'Minnie Pearl.' Initially considered an interspecific hybrid, it is actually a wild form of *P. carolina* that was found by Karen Partlow along a road in Kemper, Mississippi, and introduced into the trade by Plant Delights Nursery (T. Avent, personal communication). Thus, 'Minnie Pearl' is basically a WUS that has been vegetatively propagated and maintained; similar circumstances likely led to many cultivars of *Phlox* (Zale 2014).

18.2.3.2 Crop Wild Relatives and Wild Utilized Species in North America

18.2.3.2.1 Genepool Classifications

Interspecific sexual compatibility exists among some species of *Phlox* (Levin 1963, 1968, 1973, 1975; Levin and Smith 1966; Levy and Levin 1974; Wherry 1955), but a more comprehensive assessment of species-crossing relationships from a breeding standpoint has only recently been initiated (Zale 2014). There are reports of interspecific hybrids, some of natural occurrence, such as *Phlox* ×*procumbens* (Lehmann) Wherry (*P. stolonifera* × *P. subulata*), *P.* ×*glutinosa* Buckley (*P. divaricata* × *P. pilosa*), and *P.* ×*rugelii* Brand (*P. divaricata* × *P. amoena*) (Locklear 2011); other interspecific hybrids have been reported but poorly documented. In addition to phylogenetic distance, one possible barrier to interspecific hybridization is ploidy differences within and among species. Studies by Ferguson's group (Chansler et al. 2016; Fehlberg and Ferguson 2012a, b; Worcester et al. 2012) and by Zale (2014) have shown that cytotype variation within species may be quite frequent, although this ploidy variation may not always be readily expressed in phenotype (Chansler et al. 2016). Thus, an important need for *Phlox* genetic resources is the assessment of the ploidy of wild materials that may be used in breeding efforts.

The phylogeny of *Phlox* is still in a state of flux, but there are broad outlines that provide a guide for possible sexual compatibility between species based on phylogenetic proximity (Ferguson et al. 1999; Ferguson and Jansen 2002). For example, the status of some species, such as those of the *P. carolina/P. glaberrima* complex, as well as *P. pilosa*, is still unclear. Many of the species designations remain unresolved (The Plant List 2013). Most species exhibit extensive phenotypic and genetic diversity among populations that has resulted in a confusing taxonomic history (Zale 2014). Table 18.7 lists the principal eastern USA species arranged by subsections; also included are some western USA species. Given that interspecific hybrids have been identified, it is likely that the subsection groupings in the genus include species with sexual compatibility, at least for those within the same ploidy level (Zale 2014). However, hybridization between species of different subsections is also possible, suggesting that much of the genus may be within GP2 (C. Valin, personal communication; Zale 2014).

18.2.3.2.2 Distribution/Habitat/Abundance

Of the 65 species of *Phlox,* about 45 species occur in the western USA, and 20–23 species in the east, including much of Texas (Wherry 1955). Within the eastern region, states with the highest diversity of taxa include Tennessee, North Carolina, Virginia, Alabama, Texas, Kentucky, and Georgia (Fig. 18.4) (Zale 2014). Taxa such as *P. amplifolia* Britton, *P. floridana* Benth., *P. villosissima* (A. Gray) Small, *P. pilosa* ssp. *deamii* D. A. Levin, and others tend to be geographically remote endemics or relicts with restricted natural distributions in places of low population density and may be rare in the wild (Wherry 1955; Zale 2014). Wherry's monograph of 1955 still presents the most comprehensive assessment of the distribution of *Phlox* species; a more up-to-date evaluation of the ecogeographic patterns is clearly warranted. A detailed representation of the distribution of selected *Phlox* species is provided in Fig. 18.5 which groups species phylogenetically by subsection.

Table 18.7 Germplasm accessions of *Phlox* in the OPGC[a]

Section	Subsection	Species	Total number of accessions	Number of cultivars
Annuae	*Divaricatae*	*P. amoena* Sims	17	
		P. cuspidata Scheele	1	
		P. divaricata L.	35	9
		P. drummondii Hook.	19	13
		P. floridana Benth.	1	
		P. longipilosa Waterf.	2	
		P. nana Nutt.*	2	
		P. pattersonii Prather*	1	
		P. pilosa L.	17	4
		P. pulcherrima (Lundell) Lundell	7	
		P. roemeriana Scheele	3	
		P. villosissima (A. Gray) Small	3	
Phlox	*Cluteanae*	*P. buckleyi* Wherry	8	
	Longifoliae	*P. stansburyi* (Torr.) A. Heller*	1	
	Phlox	*P. carolina* L.	14	1
		P. glaberrima L.	14	5
		P. maculata L.	17	6
		P. ovata L.	12	0
		P. pulchra (Wherry) Wherry	6	2
	Paniculatae	*P. amplifolia* Britton	9	4
		P. paniculata L.	117	95
	Stoloniferae	*P. adsurgens* Torr. ex A. Gray*	3	1
		P. stolonifera Sims	18	6
	Subulatae	*P. bifida* L. C. Beck	13	4
		P. nivalis Lodd. et al. ex Sweet	2	1
		P. subulata L.	32	10
Occidentales	*Albomarginatae*	*P. alyssifolia* Greene*	2	
	Canescentes	*P. austromontana* Coville*	3	
		P. muscoides Nutt.*	1	
		P. opalensis Dorn*	1	
		P. pungens Dorn*	1	
		Total	382	161

[a]The emphasis of the list is on species primarily distributed in the eastern/central USA, except for the western species marked with an asterisk (*). There are 22 species (and up to 20 additional subspecies) within the eastern/central USA group (Zale 2014). Data from USDA, ARS (2017a)

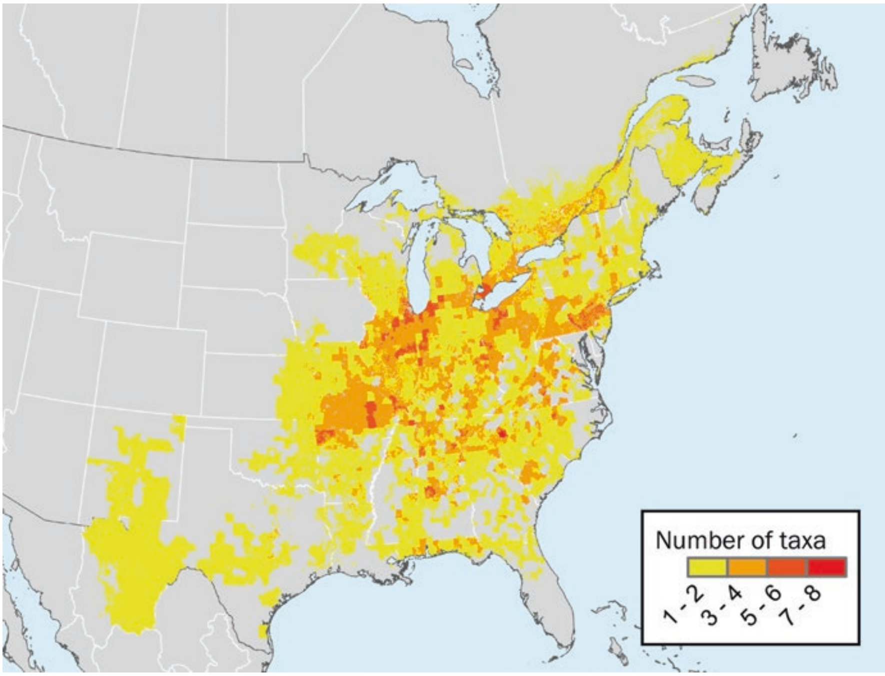

Fig. 18.4 Species richness of modeled potential distributions of *Phlox* taxa for eastern North America, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

18.2.3.2.3 Utilization and Potential for Expanded Use

The first commercial *Phlox* cultivar was released in 1824 (Symons-Jeune 1953). Since then, intensive breeding and selection has resulted in the introduction of hundreds of cultivars, primarily of *P. paniculata* and also of *P. drummondii* and *P. subulata*, but the scope of breeding efforts has been relatively limited (Zale 2014). Most of the breeding has occurred at the diploid level since the majority of cultivars in the trade are diploid (Zale and Jourdan 2015; Zale et al. 2016). Interspecific hybridization appears to have played some role in phlox cultivar development, but there is renewed interest in exploring new interspecies combinations using the germplasm that is increasingly available (Zale 2014).

The most salient feature of cultivated *Phlox* is the vivid color and abundance of flowers. Characteristics that enhance the flowering effect by providing different colors, more abundant flowers in a compact plant, and extending flower longevity are continuous goals. However, one important characteristic in need of development is resistance or reduced susceptibility to powdery mildew. The ultimate combination of traits is superior flowering with disease resistance. For some species, such as

P. paniculata, reduction in height to produce more compact plants and increasing the sturdiness of stems are also highly desirable characteristics. For *P. drummondii*, greater adaptability to more humid environments, both for landscape use and for production systems, would be desirable. For *P. subulata*, extending the flowering period or developing reblooming forms is of great interest.

As with any flowering herbaceous ornamental, novel flower colors in phlox are much sought out. The current palette centers on pinks, mauves, purples, and whites, with some gradation toward red and blue. What is lacking are strong yellows and oranges. Any germplasm that provides a way to develop these colors would be highly valued. The potential for such colors exists in the genus. Two cultivars of *P. mesoleuca* Greene, considered by some a variant of *P. nana* Nutt., showed both vivid yellow ('Paul Maslin') and fiery orange/red ('Mary Maslin') flowers; these color variants were found in the Chihuahua region of northern Mexico (Kelaidis 1984). Unfortunately, both cultivars seem to have been lost from cultivation and may even be lost in the wild (Kelaidis 2012). The principal flower pigments in phlox are anthocyanins (Bohorquez-Restrepo 2015), but carotenoids are present in some taxa, such as *P. roemeriana* Scheele and the golden-eye phlox, and it is likely that carotenoids accounted for the yellows and oranges of *P. mesoleuca*.

The potential for expanded use of phlox in constructed landscapes is significant. New plants introduced into the trade must have the desirable attributes of flower abundance and vibrant color, high quality foliage, and ease of production. *Phlox* display remarkable plasticity in growth characteristics based on growing conditions; plants that look spindly and insignificant in native habitats can display striking flowering response in cultivation. Preliminary evaluations of phlox germplasm at the OPGC suggest the combination of such traits may be possible either through different selections of wild germplasm or by interspecific hybridization. For example, *Phlox amoena* Sims and *P. bifida* subsp. *stellaria* (A. Gray) Wherry are taxa with potentially interesting horticultural attributes that could be of some value in diverse landscape settings, but more thorough evaluation of ornamental characteristics, as well as efficient propagation systems, needs to be developed to expand their use. At present, the principal challenge is the lack of availability of different accessions of the various species. Such availability will facilitate assessment of novel plants for the trade.

18.2.3.3 Conservation Status of *Phlox* Crop Wild Relatives and Wild Utilized Species in North America

18.2.3.3.1 In Situ Conservation

Most of the eastern *Phlox* taxa appear to be relatively abundant throughout their native range, but a few have restricted distributions and lower abundance, and, as a consequence, are more likely to be at risk. Among the eastern taxa, *P. buckleyi* Wherry and *P. pulchra* (Wherry) Wherry are ranked as globally imperiled and locally imperiled in their respective regions (NatureServe 2017). Two other taxa,

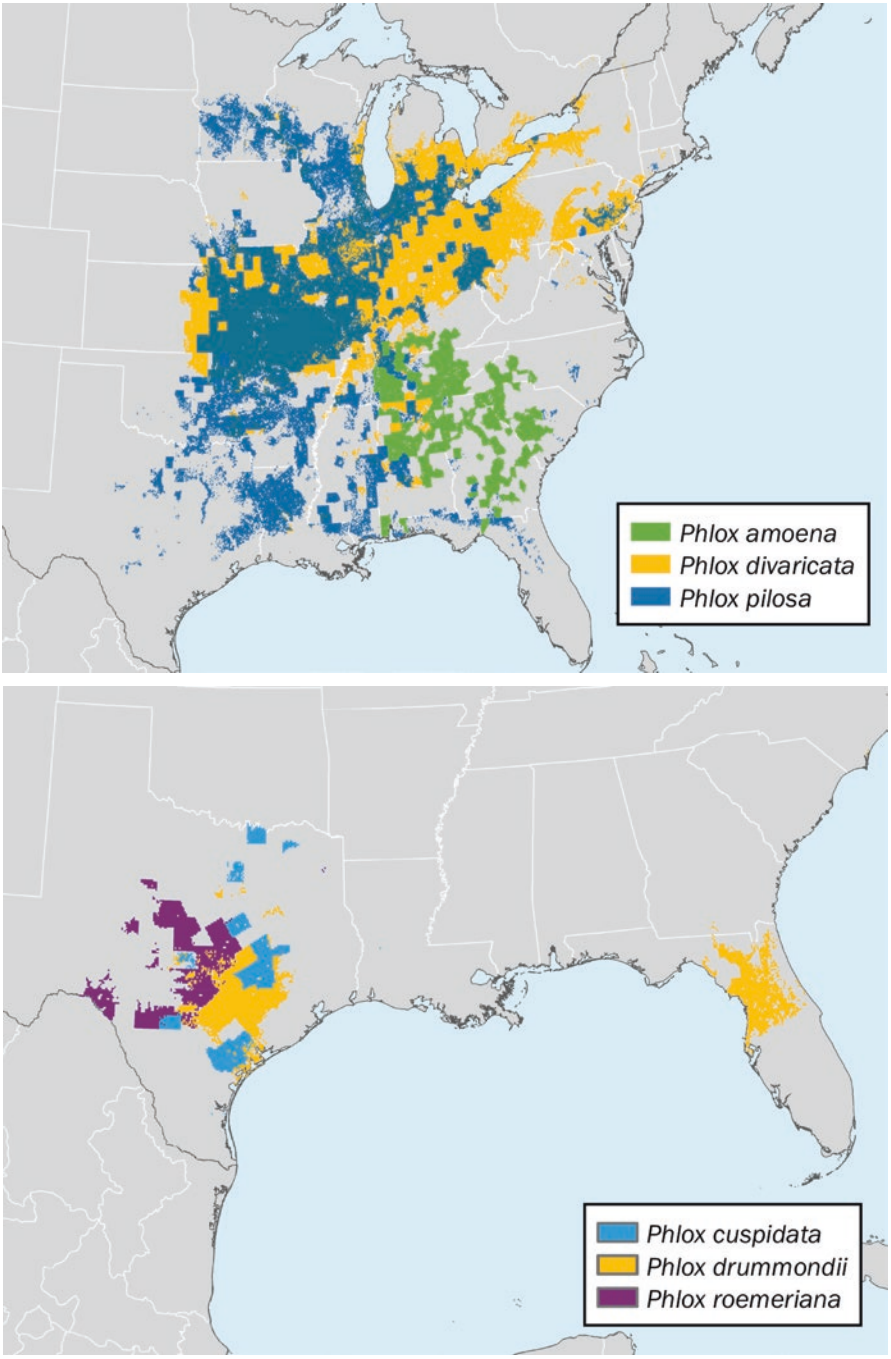

Fig. 18.5 Geographic distribution of selected *Phlox* taxa, grouped phylogenetically by subsection. (**a**) and (**b**) Subsection *Divaricatae*. (**c**) Subsection *Phlox*. (**d**) Subsection *Paniculatae.* Full methods for generation of maps and data providers are given in Appendix 1

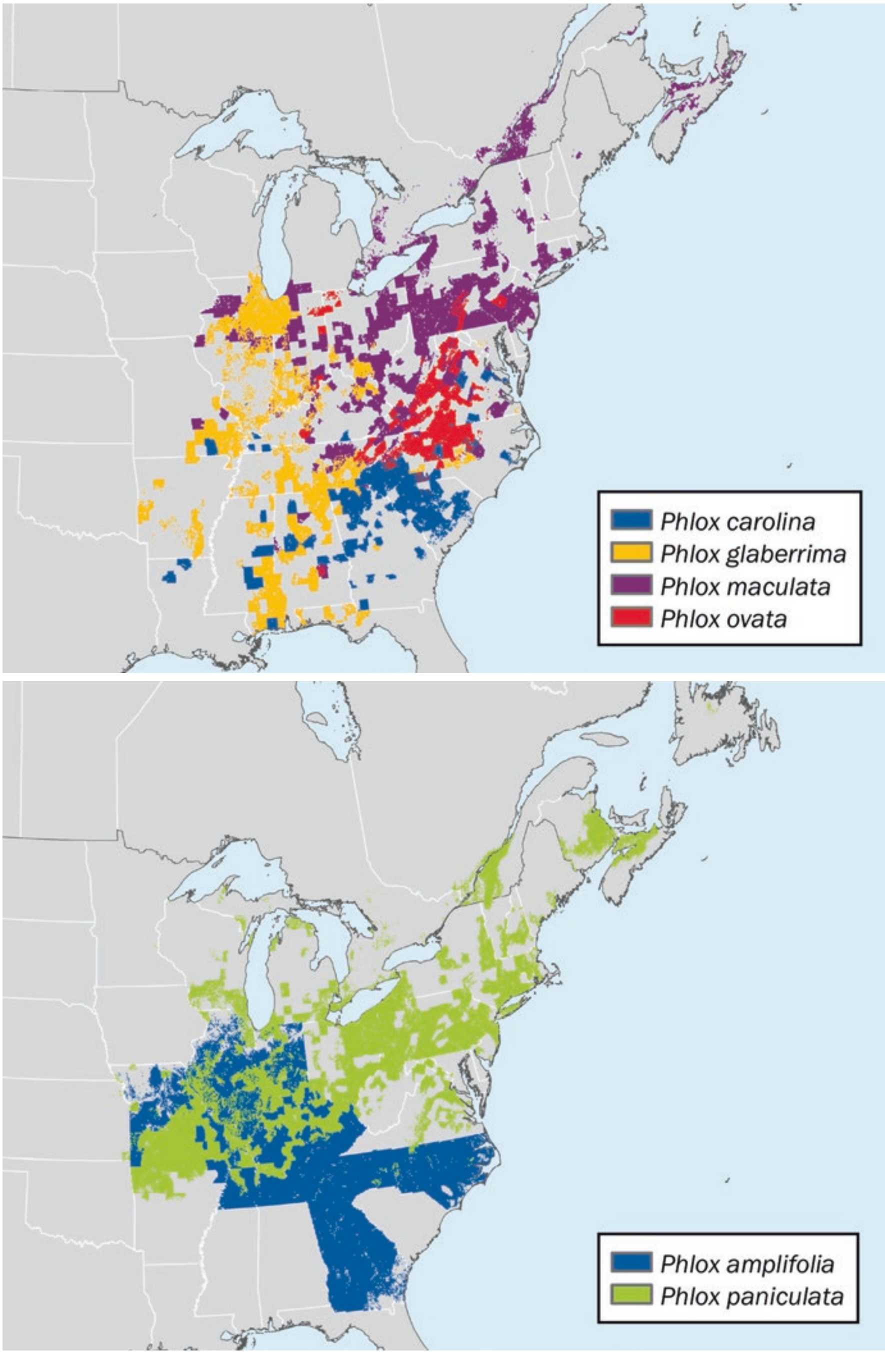

Fig. 18.5 (continued)

P. hirsuta E. E. Nelson, the Yreka phlox, and *P. nivalis* ssp. *texensis* Lundell, Texas trailing phlox, are listed as endangered by the USFWS, and recovery plans involving several agencies and organizations are in place (California Department of Fish and Wildlife 2016; ECOS 2016). The former is found in only five locations near Yreka, California (Ruane et al. 2015), and the latter is limited to fewer than 20 populations in three counties in eastern Texas (Texas Park and Wildlife 2016). *Phlox idahonis* Wherry and *P. pilosa* subsp. *sangamonensis* D. A. Levin & D. M. Sm. are included among taxa that need special conservation (Kramer et al. 2011). *Phlox idahonis* is ranked by NatureServe (2017) as critically imperiled in Idaho and *P. pilosa* subsp. *sangamonensis* as critically imperiled in Illinois. Both are also ranked as critically imperiled globally. In situ conservation efforts for *Phlox* appear to be limited to *P. hirsuta* and *P. nivalis* subsp. *texensis*. The Texas trailing phlox is under protective management at the Roy E. Larsen Sandyland Sanctuary (Texas Park and Wildlife 2016).

More extensive ecogeographic studies of phlox species are needed in order to guide possible protection of other taxa at risk. As indicated earlier, the most recent assessment of phlox distribution in the USA is more than 60 years old (Wherry 1955); thus, we do not know the extent to which changes in many populations have occurred since that time.

The yellow- and orange-flowered forms of *P. mesoleuca* indigenous to northern Mexico mentioned earlier could provide genes for pigments that may open an entire new color palette for the genus. Whether such plants still exist in the wild is uncertain, but if still present, the possibility of habitat protection is unknown. The best hope may be for ex situ conservation if it is possible under national and local laws.

18.2.3.3.2 Ex Situ Conservation

The OPGC collection of eastern *Phlox* species includes about 200 accessions obtained from natural habitats (Table 18.7). The taxa with the most accessions of wild origin include *P. divaricata, P. paniculata, P. subulata, P. amoena, P. pilosa, P. carolina, P. ovata* L.*, P. stolonifera, P. maculata, P. glaberrima*, *and P. bifida* L.C. Beck. Beginning in 2010, the OPGC initiated development of a comprehensive collection of *Phlox* germplasm, an ongoing effort that will require additional years of exploration and collection to achieve. The focus has been on eastern USA species, but selected western species are also targeted for specific traits. Because of unique characteristics of *Phlox*, the collection strategy depends not only on obtaining seed from wild sources, the preferred method, but also on collecting vegetative samples that are propagated and grown in Ohio to produce seed under controlled conditions. This strategy is needed because many taxa flower over an extended period of time and the ripened fruit readily shatter to release the seed; thus, collecting sufficient seed from some populations is restricted to a relatively narrow window of time that is easily missed. Regeneration and seed increase efforts depend on availability of various Lepidoptera pollinators because *Phlox* flowers are not pollinated by bees, a situation that challenges efforts at controlled pollinations.

There is a need for more detailed studies of phlox seed biology, including quality assessments, germination, and potential for long-term storage; this is particularly true for the perennial species. Similarly, more effective systems for controlled pollination using butterflies are needed. The analysis of genome size for the germplasm collection suggests that polyploids may be more frequent at the margins of the distribution of a species (Zale 2014). Populations of different ploidy may provide new sources of desirable traits for breeding material. Such information indicates that more comprehensive sampling of *Phlox* taxa throughout their native range is important and desirable.

The principal challenges for ex situ conservation for many of the taxa lie in the difficulty in obtaining sufficient seed of high quality that can be safely stored. The reasonable longevity in storage and germination efficiency of the annual phlox, *P. drummondii*, suggests that more effort to produce seed and study their properties in the perennial species is justified.

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