

SCIENCE

2016 YEAR IN REVIEW

Plants are fundamental to life, from the air that we breathe to the food that we eat. Science is the foundation of botanic gardens, from understanding how to grow plants in gardens to conserving biodiversity outside gardens. Thus, plant science serves as a key programmatic element at Denver Botanic Gardens.



Plant Conservation | 2016 Efforts

While much of our work is local, we play a substantial role in national and global conservation through partnerships. These partnerships guide our ongoing work and together we stay at the forefront of plant conservation.

ENGAGEMENT | PARTNERS

Botanic Gardens Conservation International
 Center for Plant Conservation
 Central Rockies Chapter, Society for Ecological Restoration
 Colorado Department of Agriculture
 Colorado Natural Areas Program
 Colorado Natural Heritage Program (NatureServe)
 Colorado Pollinator Network
 Colorado State University
 Denver Museum of Nature and Science

Ecological Restoration Alliance of Botanic Gardens
 Global Crop Diversity Trust
 Global Partnership for Plant Conservation
 Instituto Nacional de Tecnología Agropecuaria, Argentina
 National Wildlife Federation
 North American Botanic Garden Strategy for Plant Conservation 2016-2020
 Plant Conservation Alliance Non-Federal Cooperators Group
 Project BudBurst

Smithsonian's Global Genome Initiative
 Southern Rockies Seed Network
 Universidad Nacional de Río Negro, Argentina
 University of Colorado Denver
 University of Denver
 US Bureau of Land Management
 US Fish and Wildlife Service
 US Forest Service
 USA National Phenology Network
 World Coffee Research
 World Food Prize Global Youth Institute

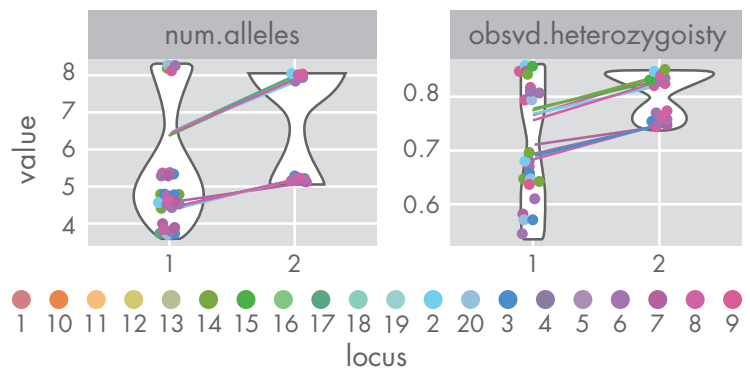
Scientific Spotlight

Ph.D. Thesis

Our genetic and morphological assessment of populations of *Astragalus linifolius* Osterh. (circled in blue) and *Astragalus rafaensis* M.E. Jones (circled in orange) from western Colorado failed to support a two species hypothesis. We suggest the populations sampled here be managed as a single species, *Astragalus rafaensis*, resulting in a more widespread species than previously thought, lessening the need for conservation action. This work is one part of **Joe Statwick's** dissertation.

Software Development

Simulations are powerful tools in molecular ecology but are not widely used due to software complexity. skeleSim (an R package), developed by a NESCent Hackathon team including **Michelle DePrenger-Levin**, will walk a user through simulations and provide population genetic statistics for a variety of marker types and demographic conditions for robust analyses to aide conservation management.



Common population genetic statistics including the number of alleles and observed heterozygosity can be quickly viewed and data exported for further analyses.



Training the Next Generation

We are expanding our scientific capacity while providing invaluable training to the next generation of scientists and conservation stewards. We supported **twelve interns**, eight of whom were undergraduates and four of whom were recent graduates, and directly advised **three graduate students**, all of whom supported and furthered our scientific and horticultural initiatives.

Our Collections

2016 HIGHLIGHTS

Denver Botanic Gardens is an American Alliance of Museums (AAM) accredited museum with natural history collections, living collections, art collections, and rare and circulating book collections.

Expanding Virtual Access

For over 50 years, the **living collection** has been scientifically vouchered and those specimens are stored on-site in the **Kathryn Kalmbach Herbarium**. However, many of those specimens are not databased nor synced to the living specimen database, **BG-BASE**. With funds from the **Stanley Smith Horticultural Trust**, a Database Seasonal is transcribing all cultivated specimens in the herbarium into BG-BASE. The data will then be ingested into the herbarium database, SEINet, ensuring that the information is available to researchers, Gardens staff and visitors.

Kathryn Kalmbach Herbarium of Vascular Plants (KHD) PHILLIPS CO.

We focus our efforts on under-collected areas. Few botanists have strayed as far east as Phillips County, with most specimens collected in the 1930s – 40s. This year, over **275 specimens** were collected in Phillips County documenting **135 county records**.



Living Collections NEW STEPPE GARDEN

More accessions were added this year than any other year. The new Steppe Garden was one of the areas where many new accessions were incorporated—a total of **430**. The Steppe Garden features landscapes similar to our shortgrass prairie from other parts of the world such as Patagonia, Central Asia and South Africa.

Sam Mitchel Herbarium of Fungi (DBG) COTTONWOOD PASS FORAY

Staff and volunteers forayed for snowbank fungi in the Cottonwood Pass area of Chaffee County. **80 species** of “Snowbankers” were collected, representing a diverse group of saprobic and mycorrhizal fungi adapted to growing in the microclimate provided by remnant snows and warm days. The foray honored Lee Barzee, founder of the Pikes Peak Mycological Society.

Collection of Arthropods (DBGA) 184% GROWTH

Our arthropod collection grew by 184%, adding **260 specimens**, all collected on the grounds of the Gardens’ York Street site. The collection now represents 89 families of insects, spiders and myriapods.

Helen Fowler Library

We cataloged **44 bound herbaria**. These historic herbaria, from 1850-1993, were donated to and are currently housed in the herbarium. These archival materials represent the intersection of the library and science at the Gardens. Creating discoverable records allows interested researchers to locate them in the collection; proper archival support preserves the materials for future use.

Total
Accessions
as of 12/31/2016

62,515
KHD

27,902
Living
Collections

18,360
DBG

426
DBGA



Accessions
Sent Out for
Scientific Research

17
KHD

50
Living
Collections

27
DBG



Conservation Initiatives

LOCAL Restoration at Denver Botanic Gardens Chatfield Farms

Deer Creek, part of the Chatfield Basin that includes over 550 plant species and 70 mammalian species, is a degraded riparian habitat as a result of intensive land management since the 1800s. We are restoring 5.5 acres of this degraded habitat to facilitate the growth of native plants, improve water quality and support the fauna that use the creek.



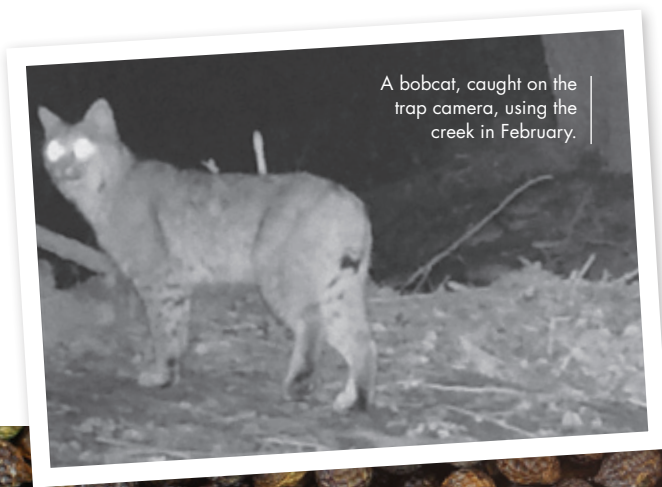
Courtesy of Google Earth

We installed **three in-stream diversions** to improve the flow of the creek and bank structure that was degraded due to historical channelization. These diversions forced the creek to meander out of its channel and into its historical oxbows. The goal is to improve the riparian habitat so it is suitable for the regeneration of native species, including cottonwoods and willows.

2016 largely focused on determining the baseline conditions of the stream, including establishing **12 permanent sampling plots** along the creek. We measured plant diversity and cover along the riparian area, and sampled water and macroinvertebrates in the creek. With two trap cameras, we documented wildlife that use the riparian corridor. In addition to baseline data collection, we staked willows from cuttings that were collected downstream on the same property and planted cottonwood saplings along the creek to facilitate restoration of these species. In 2017 we will continue to monitor the area and plant more natives.

- Deer Creek
- Historical Oxbows (which will be rewet)
- In-Stream Diversions
- Water Flow

Our Work within Global Conservation Strategies		Chatfield Farms	Coffee Conservation
Global Strategy for Plant Conservation	Objective 1	✓	✓
	Objective 2	✓	✓
	Objective 3	✓	✓
	Objective 4	✓	✓
UN Sustainable Development Goals	Goal 11		✓
	Goal 12		✓
	Goal 15	✓	
North American Strategy for Plant Conservation	Objective B	✓	✓
	Objective C		✓
	Objective D	✓	



A bobcat, caught on the trap camera, using the creek in February.

Restoration seeds.

LOCAL



GLOBAL Coffee Conservation

Coffee, a beverage millions of people enjoy daily, has a very small gene pool. Of the two commercially grown species, *Coffea arabica* (Arabica coffee) and *Coffea canephora* (robusta coffee), the Arabica coffee is the more favored one and is characterized by very low genetic diversity, a result of its origin, evolution, reproductive biology and method of distribution. To understand how we can increase and preserve the genetic pool of the crop, we are developing the Global Conservation Strategy for Coffee Genetic Resources through global collaboration.

Denver Botanic Gardens' Center for Global Initiatives partnered with the Global Crop Diversity Trust and World Coffee Research to assess the current status of the crop's gene pool held in *ex situ* genebanks and develop a strategy that would lead to increased conservation and access of the germplasm for future crop improvement.

Through previous genetic work in coffee, we found that the *ex situ* populations often have less genetic diversity than *in situ* populations. Additionally, *in situ* populations are under threat from climate change, pests, diseases and human impacts, such as deforestation and mining. Field gene banks also suffer from insecure funding, land use and unintentional cross-pollination leading to genetic erosion.

The Global Conservation Strategy for Coffee Genetic Resources will address these issues and others to ensure the genetic diversity of the crop is preserved. As part of the development of the Strategy, we visited field gene banks in **seven countries** and surveyed **31 total gene banks** on *ex situ* practices.



The coffee nursery at the Centre National de Recherche Agronomique (CNRA) coffee field genebank in Divo, Cote d'Ivoire.

Scientific
Efforts at
the Gardens
Contribute
to Global
Conservation
Strategies.

The Strategy, which will be formally disseminated in 2017, will include the following ways in which the conservation and use of coffee genetic resources can be improved:

- A framework for **germplasm exchange** between coffee genebanks
- Safety **duplication of accessions**
- Creation of a **global database** of accessions held in *ex situ* collections
- Develop **complementary conservation strategies** including conservation of *in situ* populations
- Formalize a mechanism for responding to **urgent needs**, such as natural disasters
- Use **consistent horticultural practices** across genebanks



Coffee beans. |

Outreach By the Numbers

With our goal to promote citizen science and environmental literacy and stewardship across a broad community, we connect with the public and our peers.

813 Citizen Science Measurements Collaborated with Community Collaborative Rain, Hail and Snow Network, the National Phenology Network and Project BudBurst.

Educated
1,465
visitors about
our research
through interactive tables at
5 OF THE GARDENS' SPECIAL EVENTS

LED
4
Fungal
Forays in New Mexico and Colorado with 93 amateur mycologists, students and members of the public.



Connected with
more than
2,500
Participants at
GIRLS & SCIENCE

Over 11,500 girls and their families participated in Girls & Science, an annual event held at the Denver Museum of Nature and Science. At the Gardens' booth, girls learned about trichomes, felt them on plants, observed them under the microscope and recorded their observations by working with the Gardens' School of Botanical Art & Illustration Instructors.



RESEARCH & CONSERVATION
PARTICIPATED IN
213
EVENTS
and reached
27,863
INDIVIDUALS!



Supported
8 HIGH SCHOOL
Volunteers High school students volunteered with the Horticulture Department, where they assisted in gardens management, and with the Research & Conservation Department, where they presented our research to the public through hands-on activities.

Taught Conservation Biology to
100 Undergraduate
Students
in the spring quarter at the University of Denver.

Collaborated with 2
Organizations for our **FIRST**
BIOBLITZ

In August, we held a bioblitz at the Gardens to document what lives in our gardens in addition to the plants. We collaborated with local organizations, the Denver Museum of Nature and Science and the Butterfly Pavilion, to help us capture and identify the diversity in a 24-hour period. We recorded 107 observations (pie chart) of 55 species through collections and iNaturalist.



Images like this were uploaded to our bioblitz project on iNaturalist where anyone can see our biodiversity findings.
www.inaturalist.org/projects/denver-botanic-gardens-urban-biodiversity-survey



Presentations

DeMasters, C. How do native annual and biennial species affect cheatgrass abundance? Poster presentation. Society for Ecological Restoration Northwest Chapter Regional Conference 2016, Portland, OR.

DePrenger-Levin, M.E., R.A. Hufft, R.A. Levy and M. Islam. Using herbarium records to assess shifts in phenology in alpine plants and select indicator species for climate change. Natural Areas Conference 2016, Davis, CA.

Hufft, R., T.J. Zelikova, S.Y. Atkinson, C.S. Brown, R.N. Mack and S.J. Novak. Adaptation and invasiveness in annual brome grasses. Organized oral session. Ecological Society of America 2016, Fort Lauderdale, FL.

Islam, M. Demonstration of regional interactive herbaria. Invited presentation. Colorado Rare Plant Symposium 2016, Boulder, CO.

Krishnan, S., P. Bramel, D. Horna, B. Lainoff, C. Montagnon and T. Schilling. Development of the global conservation strategy for coffee genetic resources. International Society for Horticultural Science 2016, Cairns, Australia.

Krishnan, S. Science and Culture of Coffee. Invited presentation. United States Botanic Garden and the Smithsonian Museum of Natural History. 2016, Washington, DC.

Neale, J.R. and A. Schwabe. Conservation genetic assessment of the federally protected Dudley Bluffs mustards (*Physaria congesta* and *Physaria obcordata*) with implications for oil and gas development in the Piceance Basin of Colorado, USA. Botany 2016, Savannah, GA.

Neale, J.R. and **M. Goshorn.** Examining genetic diversity in *ex situ* and *in situ* collections of the federally endangered *Penstemon penlandii* (Kremmling beardtongue). Center for Plant Conservation Annual Meeting 2016, Framingham, MA.

Recognitions

Mike Kintgen, curator of alpine collections, was awarded the Edgar T. Wherry award of the North American Rock Garden Society for outstanding contribution in the field of North American Native plants.

Publications

Desai, N.S., **A.W. Wilson**, J.S. Powers, G.M. Mueller and L.M. Egerton-Warbuton. 2016. Ectomycorrhizal diversity and community structure in sands of *Quercus oleoides* in the seasonally dry tropical forests of Costa Rica. *Environmental Research Letters* 11. DOI 10.1088/1748-9326/11/12/125007.

Elmendorf, S.C., et al. 2016. The plant phenology monitoring design for The National Ecological Observatory Network. *Ecosphere* 7 (4):e01303. **R.A. Hufft** was a contributing author.

Hufft, R.A. and T.J. Zelikova. 2016. Ecological Genetics, Local Adaptation, and Phenotypic Plasticity in *Bromus tectorum* in the Context of a Changing Climate. *Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US*. Ed. Germino, M.J., J.C. Chambers, C.S. Brown. Springer: 133-153.

Krishnan, S., D. Nandwani, G. Smith and V. Kankarta. 2016. Sustainable urban agriculture: A growing solution to urban food deserts. *Organic Farming for Sustainable Agriculture*. Ed. D.Nandwani. Springer: 325-340.

Krishnan, S. and A. Novy. 2016. The role of botanic gardens in the twenty-first century. *CAB Reviews* 11(23):1-10. DOI: 10.1079/PAVSNNR201611023

Parobek, C.M., F.I. Archer, **M.E. DePrenger-Levin**, S.M. Hoban, L. Liggins and A.E. Strand. 2017. skeleSim: an extensible, general framework for population genetic simulation in R. *Molecular Ecology Resources* 17: 101-109. DOI 10.1111/1755-0998.12607.

- github.com/christianparobek/skeleSim
- cran.r-project.org/web/packages/skeleSim/index.html

Springer Y.P., et al. 2016. Tick-, mosquito-, and rodent-borne parasite sampling designs for the National Ecological Observatory Network. *Ecosphere* 7 (5):e01271. **R.A. Hufft** was a contributing author.

Sarada Krishnan, Ph.D., was appointed to the United States Department of Agriculture's (USDA) National Genetic Resources Advisory Council (NGRAC) for a three-year term.

Statwick, J.M. 2016. Germination pre-treatments to break hard-seed dormancy in *Astragalus cicer* L. (Fabaceae). *PeerJ* 4:e2621. DOI 10.7717/peerj.2621.

Statwick, J., B.J. Majestic and A.A. Sher. 2016. Characterization and benefits of selenium uptake by an *Astragalus* hyperaccumulator and a non-accumulator. *Plant Soil* 404. DOI 10.1007/s11104-016-2842-0.

Wilson, A.W., K. Hosaka and G.M. Mueller. 2016. Evolution of ectomycorrhizas as a driver of diversification and biogeographic patterns in the model mycorrhizal mushroom genus *Laccaria*. *New Phytologist*. DOI 10.1111/nph.14270.



Grant Completion Herbarium Improvement

In 2015 we received a grant from the Institute of Museum and Library Services to add a new high density storage system and 32 new cabinets to house the Sam Mitchel Herbarium of Fungi. This allowed the plant collection to expand into the cabinets vacated by the fungi. With this expansion, the average cabinet fullness decreased from about 85% to 55%, allowing us to grow our collections for another 20 years.

The project was made possible in part by the Institute of Museum and Library Services MA-30-15-0082-15.



Courtesy of Davis Partnership Architects

Growing Capacity

The Center for Science, Art and Education marks the final step in our four-phase Master Development Plan. Housing these three elements in a single facility will make them more accessible to the public. Learn more at botanicgardens.org/csae.

Thank You to Our Funders

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|------------------------------------|--|------------------------------------|
| Borgen Family Foundation | Institute of Museum and Library Services | Society for Ecological Restoration |
| Center for Plant Conservation | Jefferson County Open Space | Stanley Smith Horticultural Trust |
| Colorado Department of Agriculture | National Fish and Wildlife Foundation | The Garden Club of Denver |
| Denver Debutante Ball | Five Star & Urban Waters Program | US Bureau of Land Management |
| Denver Botanic Gardens Guild | Plant Select™ | |

We gratefully acknowledge the many other individuals who provide financial support for our work throughout the year. Science at Denver Botanic Gardens is also supported with distributed income from Denver Botanic Gardens Endowment Funds. Denver Botanic Gardens is supported by the Scientific & Cultural Facilities District (SCFD).

To keep up-to-date with science at Denver Botanic Gardens, you can sign up for the quarterly Science e-newsletter by clicking "Subscribe" at the bottom of botanicgardens.org and selecting "Science."

Photos taken by Scott Dressel-Martin and Gardens staff unless otherwise noted.



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