

Seeds of Success: A conservation and restoration investment in the future of U.S. lands

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Abstract

Seeds of Success (SOS) is a national seed collection program led by the Bureau of Land Management. SOS represents the most comprehensive native seed repository in the United States, supporting native plant restoration, management, and research. Since inception in 2000, SOS has collected seeds from over 24,400 native plant populations from ~5,600 taxa from 43 states. Collections include species important to wildlife, pollinators, and indigenous people, and over 10,000 collections have been shared for restoration and research use. We asked how many SOS sites have burned since collection, and identified 662 fires at 631 sites. If fire continues at the pace observed since 2011, an estimated 14% of collection sites will burn by 2050 and over 24% by 2080, putting genetic diversity at risk in areas where fire is linked with invasion. Analysis of 14 native forb species from the western United States found that many collections were from the warmest and driest portions of their range, areas at the highest risk of wildfire, subsequent invasion, and local extinction. SOS provides an opportunity to understand change in natural populations, and represents a critical repository of native plant genetic resources for conservation and future use.

KEYWORDS

climate change, conservation, diversity, fire, germplasm, habitat, native plants, restoration, seeds, seed bank

1 | INTRODUCTION

In an age of uncertainty, one thing is clear: change is on its way. Across the globe, introduced species, extended droughts, changes in storm patterns, and increases in the size and frequency of wildfires are altering natural communities and challenging land management practices (Perring et al., 2015; Svejcar, Boyd, Davies, Hamerlynck, & Svejcar, 2017). With the frequency of extreme weather events unlikely to decrease and species introductions

continuing apace, it is very likely that natural communities will experience additional pressures (Seebens, 2019; Vázquez, Gianoli, Morris, & Bozinovic, 2017). In the face of uncertainty, one strategy for maintaining functioning ecosystems is to conserve diversity (Maestre et al., 2012; Schulze & Mooney, 1994), including taxonomic and ecotypic diversity (variation across a species range, Linhart & Grant, 1996). Plant diversity has been repeatedly shown to increase ecosystem services, including modulating effects of disturbance in both natural (Isbell et al., 2015) and

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managed (Kahiluoto et al., 2019) systems. Thus, as we face unprecedented extinction risks and threats to the stability of native ecosystems (Diaz et al., 2019), the maintenance of plant diversity and the restoration of diversity in disturbed areas should be a high priority for scientific and management communities, as well as human societies.

A concrete step toward maintaining plant diversity is to protect existing populations through either *in situ* (on-site) or *ex situ* (off-site) preservation of seed. *In situ* conservation is preferred because it preserves not only existing diversity, but also allows for evolutionary responses to change (Franks, Sim, & Weis, 2007; Hoffman & Sgro, 2011), and because it can happen at a greater scale than *ex situ* conservation. However, in areas where we are actively losing native plant populations, such as arid regions of the western United States where fire and invasive species are transforming plant communities (D'Antonio, 1992; Mahood & Balch, 2019), *ex situ* conservation of existing genetic resources, in the form of seed banking, is emerging as a way to preserve options for future generations and generate seed reserves needed for restoration needs (Haidet & Olwell, 2015). Seed banking is recognized as crucial for preserving diversity in wild crop relatives (Li & Pritchard, 2009) for food security and agriculture, and the importance of seed banking other native plants to maintain and restore functioning ecosystems is increasingly recognized. For example, the Millennium Seed Bank, the world's largest *ex situ* repository of native seeds, is a global network run by the Royal Botanic Gardens Kew that houses an incredible collection of over 92,500 accessions of over 40,000 plant species from around the world (www.kew.org). These collections are in long-term storage to fulfill conservation, research, and restoration needs.

Within the United States, there is another major ongoing effort to preserve genetic diversity in wild native plants. Led by the U.S. Department of Interior, Bureau of Land Management (BLM), the Seeds of Success (SOS) program originated in 2000 as a collaboration with the Millennium Seed Bank project and has been maintained as a separate project by Congressional appropriations as a way to provide native seed for the rehabilitation of plant communities. While other seed collection projects (U.S. Department of Agriculture [USDA], U.S. Forest Service, National Park Service, private sector botanic gardens, and nonprofit organizations) have focused on meeting local and regional needs, the SOS program is the only U.S.-wide native seed collection and conservation effort for restoration. This program focuses on plant species that are widely distributed and/or are important components of North American terrestrial ecosystems, and are thus considered important for restoring ecosystem function following disturbance.

The mission of SOS is to contribute to conservation efforts through seed collection and the training of future

conservation scientists (Figure 1), and SOS partners with many organizations, including federal agencies, state agencies, the seed industry, and nonprofit organizations, to achieve this goal (Haidet & Olwell, 2015). SOS seed is collected following procedures outlined in the SOS protocol (see Supporting Information). These collections are the first step in facilitating the commercial production of native plants for restoration, and collections are used to establish seed increase fields and grow woody plants for transplanting onto public lands. Providing seeds from wild collections for increase, rather than restoring directly from field collections, is an important way to provide the quantities of seed needed for restoration without compromising wild populations (Nevill, Cross, & Dixon, 2018). Seed collected by the program is also provided to research partners focused on agronomic production of native seed, improving the effectiveness of seeding treatments, and improving restoration practices.

With the 20-year anniversary of SOS in 2020, we are taking the opportunity to describe program accomplishments to-date. The authors of this article represent BLM coordinators of native plant programs, including SOS (P. O. and F. E.), partners of SOS (L. P.), and scientists with interests in native plant ecology who use the collections to answer research questions (E. A. L. and S. C. B.). Our objective in this article is to describe how current conservation efforts are keeping up with future restoration needs, with a specific focus on the SOS national seed banking program, and we address this objective with three specific goals:

First, we tabulate and present information on the SOS program, including the composition and distribution of existing collections, so future collection goals can be formulated. We also discuss the program's strengths, weaknesses, opportunities, and threats, from our perspective, and consider how to ensure the program continues to meet the U.S.'s seed needs into the future.

Second, as a measure of the potential importance of *ex situ* conservation in preserving native plant diversity, we investigated how many SOS collection sites have burned since collection. While fire is a natural component of many ecosystems, climate change, and anthropogenic activity are linked to increased fire frequency, size, and longer fire seasons (Balch et al., 2017). This is important because fire and subsequent invasion can lead to a loss of genetic resources in many systems (Banks et al., 2013; Fusco, Finn, Balch, Nagy, & Bradley, 2019). For example, in the Great Basin of the United States, which is home to one of the largest ongoing wildland seeding treatments in the world (Pilliod, Welty, & Toevs, 2017), there is a strong link between annual grass invasion, fire, and native plant population decline and extirpation (Balch, Bradely, D'Antonio, & Gomez-Dans, 2013; Chambers & Wisdom, 2009). Thus, in systems where *in situ* conservation is at risk from



FIGURE 1 The Seeds of Success (SOS) program trains conservation scientists to wild-collect seeds of native plants for conservation and restoration activities, as well as how to collect plant vouchers for herbaria. Studying and preserving native plant diversity is key for understanding native plant ecology and restoring ecosystem function as disturbances become larger and more frequent. Photos courtesy of the Desert Botanical Garden, the Chicago Botanic Garden, the U.S. Bureau of Land Management (BLM), Mike Howard (BLM New Mexico), the Student Conservation Corps, and the SOS program collection crews: CA350, CA170, CA930A, CO932, NV030, NV040, NV052, and WY932A

disturbances such as fire and invasion, SOS collections conducted before a burn may represent an irreplaceable reserve of prefire, preinvasion plant diversity.

Third, we sought to understand how SOS collections are distributed across a species' environmental range, and whether collections match restoration needs. Plant populations are known to vary greatly in response to local biotic and abiotic conditions (Baughman et al., 2019; Hereford, 2009; Leimu & Fischer, 2008), and as a first step toward understanding the breadth and distribution of the SOS collections, we created a series of models of potential habitat, based on climate suitability, for a sample of 14 high-priority forb species native to the western United States. We modeled area of occupancy for these target species, hereafter referred to as suitable habitat, and asked how well collection sites represent climatic conditions across each species' range. To determine whether collections

match conservation and restoration need, we asked two related questions, knowing that the immediate need for many of these species is for postfire restoration. First, we asked how much of each species' suitable habitat has burned since collection began, as an indication of relative need, and second, how climatic variables at collection sites of target forbs compare to conditions at historic restoration sites.

2 | METHODS

2.1 | SOS programmatic information

SOS collection data from 2000 to 2018 were compiled from 24,462 records. We tabulated the number of taxa, genera, and plant families collected, the number of collection interns since program inception, the number of

U.S. states with SOS collections, and the number of seed collections that have been distributed for restoration and research use, through 2017. We also tabulated the number of collections per year, the number of plants sampled for each collection, and the estimated population size of each collection, and compared these metrics from the first years of the SOS program (2000–2008) to the most recent years (2009–2017) using general linear models.

2.2 | Quantifying fires at SOS collection sites

We obtained geospatial fire records for fires occurring across the United States, spanning the years 2000–2018, from GeoMAC (Geospatial Multi-Agency Coordination - Wildland Fire Support accessed: November 21, 2018 (2000–2017), May 16, 2019 (2018), <https://www.geomac.gov/>). We used these data to determine how many of a subset of 18,202 populations that have been georeferenced to date have been impacted by fire since the date of collection.

2.3 | Case study of western forbs

We performed in-depth analyses on 14 focal forb species known to be specifically or generally important for providing resources for sagebrush obligate wildlife in western states (Connelly, Rinkes, & Braun, 2011; Dumroese,

Luna, Pinto, & Landis, 2016; Dumroese, Luna, Richardson, Kilkenny, & Runyon, 2015; Wood, Doherty, & Padgett, 2015), and for their current and potential use in seed increase efforts for restoration purposes. Species included: *Amsinckia tessellata*, *Astragalus filipes*, *Balsamorhiza sagittata*, *Chaenactis douglasii*, *Cleome lutea*, *Crepis acuminata*, *Erigeron pumilus*, *Erigeron speciosus*, *Heliomeris multiflora*, *Lomatium dissectum*, *Machaeranthera canescens*, *Penstemon speciosus*, *Phacelia hastata*, and *Sphaeralcea grossulariifolia*.

2.3.1 | Estimating species distributions

We created binary species distribution maps for each focal species using a Maxent modeling approach, as outlined in Barga, Dilts, and Leger (2018). Briefly, we gathered occurrence points from georeferenced herbarium data and researcher-documented point locations, and gathered environmental variables that were created using a Thornwaite water balance approach, based on PRISM temperature and precipitation data (Daly et al., 2008). Next, we separated the presence data for each species into test and training groups and created an iterative series of Maxent models that varied in both feature type(s) and regularization parameter. The best model for predicting the suitable climate for each species was selected, based on Akaike's information criterion values created using ENMTools (Warren, Glor, & Turelli, 2010),

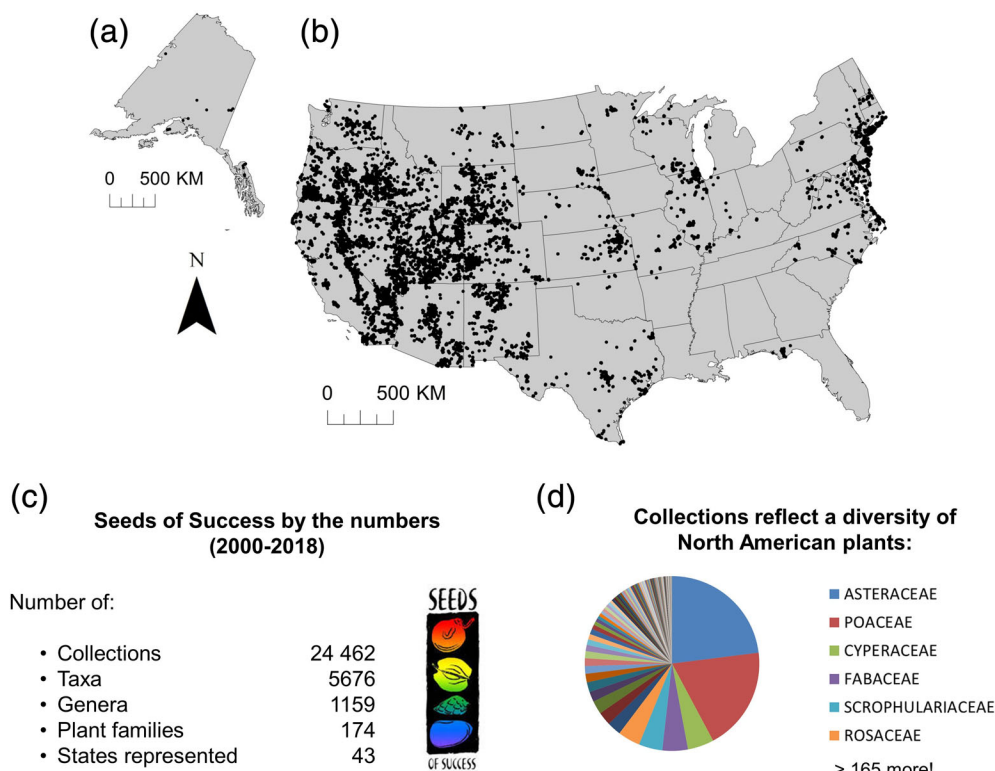


FIGURE 2 The Seeds of Success (SOS) collections contain 18,149 georeferenced SOS collection sites in (a) Alaska and (b) the lower 48 United States; note the focus on Western states, where there are abundant public lands. SOS collections also (c) represent broad taxonomic and geographic groups and (d) reflect a diverse range of plant families

and used to estimate the geographic distribution for each species. For more information on the calculation of environmental variables, model background selection, model optimization, and model selection, see Barga et al. (2018).

2.3.2 | Suitable habitat, fire history, and seed collection locations

To ask how collection locations were distributed across each species' potentially suitable habitat, we used binary species distribution maps for each of our focal species to select 500 random points across their estimated area of occupancy using ArcMap 10.5. We then extracted values for four environmental variables (annual precipitation [mm], summer [June, July, August] precipitation [mm], annual minimum and maximum temperature [$^{\circ}$ C]) from both the SOS collection locations for each species and at the random points across each species' distribution.

These variables were selected because previous work indicated that they were highly predictive of suitable climate for multiple Great Basin forbs (Barga et al., 2018). We analyzed differences in environmental variables between SOS collection sites and random points using general linear models. We also asked what proportion of the potential habitat of our focal species was affected by fire across this 18-year timeframe based on the binary species distribution maps.

2.3.3 | Conditions across seed collection locations versus areas of restoration seeding

We acquired geospatial records for all of the implemented or planned restoration seedings on public lands that were available from the Land Treatment Data Library, for the timeframe of 2000–2017 (Pilliod & Welty, 2013). We used

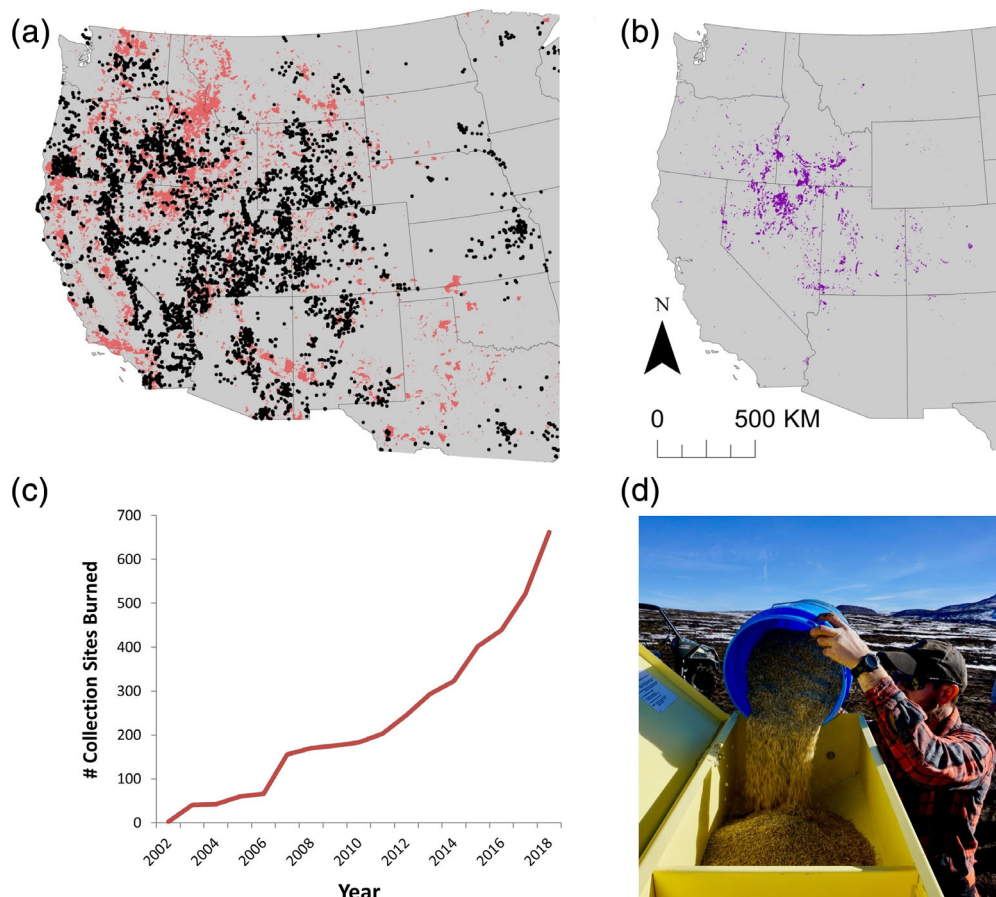


FIGURE 3 The Seeds of Success (SOS) program collections are important in the western United States, where (a) many collection sites (black dots) have been affected by fire (national fires 2000–2018 shown in red; 60.1% of these fires were within the 11 western states, which make up approximately 31.5% of U.S. lands). These fires have led to the planning and implementation of (b) restoration seeding treatments (purple) on public lands. The number of SOS collection locations burned has (c) increased dramatically over time, and SOS collections have been increased in agricultural fields for use in (d) postfire seeding efforts with native species on public lands. Here, SOS-collected and agriculturally increased native grass seeds are being sown in a test plot on the Martin Fire in Winnemucca, NV, one of the largest fires in public lands history. Photo courtesy of S.M. Kulpa, U.S. Fish and Wildlife Service

ArcMap 10.5 to extract values for the same four temperature and precipitation values (described above) from 1,500 random points distributed across the area of the restoration seedings. We then determined significant differences between the environmental values found at the SOS collection locations and the random points across restoration seedings using general linear models.

Analyses were conducted in Program R (R Development Core Team, 2016) using the *car* package (Fox & Weisberg, 2011) and *Agricolae* package (de Mendiburu, 2016) and a *p*-value of .05 was used to determine statistical significance.

3 | RESULTS

3.1 | An overview of SOS seed collections

Between 2000 and 2018, the program has curated 24,462 seed collections of over 5,600 taxa, 1,100 genera, and 170 plant families, collected across 43 states, with the help of more than 50 partners (Figure 2). Seed collection efforts have resulted in the training of more than 1,400

interns, with many of them going on to careers in botany, plant sciences, and ecology. As of 2017, a total of 10,820 samples of SOS material have been distributed for restoration and research use through The U.S. National Plant Germplasm System (NPGS) Germplasm Resources Information Network (GRIN) program (see Supporting Information), illustrating that SOS serves a major function for supporting restoration and native plant research.

The number of collections per year has increased over time ($p < .0001$), averaging ~600 per year in the first 9 years of the SOS program (2000–2008) and ~1950 collections per year between 2009 and 2017. The most common plant families in the SOS collections broadly match the most abundant plant families globally, with Asteraceae and Poaceae making up the bulk of the collections, followed by sedges (Cyperaceae) and members of the pea family (Fabaceae) (Figure 2). About 70% of collections have occurred on U.S. public lands, with the remaining collections occurring on state and private lands, with landowner permission. SOS collections are taxonomically diverse and geographically widespread, especially in western states where wildfire and BLM restoration activities are greatest (Figure 3).

TABLE 1 Comparison of environmental conditions at the SOS collection locations relative to the conditions across the estimated climatic range of the species (Ecol.) and the restoration seeding locations (Rest.) for annual precipitation, summer precipitation, minimum temperature, and maximum temperature

Species	N	Annual precipitation		Summer precipitation		Minimum temperature		Maximum temperature	
		Ecol.	Rest.	Ecol.	Rest.	Ecol.	Rest.	Ecol.	Rest.
<i>A. tessellata</i>	27	·	–	·	–	+	+	·	+
<i>A. filipes</i>	14	·	·	·	·	·	·	·	–
<i>B. sagittata</i>	46	·	+	·	+	·	+	·	–
<i>C. douglasii</i>	46	·	·	–	·	·	·	·	–
<i>C. lutea</i>	37	–	–	–	·	–	–	·	+
<i>C. acuminata</i>	35	·	+	–	·	·	·	·	–
<i>E. pumilus</i>	22	·	·	·	+	·	–	·	–
<i>E. speciosus</i>	44	+	+	–	+	·	–	–	–
<i>H. multiflora</i>	59	·	+	–	+	·	·	·	–
<i>L. dissectum</i>	38	–	+	–	–	+	+	+	·
<i>M. canescens</i>	58	–	·	–	+	+	·	+	·
<i>P. speciosus</i>	25	·	·	·	–	·	·	+	·
<i>P. hastata</i>	22	–	+	–	·	+	·	+	–
<i>S. grossulariifolia</i>	20	·	–	·	·	·	·	·	+

Note: Minus signs (–) indicate that SOS collections are from areas with significantly lower measures and plus signs (+) indicate that SOS collections are from areas with significantly higher measures than either conditions across their range (Ecol.) or across restoration seeding locations (Rest.). Dots (·) indicate no significant difference between conditions in SOS collection locations and the conditions across the climatic range of the species (Ecol.) or restoration seeding locations (Rest.). Numbers in the second column represent the number of SOS collections (N) included in the analysis.

Abbreviation: SOS, Seeds of Success.

3.2 | Fire and SOS seed collection sites

Our examination of the impact of fire on SOS collections revealed that, since collection, there have been 662 fires at 631 sites, or 3.5% of georeferenced collection sites

(Figure 3). Of these, 27 sites have burned twice since collection and two sites have burned three times. SOS collection populations have burned at a frequency of ~29 populations per year since 2000, with an increase to ~48 populations burning per year since 2011.

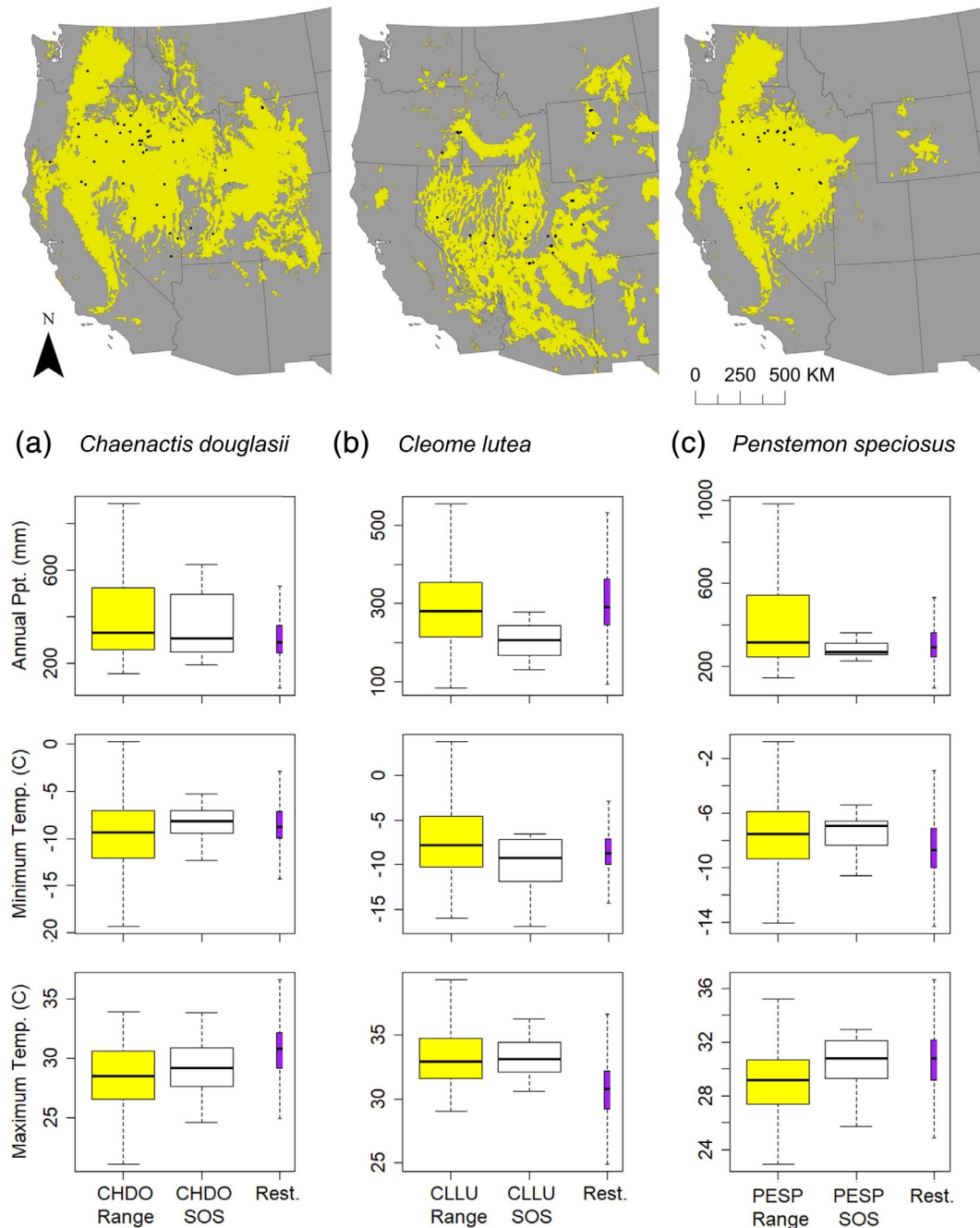


FIGURE 4 Estimated area of climate suitability for (a) *Chaenactis douglasii*—CHDO, (b) *Cleome lutea*—CLLU, and (c) *Penstemon speciosus*—PESP, with Seeds of Success (SOS) collection locations shown as black dots. Boxplots showing values for environmental conditions across the potential area of occupancy for each species (yellow), at SOS collection sites for each species (white), and at restoration seeding locations on public lands (purple) for annual precipitation (Ppt.), minimum temperature (Temp.), and maximum temperature. Note that the scale along the y-axis varies

3.3 | Western forb case study: Suitable habitat, fire impacts, and restoration sites

Our in-depth analysis of priority forb species showed that models of climatically suitable habitat varied among the 14 species, with potential areas of occupancy ranging from ~460,000 to ~1,650,000 km². Species varied in the degree to which their suitable habitat overlapped with fires between 2000 and 2018, with an average of 9.8% of suitable habitat affected by fire across all priority species.

SOS collections tended to be from either climatically average or drier, warmer areas of species' suitable habitat, with few exceptions (Table 1, Figure 4). Of the 14 species, average annual precipitation at collection sites for nine species was comparable to their suitable habitat, four species were collected from, on average, sites with lower annual precipitation, and only one species (*E. speciosus*) was collected from sites with, on average, greater annual precipitation. All species were collected from areas with comparable (six species) or lower (eight species) summer precipitation. For both average mean annual maximum and mean annual minimum temperatures, four species were collected from warmer than average areas, one from cooler than average areas, with the remaining nine species collected from areas representative of the average temperature range.

Results were more variable when comparing climatic conditions at collection sites to conditions found in areas of planned or implemented restoration seeding activities (2000–2017): 8 of 14 species were collected from areas with more precipitation (either summer or annual) than restoration sites, five species from areas with lower precipitation, and there were mixed results for temperature and elevation (Table 1, Figure 4). Notably, eight species were collected from, on average, areas with cooler maximum temperatures than were typical of restoration sites, which is not ideal for restoration seed sourcing.

4 | DISCUSSION

Plant populations are in a state of constant change, either evolving in situ in response to environmental change, migrating to new areas, or, barring these options, going locally or globally extinct (Jump & Peñuelas, 2005). Currently, climate change, increased fire frequency, colonization by non-native plants, and anthropogenic activities are outpacing both ecosystem recovery and the ability of some species to evolve or migrate (Ackerly et al., 2010; Corlett & Westcott, 2013; Kroël-Dulay et al., 2015). Thus, demand for native seed to maintain and restore ecosystems will only increase. Seed banking not only provides a way to preserve the outcome of millions of years of

evolution and adaptation, it also provides the resources needed to meet future land management challenges.

SOS collections are taxonomically diverse and widespread, and represent a wide range of plant diversity in the United States, especially in western states where restoration activities are extensive (Copeland et al. 2018; Pilliod et al., 2017); this is a major programmatic strength (Table 2). Multiple partnerships increase the reach of this program, and the training of over 1,400 interns in plant identification and field skills has created opportunities for emerging plant scientists to increase their skills, combating “plant blindness” (Balding & Williams, 2016) and training the next generation of botanists, which is important as formal avenues for botanical training are on the decline (Havens, Kramer, & Guerrant, 2014).

Our analysis of fires between 2000 and 2018 indicates that SOS collection populations are burning at an increasing frequency, with about 72% of these occurring since 2011, when there was a notable increase in the extent of wildfires (Balch et al., 2017). If fire frequency continues at the pace observed since 2011, an estimated 14% of these collection sites will burn by 2050, and over 24% will burn by 2080; any increase in fire size or frequency in the intervening years would increase these estimates. This is important because in much of the western United States, the spread of non-native annual grasses, which are competitively displacing many native species, are contributing to an accelerated fire cycle, where fire and invasion combine to replace native communities. Thus, we are very likely to lose SOS populations due to the combined impacts of fire and invasive species (D'Antonio, 1992; Mahood & Balch, 2019), meaning these existing collections are the only repository of genetic variation found at these locations. Further, fire and other disturbances are likely to threaten additional plant populations (Abatzoglou & Williams, 2016; Balch et al., 2017), and there is risk of losing important plant genetic diversity before it can be preserved in ex situ collections (Table 2).

When selecting species for conservation, it is essential to ensure that limited resources are used effectively (Breed et al., 2018; Brown & Amacher, 1999). There are an estimated 18,000 native plant species in the continental United States, and the SOS program, with over 5,600 species in storage, has collected ~30% of this diversity. The SOS program focuses on species commonly used in restoration, not on rare and endangered plant species (rare plant collections are conducted by the Center for Plant Conservation National Collection program). Therefore, SOS will never collect all of the nation's plants, but there are certainly additional regions and species that should be targeted. For example, a next focal area of collection could be the southeastern United States, of which six states are not currently represented in SOS seed

TABLE 2 Outline of the strengths, weaknesses, opportunities, and threats for SOS, a national seed banking program that collects and stores native seeds for research and restoration activities

Strengths • Diverse partnerships ensure wide geographic reach • Extensive and diverse seed collections available for use • Seed collections focusing on regional and climatic areas of greatest need • Mechanism for sharing seeds with growers, practitioners, and researchers • Well-defined seed collection protocols that can be applied across ecosystems • Trains next generation in plant science and restoration • Species collected also include crop wild relatives that provide protection to food security • Species collected also include pollinator, sage-grouse, and other wildlife preferred forbs	Weaknesses • No guaranteed annual funding for seed collections, seed distribution, or seed storage • Programmatic funding is primarily dependent on one federal department, the U.S. Department of the Interior • Seed collection protocol precludes collections from small populations, reducing ability to collect from already impacted regions
Opportunities • Potential for programmatic growth in era of major restoration focus worldwide • Potential to use risk assessment and seed transfer guidelines to identify priority species, populations for further collection • Increase collection in regions less represented in current collections • Consider modifying seed collection criteria to allow for collection from smaller, already impacted populations • Major scientific value of existing collections • Opportunity for seed increase to bolster agricultural communities across the United States	Threats • Lack of adequate funding for native plant protection, conservation, and restoration • Ongoing disturbance leading to shrinkage and loss of wild populations before collections are made • Loss of funding to preserve existing collections • Loss of seed viability in long-term storage • “Plant blindness” and a lack of botany programs to train next generation of plant scientists

Abbreviation: SOS, Seeds of Success.

banking efforts (Figure 2). This is of particular concern, considering the Gulf Coastal Plain is experiencing increased intensity and frequency of extreme weather events (Skeeter, Senkbeil, & Keellings, 2019), and this region presents an opportunity for future focus (Table 2).

In our assessment of fire impacts on a suite of priority forb species, our analysis confirmed that some species are more vulnerable to fire, and potentially population loss, than others. Similar habitat modeling and risk assessment could help focus our future collections on unrepresented species that are at high risk from factors such as fire, invasive species, or other pressures (Table 2). Recent advances in methods to monitor threats to species and ecosystems (e.g., Reif & Theel, 2017) will be of prime importance for focusing future collections in areas that are at higher risk of disturbance and need for restoration, so that we can collect from appropriate species and communities to meet restoration needs.

There is widespread genetic differentiation among wild plant populations, and there is abundant evidence that natural selection results in locally adapted populations for many plant species (Baughman et al., 2019; Hereford, 2009; Leimu & Fischer, 2008). In our investigation of 14 priority forb species, we found that SOS collections are focused on areas representing

average conditions in species' ranges, or, when deviating from average, collections usually focused on the warmer, drier portion of species' ranges. This may be because many SOS collections are on public lands, including many collections on lands managed by the BLM, which manages predominantly land at lower elevations. This could be driving current patterns of collection, especially in western plants, and these seed sources may become valuable for other regions, considering the potential for additional climate warming in areas that will require restoration. However, when comparing climatic conditions at SOS collection sites versus those in restoration sites, we found that collection sites were often cooler and wetter than restoration areas. Thus, we may consider shifting our program focus to collecting populations from the warmest and driest areas of species' ranges, to match restoration needs. This shift may require an adjustment in the SOS protocol to enable collections from smaller populations, because populations from lower elevations and warmer climates commonly show signs of previous degradation by wildfire, invasive species, and anthropogenic activities (Brooks & Chambers, 2011). Seed transfer guidance and online seed source selection tools, designed to provide alternative approaches to sourcing seed for restoration projects, may also be helpful for guiding priority

areas for SOS seed collection (e.g., Doherty, Butterfield, & Wood, 2017), identifying populations that may fill particular environmental niches.

Currently, the SOS program is funded annually through Department of Interior appropriations to the BLM, with strong partnerships with private partners such as Chicago Botanic Garden, Greenbelt Native Plant Nursery, Native Plant Trust, North Carolina Botanical Garden, and Rancho Santa Ana Botanic Garden. While this structure has maintained the program for almost 20 years, expanding partners to other federal and state land management agencies such as the U.S. Forest Service, U.S. Fish and Wildlife Service, National Park Service, and State agencies could have multiple benefits, including improving geographic coverage of species and populations and diversifying support mechanisms. The SOS collections are an unparalleled national resource, analogous to a Library of Congress for plants, but there is no guaranteed annual funding source for continued SOS seed collection or for long-term storage, representing perhaps the greatest threat to this program (Table 2). Putting systems in place to ensure these collections continue to be curated and stored in a way that maximizes long-term seed viability and accessibility would maintain these genetic resources for the future.

Finally, while the primary purpose of SOS collections is to conserve native plant materials that will support current and future restoration needs, they also represent an unparalleled opportunity to answer basic science questions. With georeferenced locations, multiple collections per species, and collections through time, the SOS repository is an ideal resource for asking questions about the distribution of plant population diversity, and how plant populations change over time. Depending on accession size, a small quantity of seed may be requested for research and increase through the U.S. NPGS GRIN, which is managed by the USDA Agricultural Research Service. To-date, over 12,000 seed packets containing seed from SOS collections have been distributed in response to over 2,600 orders originating from a range of state and federal agencies, nonprofits, academic institutions, and individuals, who are using the collections to study plant genetics and taxonomy, research crop wild relatives, investigate medicinal uses of plants, and for restoration research (Greene et al., 2019). Thus, these seed collections are an important resource for multiple types of scientific work.

5 | CONCLUSIONS

The value of native plant communities is recognized worldwide: the United Nations FAO report (FAO, 2019) described how native plants and their ecosystem services are critical

for food security, and restoring biodiversity and resilience to landscapes following natural disasters, such as drought, wildfire, and hurricanes. In addition to their intrinsic value, wildlands, forests, and rangelands provide tangible economic benefits and contribute billions of dollars, directly and indirectly, to the U.S. economy. For example, in fiscal year 2017, outdoor recreation on BLM land alone created \$6.7 billion in economic output that supported millions of American jobs; without native plants, the iconic landscapes and wildlife people visit would not exist. Native plants on BLM land support \$2.4 billion in grazing for livestock (US Department of the Interior – Bureau of Land Management, 2018) and provide \$35 million in benefit from seed purchases (Josh Seidon, 2016). Thus, seed collection and seed banking programs, such as SOS, are critical for maintaining functioning ecosystems that support our national economy, both now and into the future.

Carefully selecting priority species and populations for seed collection and restoration will become increasingly important for achieving our conservation objectives, especially as disturbance and invasive species become more prevalent. The future health of U.S. lands hinges on our present seed collection and seed banking activities. Engaging more partners may be an effective way to secure the resources necessary to conserve our national flora, and the SOS program welcomes partnerships with state, federal, and nonprofit institutions to ensure the longevity of the program and aid in conserving the unique resources found in our nation's terrestrial ecosystems.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Sarah C. Barga is the corresponding author. Sarah C. Barga, Elizabeth A. Leger, Peggy Olwell, and Fred Edwards conceived and designed the experiment. Peggy Olwell, Fred Edwards, and Leah Prescott provided the SOS dataset and photos. Sarah C. Barga performed the analyses. Sarah C. Barga and Elizabeth A. Leger produced the figures. Sarah C. Barga, Elizabeth A. Leger, Peggy Olwell, Fred Edwards, and Leah Prescott wrote and edited the manuscript.

DATA ACCESSIBILITY

Data can be accessed on the Dryad Digital Repository (DOI: <https://doi.org/10.5061/dryad.s7h44j144>).

ETHICS STATEMENT

This manuscript is solely the work of the authors. This study did not involve any experiments on animal or human subjects.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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