SCIENCE

2024 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.

DENVER BOTANIC GARDENS

Science at the Gardens

In 2024 staff and students fanned out across the southern Rockies to conduct our work. With efforts focused primarily on existing projects, the intensive data collection occurred directly through digital platforms. Data was collected not only across a broad geographic range but varying landscapes from a golf course to an urban recreational greenway, to the high plateaus of the Colorado western slope and the vast expanse of Wyoming. There, a crew of botanists traveled across the state documenting populations of native plants desirable for large scale restoration work with the U.S. Bureau of Land Management (see page 4).

Experimental work assessing factors influencing restoration success moved forward. The team is busy assessing genomic data to understand how genetic diversity plays into restoration success. At Chatfield Farms restoration work is transforming not only Deer Creek but the meadow surrounding the outdoor chapel and informing the impact of site prep and water restrictions on plant success.

Beyond the field, our collections continued to grow through focused collecting efforts to further our knowledge of plant and fungal diversity in urban and montane habitats. Our collections serve both the local and global scientific communities. With more than 30 active loans of plant material, we are sharing specimens and the valuable data they hold to help elucidate evolutionary relationships and chemical signatures as well as species distributions.

Along with Betty Ford Alpine Gardens (Vail, CO), we were awarded a Museums for America Collections Stewardship Grant from the Institute for Museum and Library Services (MA-255890-OMS-24) to implement components of the North American Botanic Garden Strategy for Alpine Plants. Over the next three years, we will push our knowledge of alpine plants, and their conservation needs forward, informing further coordinated efforts to protect these fragile plants and habitats.

Partnerships not only further the impact of our work but they enhance the value of the outcomes. Diverse partners and perspectives strengthen our projects, and we are better because of them. Internally our collaborations bring together ecological and floristic methods to provide rich datasets (see pages 5-6). Collaboration is a cornerstone of many of our projects, lending expertise and new perspectives, which can inform the questions we ask and provide insights into how our findings can be applied to real-world applications. In times of grave conservation concern, the intellectual and financial support of partners provides resilience. We look forward to continued growth and understanding.

Thank you, Dr. Ackerfield!

Dr. Jennifer Ackerfield served as the Gardens' Head Curator and Associate Director of Biodiversity Research for the last five years. We are grateful for her love of plants and her passion for teaching all those around her to love plants too.

Congratulations Dr. DePrenger-Levin!

Research Associate Michelle DePrenger-Levin successfully defended her Ph.D. in the spring. Michelle pursued a Ph.D. to further her analytical skills used to assess plant population dynamics over time. She has been collecting data on several species for more than 20 years and each year finds new questions to ask. Through her dissertation, she dove into the methods used to detect plants in the field and evaluated how to mathematically contend with the inevitable fact that all plants can't be counted and measured every year. We look forward to seeing where Michelle's questioning and analytical modeling skills will take her research next.

Science-Art Symposium: Mechanisms of Change

2024 saw the realization of a dream – to activate the Freyer – Newman Center as a hub for the intersection of science and art. We developed and hosted our first Science-Art Symposium, a two-day event with invited speakers from across the country. Artists and scientists shared their passions, their projects and their deep understanding of both fields. The mixed-career panels offered varied perspectives on the themes of climate resilience and explorations of land, storytelling or collaboration. Through presentations, film screenings, moderated Q&A sessions and networking, we formed a community deeply committed to the knowledge that science and art are not only similar in process, but essential for the success of the other. We walked away deeply awed at the unique space we were able to create during the two-day event and full of ideas for how to keep the conversation going. The Freyer – Newman Center truly is a Center for Science, Art and Education.

Featured Projects

Urban Trees and the Herbivores (and Pathogens) That Love Them

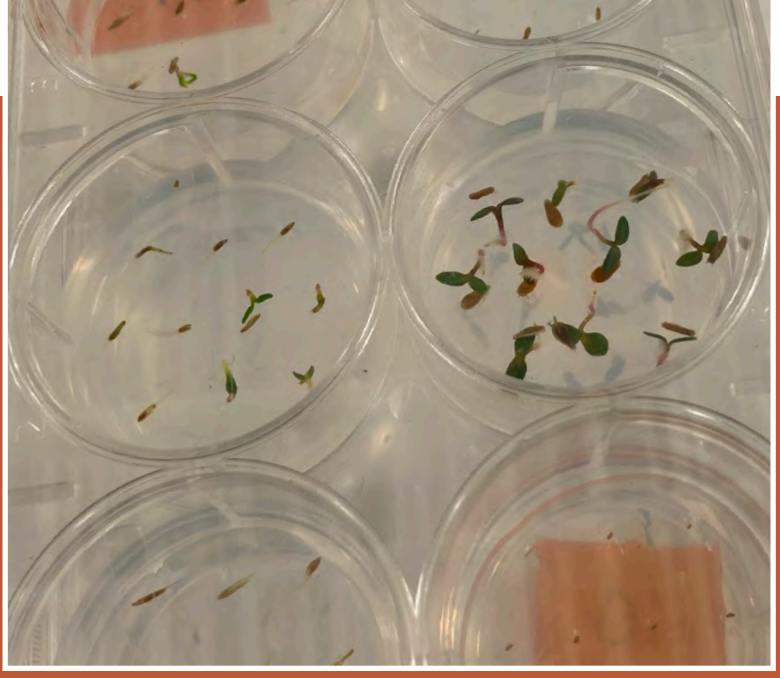
We are now in year three of monitoring the survival and growth of nearly 400 individuals of 10 species of urban trees along the High Line Canal greenway in Denver. This year, we continued developing an exciting component of monitoring: assessment of herbivores and pathogens on the trees. We made specimen collections of affected leaves and scored levels of damage by type (for example, chewing, mining and rasping damage). Ultimately, we aim to answer questions about how the various tree species that comprise our urban planting palette function as host plants for beneficial arthropods or reservoirs for pests.

Penstemon penlandii

In 2023, we initiated a study to test the suitability of transplanting federally listed *Penstemon penlandii* as a mitigation strategy. To make transplanting a viable option for thousands of individuals, we limited the distance plants were moved and we selected locations that appeared suitable but that did not contain *P. pendlandii*. One year later, we found that spring transplants had higher survival rates than fall transplants and reproductive individuals were unaffected by transplant timing. While it is too early to determine if this is a viable mitigation strategy, we will continue to monitor and learn about the life history of this endangered species.

Restoration Seed Sourcing

We continued studying the importance of genetic diversity on seed source selection for restoration. This project is an ongoing collaboration with the U.S. Bureau of Land Management and the Royal Gorge Field Office near Cañon City, Colorado. This year, we collected survival and flowering data, as well as leaf tissue for genomic sequencing, on all surviving plants that were seeded two years prior. We observed relatively high survival and flowering rates in *Artemisia frigida*. We will continue collecting data annually to determine how different seed mixes impact plant performance, retention of genetic diversity, and ultimately the success of ecological restoration.



Does Elevation Predict Germination Requirements?

Germination behavior can vary among populations of the same species, often showing adaptation to habitat, elevation and climate. As the climate changes, winters are expected to shorten, which will impact the period of chilling time (called "stratification") that many plant species need prior to germination in the spring. The effect of different stratification lengths was tested on populations of nine native Colorado species sourced from a range of elevations in Boulder County. Contrary to our hypotheses, source elevation did not significantly explain germination behavior for most of the species in our study, suggesting that shorter winters will only negatively impact species that require long periods of stratification, regardless of elevation.

CommonGround Golf Course Restoration

We are partnering with the Colorado Golf Association to help improve wildlife habitat on CommonGround Golf Course. After conducting a floristic inventory in 2022, we began to test the effectiveness of a low-cost, minimal-site-preparation technique. Some of the seeded species did germinate and persist for two growing seasons despite no or minimal ground preparation or weed removal prior to seeding. Even though the overall native plant density was very low, there was still a significant increase in pollinators. This relatively easy and inexpensive technique can be used to improve pollinator habitat in areas where additional site preparation is not possible or as a temporary restoration solution.

Seeds of Success

Seeds of Success (SOS) is the national native seed collection program, led by the U.S. Bureau of Land Management (BLM). SOS's mission is to collect wildland native seeds for research, development, germplasm conservation and ecosystem restoration. We supported the SOS program this year by collecting seeds on BLM lands in Wyoming. A crew of six botanists scouted 399 potential collection locations and made 25 large seed collections. These seeds will be cleaned at a federal seed cleaning facility and then become available for restoration on federal lands.

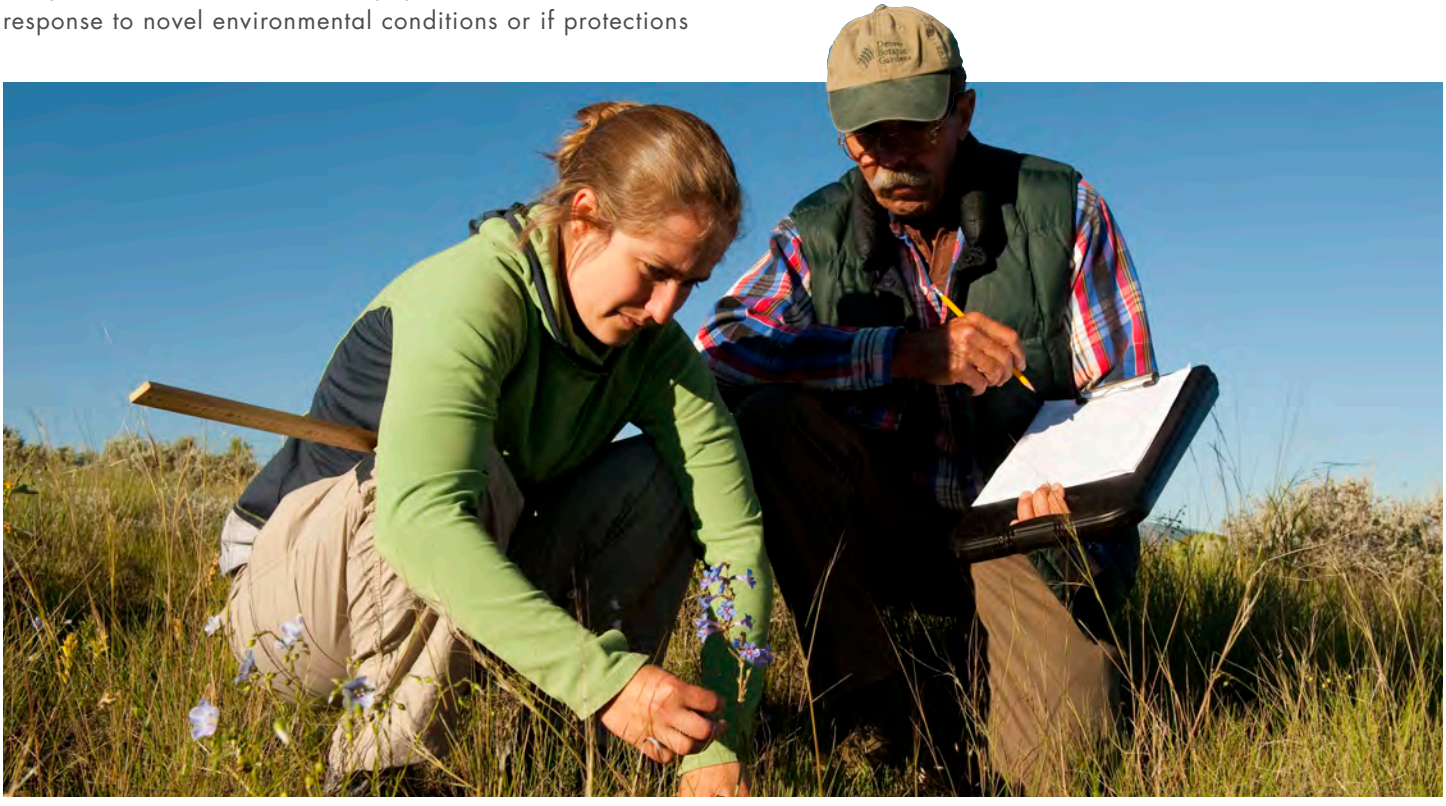
Rooted in Time
30 Years of Insights from Long-term Plant Monitoring

As botanic gardens continue to broaden conservation efforts beyond the garden gates, we are uniquely positioned to provide robust ecological data to land managers and a range of partners. At Denver Botanic Gardens, we use plant monitoring as a key tool for informing everything from federal rare plant listing status to which trees cities might plant in a changing climate. We value the opportunity to build long-term, question-driven and innovative monitoring approaches that our partner entities may not have the capacity to develop, despite having a pressing need for the data. Here we highlight some of the conservation outcomes that have come from this rich data collection.

Long-term Demographic Monitoring

With up to 30 years of demographic monitoring of several Colorado rare plant species, our data has informed determinations not to list species under the Federal Endangered Species Act (*Eriogonum brandegeei* and *Astragalus microcymbus*) and enabled the delisting of *Sclerocactus glaucus*. Delisting of *S. glaucus* was possible because of our demographic monitoring and the continued protection of critical habitat by the U.S. Bureau of Land Management. We documented stable population trends and have a better understanding of how this species will respond to future climate conditions. We will continue to study this cactus to determine if populations decline in response to novel environmental conditions or if protections of critical habitat are removed. Should listing become necessary in the future, we will be prepared with the best scientific knowledge.

We have also used our demographic data to find general patterns of extinction risk by life history. The longitudinal data we collect is essential to understanding the factors that contribute to extinction risk and actions that can increase a species' climate resilience. However, there are many species threatened with extinction that lack long-term data. To address the urgent need to understand climate resilience of data deficient species, we are working to improve and adapt our methods. We have begun to address noise in the data that limits our understanding of climate resiliency with advances in field and statistical methods for both new and long-term studies.



Question-driven Monitoring of Urban Trees

Municipal trees are expensive to plant and maintain, and marked attrition can happen in the first few years post-planting. Despite this challenge, few studies exist that parse the interrelated factors (soil moisture, light, topography, and plant competition) that shape tree survival post-planting. This data gap is problematic given that many large-scale tree-planting efforts are being undertaken across cities worldwide. Tree canopies in semi-arid cities like Denver, which would be a treeless grassland without human intervention, are particularly vulnerable under climate change. With funding from local nonprofit partners, including the High Line Canal Conservancy and Metro Denver Nature Alliance, we are monitoring nearly 400 trees to empirically test what shapes tree planting success in relation to planting location. This information will be used to help inform future planting efforts.

Innovation in Monitoring Biodiversity

Most plant communities are similarly organized, with a few common species contributing disproportionately to biomass and ecosystem function, and numerous, uncommon species contributing disproportionately to diversity. Given this widespread pattern, biodiversity documentation should strive to simultaneously characterize both dominant and rare species yet monitoring methods do not typically capture both sides of this continuum. We fused sampling approaches used by ecologists (plot- and transect-based monitoring of abundances) and floristic botanists (meandering coverage of an entire area of interest to find uncommon species) to illustrate the complementarity of these approaches in the context of an urban greenway. The transect-based approach showed that three non-native grasses comprised the bulk of plant cover along the greenway, while the floristic approach revealed incipient spread of uncommon garden plants onto the greenway. Each approach provided unique information needed to inform land management decisions. We now aim to incorporate this hybrid monitoring approach across a range of projects including urban restoration, rare plant and high alpine study systems.

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 record of our natural world – documenting morphological, genetic and distributional information all in a single collection. Together, these specimens provide precious evidence of landscape, ecosystem and population change over time. As a museum, the Gardens' natural history collections support and engage all who are curious about the natural world. And as records of the past, they provide invaluable, irreplaceable resources for protecting our future.

Frasera coloradensis

Frasera coloradensis, or Colorado green gentian, is a rare flowering plant found only in Colorado's southeastern plains, specifically on limestone outcrops. Due to its restricted range, it's considered imperiled in the state. With support from Botanic Gardens Conservation International and the U.S. Forest Service, we visited all known sites of this species on Comanche National Grassland to identify areas for future seed collection. From each site, we preserved a specimen for the Kathryn Kalmbach Herbarium. Due to the hot, dry summer, seed collection was successful at only one location. These seeds are now stored for potential future restoration efforts on Comanche National Grassland.

Physaria X1 update

Research sometimes brings surprises, like in our collaborative study of *Physaria* X1. We initially investigated whether *Physaria* X1, thought to be a hybrid between the rare *P. bellii* (Bell's twinpod) and the more common *P. vitulifera* (fiddleleaf twinpod), should be recognized as its own species. During this research, we discovered a potentially new, undescribed species of *Physaria* that was originally identified as *P. vitulifera*. Further sampling confirmed that the *Physaria* plants at this location are indeed genetically and morphologically distinct from *P. vitulifera*. We are now working on officially giving this new species a formal scientific name.

Collaborative Bioblitz at the Leopold Family's Shack West

To honor the 75th anniversary of "A Sand County Almanac," we joined a collaborative bioblitz at Shack West, Colorado's tribute to Aldo Leopold's legacy of environmental ethics. Organized by the Colorado Natural Heritage Program, the event aimed to catalog the property's biodiversity. Our team contributed by making iNaturalist observations alongside plant and fungal collections. Experts in botany, mycology, ecology, mammalogy, ornithology and entomology—from universities, agencies and even the Leopold family—collaborated to build a comprehensive species list. Shack West, founded by Estella Leopold, embodies Aldo Leopold's vision, uniting science and stewardship to safeguard biodiversity for future generations.

Surveying Wyoming's Alpine Species of Concern

Alpine species are especially vulnerable to climate change, making their documentation and seed collection vital for conservation. Botanists from the research and horticulture departments teamed up to conduct a trip to Wyoming's Shoshone National Forest to find and document alpine species of concern. Working in grizzly country, we had to maintain vigilant bear safety practices, such as always having a person on bear watch. We collected seed from two species of concern and made 24 voucher collections—documenting rare species, their associated taxa and common but underrepresented specimens. This work supports the protection of fragile alpine ecosystems and their unique biodiversity.

Sam Mitchel Herbarium of Fungi

This year the Sam Mitchel Herbarium of Fungi processed over 500 specimens representing more than 270 species. These specimens were collected in 2022 and 2023, while at least another 600-700 specimens were collected in 2024. With these collections, the fungarium now holds over 2,900 species from more than 24,000 specimens. Since this represents the largest collection of macrofungi from the Rocky Mountain region, we are working with colleagues to include fungi in Colorado's natural history conservation efforts. In collaboration with the Colorado Natural Heritage Program, we are working to identify rare fungi in need of monitoring.

Outreach Highlights

This year, we connected the public with the science of nature through hands-on events, engaging social media content and storytelling with National Geographic Explorers. We organized the Denver-Boulder City Nature Challenge, a global competition documenting urban biodiversity, and Insects Illuminated, a nighttime event observing nocturnal insects under UV light. Herbarium tours and community programs like Night at the Museums showcased the significance of our research and collections in protecting and understanding biodiversity. By blending education and exploration, we inspired curiosity and a deeper appreciation for the natural world, highlighting how science and community can work together to protect biodiversity.

Graduate Training

The Research & Conservation Department is committed to training future and current scientists through immersive research opportunities. Partnering with the University of Colorado Denver, students work with a lead scientist at the Gardens to answer questions pertaining to ecology, biodiversity and conservation. This partnership helps us answer important biological questions while teaching students how to conduct research and contribute to science.

Francis Anaya is a master's student interested in forest vegetation recovery post-high severity wildfires. Her research uses Bureau of Land Management data to determine if aerial seeding of the Beaver Creek (Colorado) burn scar aided native vegetation regeneration and surface stabilization. She now works for the Natural Resources Conservation Service.

Brielle Cerep-Funke is a second-year master's student testing how native horticultural plants perform under increasing drought stress by completing a common garden experiment at our Chatfield Farms location.

Ash Kerber is a first-year master's student exploring the taxonomy of rare alpine plants, specifically in the genus *Polemonium*, using floral scent and genetics. She plans to demonstrate how diverse alpine angiosperm adaptations can be, especially those that humans cannot see.

My-Lan Le is a second-year master's student studying the ecology of a rare plant endemic to Colorado (*Physaria alpina*). This summer, she collected data in the Mosquito Range and the west Elk Mountains with the help of undergraduate students from Denver-based colleges and universities as well as other volunteers.

Jessica Loeffler is a second-year master's student studying the fungal diversity associated with two plants (*Pyrola asarifolia*, and *Chimaphila umbellata*), who utilize carbon sourced from fungi during different stages of their development.

Justin Loucks is a third-year master's student interested in DNA barcoding and is examining the taxonomic and systematic diversity of the ectomycorrhizal mushroom genus *Boletopsis* (Bankeraceae, Thelephorales) within western North America.

Meredith Prentice is a first-year master's student studying how repeat fire impacts the successional trajectories of understory vegetation communities in Colorado's Front Range.

Roy Rutherford is a second-year master's student interested in surveying, maintaining, and improving biological diversity in urbanized settings that represent restoration and/or conservation challenges.

Audrey Spencer is a fourth-year Ph.D. candidate researching the systematics and biogeography of *Physocarpus* (ninebark), helping elucidate the origins of the flora of the Southern Rockies. Broadly, she uses genomic tools to tell the biogeographic story of plants with disjunct distributions.

Citations

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Ackerfield, J. 2024. Diversification of *Cirsium* in North America. International Botanical Congress. Madrid, Spain.

Alba C., 2024. Botanical specimens as a throughline: From data to delight. Science-Art Symposium, Denver Botanic Gardens. Denver, CO.

Alba C., 2024. Conservation biology at Denver Botanic Gardens. North American Rock Garden Society, Rocky Mountain Chapter Symposium. Denver, CO.

Alba, C., Hartley, L. 2024. Soil moisture, topography, and light -- Oh my! Structural equation modeling as a powerful tool for untangling multivariate effects of planting environment on urban trees. Ecological Society of America Annual Meeting, Long Beach, CA.

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BIOFAIR DATA NETWORK

BCON WELCOMES EMERGING & EARLY CAREER MEMBERS TO THE BIOFAIR DATA NETWORK LEADERSHIP TEAM

bcon.aibs.org/biofair/

BioFair

Six early career professionals, including Natural History Collections Assistant Matthew Sheik (pictured far right), joined the BIOFAIR Project. The BIOFAIR Project, led by the Biodiversity Collections Network (BCoN) in partnership with the American Institute of Biological Sciences (AIBS), aims to initiate collaboration across biodiversity, ecology, and environmental data users and providers. Fostered through virtual listening sessions and an interdisciplinary workshop, these collaborations aim to create a roadmap toward a Findable, Accessible, Interoperable and Reusable (FAIR) data ecosystem. The initiative emphasizes diversity, access, and the identification of shared needs to enhance integration and drive forward biodiversity research, education and community science.

Thank You to Our Funders

Alice Eastwood Fellowship Program
Botanic Gardens Conservation International
Boulder County Parks and Open Space
Center for Plant Conservation
Charles Maurer Fellowship
Colorado Golf Association
Colorado Mycological Society
Garden Club of Denver
High Line Canal Conservancy
Institute of Museum and Library Services
Mycological Society of America
National Science Foundation
North American Mycological Association
The Nature Conservancy
Tri-State Generation and Transmission Association, Inc.
United Airlines
U.S. Bureau of Land Management
U.S. Department of Agriculture
U.S. Forest Service

We gratefully acknowledge the many other individuals who provide financial support for our work throughout the year as well as our dedicated volunteers who share their time and expertise. 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 funded by the taxpayers of the Denver metro area.

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."

How to cite this publication: Neale, J.R., Ackerfield, J.A., Hufft, R.A., and K.R. Meza. 2024. Science 2024 Year in Review. Denver Botanic Gardens.

Content contributors: Christina Alba, Michelle DePrenger-Levin, April Goebl, Alissa Iverson, Richard Levy, Alexandra Seglias, Matthew Sheik, Andrew Wilson.

Photos taken by Scott Dressel-Martin and Gardens staff.

DENVER BOTANIC GARDENS

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