

SCIENCE

2021 YEAR IN REVIEW

Biodiversity is fundamental to life; from the air we breathe to the food we eat. The scientific study of biodiversity is the foundation of botanic gardens, allowing 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.



Science at the Gardens

Even though 2021 was not quite a normal year, we tackled a lot of projects. We spent time in the fresh air of Colorado's varied habitats collecting project data and specimens for our collections. We connected with communities near and far through our EcoFlora outreach and participation in national meetings largely held virtually. We capitalized on the opportunities our new space within the Freyer – Newman Center affords and refined protocols as well as collections plans and policies. A new strategic plan helps provide focus and direction for the next five years.

Our team continues to grow through the addition of staff and graduate students. We even hosted eight high school interns over the summer introducing them to scientific careers at a botanic garden. We had three graduate students within the Department of Integrative Biology at the University of Colorado Denver successfully defend their theses and graduate in 2021.

Katherine Fu successfully defended her Ph.D. on the implications of seed source on North American shortgrass prairie restoration under climate change. Working with her advisor Dr. Rebecca Hufft, Katherine is our first Ph.D. graduate since we initiated our partnership with UC Denver. Congratulations to Katherine on her dedication and commitment to her research and completing this milestone in her career.



Katherine Fu



Amanda Miller



Gary Olds

Implementing Best Practices

The Freyer – Newman Center for Science, Art and Education is a state-of-the-art facility specifically designed to care for the Gardens' non-living collections. We are now reworking existing workflows and protocols to implement museum best practices. All organic material entering the natural history collections must now be frozen to limit the introduction of pests into the collections. When fresh plant and fungal specimens come in from the field, they are frozen before entering the research collection, a practice not possible in our previous space.



Amanda Miller successfully defended her master's thesis this spring. Advised by Dr. Rebecca Hufft, she conducted research at Chatfield Farms to understand how restoration techniques impact pollinator habitat as part of a larger grassland restoration project we are conducting with collaborators. She now has a fulltime job with a restoration consulting company.

Gary Olds, advised by Dr. Andrew Wilson, successfully defended his master's thesis where he produced a way to DNA barcode hundreds to thousands of specimens in a cost-effective manner. Because so many fungal collections contain specimens that are unidentified, or have identifications that are suspicious, being able to produce DNA sequence data from large numbers of specimens will help us to use fungaria more effectively in the exploration of fungal diversity.

Through external funding support we tackled new and on-going projects, expanding our impact and understanding of regional biodiversity. Through additional funding support we have new projects lined up for 2022. We'll expand data collection on plant diversity and soil quality at multiple locations along the High Line Canal. The next generation of scientists will be trained through this project by building field-based curricula for undergraduates at the University of Colorado, Denver. Our restoration studies in collaboration with the Bureau of Land Management continue to expand and we'll be initiating field experiments both at Chatfield Farms and near Cañon City to examine seed source and seed mixes for restoration. A new partnership with the Colorado Golf Association will fund a floristic survey of the rough areas of a local golf course, the first step to restoring these areas to native habitat. We have also received our first direct funding award from the National Science Foundation (NSF). We will be working with collaborators to study fungal diversity across North America, but here in Colorado we will examine what promotes the production of mushrooms in the alpine zone.

Saving Tiny Plants Through Big Collaboration

Born out of a continental desire to protect our rarest habitats, we have published the [North American Botanic Garden Strategy for Alpine Plant Conservation](#) in collaboration with the Betty Ford Alpine Gardens in Vail, Colorado. The strategy, modeled after the Global Strategy for Plant Conservation, lays out a comprehensive framework for documenting and conserving alpine plants and habitats.

Collectively we aim to understand and document alpine plant diversity, to conserve alpine plants both in situ and ex situ, to promote an understanding of the alpine and the protection efforts needed to conserve these fragile systems and to expand our capacity to take action.

Ripley, N., Neale, J.R., Kuich, N., Kintgen, M., Hufft, R.A., Schneider, A., 2020. North American Botanic Garden Strategy for Alpine Plant Conservation. Betty Ford Alpine Gardens, Vail, Colorado. 20pp.



Projects

Rare Alpine Plants and the Chamber of Warming

Alpine habitats are particularly vulnerable to climate change and are experiencing drastically different conditions than those to which they have been adapted for hundreds to thousands of years. We have begun a project studying the response of a rare alpine species to experimental warming using open-top chambers. These chambers will raise the temperature by ~1.5°C in a population of *Physaria alpina* on a mountain outside of Fairplay, Colorado. Data on growth, reproduction, and survival will be collected over the next five years to understand the impacts of increased temperature on this rare Colorado endemic. This information will help us prioritize conservation efforts in the face of global climate change.



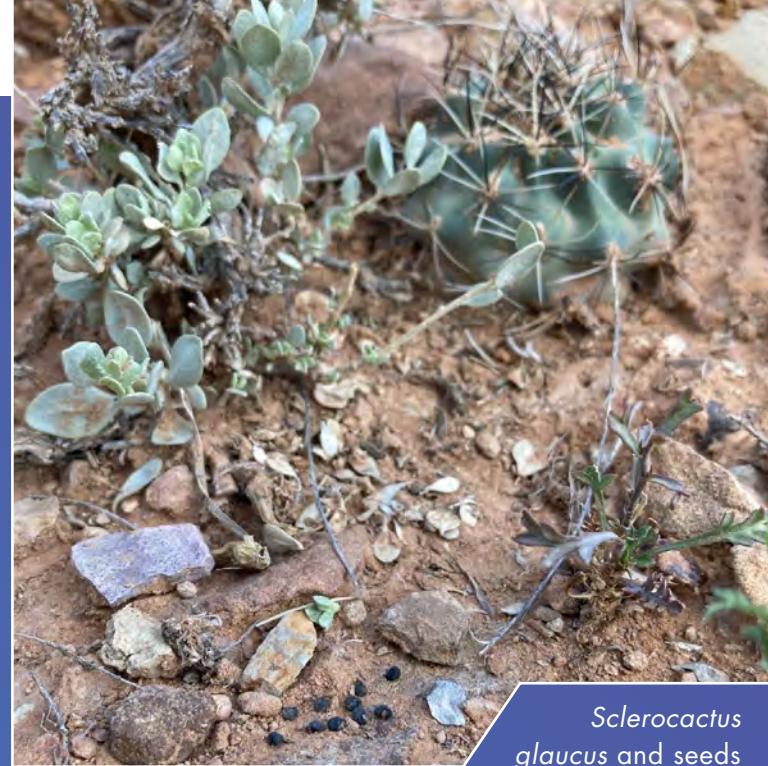
Physaria alpina

Plant Community Response to the 2020 CalWood Fire

This summer, we sampled plant communities north of Boulder, Colorado, to explore how land management decisions shape plant community response to fire. In partnership with Boulder County Parks & Open Space, we asked how plant communities responded to fire in areas where the winter annual cheatgrass (*Bromus tectorum*) was treated with an herbicide that targets short-lived species, versus areas without herbicide. We observed a post-fire “bump” in the performance of non-native species generally—but not in cheatgrass itself. This may short-circuit the often-observed positive feedback loop between cheatgrass and fire. Our ongoing analyses will explore how short-lived native species—which may also be impacted by the herbicide—fared post-fire.



Scorched ponderosa pine (*Pinus ponderosa*) trees with light-colored swaths of cheatgrass (*Bromus tectorum*) in the foreground.



Sclerocactus glaucus and seeds

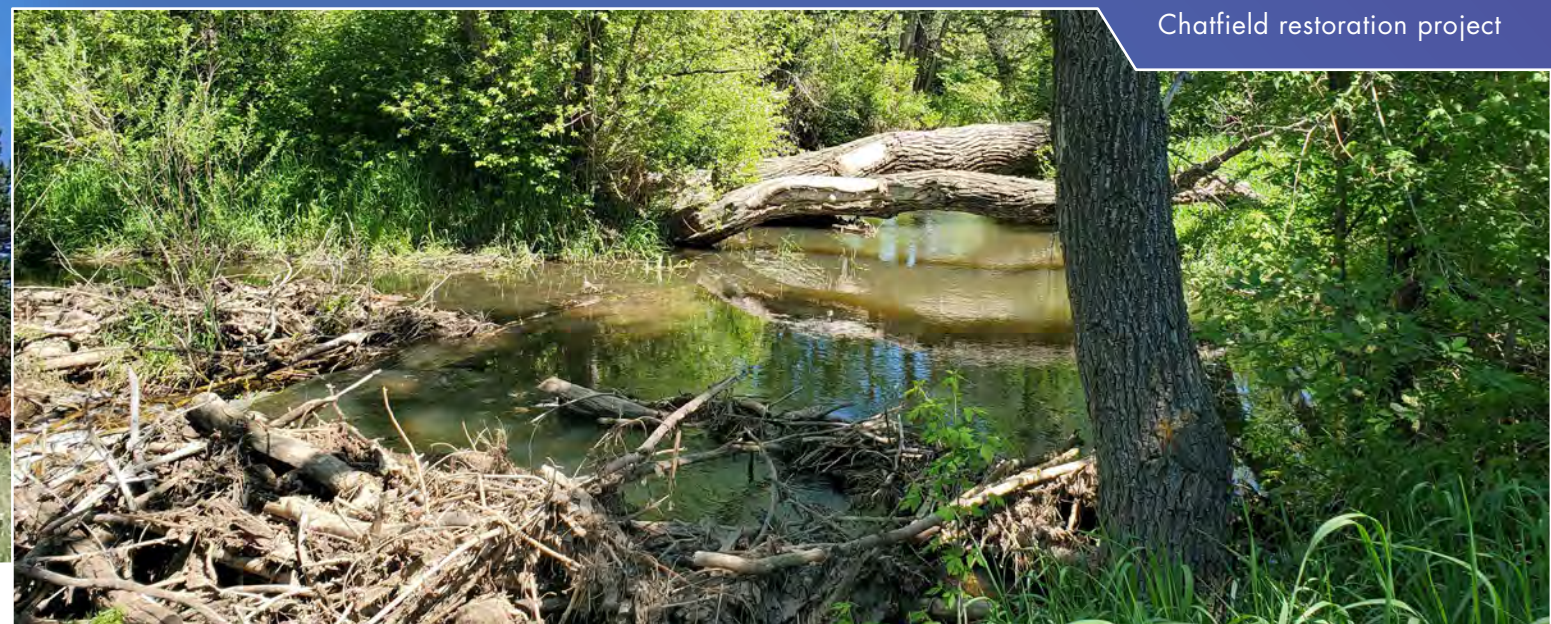
UPDATE | *Sclerocactus glaucus* Monitoring

Sclerocactus glaucus has been recommended for delisting under the Endangered Species Act due to updated estimates of abundance and data from the Gardens from over a decade of demographic monitoring and population genetic analyses. However, climate change could continue to put the species at risk depending on the nuances of changing conditions and the ability of the cactus to adapt. We have initiated studies on seed dispersal, population size estimation methods, associated vegetation communities and the potential for community shifts from diversity held in the soil seed bank.

Chatfield Farms Restoration

As we begin the [UN Decade on Ecosystem Restoration](#), we are doing our part to help restore creek and meadow habitats at [Chatfield Farms](#) and work to develop better practices for restoration. Beavers restore part of the property, and we mimic their work on areas where they aren't active. Since beginning riparian restoration work in 2016, we have successfully restored three historical oxbows to their original flow and have planted 2,725 willow stakes throughout the creek restoration area. Annual monitoring along the creek helps us track project progress.

Chatfield Farms staff have been restoring the on-site grasslands for many years, working to clear non-native grass areas with burning and spraying followed by seeding with different mixes of native grasses and forbs. In 2018 we began working with external partners to expand our grassland restoration. These researchers are testing different management treatments (e.g., tilling and herbicide intensity), seed mixtures and seed treatments to better understand the most efficient ways to get rid of non-native grasses, help with seed establishment and create a diverse plant community. As part of the Chatfield Farms Master Development Plan, we hope to continue to expand our restoration work, continuing to not only improve habitats we manage but also serve as a demonstration site for restoration methods at a larger scale.



Chatfield restoration project

Denver EcoFlora Project

The Denver EcoFlora Project provides numerous opportunities to connect community members with nature while at the same time establishing a baseline of plant biodiversity for the greater Denver metro area. This year we were able to fully implement the project that began in 2020, hosting several in-person events, each one enhancing our outreach to the local metro community, and in turn, enhancing our service to the mission of the Gardens – to connect people with plants. It was a busy summer for the EcoFlora outreach team – all in all, we held 12 youth and 20 adult nonprofit environmental outreach education events for the project. In addition to exploring nature and learning about plants, outreach event participants were taught how

to use the iNaturalist app to observe and document biodiversity for inclusion in the Denver EcoFlora Project.

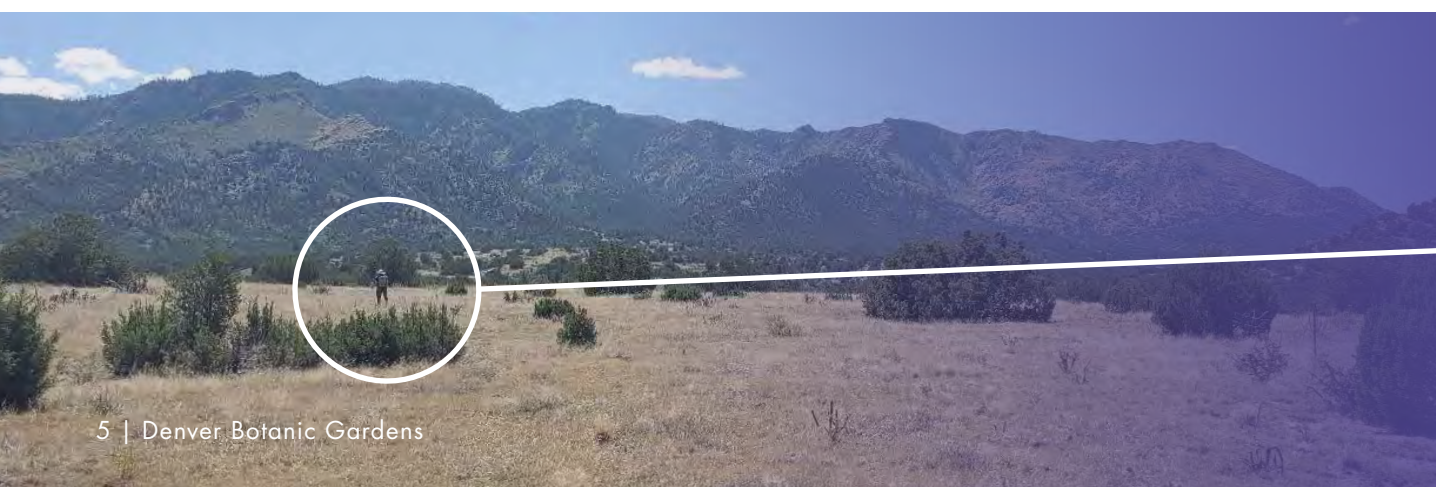
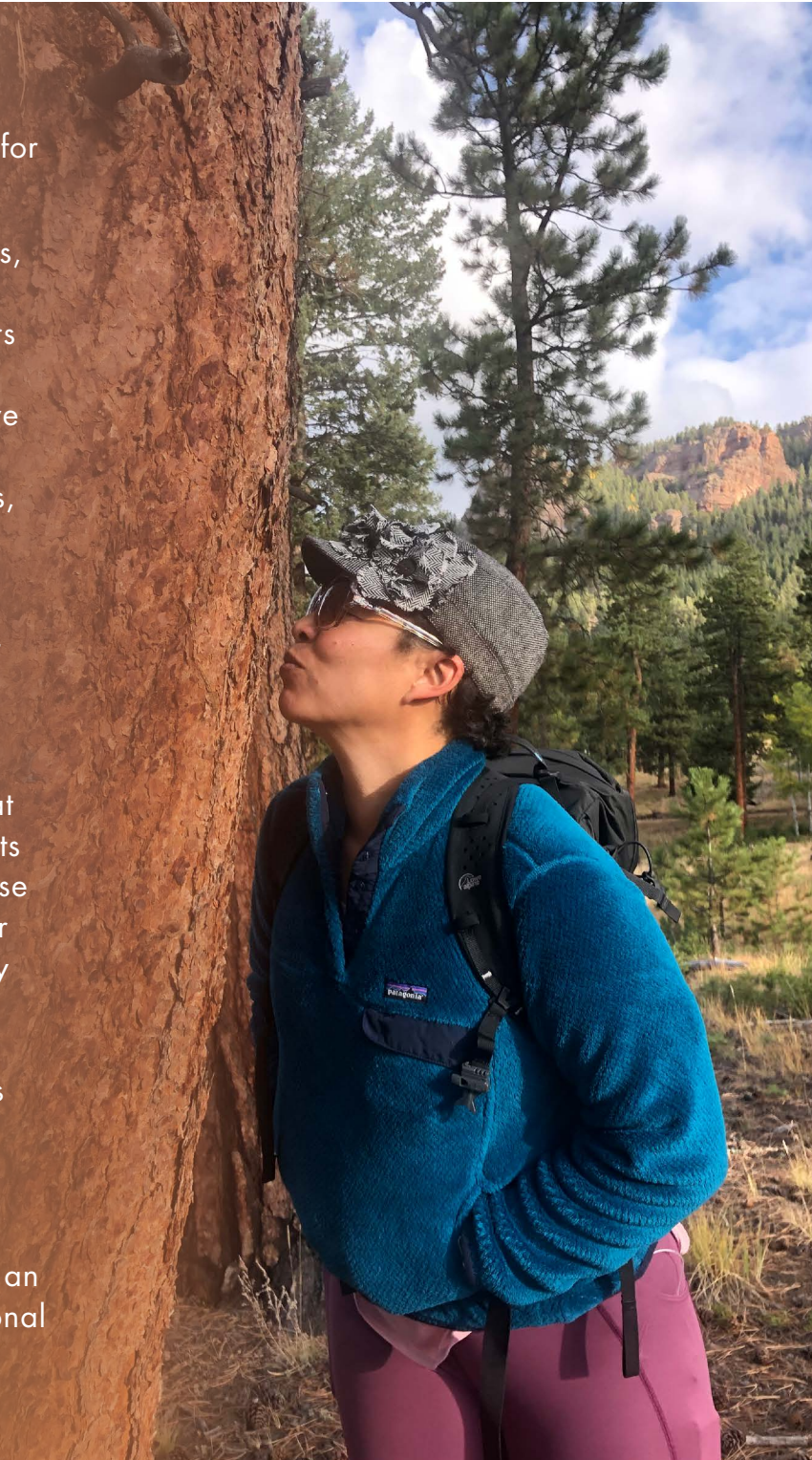
Event highlights include the “*fruta o fruto?*” program in the Westwood neighborhood with My Outdoor Colorado. We led a hunt for hidden grocery store fruits (*frutas*) and botanical fruits (*frutos*) in the park and handed out prizes to the young fruit investigators. We reached diverse audiences by leading hikes for organizations such as Outdoor Afro and Urban Trekkers. Our Meetup group hikes developed into fantastic avenues for us to explore biodiversity in and around Denver while getting to know the community. As we hiked, we documented the different types

of plants we saw. Afterwards, we helped each other identify the plants in the photos we took for iNaturalist.

In addition to hosting in-person outreach events, we continue to send out monthly EcoQuests. These unique “quests” help community members discover and document biodiversity in the metro area. Whether it’s hunting for an invasive plant or learning the differences among three commonly misidentified yellow-flowering asters, all EcoQuests are designed to engage and educate community members.

One unique EcoQuest focused on the Amache-Granada War Relocation Center, a WWII Japanese internment camp in southeastern Colorado. While Amache is over 200 miles away from Denver, it turns out that the plants at Amache are not all that different from the plants in the metro area. By highlighting a few of these shared species, we were able to make broader connections within the community to the history of Amache. Each quest connects participants with the local flora helping build appreciation of the biodiversity all around us. And once this biodiversity is appreciated, it is our hope that a greater effort will be made to preserve it for future generations.

The [Denver EcoFlora Project](#) is funded through an Institute of Museum and Library Services National Leadership Grant to the New York Botanical Garden (Award #[MG-70-19-0057-19](#)).



UPDATE | BLM

This year we began an expansion of our restoration efforts on federal lands in partnership with the **U.S. Bureau of Land Management (BLM)**. We will be conducting research on seed sourcing guidelines and adaptation. We began scouting field sites around Cañon City, Colorado. Seeds collected from populations throughout the western U.S. are currently in stratification and will be planted into field sites in 2022.

Natural History Collections

Natural history collections are snapshots in time, capturing the biodiversity of a particular place at a specific moment. Each specimen is a permanent record of our natural world – documenting morphological, genetic and distributional information all in a single collection. Together, these collections provide precious evidence of how landscapes, ecosystems and populations change over time. As a museum, the Gardens' collections support and engage all who are curious about the natural world, including scientists, artists and activists.

Botanical Adventures

This year the wildflowers were abundantly plentiful, and we were excited to return to field work. Collection expeditions took us to the southeastern plains, Axton Mountain Ranch outside of Denver and the La Sal mountains of Utah, with each trip designed to increase our knowledge of plant biodiversity in the Southern Rocky Mountains.

On the southeastern plains, we collected plants from limestone breaks and were even invited to feed bison, wild horses and Texas longhorns. We came back to the plains in September and made over **100 COLLECTIONS** from the Comanche National Grassland, specifically targeting grasses. A trip to the La Sal mountains supported native thistle research, with a goal of collecting type specimens for a new species of thistle. These type specimens will serve as a reference for this new species.



Solidago wrightii in Vogel Canyon

Partnership with Denver Mountain Parks: Axton Mountain Ranch

Our first season inventorying the plants of a soon to be Denver Mountain Park, Axton Mountain Ranch, was a resounding success. The project, which involved numerous students, staff and volunteers, documented an impressive amount of diversity with **415 SPECIMENS** representing over **300 SPECIES** of vascular plants. Highlights include six species of orchids, **17 DIFFERENT SEDGES** (*Carex*) and two rare species. Ultimately, this project will help Denver Mountain Parks better understand the biodiversity of the area and provide invaluable information for best land management practices.



Collecting specimens at Axton Mountain Ranch

Magical and Magnificent Mushrooms of 2021

Early and frequent rains stimulated mushrooms, creating one of the most exciting years for mycology in over **50 YEARS**. During the North American Mycological Association's Annual Foray near Granby, Colorado, a beautiful *Leptonia* species was collected. These blue mushrooms with pink gills are often found in the mossy forests along the pacific coast, but rarely encountered in the Rockies.

We then traveled to the Telluride Mushroom Festival, which was also recently blessed by rain. There we encountered the enigmatic *Neolecta vitellina*, the always mesmerizing blue-green *Chlorociboria aerugenascens*, and heaps of chanterelles. All in all, the two forays resulted in over **250 SPECIMENS** added to the Sam Mitchel Herbarium of Fungi.



Neolecta vitellina



Chlorociboria aerugenascens

A Rare and Exciting Find on the High Line Canal

In 2018, then graduate student Liam Cullinane conducted a survey of bee communities along the High Line Canal in the Denver metro area. This year, upon further investigation, we determined that he had collected a specimen of *Bombus occidentalis*, a bumble bee that has seen serious decline in the past two decades and was last collected in Colorado in 2011. While only a single individual was documented, this is welcome news for the species and demonstrates the value of green spaces as a resource for biodiversity within highly urban areas.



The Research and Conservation Department at the Gardens is committed to training future and current scientists through immersive research opportunities. Students pair with a lead scientist at the Gardens to answer questions pertaining to ecology, biodiversity and conservation. Research opportunities not only help us answer these important questions, but also teach students how to conduct research and contribute to science.



Megan Clark is a first-year master's student advised by Dr. Rebecca Hufft working on a BLM-funded restoration project. She is interested in plant and restoration ecology and will examine the importance of seed sourcing in restoration projects at Chatfield Farms using experimental plots to grow seeds sourced from a variety of populations around the Western United States. By growing these populations in a common environment, she hopes to see if local adaptation exists within these species, testing the long-standing theory that "local is best" when it comes to sourcing seeds.



Michelle DePrenger-Levin is a Ph.D. candidate working with Dr. Michael Wunder (UCD faculty) exploring biological traits that predispose a species to extinction. Her research builds off more than two decades of studying population dynamics of rare and threatened Colorado plants with the Gardens. She is interested in how life history traits and variation in response to environmental forces impact the persistence of a species across its range. She will be critically examining available methods to detect declines in population size or range that increase extinction risk.



Tiffany Gentry is a first-year master's student, advised by Dr. Jennifer Ackerfield and Dr. Leo Bruederle (Gardens adjunct researcher). She is interested in the processes of evolution and speciation. Her research involves examining the phylogenetic relationships within the genus *Eutrema*, specifically through the lens of chromosome duplication. She is exploring how this phenomenon contributes to within-genus diversification and distribution.



Alissa Iverson is a second-year master's student advised by Dr. Christina Alba. She examines the composition of the soil seed bank of a Denver urban canal that is undergoing hydrologic change due to implementation of Green Stormwater Infrastructure. By uncovering what species of plants have seeds in the soil, and what traits those species have, she can make comparisons to the above ground vegetation and consider the capacity for the habitat to respond to the change. This year she conducted a germination experiment.



Emily Orr is a master's student working with Dr. Jennifer Neale on a population analysis of *Astragalus microcymbus*, a rare plant found in western Colorado. Emily has collected population genomic data from more than 300 individuals representing 10 populations of the rare plant. She is working through the bioinformatic analyses on the more than 16,000 SNPs (Single Nucleotide Polymorphisms) to assess population genetic diversity and distribution. The outcomes will be shared with land managers to further inform management practices.



Audrey Spencer is a Ph.D. student advised by Dr. Jennifer Ackerfield and Dr. Leo Bruederle. She is interested in the origins of the flora of the Southern Rocky Mountains and the biogeographical history of disjunct distribution patterns. Her research will use a combination of phylogenetics, morphology and geography to clarify the taxonomic relationships as well as the biogeographic history of a genus of shrubs, *Physocarpus* (ninebark). Over the summer, Audrey led the floristic inventory of Axton Mountain Ranch.

Select Publications

Alba, C., Levy, R., Hufft, R. 2021. Combining botanical collections and ecological data to better describe plant diversity. *PLOS ONE* 16(1): e0244982

Krishnan, S., H. Kirk-Ballard, E. McGinnis, and L.G. Chance. 2021. Critical Issues in Consumer Horticulture: Gaps in Research and Public Gardens' Involvement in Consumer Horticulture. *HortTechnology* 32:1. <https://doi.org/10.21273/HORTECH04934-21>

Krishnan, S., S. Pruvot-Woehl, A.P. Davis, T. Schilling, J. Moat, W. Solano, A. Al Hakimi, and C. Montagnon. 2021. Validating South Sudan as a Center of Origin for *Coffea arabica*: Implications for Conservation and Coffee Crop Improvement. *Frontiers in Sustainable Food Systems*. 5:761611. <https://doi.org/10.3389/fsufs.2021.761611>.

Krishnan, S., T. Matsumoto, C. Nagai, J. Falconer, S. Shriner, J. Long, J. Medrano, and F. E. Vega. 2021. Vulnerability of coffee (*Coffea* spp.) genetic resources in the United States. *Genetic Resources and Crop Evolution*. 68:2691-2710. <https://doi.org/10.1007/s10722-021-01217-1>.

Select Presentations

Ackerfield, J. 2021. EcoFlorals of North America AND Field work for the 21st century. American Public Gardens Association Annual Meeting.

Ackerfield, J. 2021. How to identify the thistles of Colorado. Colorado Native Plant Society Workshop.

Ackerfield, J. 2021. Plant defenses and survival strategies AND Carnivorous plants of Colorado. Crested Butte Wildflower Festival. Crested Butte, CO.

Ackerfield, J. 2021. Revised taxonomy of the *Cirsium eatonii* complex. CalPoly Biology Department Seminar. San Luis Obispo, CA.

Ackerfield, J. 2021. Status of rare thistles in Utah: an update on taxonomy and new species. Utah Native Plant Society.

Ackerfield, J. 2021. The California Floristic Province adaptive radiation of thistles. California Botanic Garden. Claremont, CA.

Ackerfield, J. 2021. The Denver EcoFlora Project AND Using Hyb-Seq to resolve relationships among North American *Cirsium* (thistles). Botany 2021 conference.

Ackerfield, J. 2021. The Denver EcoFlora Project and iNaturalist. Colorado Native Plant Society. Denver, CO.

Ackerfield, J. 2021. The funky thistle: a new species of thistle dedicated to Dr. Vicki Funk. The International Compositae Alliance.

Ackerfield, J. 2021. Untangling the taxonomy of *Cirsium* (thistles) in North America using Hyb-Seq data. University of Colorado Department of Integrative Biology Seminar Series. Denver, CO.

Ackerfield, J. 2021. Update on the second edition of the *Flora of Colorado*. Colorado Native Plant Society Annual Meeting. Trinidad, CO.

Alba, C. 2021. Combining botanical floristics and ecological sampling to better understand biodiversity on the southeastern plains. Colorado Native Plant Society Annual Meeting. Trinidad, CO.

Alba, C. 2021. Growing into my role as a plant ecologist at a public garden AND Transforming an urban canal for use as green stormwater infrastructure: The potential role of in situ vegetation and soils. Ecological Society of America Annual Meeting.

Alba, C. 2021. Native shrubs of Colorado, Part II. Colorado Native Plant Society Workshop.

Alba, C. 2021. Vegetation and soils as an ecological backdrop for green stormwater infrastructure function. Presentation to Stormwater Enhancement and Improvement Technical Leadership Team.

Berta-Thompson, J.W., C.G. Olds, J.J. Loucks, R.A. Levy, and A.W. Wilson. 2021. Exploring variation in deep short-read sequencing of preserved fungal specimen nrITS2 barcodes: What's in a fungarium specimen? Mycological Society of America Annual Meeting.

DePrenger-Levin, M. 2021. Addressing uncertainty in extinction risk due to projection length. Ecological Society of America.

DePrenger-Levin, M. 2021. Soil seed bank dynamics, dispersal, and distribution of *Sclerocactus glaucus*. Colorado Rare Plant Symposium. Trinidad, CO.

Hufft, R., Shakelford N., **Yousse M., Miller A., Stacy A., Voss K.** 2021. Enabling the study of multi-trophic responses in restoration. Society for Ecological Restoration.

Hufft R. 2021. A multi-trophic approach to monitoring and evaluating conservation. International Congress for Conservation Biology.

Levy, R., C. Alba, and R. Hufft. 2021. Point-intercept: a field-to-database web application for quantifying ground cover and vegetation. Digital Data in Biodiversity Research. Gainesville, FL.

Loucks, J.J., C.G. Olds, J.W. Berta-Thompson, and A.W. Wilson. 2021. Macrofungi of the Lemhi Range (Idaho, USA) Documenting Diversity in An Underexplored Region of North America. Mycological Society of America Annual Meeting.

Neale, J. 2021. Beyond the Gardens: Research efforts at Denver Botanic Gardens, Osher Lifelong Learning Institute. University of Denver. Denver, CO.

Neale, J. 2021. Denver Botanic Gardens Program Update. Center for Plant Conservation Annual Meeting.

Neale, J. 2021. Genetic Considerations in Rare Plant Conservation. UC Santa Barbara & Santa Barbara Botanic Garden. Santa Barbara, CA.

Neale, J., M. Kintgen, A. Schneider, R. Hufft, N. Ripley, N. Kuich, and E. Griffoul. 2021. Approaching alpine plant conservation through strategic partnerships. American Public Gardens Association Annual Meeting.

Neale, J., M. Kintgen, A. Schneider, R. Hufft, N. Ripley, N. Kuich, and E. Griffoul. 2021. The North American Botanic Garden Strategy for Alpine Plant Conservation: How you can engage. Colorado Rare Plant Symposium. Trinidad, CO.

Olds, C.G., J.W. Berta-Thompson, J.J. Loucks, R.A. Levy, and A.W. Wilson. 2021. Applying a Modified Metabarcoding Approach for the Sequencing of Macrofungal Specimens. Mycological Society of America Annual Meeting.

Seglias, A. 2021. Using open top chambers to understand how two rare alpine plants will respond to increased warming. Colorado Rare Plant Symposium. Trinidad, CO.

Wilson, A.W. 2021. Introduction to the Mushrooms of the Rockies: Documenting Fungi in Colorado's Forests. Telluride Mushroom Festival. Telluride, CO.

Wilson, A.W. 2021. NAMA Voucher Reports, and How to collect, document, and voucher specimens. North American Mycological Association Annual Foray. Granby, CO.

Reports and Datasets

DePrenger-Levin, M., R. Hufft. 2021. Life history and demography of *Astragalus microcymbus* Barneby (Fabaceae). Prepared for the U.S. Bureau of Land Management, Colorado State Office.

DePrenger-Levin, M., R. Hufft. 2021. Demographic monitoring of *Sclerocactus glaucus*, an endemic species of western Colorado. Prepared for the U.S. Bureau of Land Management, Colorado State Office.

DePrenger-Levin, M., R. Hufft. 2021. Population monitoring of *Penstemon harringtonii* (Plantaginaceae), an endemic species of Colorado, USA. Prepared for the U.S. Bureau of Land Management, Colorado State Office.

Kathryn Kalmbach Herbarium (Denver Botanic Gardens). 2021. **Denver Botanic Gardens Collection of Arthropods.** Occurrence dataset <https://doi.org/10.15468/tdocff> accessed via GBIF.org on 2021-12-02.

Kathryn Kalmbach Herbarium (Denver Botanic Gardens). 2021. **Kathryn Kalmbach Herbarium.** Occurrence dataset <https://doi.org/10.15468/axrelr> accessed via GBIF.org on 2021-12-02.

Levy, R. 2021. DBG Tissue and DNA Bank. Version 1.9. VertNet. Occurrence dataset <https://doi.org/10.15468/caz5u8> accessed via GBIF.org on 2021-12-02.

Sam Mitchel Herbarium of Fungi (Denver Botanic Gardens). 2021. **Denver Botanic Gardens, Sam Mitchel Herbarium of Fungi.** Occurrence dataset <https://doi.org/10.15468/kvqagug> accessed via GBIF.org on 2021-12-02.



Intern Program

As part of our commitment to training and diversifying the next generation of scientists, we are expanding our internship and mentoring opportunities. Last summer, we hosted eight high school interns in the department, many from diverse backgrounds and underrepresented communities. They learned about the career path of a scientist, gained valuable work experience, built their professional skillsets and made new friends. As one intern said, "I will never forget this once-in-a-lifetime experience... I can now see myself doing this in the future." We look forward to continuing and expanding our internship program.

Thank You to Our Funders

Alice Eastwood Fellowship
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Boulder County Parks &
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Center for Plant Conservation

Colorado Mycological Society

Colorado Native Plant Society –
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Desert Ecosystem Analysis
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Garden Club of America

Garden Club of Denver

Henry Shaw Cactus Society

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Mycological Society of America

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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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