Regenerative Restoration Plan
Vireo Preserve and JJ&T Tracts

Balcones Canyonlands Preserve

February 2016

Before Restoration

August 2016

Following Earthwork, Mulching, & Plantings

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Tract Descriptions

Size and Location: The JJ&T (1730 acres) and Vireo Preserve (214 acres) tracts are owned and managed by the City of Austin as part of the Balcones Canyonlands Preserve (BCP) in western Travis County, Texas.

Ecoregion: The BCP is in the Balcones Canyonlands Level IV ecoregion, which forms the southern and eastern border of the Edwards Plateau. This ecoregion is characterized by a dissected limestone karst terrane with streams and rivers both above and below ground (Small et al. 1996). Soil depth varies by topography: hilltops have shallow soils, while flat areas and lowlands have thicker soils. Soil textures depend on underlying parent material and surface vegetation. This area is prone to high intensity rainfall events, which can lead to flash-flooding and erosion (Riskind and Diamond 1988). Agriculture and urban areas downstream depend on water supplies from the Balcones Canyonlands ecoregion. The predominant plant associations include evergreen and deciduous forests, although more open woodlands and shrublands also occur in this area. This ecoregion is a biodiversity "hot spot" with many endemic and imperiled species (Hamilton et al. 2022), including rare plants, cave and spring invertebrates, aquatic salamanders, and the golden-cheeked warbler (*Setophaga chrysoparia*).

Elevation, Geology, and Hydrology: Elevations on the JJ&T tract range from 500 feet near Lake Austin to 940 feet on the hilltops, and from 680 feet to 980 feet on the Vireo Preserve. Both tracts are predominantly on the Glen Rose geologic formations, where alternating beds of hard limestone and soft marl form the terraced "stair-step" topography that are characteristic of the Balcones Canyonlands. The flat-topped ridges and hills on the Vireo Preserve are capped with Walnut and Edwards formations. JJ&T is in the Lake Austin (Colorado River) watershed, and the Vireo Preserve is in the Bee Creek watershed.

Vegetation: Vegetation on JJ&T and Vireo Preserve consists of a mixture of woods, shrubs, and grasses. Based on the Texas ecological mapping systems (Elliott et al. 2009-2014), these tracts support primarily Ashe Juniper Motte and Woodlands on the uplands and Ashe Juniper Slope Forest in the ravines. Other vegetation communities include Ashe Juniper-Live Oak shrubland, Deciduous Oak-Evergreen Motte, Riparian Ashe Juniper Forest, and Oak-Ashe Juniper Slope Forest. Dominant and common tree species include Ashe juniper (*Juniperus ashei*), plateau live oak (*Quercus fusiformis*), Texas red oak (*Q. buckleyi*), cedar elm (*Ulmus crassifolia*), and shin oak (*Q. sinuata* var. *breviloba*). Common understory species may include seedlings and saplings of canopy trees, Texas persimmon (*Diospyros texana*), agarita (*Mahonia trifoliata*), yaupon (Ilex vomitoria), Lindheimer silk-tassel (*Garrya ovata* var. *lindheimeri*), evergreen sumac (*Rhus virens*), Texas mountain laurel (*Dermatophyllum secundiflorum*), elbowbush (*Forestiera pubescens*), and Texas redbud (*Cercis canadensis* var. *texensis*).

Endangered and Rare Species: The JJ&T and Vireo Preserve support habitat for the golden-cheeked warbler. The Vireo Preserve historically supported a large colony of black-capped vireos (*Vireo atricapilla*), which are currently observed intermittently.

Management Goals

The JJ&T and Vireo Preserve tracts are part of the BCP, which protects multiple endangered and rare species and serves as mitigation for habitat loss due to urban expansion in western Travis County. The BCP was created in 1996 under an Endangered Species Act incidental take permit issued by the U.S. Fish and Wildlife Service to the City of Austin and Travis County. Permitted species include the golden-cheeked warbler, black-capped vireo, karst invertebrates, canyon mock-orange (*Philadelphus ernestii*), and Texabama croton (*Croton alabamensis* var. *texensis*). A collection of documents guides management of these species and their habitats within the BCP, including the permit, the Balcones Canyonlands Conservation Plan, and tiered land management plans. The land management plans provide guidelines for the permitted species, overarching land management activities (Tier II), and BCP tracts (Tier III). The Tier II land management plan for the golden-cheeked warbler includes promoting regeneration of juniper-oak woodlands in areas that have been previously cleared, thinned, or burned (BCP 2007a). The Tier II plans for both the golden-cheeked warbler and black-capped vireo include revegetation efforts to improve habitat and reduce habitat fragmentation (BCP 2007a, b).

Both the JJ&T and Vireo Preserve tracts have Tier III land management plans (BCP 1999a, b; 2007c, d). The 1999 plan for JJ&T states that regeneration of golden-cheeked warbler and black-capped vireo habitat on the uplands could provide additional habitat for these species over the long term. Management goals include restoring degraded habitat for all endangered species and species of concern and promoting regeneration of oak-juniper woodlands in areas previously cleared, thinned, or burned. Other management goals for both tracts include controlling erosion, non-native plants and animals, oak wilt, and browse of Texas red oak.

Consistent with these guiding documents, this plan includes regenerative techniques to support restoration of degraded and recovering habitats. Regenerative restoration employs multiple methods in combination from the ground up, including:

- Promote carbon sequestration and rainwater/groundwater infiltration by protecting existing woodlands and forests, protecting soils and mycorrhizal networks, increasing soil organic matter, and reforestation
- Promote mesic conditions by providing shade and capturing, spreading, and sinking rainfall (e.g., https://www.youtube.com/watch?v=PNlHfyVdePs&t=5s)
- Promote connectivity with other forests and protected areas
- Build soil health, structure, and microbiology (promote soil carbon sponge)
- Increase native plant and structural diversity (ground cover, shrub cover, canopy)
- Protect and restore karst ecosystems
- Protect native seed banks and promote habitat for pollinators
- Manage invasive species
- Recycle dead biomass of invasive plants
- Promote land stewardship and education/outreach

Regenerative restoration begins with identifying and stabilizing eroding sites. These can be small or large patches that are not currently habitat for the permitted species. Within these patches on the BCP, restoration is designed to “jump-start” the reforestation process by controlling erosion, building soil biology, and planting/seeding with native species to provide a species-rich, diverse connection to mature habitat. The goal is to begin the road toward a self-sustaining system that is resistant and resilient to climate-related impacts and other threats. This plan is based on an adaptive management approach (Millar et al. 2007, Williams et al. 2009), and restoration techniques will be modified as needed based on new information and monitoring.

While the focus of this plan is on the Vireo Preserve and JJ&T tracts, these techniques can be incorporated on other public and private lands, trail systems, as well as construction sites and development projects, to prevent erosion, sedimentation, and nutrient runoff and improve water quality and quantity downstream. The scale of these techniques is site-specific and project-dependent, and can be scaled up depending on need and available resources.

Support for Other City of Austin Long-Range Plans

Implementation of the regenerative restoration strategies identified in this plan supports multiple goals in several Austin's long-range plans, including:

- Austin Climate Equity Plan (https://www.austintexas.gov/sites/default/files/files/Sustainability/Climate%20Equity%20Plan/Climate%20Plan%20Full%20Document__FINAL.pdf)
    - Natural Systems Goal 1: By 2030, legally protect an additional 20,000 acres of carbon pools on natural lands and manage all new and existing natural areas (approximately 70,000 acres), focusing on resilience;
    - Natural Systems Goal 3: Achieve at least 50% citywide tree canopy cover by 2050, focusing on increasing canopy cover equitably
    - Natural Systems Goal 4: By 2030, include all City-owned lands under a management plan that results in neutral or negative carbon emissions and maximizes community co-benefits.
- Austin Urban Forest Plan (https://www.austintexas.gov/sites/default/files/files/Parks/Forestry/AUFP_Final_DRAFT_01-07-14_No_Appendices.pdf)
    - Protection and Preservation
    - Sustainable Urban Forest
    - Planting, Care & Maintenance
    - Planning & Design
    - Education & Outreach

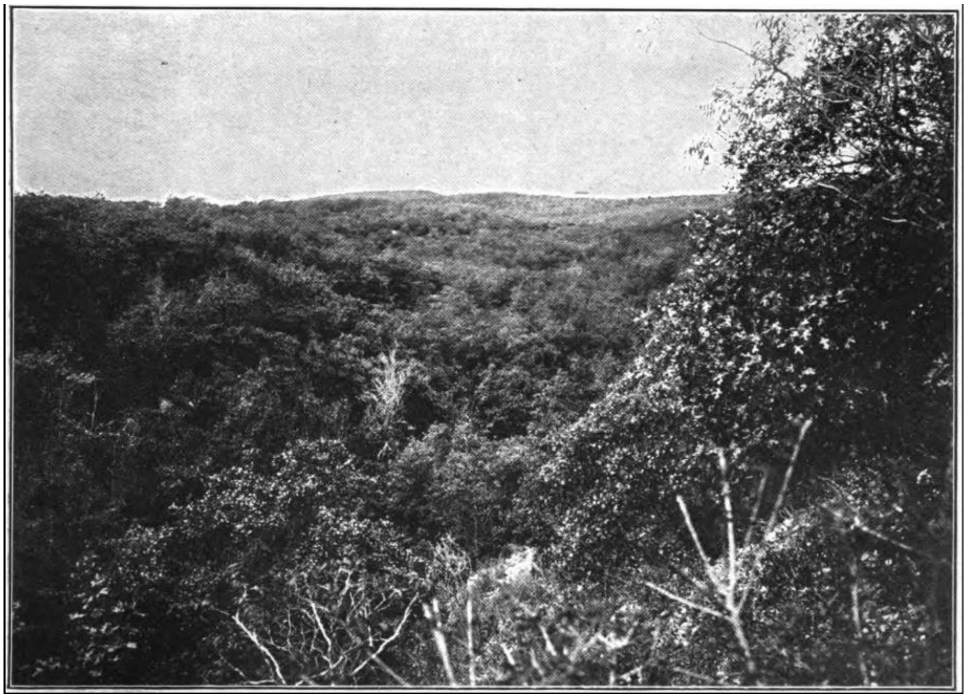
- Austin Strategic Direction 2023 (https://www.austintexas.gov/edims/document.cfm?id=341820)
  - Health & Environment
- Imagine Austin Comprehensive Plan (https://www.austintexas.gov/sites/default/files/files/Imagine_Austin/IACP_2018.pdf)
  - Priority Program 2: Sustainably Manage Our Water Resources
  - Priority Program 4: Use Green Infrastructure to Protect Environmentally Sensitive Areas and Integrate Nature into the City
- Vulnerability Assessment of Austin's Urban Forest and Natural Areas (Brandt et al. 2020)
  - See Management Considerations, Natural Areas, p. 62
  - The regenerative restoration strategies being implemented at the Vireo Preserve are featured as a demonstration project on the Climate Change Response Framework website: City of Austin Balcones Canyonlands Preserve : Vireo Preserve Restoration: Cooling Strategies for a Warming Climate | Climate Change Response Framework (forestadaptation.org)

Land Use History

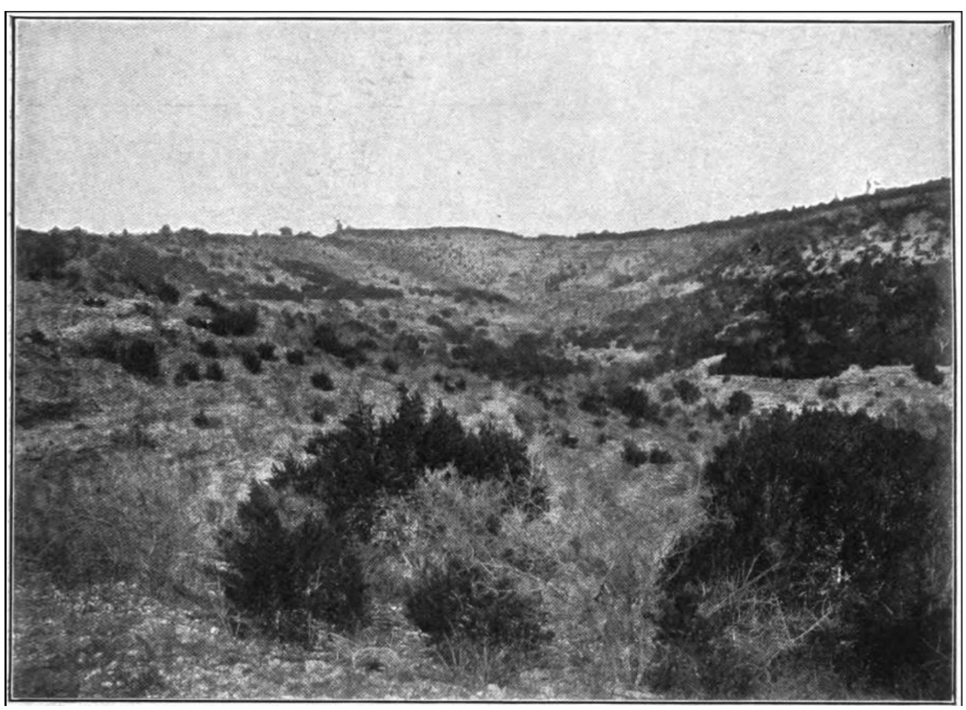
Researching land use history is key to identifying factors that have led to current ecosystem conditions (Eagan and Howell 2001), including habitat conversion and succession. This information can then be used to identify sites that have been degraded, are continuing to degrade, and/or are recovering from anthropogenic disturbances, and to design a plan that facilitates restoration using natural processes.

While our knowledge of Indigenous land use within the Balcones Canyonlands ecoregion is limited, archeological evidence of encampments exists throughout this area (Black and Creel 1997, Houk et al. 2008). Foster (1995) and Wade (2003) describe Indigenous peoples living in and around this ecoregion as primarily hunters and gatherers. Foster (1995) provides a list of wildlife and plants recorded and some of their traditional uses. Traditional uses of Ashe juniper, a dominant tree in the Balcones Canyonlands ecoregion, include food, medicine, and ceremonial practices (Texas Beyond History 2020). Further west, Koyiyumptewa and Colwell (2017) describe the Hopi's view of one-seed juniper (*J. monosperma*) forests in Arizona: "Junipers provide shade to other plants, they give shelter and food to wildlife, their roots retain the soil, keeping erosion at bay." Junipers are viewed as part of the hydrologic cycle, where the "trees bring the rain…they are like our rainforest."

To get an idea of what the predominant plant communities were prior to European settlement and changes that occurred following settlement, O'Donnell (2019) summarizes eyewitness accounts and other documents (original land grants, photographs, maps, tree ring and fire scar data) from the eastern edge of the Edwards Plateau during the 1700 to 1900 time period. Bray (1904) provides both written and photographic documentation of plant communities and land use changes on the Edwards Plateau, including the area near what is today the Vireo Preserve and adjacent Wild Basin tracts:



“North Gorge from Lone Tree Hill” [near what is today Vireo Preserve/Wild Basin tracts on the Balcones Canyonlands Preserve] described as having “almost impenetrable growth of cedar and mixed timber” and a “deep layer of rich soil” (Bray 1904)

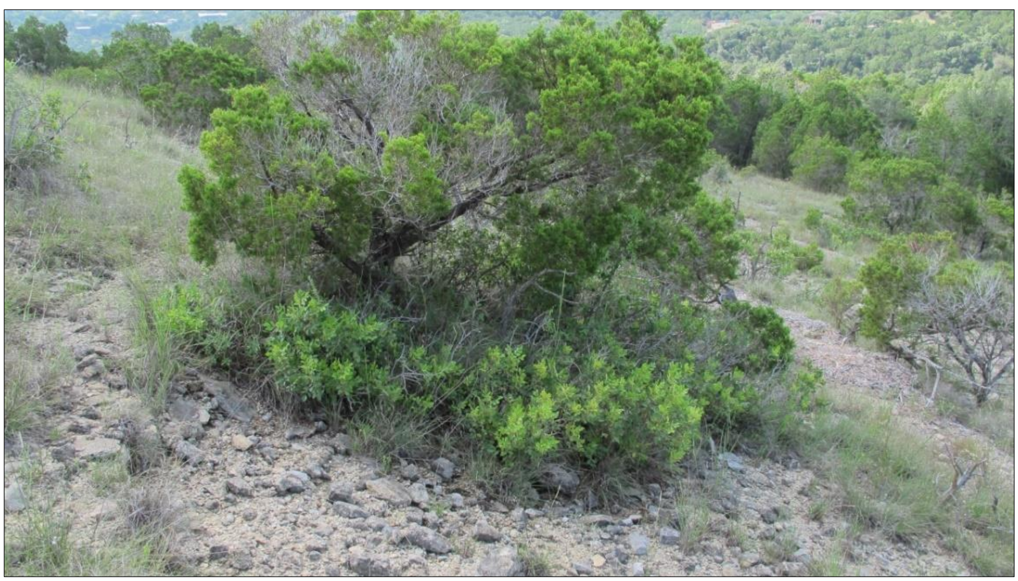


“South Gorge at its head under Lone Tree Hill” described as having been cleared of most of the woody vegetation and “denuded of soil down to the rock and adobe” (Bray 1904)

Some of the landscape on what is today the Vireo Preserve and Wild Basin looks similar to the “south gorge” described by Bray (1904):

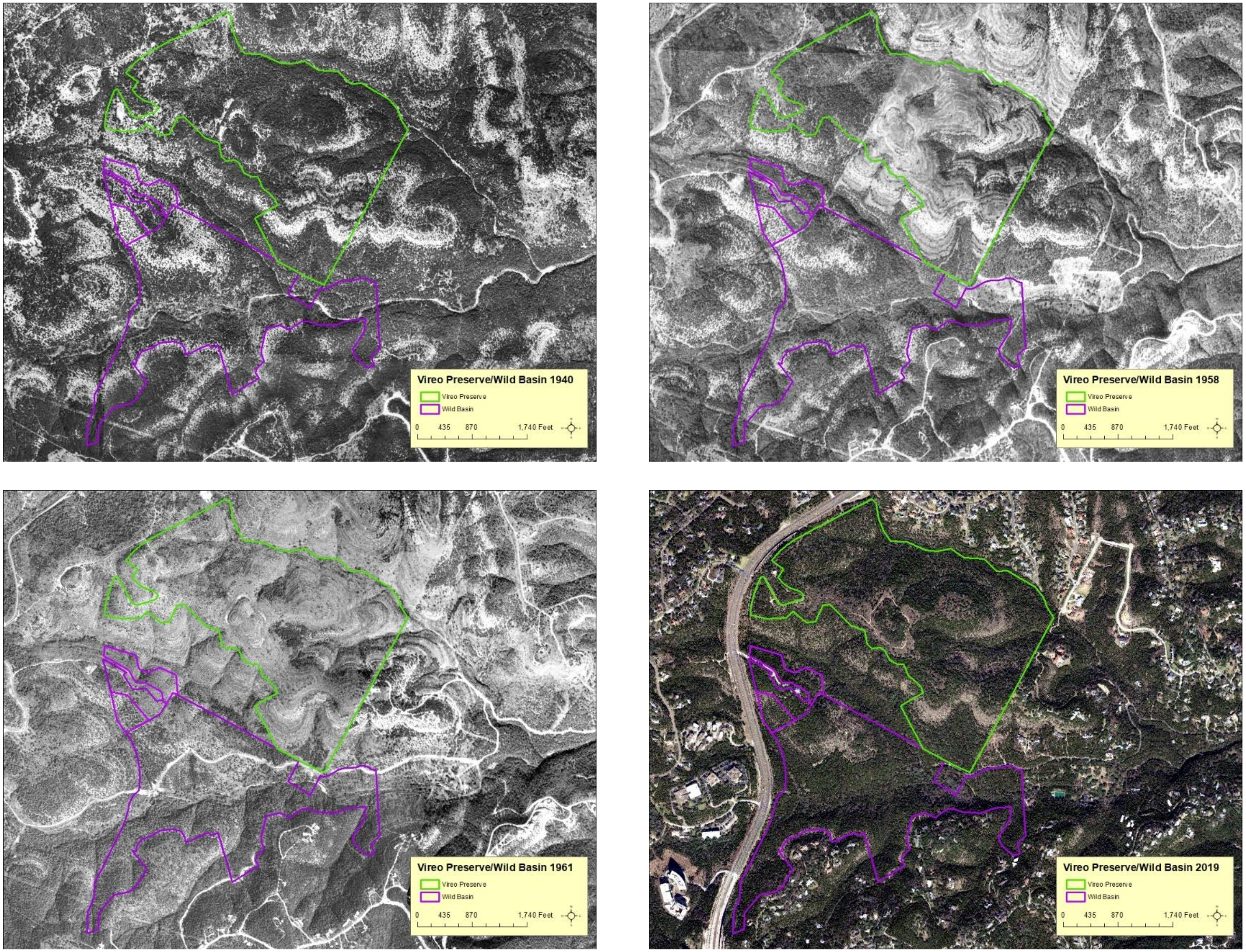
Vireo Preserve and Wild Basin [near Lone Tree Hill], 2019

Much of the plant life on these slopes exists under Ashe juniper-oak mottes, which support high organic matter compared to areas beyond the tree/shrub canopy:



Ashe juniper motte, Vireo Preserve, 2019

Using aerial photographs from 1940 to current, we examined changes in canopy cover over time on the Vireo Preserve and JJ&T tracts and identified patches of older-growth forests, recovering forests, and degraded areas (sites with little to no vegetation due to past land clearing practices):



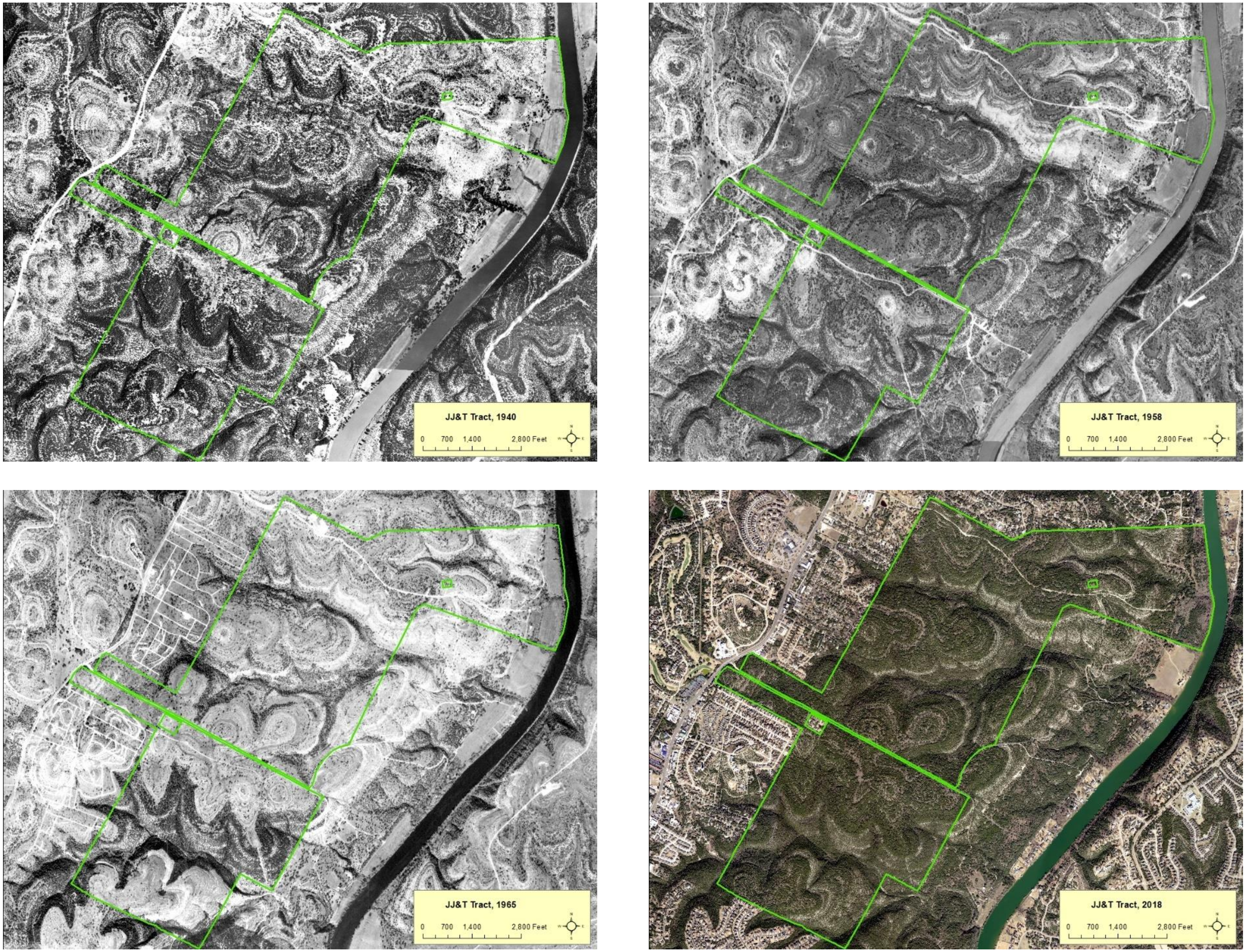
Aerial photographs of the Vireo Preserve/Wild Basin tracts, 1940-2019

The series of aerial photographs for the Vireo Preserve shows this site was predominantly forested in 1940, with a few areas that have been barren continuously throughout the series. The 1958 aerial shows an approximately 2600-foot wide clear-cut swath through the entire tract, aligning with the current eastern boundary. The 1965 aerial shows additional loss of canopy across all but a few remnant forest patches following the 1950s clearcutting and April 1961 wildfire, the largest known fire on the BCP (O'Donnell and Nesvacil 2020). Re-sprouting hardwoods following this fire created prime black-capped vireo habitat, with an estimated 35 territories on the Vireo Preserve and adjacent Wild Basin during the 1980s; the number of territories declined rapidly during the latter part of this decade, and the last territory was documented in the mid-1990s. Males have been observed intermittently since then, and a female was documented for the first time in over 25 years in 2022. The remnant forest patches are the epicenter of where we find golden-cheeked warblers on the Vireo Preserve today. The 2019 aerial shows forests growing back across much of the tract.

Old tree stumps with hatchet marks and fire scars are found throughout the Vireo Preserve, including the sites that have been barren since the 1940s. Steep slopes may be slowing the forest recovery on some of these sites, since the soil quickly washes off during rain events. Other degraded sites show evidence of bulldozing for roads and chaining.

Old juniper stumps with hatchet marks and burn scars,
evidence of forest remnants on the Vireo Preserve

According to the original land grants, the JJ&T tract was owned by railroad companies in the latter part of the 1800s, presumably to extract the timber for railroad ties and other materials. The aerial photos also provide evidence of land clearing between 1940 and present day. While some large trees remain, much of the JJ&T tract is recovering forest, interspersed with patches of little or no vegetation:



Aerial photographs of the JJ&T tracts, 1940-2018

Based on information from the Balcones Canyonlands ecoregion, historic documents, aerial photographs, and field surveys, much of the Vireo Preserve and JJ&T were historically forested. The historical aerial photographs are used to identify prime golden-cheeked warbler habitat (forests visible continuously from 1940 to present), recovering woodlands and forests (reforestation visible following land clearing), and degraded sites (barren areas visible continuously from 1940 to present due to past land clearing).

Infrastructure for Restoration

For project planning, we have a GIS database that includes aerial photos (1940-present), 20-foot contour lines, vegetation communities (Elliott et al. 2009-2014), hydrology, roads, golden-cheeked warbler and black-capped vireo survey data, rare plants, oak wilt, and invasive plants.

On-site infrastructure available to support restoration includes fenced enclosures to support native plant nurseries, site access, and supplemental water. For the Vireo Preserve and JJ&T tracts, we identified restoration sites on or adjacent to existing roads where equipment can be used with minimal additional disturbance, vegetation removal, or soil compaction. We have installed one large rainwater collection system on JJ&T, which consists of a 2,400 square foot rainwater barn with four 6,600-gallon tanks (holding capacity of 26,400 gallons) and room for four additional tanks. We currently have nine rainwater collection systems on the Vireo Preserve, ranging from small (150-gallon tanks) "mobile" systems designed to be moved to a new restoration site once restoration at the existing site has been completed, to larger (up to 3,000 gallons) permanent systems. Remote sites without road access and supplemental water sources are limited to seeding with native plants.


Rainwater barn at JJ&T


"Mobile" rainwater system at Vireo Preserve

Locally-sourced materials are used as much as possible to limit introduction of invasive species. This includes native seeds and cuttings collected on the BCP and mulch derived from other BCP projects (i.e., shaded fuel breaks and fencing). In addition to mulching around planted trees and shrubs, we use a thin layer of mulch to create temporary "restoration pathways" that concentrate foot traffic and limit trampling of vegetation and soil compaction. These pathways are recycled into the ecosystem once restoration is complete. Where off-site resources are needed, materials are inspected prior to introduction, and restoration sites are monitored frequently so invasive species can be quickly identified and removed.

Examples of using mulch to create temporary "restoration pathways"

Protecting and Enhancing Existing Woodlands and Forests

Existing woodlands and forests protect both above- and belowground processes, including rainwater infiltration and reduced flooding, carbon sequestration, soil biology, more stable air and soil temperatures, reduced wind and drying conditions, native seed banks, and pollinator habitat (Ellison et al., 2017, Watson et al. 2018, Moomaw et al. 2019). Dormant seeds occur in most soils and allow for re-establishment of plants following ecosystem stressors (e.g., wildfire, drought, land clearing). These seed banks are often crucial for the persistence of plants and long-term ecosystem stability and thus a critical component of restoration.

Ashe juniper-oak forest

Older-Growth Woodlands and Forests: Areas that have been continuously forested since 1940 provide a good indication of prime golden-cheeked warbler habitat. These sites also serve as refugia for native plants and animals and a source of seeds to increase native plant diversity at restoration sites. The focus of restoration in these older-growth areas includes preventing removal of native vegetation, identifying and removing non-native plants and animals, suppressing oak wilt, and minimizing browse from white-tailed deer. Native seeds can be planted to replace invasive plants that are removed.

Recovering Woodlands and Forests: For woodlands and forests that are growing back following land clearing, restoration is focused on increasing native plant diversity by sowing seeds where access to supplemental water is limited, and planting seedlings or saplings where a supplemental water is available. As in older growth woodlands and forests, the focus of restoration also includes preventing further damage to native vegetation, identifying and removing non-native plants (replacing with native seeds) and animals, suppressing oak wilt, and minimizing browse from white-tailed deer. Where appropriate, we use some of the earthwork techniques discussed below to slow down runoff.

Restoring Degraded Sites

Restoration of degraded sites begins with a site assessment to identify the source of the degradation and which remedial techniques are appropriate. The site assessment includes an evaluation of topography, slope, and aspect; soil depth and structure; rainwater infiltration; plant species diversity; amount of organic matter and biomass; and proximity to other features (e.g., woodlands, roadways, ravines). Conducting these assessments during rain events is especially helpful to determine where water runs off and contributes to erosion rather than soaking into the ground.


Examples of degraded sites where water quickly runs off

Regenerative restoration projects on the JJ&T and Vireo Preserve focus on degraded sites that have been barren since the 1940s that are on or adjacent to old roads. Based on the land use history and site assessment, degraded sites have a history of past land clearing, and some sites show evidence of fire, quarrying, chaining, and/or bulldozing. Due to erosion and runoff, degraded sites on JJ&T and Vireo Preserve are primarily exposed caliche subsoil with few plants and little accumulation of leaf litter and woody debris. Restoration begins at the source of the erosion, or as high in the landscape as possible. Using earthworks to control erosion, the initial focus is on stabilizing soil, infiltrating water, and planting pioneer woody and ground cover species. As shading increases and soil biology improves, the focus shifts to later successional plants. These efforts are intended to reduce habitat fragmentation by connecting existing woodlands and forests. Restoration can also protect adjacent woodlands and forests by slowing runoff that can cause treefall downslope. We select native plants to provide "food forests" for wildlife that can then disperse seeds beyond the project areas.

Earthworks: Earthworks are erosion control structures designed to capture, spread, and sink rainwater on contour, and provide a foundation for soil building and planting. Because existing woodlands and forests provide this ecosystem service, earthworks (with the exception of brush berms) are intended solely for degraded sites with erosion issues.

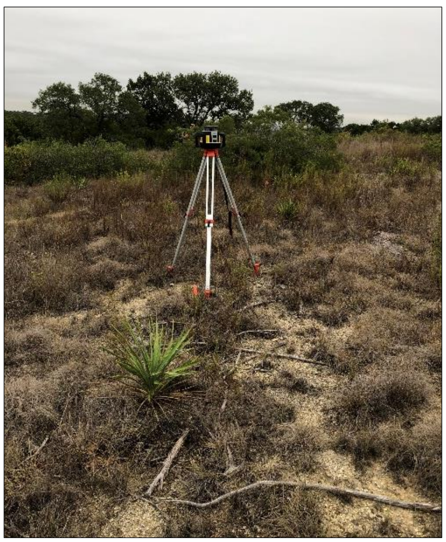
Earthworks are the first step to restoring soils by increasing rainwater infiltration and preventing further erosion. This allows soil and leaf litter to accumulate, which provides an environment for soil microorganisms and plants to thrive, accelerating the soil building process and native plant growth. As the plants grow, they continue to restore the soil by slowing the force of rainfall so that more soaks into the ground, shading the ground to reduce temperatures and evaporation, providing organic matter that feeds the soil biota, and holding the soil in place. Increasing native plant diversity in turn increases the resilience of the plant community to environmental stressors (e.g., drought, pathogens).

We began experimenting with a variety of regenerative restoration techniques on JJ&T and Vireo Preserve in 2013. Efforts initially included only the addition of mulch and native plant seeds. After observing these treatments wash away during rain events, we began implementing earthworks to address the erosion issues. In 2016, we hand-dug a series of earthworks, which reduced runoff so the mulch and seeds remained in place. Following the success of these experimental pilot projects, we began using a mini-excavator to install larger earthworks ("bioswales") in 2018.

The following techniques provide an overview of earthworks we have used on the JJ&T and Vireo Preserve tracts. For details more details on earthworks and methods of installation, see Zeedyk and Jansens (2009), Lancaster (2013), and Sponholtz and Anderson (2013).

- ***"Bioswales"*** – "Bioswales" (also called contour bioswale, berm and swale, berm 'n basin, contour berm, terracing) are shallow troughs (swales) with sloping sides (berms) that follow the contour of the hillside. The swales collect the rainwater, and native grasses, wildflowers, trees, and shrubs are planted along the berms. Similar to terracing on a slope, bioswales rehydrate dry hillsides by capturing, spreading and sinking rainwater. Installed high in the landscape, they control erosion, slow runoff, and reduce flooding. We install bioswales on eroded/eroding sites that have rapid runoff, gentle slopes (less than 20 degrees), access near existing roads, and low plant species diversity. Sites that are on steep slopes (greater than 20 degrees) require different techniques such as rock/brush berms. Restoration on sites with restricted access may be limited to available materials onsite (e.g., rocks, brush) and seeding.

We use bioswales on the JJ&T and Vireo Preserve tracts to “jump-start” the reforestation process, beginning with a laser level to align the bioswales on contour. On steeper slopes (closer to 20 degrees), the swale is typically 8 to 10 feet wide and about 1.5 feet deep; on more gentle slopes (less than 10 degrees), a wider swale of 10 to 12 feet is preferred to provide adequate head pressure. With adequate head pressure, water soaks down until it hits bedrock and then plumes downhill. The swales capture thousands of gallons of water and plume into the planted berms. Water continues to move slowly downslope, irrigating plants and improving soil structure.



Installing Vireo Preserve bioswales, using a laser level to align on contour and digging with mini-excavator

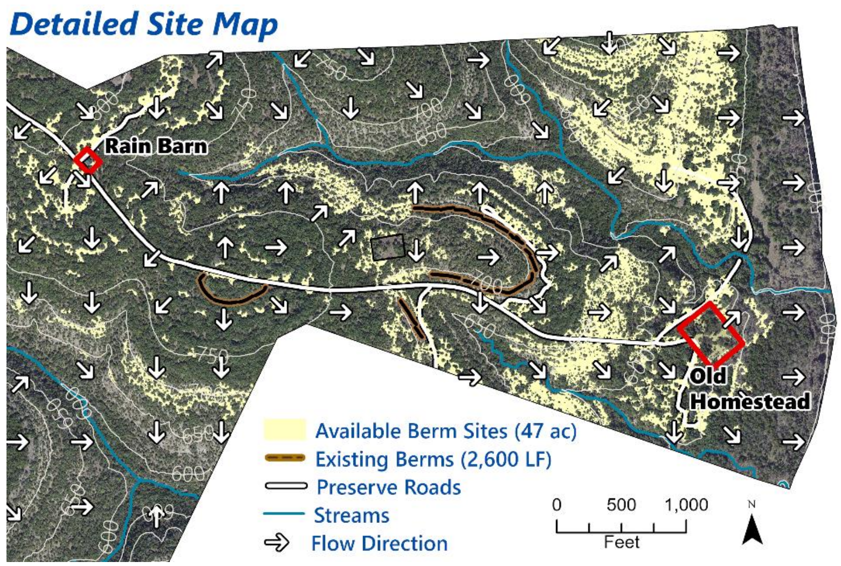
Vireo Preserve bioswale, showing direction of water movement and infiltration

We add compost, mulch, native woody plants, and native grass and wildflower seeds to the berms and line the swales with mulch. As the soil biology continues to improve, water is able to move down through the berms and plume out more efficiently. The underground plume may be evident by the increased aboveground plant growth on the downslope side of the bioswale. Once these changes occur, we plant native trees and shrubs below the bioswale.

Adding compost, mulch, and native grasses, wildflowers, trees and shrubs to bioswale

Vireo Preserve bioswale 6 months following installation (May 2020)

A bioswale suitability analysis was conducted for the JJ&T tract as a class project for Austin Community College during spring 2022 (Richter 2022). Criteria for suitable bioswale sites included vehicular access (existing dirt road), slopes less than 20 degrees (gentler slopes preferred), and sandy and loamy soils with little or no existing vegetation. Aspect facing northeast (ideal) is preferred over southeast or northwest (moderate) and southwest (worst). Bioswales should be at least 50 feet from a creek or river. These sites have been incorporated into Exhibit A.



Bioswale suitability analysis, JJ&T (Richter 2022)

- ***Boomerang berms –*** "Boomerang berms" (also called micro-catchments) are half-moon mounds of mulch or rock that are placed on the downslope side of native vegetation to slow and sink water.

- ***Net and Pan*** – Net and Pan is a series of boomerang berms that are interconnected to form a "net" over a hillside with "pans" where rainwater infiltrates within each segment of the "net".

- ***Rock Rundo****wn* – Rock rundowns are installed to repair severely eroded sites that have resulted in headcuts. Once the headcut has been smoothed to a gentler slope, flat rock is used to armor the headcut. This allows water to go down the headcut into the rock rundown to control erosion. The area around the headcut is seeded with native grasses to hold the soil in place.


Rock rundown, Vireo Preserve

- ***One-Rock Berms*** – One-rock berms are designed to slow and spread water as it moves across a gentle slope, typically at the base of a bioswale or rundown. They are built on contour on gentle slopes with low head pressure. They are only one rock high and about three feet wide on ground that has been pre-seeded with native grasses, wildflowers, and woody plants. The rocks are about 4 to 5 inches in diameter (approximately the size of a softball).

One-Rock Berm, Vireo Preserve

- ***Rock Berms*** – Rock berms are rocks placed on contour to slow runoff and trap sediment, gradually increasing rainwater infiltration while leaving the underlying subsoil in place. These work best on gentle slopes of 10% or less.

Rock berms, Vireo Preserve

- ***Brush Berms*** – Brush berms are made by collecting dead brush or cutting dead lower limbs and loosely weaving these together into a berm that is about 2 feet wide and about 1.5 feet high. They are placed on contour on ground that has been pre-seeded with native grasses, wildflowers, and/or woody plants. Brush berms are typically used high in the landscape to slow down runoff, capture moisture, protect seedlings, and provide habitat for wildlife. They can be placed in degraded sites and recovering woodlands and forests to make use of deadwood and increase native plant diversity.

Oak seedlings growing through brush berm

- ***Check Dams*** – For sites that do not yet have good infiltration due to lack of vegetation, we may combine revegetation efforts with check dams to slow down water. These are pervious dams made of dead tree limbs placed in a drainage to slow and spread water and encourage vegetation to grow along the water's edge.

- ***Auger Holes*** – Auger holes are a quick way to install holes for planting native trees and shrubs in compacted subsoil. An auger is used to dig multiple holes (about 2 to 3 feet deep) in a random pattern. A rock bar or shovel can be used to square off the rounded edges and make sure the edges are not smooth. As trees and shrubs are planted, the holes are backfilled with soil to the appropriate depth. The plants are mulched and watered. In addition to quickly digging multiple holes for planting, auger holes allow the root systems to extend deeper, increasing their chances for survival during drought conditions.

Planted auger hole (left), unplanted hole (right)

- ***Zuni Bowls*** – Zuni Bowls are series of rock-lined step falls and plunge pools to dissipate flowing water and stabilize an eroding headcut. By maintaining soil moisture at the headcut, Zuni Bowls also encourage vegetation growth.

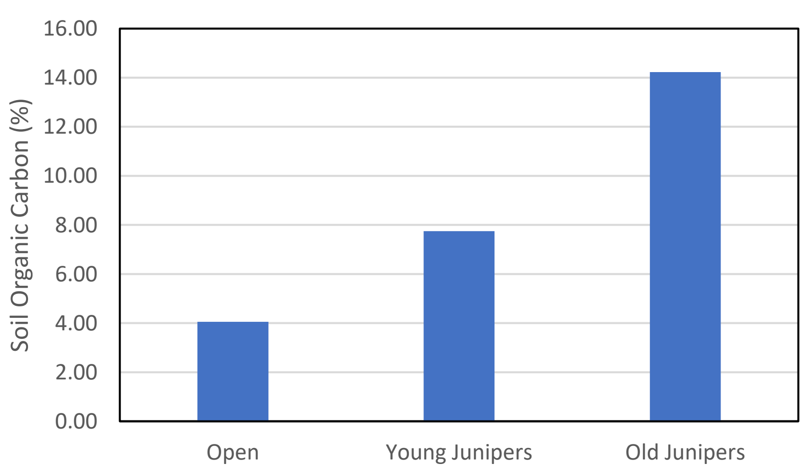
Example of Zuni bowls to help slow and infiltrate
water along hiking trails at Randall Davy Audubon Center
Santa Fe, New Mexico

Rebuilding the Soil Sponge: Once the earthworks are in place, restoration can focus on rebuilding soils. “Soil sponge” refers to healthy soils that infiltrate rainwater, enhance access to essential nutrients, and support diverse microbial processes. As above-ground plant communities draw down atmospheric carbon through photosynthesis, the carbon is sequestered and stored in the soils by plant roots and soil biota. Approximately 58% of soil organic matter is organic carbon, and the carbon acts much like a sponge. This “sponge” captures and stores more rainfall while reducing runoff, is less vulnerable to erosion and more resistant to drought, and stores and supplies nutrients, increasing soil fertility (Masters 2019).

> “Soil without biology is just geology.” -- Ray Archuletta, Soil Health Academy

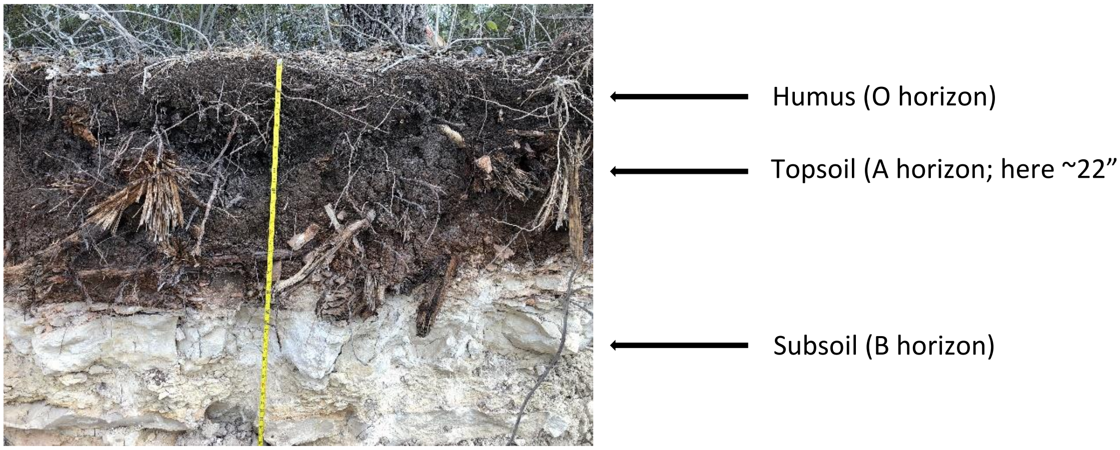
Topsoil from under Ashe Juniper-oak forest canopy (left) and caliche subsoil- (right)

Within the BCP, we consistently find that soil organic matter increases under woody plants and with increasing stand age. While soil organic matter in the U.S. is often cited as less than 10 percent (Brown 2018), we have found over 24% under old-growth trees and shrubs (City of Austin, unpublished data).



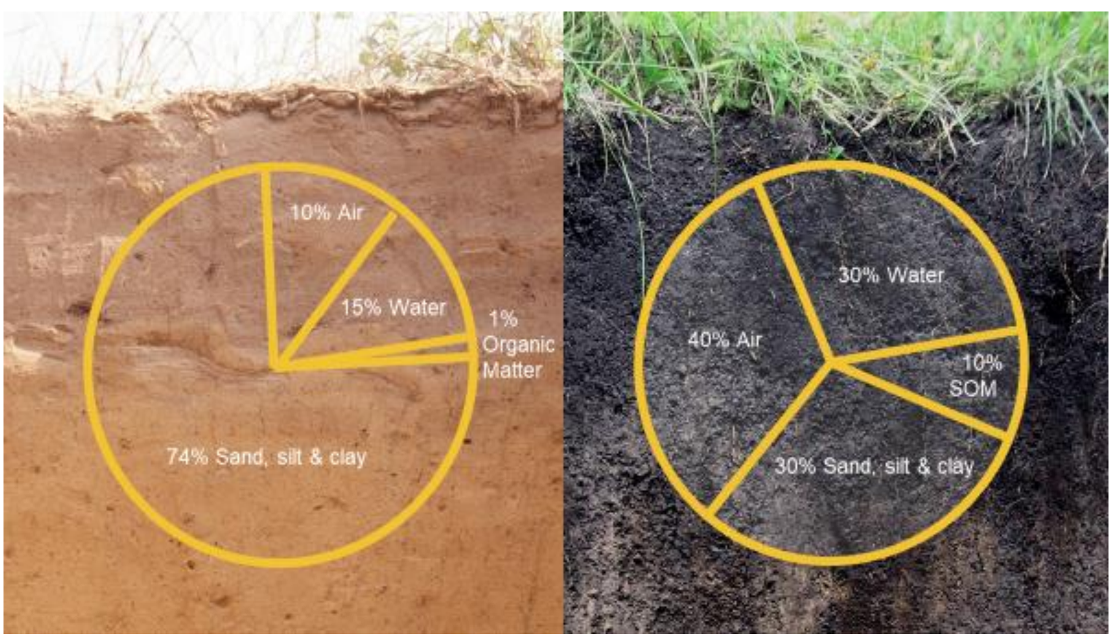
Soil organic carbon, Balcones Canyonlands Preserve

Degraded sites lack this soil sponge. The humus (O horizon) and topsoil (A horizon) layers have eroded away to expose subsoils (B horizon). The caliche subsoils tend to be hard and compacted, low in organic matter, and hydrophobic. These conditions result in further erosion and runoff and are inhospitable to the germination and growth of many plants.

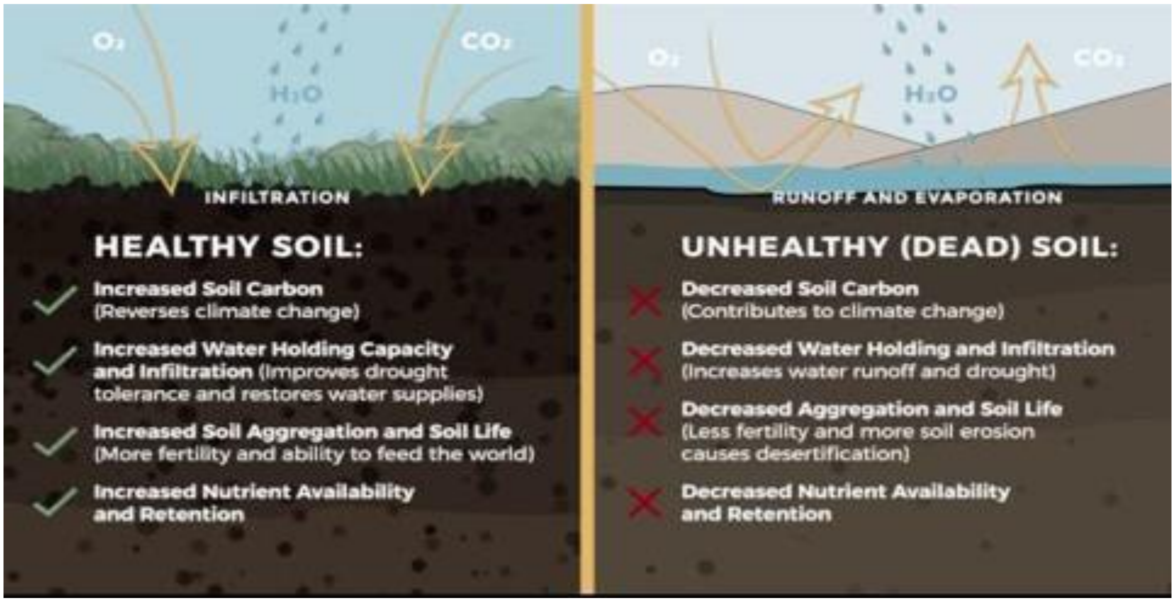


Typical soil profile near JJ&T tract

The basic components of soil include mineral matter (sand, silt, and clay), air, water, and organic matter. Biological processes occurring within the organic matter are essential to break down minerals and make them available for plants (Lowenfels and Lewis 2010). Air and water-holding capacity also increase with increasing soil organic matter. Healthy soil includes organic matter, water-holding capacity and infiltration, increased soil aggregation and soil life, and increased nutrient availability and retention. These qualities are reduced or lacking in unhealthy soils, or “dirt”, which tends to be compacted with little or no space for air, water, or roots. This leads to reduced plant cover, high albedo and heat, poor drainage, and evaporation.



Graphics by Kiss the Ground



Graphics by Kiss the Ground

Rebuilding soil begins with protecting the ground from further erosion by redirecting water flow into earthwork systems that benefit tree plantings and/or planting native trees and shrubs that can survive in the harsh subsoil conditions. Efforts should be made to cover exposed ground with mulch and plants to reduce evaporation and protect the ground from very hot or cold temperatures. Due to the lack of topsoil, off-site resources may be needed initially to provide a substrate for seeds and plants to grow. Any offsite resources used are carefully inspected for invasive species prior to bringing them to the restoration site. The restoration sites are then monitored frequently to allow for quick removal of invasive plants or animals.

- ***Open Compacted Soil*** – Opening compacted soil involves an initial one-time disturbance to reduce compaction and allow water to infiltrate. This can be done by hand in small areas with a pick or in larger areas with a ripper. The areas are then mulched and seeded with native grasses, wildflowers, and woody plants. The goal is promote conditions that allow plant roots to grow so that water then infiltrates naturally.

- ***Leaf Litter*** – Leaf litter provides organic matter and nutrients that help build healthy soil and retain moisture. It also provides winter cover for pollinators and many other invertebrates, and food for emerging caterpillars. These macroinvertebrates are part of the soil food web and support wildlife that rely on them for food. For the JJ&T and Vireo Preserve projects, we frequently include Mexican buckeye (*Ungnadia speciosa*), flameleaf sumac (*Rhus lanceolata*), and false willow in the initial pioneer plantings to provide a renewable supply of leaf litter. Oaks are a later successional species that provide leaf litter for pollinators and other insects.

- ***Organic Matter*** – Covering bare ground reduces soil temperatures, evaporation, runoff, and erosion. This minimizes soil crusting, which in turn increases water infiltration. Offsite materials may be needed initially, such as compost, mulch, wood chips, leaf litter, and soil. Shaded fuel breaks implemented on the BCP provide much of the mulch and wood chips for the JJ&T and Vireo Preserve projects. Compost is made at the Vireo Preserve using on and offsite materials. Pine straw may be used as an initial covering for native grass and wildflower seeds and breaks down quickly as the ground cover gets established. These materials provide a base for initial seeding and protect plants from heat and drying until the plants provide organic matter on their own and the system becomes independent.

Compost bin, Vireo Preserve

- ***Ramial Wood*** – Quick-growing native woody plants such as false willow (*Baccharis neglecta*) can be used to increase organic matter. The plants are coppiced in November, and the fresh wood is cut into small pieces, covered with compost (nitrogen source), and planted with other native woody species. With winter rains, these areas collect moisture needed for plant growth. As false willow grows back in the spring, it provides shade to protect oak and other seedlings and saplings during summer droughts. The nectar provides food for songbirds and the blooms provide food for Monarch butterflies and other pollinators.

- ***Sheet Mulching*** – Sheet mulching is the layering of organic matter, including leaves, hardwood mulch, and tree trimmings (e.g., *B. neglecta*), with compost on caliche subsoil. These patches are then seeded and planted with native species.

Two rows of rock berms and sheet mulching

Planting and Seeding: Plant roots feed soil microorganisms and are thus key to soil building. In turn, soil microbes are key to the production of humus, which is rich in organic carbon and retains soil moisture. "When soil is enhanced at depth, the function of the entire watershed is improved" (Brown 2018).

> "Diverse plant communities support diverse soil microbiomes….Microbial activity also drives the process of soil aggregation, enhancing soil structural stability, aeration, infiltration, and water holding capacity. All living things, above and below ground, benefit when the plant microbe bridge is functioning effectively." --Dr. Christine Jones, Soil Ecologist

- ***"Hyperlocal"*** – We focus on native seeds and plants that occur within the BCP ("hyperlocal") and Balcones Canyonlands ecoregion. As stated in the Tier II land management plan for the black-capped vireo (BCP 2007b), using seeds and plant materials from within the BCP avoids the introduction of non-local genotypes into the plant community. Nursery stock (i.e., any vegetation that is not planted from seed) are checked for signs of disease and invasive species (including red imported fire ants, tawny crazy ants) to minimize introductions to the BCP. While a limited number of plants are purchased from local nurseries for the initial plantings, "hyperlocal" ensures locally-sourced, first generation plants that are adapted to the restoration site. For native grasses and forbs, we also work with vendors who have a low incidence of non-native plants in their seed mixes.

- ***Seeds vs. Seedlings/Saplings*** – Benefits of planting native woody plant seeds versus seedlings and saplings are also considered. Planting seeds directly in the field requires little to no maintenance after planting, provided seeds are planted in a suitable environment. However, seeds may be limited in availability and/or production, may require scarification and/or stratification for germination, may have low survival rates, and seedling growth tends to be slow without supplemental water. We generally sow woody plant seeds on sites with no access to supplemental water, ideally with sowing timed before a rain event. Seedlings and saplings are suited for sites where they can be watered for at least 2 to 3 years after planting.

- ***Collecting Seeds, Cuttings, and Transplants*** – Staff and volunteers collect seeds on the BCP for sowing in the nursery or directly in the field. To avoid overcollection, less than 10% of seeds are collected from a given plant or site, ideally along a road or path where fallen seeds would have little chance for survival. Seeds may be collected from the plant or on the ground (if recently dropped) and are inspected for freshness and insect damage. Acorns can be "float-tested" (Morina et al. 2017) and/or squeezed (should be firm, not soft) to assess viability. Plants may also be collected from local sites scheduled for vegetation removal ("plant rescue") and transplanted on restoration sites with access to water. Nokes (2001) provides recommendations for collecting and propagating many native Texas plant species from seeds, cuttings, and transplants.

- ***Timing of Planting*** – Seeds should be planted soon after collection or scarification/ stratification treatment to increase germination and survival. Trees and shrubs are planted October 1 through March 31, ideally as early as possible to ensure root establishment prior to the growing season. We seed wildflowers in the fall, and grasses in the spring.

- ***Placement*** – Seeds, seedlings, and saplings should be planted in locations suited to their habitat requirements. For oak species, we have conducted a series of experiments at several sites on the BCP over multiple years and found that shade is critical for survival during summer drought. Prior to our experiments, we planted in open areas but observed that the oak seedlings experienced nearly complete mortality (O'Donnell et al. 2020, City of Austin unpublished data). We now plant oaks as a later successional species along woodland edges, under dead trees, and under the shade of more light-tolerant plants.

Texas red oak seedlings, August 2019
under tree canopy (left) and no shade (right)

- ***Pioneer and Later Successional Species*** – We retain as many existing trees and shrubs as possible, including Ashe juniper, which is both a pioneer and late successional species. We then plant other drought-tolerant pioneer species, including legumes, that open the soil (deep roots). These plants also provide shade and organic matter, reduce soil temperature, and release nitrogen into the soil. Lower branches may be cut to shape trees so they provide more shade (umbrella shape), and cuttings can be used at the base of trees as mulch. Young trees and shrubs that are palatable to deer are caged to protect them from browse. As pioneer plants grow, later successional plants that require shade, such as oak seedlings and saplings, can be planted underneath.

Texas kidneywood, flameleaf sumac, and other drought-tolerant plants

- ***Plant Selection*** – In selecting native trees and shrubs to plant on restoration sites, consideration should also be given to availability, hardiness (including drought and cold tolerance), and habitat for pollinators, including host plants for butterflies and moths, and other arthropod-producing plants that support insectivorous species. For example, one Carolina chickadee (*Poecile carolinensis*) brood requires 6,000 to 9,000 insects to become independent (Narango et al. 2017). Native oaks and cherries (*Prunus* spp.) are keystone host plants for butterflies and moths (Narango et al. 2020). Wafer ash (*Ptelea trifoliata*), cedar elm, and Texas kidneywood (*Eysenhardtia texana*) are also excellent native host plants (Weber et al. 2018).

Golden-cheeked warblers feed on caterpillars & other insects (photo by volunteer Gary Sertich)

- ***Tree Care*** – We typically cage seedlings and saplings until they grow large enough to survive deer browse (approximately 3 years). Due to the tendency of wildlife to damage irrigation hoses, we hand-water plantings as needed for the first two to three years. This also allows us to monitor the health of the plants and check for invasive species. As the restoration sites mature (increased shading and improved soil biology), we focus on diversifying both plant species and structural diversity (ground cover, understory, canopy). These high diversity "food forests" also provide more habitat for soil biota and wildlife that further help to rebuild soils and spread seeds beyond the restoration projects.



Volunteers planting, caging, and watering seedlings and saplings

Incorporating Fungi

Saprotrophs: Saprotrophic fungi are primary recyclers that break down surface detritus on the forest floor, where it becomes accessible to other organisms. The process of wood decomposition contributes to soil development and productivity, nutrient cycling, moisture retention, and forest regeneration. We have used a native wood-decomposing species, turkey tail (*Trametes versicolor*), to break down logs of invasive glossy privet (*Ligustrum lucidum*) and other non-native plants (O'Donnell et al. 2019). Turkey tail is a nonparasitic but aggressive decomposer of dead wood that grows mainly on hardwoods. Inoculating logs with turkey tail is an easy method for expediting wood decomposition and treating slash generated from removal of invasive hardwoods, effectively recycling the biomass back into the forest ecosystem and reducing fire risk concerns. Inoculated logs can also be used to assist with habitat restoration, including erosion control, water retention, and seedling establishment.

Volunteers inoculating *L. lucidum* logs with turkey tail

L. lucidum log, 8 months after inoculation

Decomposed *L. lucidum* log, 24 months after inoculation

Endophytes: Endophytes are bacteria or fungi that live within a plant (e.g., bark, leaves) without causing apparent disease. They may enhance their host plant's growth, nutrient acquisition, ability to tolerate abiotic stresses (e.g., drought), and resistance to insects, pathogens and herbivores. As with mycorrhizal fungi, endophytes receive carbon for energy from the host plant. Moriah Sandy and her students at the University of Texas at Austin found one endophyte collected from Ashe juniper that outcompeted the oak wilt fungus in a petri dish (Sandy et al. 2019), although the significance of this finding in the wild is unknown.

Mycorrhizae: Mycorrhizal fungi serve as extensions of plant roots, transporting water and nutrients through the soil and sequestering carbon derived from photosynthesis. They provide diverse ecosystem services that support land management from the ground up, including enhanced water and nutrient uptake, increased drought resistance, increase pathogen resistance, increased plant health and stress tolerance, and carbon sequestration and storage in soil (Pickles and Simard 2017). We have a 5-year (2022-2026) contract with Northern Arizona University to conduct research on mycorrhizal fungi to support habitat protection and management within the BCP. In September 2022, we hosted a “MycoBlitz” for BCP staff, partners, and volunteers. Together, we collected 250 root samples from Ashe juniper and 250 samples from live oak and Texas red oak across the BCP. These samples will provide baseline information on the mycorrhizae of these co-dominant host plants. The primary goal of this project is to integrate basic mycorrhizal research with site-specific, applied studies focused on improving habitat quality, soil moisture, water quality, and forest health and regeneration. These efforts will also showcase the BCP as an international model for leveraging both community science and applied soil biology for forest management. A separate report on these findings will be prepared as part of that project.

BCP staff and volunteers with collections of roots and mycorrhizae
Fall 2022 “MycoBlitz”

Monitoring and Adaptive Management

Survival of Native Trees and Shrubs: We record the number and species of native trees and shrubs planted. Following late summer drought, we track the percentage of plants that survive. To date, survival has been high (approx. 85%). If survival is low, plant selection, placement, and care will be addressed as needed.

Invasive Species: Restoration sites are closely monitored for introduction of invasive species. If identified, these will be removed, and efforts made to prevent further introduction and/or spread.

Habitat Succession: On the degraded sites, our goal is to prevent erosion and runoff, build soil, increase rainwater infiltration, and facilitate succession from native grasses, forbs, and drought-tolerant trees to a more shade-tolerant woodland/forest ecosystem with structural diversity. We monitor this transition using frequent observation, drone footage, and photo points.

Video and Photo Documentation: A professional videographer has recorded drone footage prior to installation of berm and swale projects at JJ&T and Vireo Preserve. The Vireo Preserve footage was used to create a YouTube video for social media (https://www.youtube.com/watch?v=PNlHfyVdePs). We also have a series of photo points at JJ&T and take new photos in the spring to document habitat changes over time.

Soil Conditions: As an indicator of tree health and carbon sequestration, we will monitor changes in soil organic matter over time (Pearson et al. 2007, Le et al. 2012, Obalum et al. 2017, Van Geel et al. 2019). We will monitor soil depth, temperature and moisture within the restoration sites as well. Soil moisture data are of particular interest for their potential use in wildfire risk assessment (Levi et al. 2019). If funding allows, we will also monitor biological activity (e.g., PLFA - Ward Laboratories, Inc.).

Forest Canopy

Barren Caliche

Soil temperatures with (~87 ºF) and without (120ºF) canopy
air temperature = 104ºF

Building Community

It takes a community to restore an ecosystem. Volunteers play an invaluable role and assist with building rainwater collection systems and earthworks; building soil biology; collecting native seeds; propagating, planting, and caring for native plants; and monitoring. We work with volunteers twice a week at both JJ&T and Vireo Preserve. A few of our volunteers also work independently on both tracts. Both of these projects provide an educational platform to share information and promote land stewardship that can be used beyond the BCP.

Community volunteers, including neighbors, have been growing both in numbers and skillsets. This includes native plant propagation from seeds and cuttings collected on the BCP and expanding the nurseries at both JJ&T and Vireo Preserve. Texas Conservation Corps and Austin Civilian Conservation Corps crews have said that JJ&T and Vireo Preserve are favorite assignments, where they learn how to plant trees and reduce erosion, and many have subsequently expressed interest in environmental restoration as a career.

Our community includes:

Many volunteers!
Master Naturalist Chapters
Texas Conservation Corps, Austin CCC
Northern Arizona University
Central Texas Mycological Society
Boy Scout Eagle Projects
TreeFolks
Development Services/
Urban Forest Fund
Van Dyck Earthworks & Design
(contractor)

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BCP. 2007b. Land management plan, Tier IIA-8, black-capped vireo management. City of Austin and Travis County, Austin, Texas.

BCP. 2007c. Tier III land management plan, Black-capped Vireo Research Area, West Austin macrosite. City of Austin, Austin, Texas.

BCP. 2007d. Tier III land management plan, South Lake Austin tracts (Reicher Ranch, Double J&T, Bohls), South Lake Austin macrosite. City of Austin, Austin, Texas.

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Videos

Balcones Canyonlands Preserve Forest Restoration Series

- Introduction and Historical Ecology of the Texas Hill Country: https://www.youtube.com/watch?v=PSNqoUDDOEY

- Woody Plant Identification: https://www.youtube.com/watch?v=BineIADXa-E

- Tree Planting: BCP Forest Restoration - Tree Planting - YouTube

- Tree Planting Demo with BCP Volunteers: Tree Planting Demo with BCP Volunteers - YouTube

- Non-Native Invasive Tree ID and Removal: BCP Forest Restoration - Non-native Invasive Tree ID and Removal - YouTube

- Demonstration of Invasive Tree Girdling with Cliff Tyllick: Demonstration of Invasive Tree Girdling with Cliff Tyllick - YouTube

- Rehydration of the Landscape: BCP Forest Restoration Rehydration of the Landscape - YouTube

- Soil Biology and Geology: BCP Forest Restoration Series Soil Biology and Geology - YouTube

- Incorporating Mushrooms into Restoration: BCP Forest Restoration Training Series: Incorporating Mushrooms into Restoration - YouTube

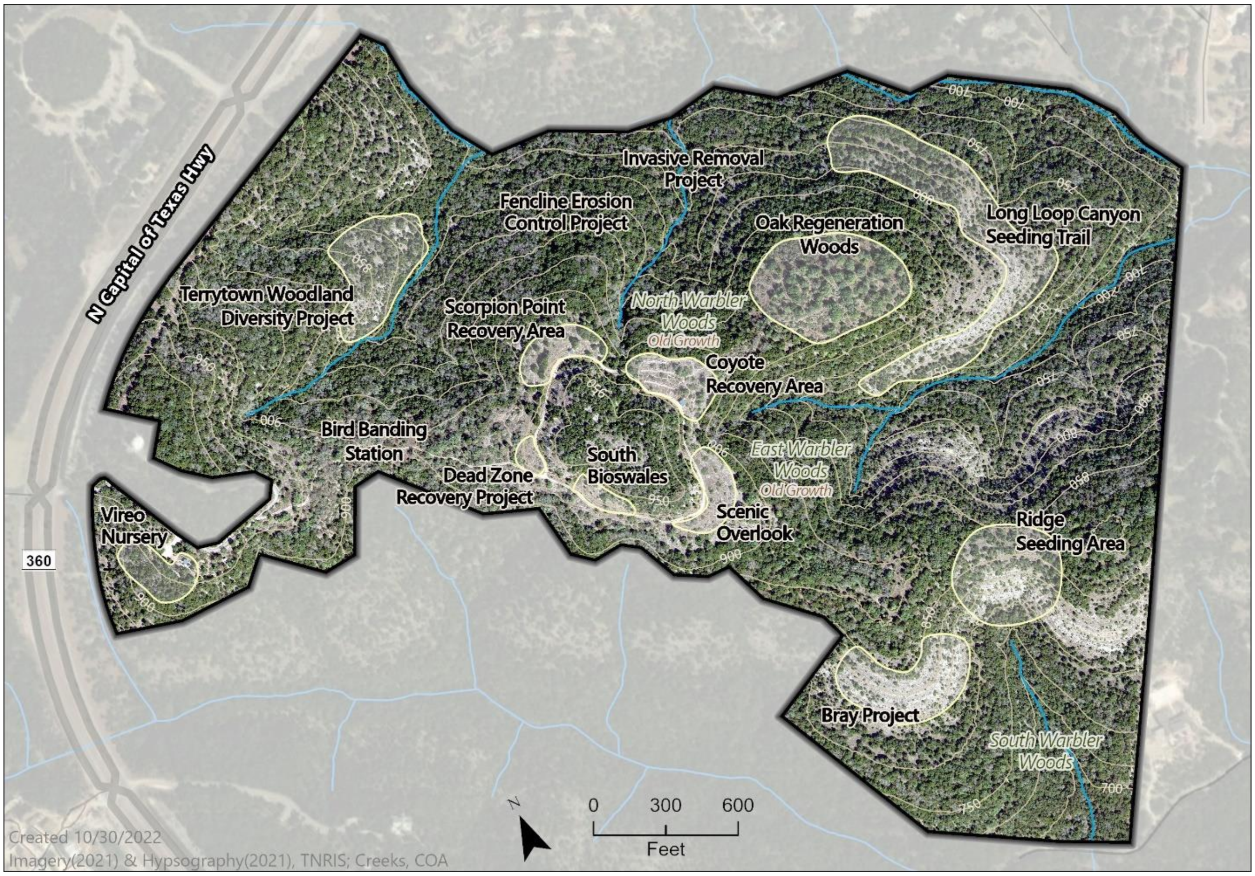
Dispelling Ashe Juniper (aka "Cedar") Myths: https://www.youtube.com/watch?v=FG6FR-2jrfw

Vireo Preserve Bioswales: https://www.youtube.com/watch?v=PNlHfyVdePs

Wild Neighbors: Reforesting Degraded Landscapes: Wild Neighbors: Reforesting Degraded Landscapes - YouTube

Exhibit A: JJ&T Restoration Plan

Exhibit B: Vireo Preserve Restoration Plan



Note: Restoration projects on the Vireo Preserve are given names to facilitate communication with volunteers. Below is a key to sites on the map:

- ***Older growth woodlands and forests*** - North Warbler Woods, East Warbler Woods, South Warbler Woods
- ***Recovering woodlands and forests (with supplemental water for planting native species)*** – Terrytown Woodland Diversity Project
- ***Recovering woodlands and forests (limited access)*** – Oak Regeneration Woods, Invasive Removal Project, Ridge Seeding Area, Long Loop Canyon Seeding Trail, Fenceline Erosion Control Project
- ***Degraded Sites (with vehicular access and supplemental water)*** - Scorpion Point Recovery Area, Coyote Recovery Area, South Bioswales, Dead Zone Recovery Project, Scenic Overlook
- ***Degraded Sites (limited access)*** - Bray Project