SCIENCE

2018 YEAR IN REVIEW

Biodiversity is fundamental to life, from the air that we breathe to the food that we eat. The scientific study of biodiversity is the foundation of botanic gardens as it allows us to conserve diversity at home and around the world through greater documentation and understanding. Thus, science serves as a key programmatic element at Denver Botanic Gardens.

DENVER BOTANIC GARDENS

ON THE COVER
Gardens mycologist examining a specimen during a foray

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Rehousing our collections

2018 marked the beginning of construction on the long-awaited Freyer – Newman Center. The Center will allow the Gardens to celebrate the intersection of science, art and education. The Institute of Museum and Library Services awarded us nearly $250,000 to enable **world-class stewardship of the non-living collections** — natural history, art and archives — that underpin and enable this intersection. 2019 will be a year of intense preparation for our early 2020 move into the Center.

Staff working in the current natural history collections

Science at the Gardens

Scientific endeavors at the Gardens are numerous and continually expanding. Whether tracking individual plants over time through demographic monitoring, expanding natural history collections with targeted surveys, or examining DNA to give an organism a "name," we are driven by the goal of understanding biodiversity through the application of scientific studies.

The scientific process grounds our work and drives our projects toward excellence. We are constantly challenging ourselves to ask meaningful questions and collect robust data to seek answers. Data standards and collection methodology were improved in 2018, providing linkages between projects and expanding how the resulting data can be used. Our work along the High Line Canal is just one example of bringing expertise and diverse perspectives together to accomplish more as a team than as individuals.

Collaboration and communication are core concepts to the scientific work at the Gardens. Sharing our work with our peers, stakeholders and science enthusiasts enhances its value. Through numerous publications and presentations, we shared our work, learned from others and developed new ideas to explore. Staff across the organization contribute to regional, national and global conservation strategies. We train the next generation of botanists, mycologists and conservation biologists through internship opportunities with regional universities and through our graduate program in affiliation with the University of Colorado Denver. Our program expands each year, thus furthering our collective impact to conserve biodiversity.

As construction on the Freyer – Newman Center for Science, Art and Education proceeds, we await our move with anticipation and excitement. With expanded space and facilities, we are dreaming big about the possibilities that lie ahead.

Working with a master's student to identify herbarium specimens

Staff and volunteers on a *Sclerocactus glaucus* monitoring expedition

Saussurea weberi, one of the seed collections made in 2018

A specimen of *Gentiana algida* from our natural history collection

Featured Projects

Some of the species that showed a significant change in flowering time over the course of 61 years.

Gentiana algida

Castilleja occidentalis

Antennaria rosea

Climate Change Monitoring

Phenology, the timing of biological events, is recognized as one of the best indicators of biological responses to climate change. Using observations of plant phenology, like the timing of flowering, we can track how plants have responded to climate change and predict future changes in plant communities. While we regularly record phenological measurements to understand seasonal and recent phenological patterns, we use herbarium specimens to look back in time and measure how plant phenology has changed over longer periods. Our 2018 publication "Using Herbarium Specimens to Select Indicator Species for Climate Change Monitoring," explains our process of doing so. Studying species in Colorado's alpine areas, we analyzed herbarium specimen data to look at flowering time over the course of a 61-year period and its relationship to temperature and precipitation. **We found that, on average, species that showed earlier bloom times than in previous years bloomed 39 days earlier at the end of the 61-year study than at the beginning.** This indicates the sensitivity of these species to climate change.

Ex Situ Conservation Collections

Seed banks have become a primary method of ex situ conservation collections for native plant species. To work toward the conservation of the world's threatened plant species, we collect seed of native Colorado plants — with a focus on rare and threatened species — to ensure that these species are available for recovery and restoration. In 2018, we scouted for 30 species across the state, often collecting from multiple populations for each species. Because it was such a dry year in Colorado, many populations, particularly those in more arid areas of the state, were not healthy enough to support seed collection. Despite this, **we were able to collect from 10 populations in primarily high elevation habitats, resulting in the acquisition of seeds from nine species: one common and eight rare.** Seven of the species are new to our ex situ collection.

A beaver dam along Deer Creek creates a deep pond

Ecological monitoring along the High Line Canal Trail

Measuring plant growth as part of the greenhouse drought experiment

Restoration research improves ecosystem function and informs land management.

Data Standardization

2018 saw a reimagining of the data our scientists collect. In years prior, different research teams operated independently and data collection focused on their project's specific needs. A growing demand in ecology, botany and environmental sciences for flexible and highly contextualized datasets has led us to rethink our methods. **We developed a standardized set of data types for each team to collect, held a pre-field season workshop to emphasize projects on which multiple teams could collaborate and created custom field notebooks to collect consistent data across all projects.** This new approach allows our data to be integrated and published as a package, enriching the auxiliary information about any one plant or location we study and making it more useful for current and future scientific analyses.

Prairie Restoration

In Colorado and much of the Southwestern United States, drought frequency, duration and severity are expected to increase. Success of ecological restoration is dependent upon high plant performance in changing environments. Ph.D. student Katherine Fu spent 2018 conducting a greenhouse drought experiment using wild and cultivated seed of seven plant species commonly used in prairie restoration. She also started a multi-year common garden experiment on the same species at Chatfield Farms. **Both experiments will help us understand how seed origin relates to performance in different conditions**. This research will help create evidence-based seed sourcing recommendations for successful prairie restoration both now and in the future under climate change.

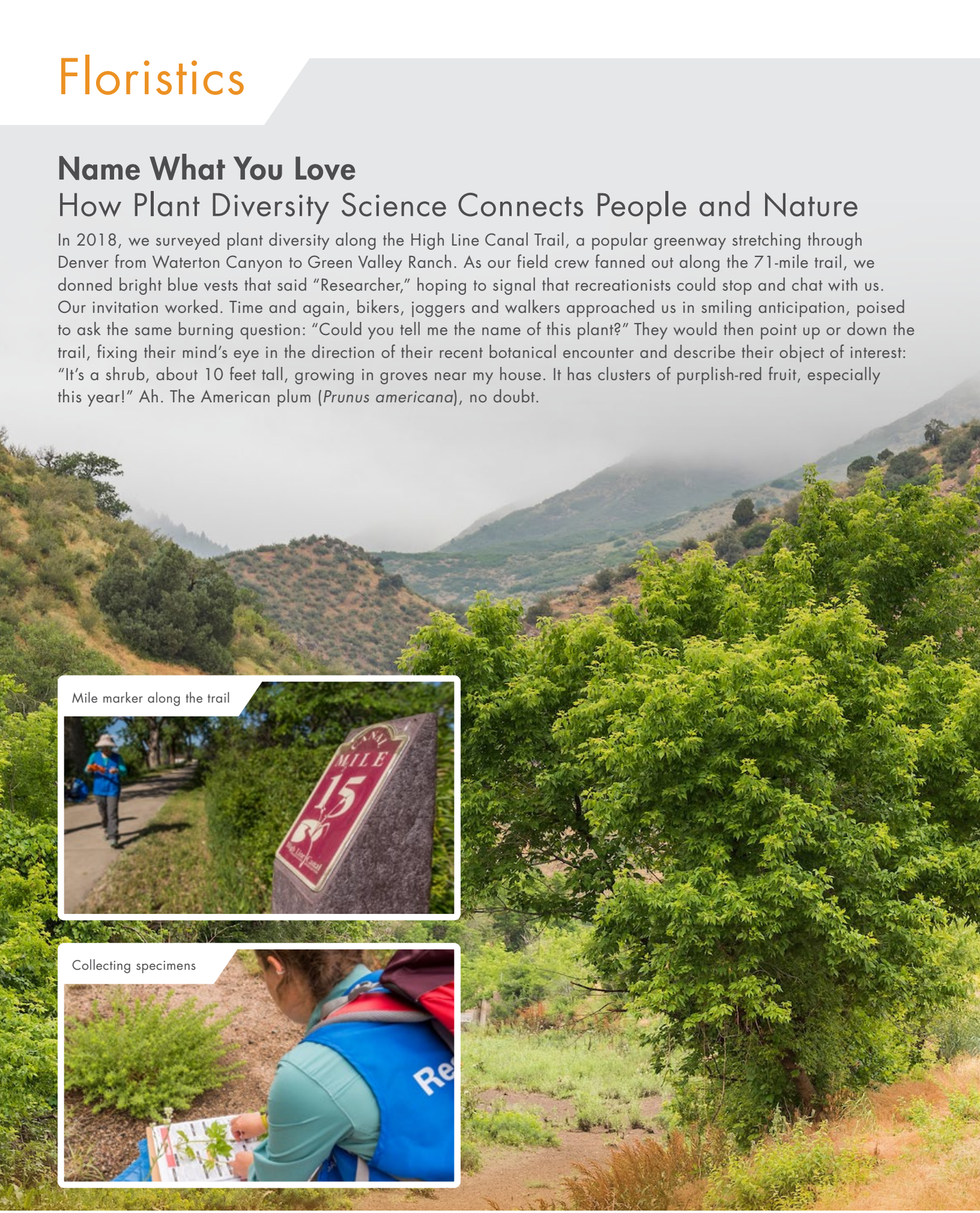
Riparian Restoration at Chatfield Farms

In 2018, we embarked on the third year of our riparian restoration project along Deer Creek at Chatfield Farms. Our project includes the installation of in-stream structures to create more natural stream flows as well as long-term plant and aquatic monitoring. We received funding from the Colorado Water Conservation Board to expand our restoration efforts upstream in partnership with Jefferson County Open Space. To facilitate this expansion, **we are partnering with Metropolitan State University of Denver to propose appropriate locations along the creek to consider for additional in-stream structures**. The addition of these structures, along with the great work that beavers are doing along the creek, will help restore natural flows to the creek and improve plant and water quality. This funding also allowed us to bring on a third graduate student in the fall of 2018, Margo Paces, who will be focusing on riparian restoration for her thesis research.

Name What You Love

How Plant Diversity Science Connects People and Nature

In 2018, we surveyed plant diversity along the High Line Canal Trail, a popular greenway stretching through Denver from Waterton Canyon to Green Valley Ranch. As our field crew fanned out along the 71-mile trail, we donned bright blue vests that said "Researcher," hoping to signal that recreationists could stop and chat with us. Our invitation worked. Time and again, bikers, joggers and walkers approached us in smiling anticipation, poised to ask the same burning question: "Could you tell me the name of this plant?" They would then point up or down the trail, fixing their mind's eye in the direction of their recent botanical encounter and describe their object of interest: "It's a shrub, about 10 feet tall, growing in groves near my house. It has clusters of purplish-red fruit, especially this year!" Ah. The American plum (*Prunus americana*), no doubt.



Mile marker along the trail

Collecting specimens

Our survey has revealed more than **400 plant species** – and counting – along the canal.

People want to name the things they love. Why? Because it is the first step in attaching meaning to that thing. In terms of plants, **proper identification is the critical gateway to further ecological understanding**. For example, once we name the American plum, we know that it is a native plant growing at the western edge of its North American distribution. We also know that in dry areas such as Colorado, it occurs in pockets along streams and man-made canals, where it provides critical habitat and food for wildlife.

Now consider scaling up the naming of one plant to an expansive, data-driven exploration of all the plants that occur along the High Line Canal Trail. Consider also the power of linking the date, location and habitat characteristics of every plant to a physical specimen to be kept in perpetuity as **an immutable snapshot of biodiversity** along the canal. Such a snapshot is an irreplaceable baseline of the canal's botanical character under current climatic and hydrologic conditions, to be used by any researcher, organization or citizen who may have need of it in the future. And, this is what our survey will produce.

Here we must recognize the importance of research partnerships in generating such valuable data. The High Line Canal Conservancy provided partial funding for our botanical survey to support their mission of stewarding the greenway for plants and people alike. Our survey has revealed more than 400 plant species – and counting – along the canal. As our botanists name them, they invite ecological meaning: native, non-native, water-loving, shade-tolerant, abundant or a rare gem.

Once the survey findings are made public, users of the canal can attach their own meaning to the plants that lay down roots in the very neighborhoods where we do the same. Name the cottonwood, the willow, the sunflower, and they will tell you their story.

Asclepias speciosa

Prunus americana

Researchers walking along the trail in Waterton Canyon |

Natural History Collections

At their core, natural history collections capture species diversity and distribution. **Not only do these collections hold the precious evidence of how landscapes and populations change over time, but they are also physical time capsules of genetics and morphology**. These collections express humanity's interest in the natural world and are on the frontlines of understanding and conserving biodiversity. As a museum, the Gardens' collections support all who are curious about the natural world from artists to scientists to activists.

Colorado Mycoflora Project
Sam Mitchel Herbarium of Fungi

In 2018, we ended several presentations on the Colorado Mycoflora Project with a picture of a fungus and asked, "What is this thing?" The featured fungus was violet-purple with long, slender, finger-like structures shooting out of the ground. It resembled the Colorado species *Alloclavaria purpurea* but did not quite match in appearance. It also resembled *Clavaria zollingeri* and *Clavulina amethystinoides*, but neither species seemed to be a perfect fit.

Confusion in fungal species identification is common — this is precisely why we launched the Colorado Mycoflora Project. **This project aims to document Colorado's macrofungal species diversity and distribution to create a functional mycoflora**, which will enable the conservation and preservation of Rocky Mountain forests.

To resolve the "What is this thing?" question posed at our presentations, we retrieved the DNA sequence from the pictured specimen. Sure enough, with a 99.8% similarity in DNA sequence, the specimen was in fact *Alloclavaria purpurea*. This is an example of the mysteries we are solving with DNA. This last year, along with students and volunteers, we advanced our understanding of Colorado macrofungi by collecting DNA sequences from specimens held at the Gardens' Sam Mitchel Herbarium of Fungi. This process of obtaining a genetic sequence for each specimen also helps us give the specimen a name.

2018 laid the groundwork for the Colorado Mycoflora Project. In 2019, we plan on making even greater strides in documenting the diversity of fungi in the Southern Rockies using our collections, and we will continue to solve mysteries.

Alloclavaria purpurea

Flowers at May Valley Ranch in Prowers County

Exploring the Eastern Plains
Kathryn Kalmbach Herbarium of Vascular Plants

Between the cultivated areas of Colorado's Eastern Plains is a vibrant sea of grasses, forbs and shrubs that supports an exquisite diversity of native organisms, some of which occur no where else in the world. **The Eastern Plains provide critical support** to us through food production, carbon sequestration and clean air and water. Yet, they are **one of Colorado's most vulnerable landscapes**.

Over the past few decades, the prairies of Southeastern Colorado have suffered extreme drought and often appear less than vibrant. In 2018, however, Gardens scientists were lucky to venture out after heavy monsoon rains and experience the transformation of the dry, dusty prairie into a pulsating sea of colors. Through our new partnership with the Colorado Cattlemen's Agricultural Land Trust, we surveyed plant diversity on a private ranch of more than 16,000 acres in Prowers County.

Throughout our survey, **we collected over 380 plant specimens representing 237 species** — each to be held in the Kathryn Kalmbach Herbarium of Vascular Plants. More than one-third of the species collected had not been previously documented in Prowers County. On our last trip, the ranch's true beauty was revealed as bright purple liatris hummed with bees, monarch butterflies flocked to the cottonwood stands and the plains burst into whites, reds, pinks and purples as the dormant plants sprang to life after the monsoons. We may not see this riotous tableau again for many years, but the experience will keep us documenting plant life on the understudied and overlooked Eastern Plains for decades to come.

Bombus huntii along the High Line Canal

Documenting Bee Diversity
Arthropod Collection

Our floristics team was not alone in documenting life along the High Line Canal Trail in 2018. Walking among Gardens scientists, net in hand, was graduate student Liam Cullinane. Rather than documenting plants or fungi, Liam traversed the 71-mile trail to conduct a bee survey. **Documenting the diversity and abundance of bees along the canal will help us determine how they are impacted by local plant communities and surrounding urban development.**

Using two common bee-collecting methods (bee bowl trapping and hand netting), bee diversity was documented across all sites. Collected bees were then identified to genus level. In total, 29 of the 70 bee genera found in Colorado were identified along the canal, indicating the importance of this ecosystem for both bee diversity and abundance. The majority of the collected bees are native to North America. Not surprising, common introduced bees, such as the European honey bee (*Apis mellifera*) and the alfalfa leafcutter bee (*Megachile rotundata*) were also collected. All collected bees were accessioned into our anthropod collection, where they will be held in perpetuity with the plant specimens collected along the same trail.

Engagement

Outreach

Global water issues: The Gardens and the One World One Water Center co-hosted a workshop on the Water, Food, Energy and Environment Nexus with the UNESCO World Water Assessment Programme in Perugia, Italy. **Two staff spoke about soil management strategies for achieving water efficiency in small-scale agriculture and the Gardens' overall water stewardship initiatives.**

Science education: At three regional conferences, educators **presented the collaboration tool kit of the Growing Scientist Partnership**, a program that provides teachers with content and field trips for early elementary school students.

Community partnerships: The Urban Advantage partnership continued supporting Denver Public Schools in **implementing Next Generation Science Standards for middle school teachers and instructors**.

Salix humilis

Pinus jeffreyi at Lake Tahoe

Living Collections Expeditions

The Lesotho Highlands: Gardens staff joined a small group of scientists and horticulturists from the Munich Botanical Gardens to collect seed and provide horticultural training to staff members of the Katse Botanical Garden.

Republic of Georgia: In collaboration with the Plant Collecting Collaborative, seed collections of selected geophyte taxa were targeted in the Republic of Georgia.

Jeffrey pine (*Pinus jeffreyi*) expedition to Lake Tahoe: Gardens horticulturists conducted a collection expedition on the east side of Lake Tahoe, collecting seed cones and scion material for grafting from trees selected for their unique characteristics.

Prairie willow (*Salix humilis*) expedition in the Midwest: This species has great potential for use in the Denver landscape and throughout the horticultural community. Gardens staff explored Nebraska, Iowa and North and South Dakota for specimens of *Salix humilis* and associated species.

Bighorn and Beartooth Mountains of Wyoming: Seed collections were made from 102 taxa across the Wyoming mountain ranges with the goal of expanding and diversifying the Gardens' native and alpine collections with material from the central Rockies.

Select Publications

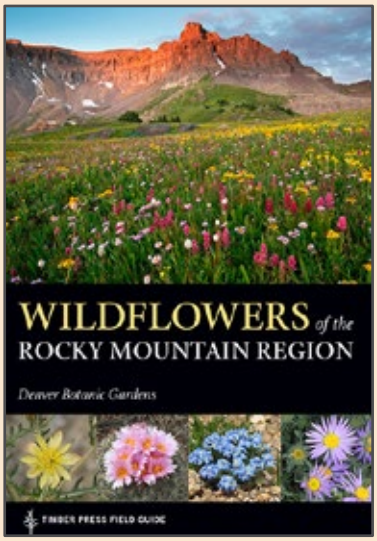
Aime, M. C., C. D. Bell, and **A. W. Wilson**. 2018. Deconstructing the coevolutionary complexity between rust fungi (Pucciniales) and their plant hosts. Studies in Mycology 89: 143-152.

Cho, H. J., M. S. Park, H. Lee, S-Y. Oh, **A. W. Wilson**, G. M. Mueller, and Y. W. Woon Lim. Taxonomic re-evaluation of *Laccaria* (Agaricales, Basidiomycota) in Korea based on morphological and molecular evidence. Mycologia 110: 948-961.

Coopman, J. and M. E. Kane. 2018. Greenhouse acclimatization methods for field establishment of in vitro-derived ghost orchid (*Dendroohylax lindenii*) plants. Native Plants Journal 19(2): 100-108.

Coopman, J. and M. E. Kane. 2018. In vitro desiccation tolerance of the epiphytic Ghost Orchid, *Dendroohylax lindenii* (Lindl.) Benth x. Rolfe. In Vitro Cellular and Developmental Biology – Plant: 1-11.

Denver Botanic Gardens. 2018. "Wildflowers of the Rocky Mountain Region". Timber Press.



Endriss, S. B., **C. Alba**, A. P. Norton, P. Pyšek, and R. A. Hufbauer. 2018. Breakdown of a geographic cline best explains high performance of introduced populations of a weedy invader. Journal of Ecology 106: 699-713.

Flory, S. L., **C. Alba**, K. Clay, R. Holt, and E. Gross. 2018. Emerging pathogens can suppress invaders and promote native species recovery. Biological Invasions 20: 5-8.

Flory, S. L., **C. Alba**, K. Clay, R. Holt, and E. Gross. 2018. Long-term studies are needed to reveal the effects of pathogen accumulation on invaded plant communities. Biological Invasions 20: 11-12.

Hufft, R. A., **M. E. DePrenger-Levin**, **R. A. Levy**, and **M. B. Islam**. 2018. Using herbarium specimens to select indicator species for climate change monitoring. Biodiversity Conservation 27: 1487-1501.

Krishnan, S. 2018. Ensuring the genetic diversity of coffee. Pp. 68-82 in Achieving Sustainable Cultivation of Coffee, vol. 1 Breeding and quality traits, ed. P. Lashermes. Philadelphia: Burleigh Dodds Science Publishing.

Krishnan, S., P. Bramel, D. Horna, B. Lainoff, C. Montagnon, and T. Schilling. 2018. Development of a global conservation strategy for coffee genetic resources. Acta Horticulturae 1205: 505-508.

Lea, M. V., J. Syring, T. Jennings, R. Cronn, L. P. Bruederle, **J. R. Neale**, and D. F. Tomback. 2018. Development of nuclear microsatellite loci for *Pinus albicaulis* Engelm. (Pinaceae), a conifer of conservation concern. PLoS ONE 13(10): e0205423.

NeSmith, J. E., **C. Alba**, and S. L. Flory. 2018. Experimental drought and plant invasion additively suppress primary pine species of southeastern US forests. Forest Ecology and Management 411: 158-165.

Ning, C., G. M. Mueller, L. Egerton-Warburton, **A. W. Wilson**, W. Yan, and W. Xiang. 2018. Diversity and functioning of ectomycorrhizal fungal communities following nitrogen fertilization in an urban-adjacent pine plantation. Forests 9(3), art. no 99.

Seglias, A. E., E. Williams, A. Bilge, and A. T. Kramer. 2018. Phylogeny and source climate impact seed dormancy and germination of restoration-relevant forb species. *PLoS ONE* 13(2): e0191931.

Thomson, S. A. et al. (incl. **M. B. Islam**). 2018. Taxonomy based on science is necessary for global conservation. PLoS Biol. 16(3): e2005075.

Select Presentations

Alba, C., **R. A. Levy**, **J. Berta-Thompson**, **M. B. Islam**, and **J. Wingate**. Increasing the value of botanical collections for understanding grassland biodiversity in Colorado. Western Forestry and Conservation Association, Great Plains Grassland Summit 2018. Denver, CO.

Alba, C., **R. A. Levy**, and **M. B. Islam** 2018. We're all outstanding in our fields: Combining botanical collections and ecological data to improve knowledge of plant diversity. Botany 2018. Rochester, MN.

Charley-Suarez, C., G. M. Mueller, and **A. W. Wilson**. 2018. Phylogenetic delineation and geographic distribution of *Laccaria nobilis* and phenotypic relatives. 11th International Mycological Congress. San Juan, Puerto Rico.

Cullinane, L. 2018. Using a baseline bee survey and ecological monitoring to inform management along an urban greenway. Natural Areas Conference 2018. Bloomington, IN.

DePrenger-Levin, M. E. 2018. Accounting for spatial error in herbarium records for species distribution models of rare plant species. Natural Areas Conference 2018. Bloomington, IN.

Fu, K. 2018. Effects of seed source on drought performance and implications for native prairie restoration. Natural Areas Conference 2018. Bloomington, IN.

Hufft, R. A. 2018. South Platte River Basin Restoration. Ecological Restoration Alliance of Botanic Gardens, 4th Public Symposium. Ontario, Canada.

Hufft, R. A., **M. E. DePrenger-Levin**, **R. A. Levy**, and **M. B. Islam**. 2018. Using herbarium specimens to select indicator species for climate change monitoring. Ecological Society of America 2018. New Orleans, LA.

Krishnan, S., P. Bramel, C. Montagnon, and T. Schilling. 2018. The Global Conservation Strategy for Coffee Genetic Resources. Association for Science and Information Conference. Portland, OR.

Krishnan, S. 2018. Germplasm Resources and Innovation in Waterlilies: Intersubgeneric Hybrids. Chenshan International Waterlily Symposium. Shanghai, China.

Krishnan, S. 2018. Role of U. S. Department of Agriculture's National Genetic Resources Advisory Council (NGRAC) in Providing Strategic Recommendations for Strengthening National Genetic Resources Conservation and Use. International Horticulture Congress. Istanbul, Turkey.

Krishnan, S. 2018. United States Germplasm System and Crop (Coffee) Conservation Strategy. ASEAN Workshop in Conservation and Exchange of Plant Genetic Resources for Food and Agriculture. Vientiane, Laos.

Krishnan, S. 2018. World Food Prize Global Youth Institute. American Society for Horticultural Science, Annual Conference. Washington, D.C.

Levy, R. A. 2018. A Case Study for Connecting Collections and Ecological Research. The Society for the Preservation of Natural History Collections + Biodiversity Information Standards 2018 Conference. Dunedin, New Zealand.

Levy, R. A. 2018. Introduction to the Global Genome Initiative-Gardens. American Public Gardens Association, Collections Symposium. Vancouver, BC.

Levy, R. A. 2018. A Workflow for Adding Specimen Metadata to Images Captured in the Field. The Society for the Preservation of Natural History Collections + Biodiversity Information Standards 2018 Conference. Dunedin, New Zealand.

Loucks, J., **V. S. Evenson**, and **A. W. Wilson**. 2018. Tales of the Pale Panther: Systematics of Rocky Mountain *Amanita pantherine* var. *multisquammosa*. 11th International Mycological Congress. San Juan, Puerto Rico.

Neale, J. R. 2018. Denver Botanic Gardens: GGI-Gardens Symposium. American Public Gardens Association, Annual Meeting. Anaheim, CA.

Neale, J. R. and **R. A. Levy**. 2018. Data standardization at Denver Botanic Gardens. Center for Plant Conservation, Annual Meeting. Fort Worth, TX.

Seglias, A. E. 2018. Conservation of a Colorado high alpine endemic. Institute of Museum and Library Services Tissue Culture Workshop. Cincinnati, OH.

Seglias A. E. and Kramer, A. 2018. The effects of frozen storage on seed dormancy and germination patterns of native southwestern forb species. Botany 2018. Rochester, MN.

Wilson, A. W., S. A. Wright, and **V. S. Evenson**. 2018. Towards a Colorado Mycoflora Project: Molecular diversity of mushrooms from the Southern Rockies. 11th International Mycological Congress. San Juan, Puerto Rico.

Collecting tissue samples with an intern |

Expanding Global Access to **Biodiversity Resources For Future Research**

As contributors to the Global Genome Biodiversity Network, we are expanding the inventory of plant tissue available for research by supporting the goal of making tissue samples of all living plant species accessible to researchers. Every new herbarium specimen we collect includes a tissue sample that is then discoverable online. Collections are also made of unique taxa in our living collections and those of Betty Ford Alpine Gardens. Presentations at both the American Public Gardens Association Annual Meeting and Collections Symposium encouraged others to participate in the program.

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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."

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DENVER BOTANIC GARDENS

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