Vernal Pool Restoration on the Whetstone Savanna

Earth-moving for habitat conservation and species recovery

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REPORT PRODUCED BY
The Nature Conservancy in Oregon 2020

ACKNOWLEDGEMENTS

Equipment operators and maintenance managers:
Wayne Scriven, Craig Maxwell, Doyle Summers, Billy Smith, Perry Gibson, Jim Holtzapple, Brian Wood, Steve Stone, Gary Lollar, Everett Carroll.

Supporting staff and volunteers:
Jake Kercher, Doug Sharp, Molly Morison, Amanda Rau, Melissa Olson, Lyndsey Lascheck, Derek Olson, Ian Knight, Evan Barrentios, Vanessa Rojas, Marisa Mancillas, Sarah Ratay, Karen Hussey, Liz Smith, Ann Kercher, Jessica Bochart, Alicia Fitzgerald, Lyndia Hammer, Chris Lynch, The Thursday Crew, Sara Red-Laird.

Advisors and reviewers:
Darren Borgias, Jim Thrailkill, Sam Friedman, Brad Livingston, Phil Scholes, Doug Kendig, Bryan Wender, D. Christopher Rogers, George Cox, Craig Tuss, Dana Field, Russ Klassen, Andrea Wagner, Jim Collins, Ryan Haugo, Kerry Metlen, Debora Coen.

Contributing agencies, organizations, and contractors:
U.S. Fish and Wildlife Service, Bureau of Land Management, U.S. Forest Service J. Herbert Stone Nursery, Natural Resources Conservation Service, Army Corps of Engineers, Oregon Department of Agriculture, Oregon Department of Forestry, Oregon Department of State Lands, Oregon Department of Fish and Wildlife, Southern Oregon University Laboratory of Anthropology, Oregon Vernal Pool Information Network, Grayback Forestry Inc., The Freshwater Trust, Rogue Native Plant Partnership, Strauss Ecological Services, Plant Oregon Nursery, Black Dog Design.

Summary

Innovative earth-moving restoration has successfully returned wetland function, natural landform, and abundant native species across 190 acres of mounded vernal pool habitat in the Rogue River Valley of southwest Oregon. Led by the Oregon Department of Transportation in collaboration with The Nature Conservancy, the restoration meets compensatory mitigation goals and demonstrates effective methods for recovery of threatened and endangered species: vernal pool fairy shrimp, Cook's desert parsley, and large-flowered woolly meadowfoam. The project and restoration site, the Whetstone Savanna, exemplify the strength of mitigation banking integrated with local and regional conservation planning.

This report presents the restoration within a context of local vernal pool ecology, natural history, and habitat conservation. Planning and implementation methods, monitoring results, and lessons learned are documented here to provide an example of repeatable success in vernal pool restoration. On the ground work was completed from 2011 – 2019 by a team of ecologists and equipment operators. Advanced mapping tools, adaptive workflows, and precision grading enabled restoration of topography and hydrology damaged by past alterations. Grading was strategically combined with prescribed burning and seeding to restore native plant communities and listed species populations.

Annual monitoring for mitigation performance established a four-year baseline and tracked changes during and after eight years of active restoration. Vernal pool habitat doubled in area, and occupancy by vernal pool fairy shrimp increased to four times the pre-restoration level. Populations of endangered plants numbering in the thousands have established from widespread sowing. Following restoration, native plant abundance more than doubled on uplands and nearly tripled in pools, accompanied by substantial gains in native species diversity and a dramatic reduction in non-native invasive weeds. This type of transformative restoration is needed on other degraded vernal pool sites to achieve effective long-term habitat conservation and lasting species recovery at a landscape scale.

The Nature Conservancy Oregon | Oregon Department of Transportation | CC Patterson & Associates — Geographic Information Systems, Remote Sensing, Geospatial Consulting, Natural Resource Mapping

COVER PHOTOS: Before and after repeat photography of degraded (upper left) and restored (lower right) mounded vernal pool habitat during peak winter inundation, Whetstone Savanna, Rogue River Valley, Oregon. © Keith Perchemlides/TNC. An excavator operator removes soil to restore a buried vernal pool (upper right). © Evan Barrientos/TNC. Endangered large-flowered woolly meadowfoam blooms along the edge of a restored pool (lower left). © Evan Barrientos. OPPOSITE PAGE: Spring growth emerges through the water of a restored vernal pool on the Whetstone Savanna. © Evan Barrientos

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Native wildflowers highlight the natural mound and basin topography of Rogue River Valley vernal pool habitat. © *Keith Perchemlides/TNC*

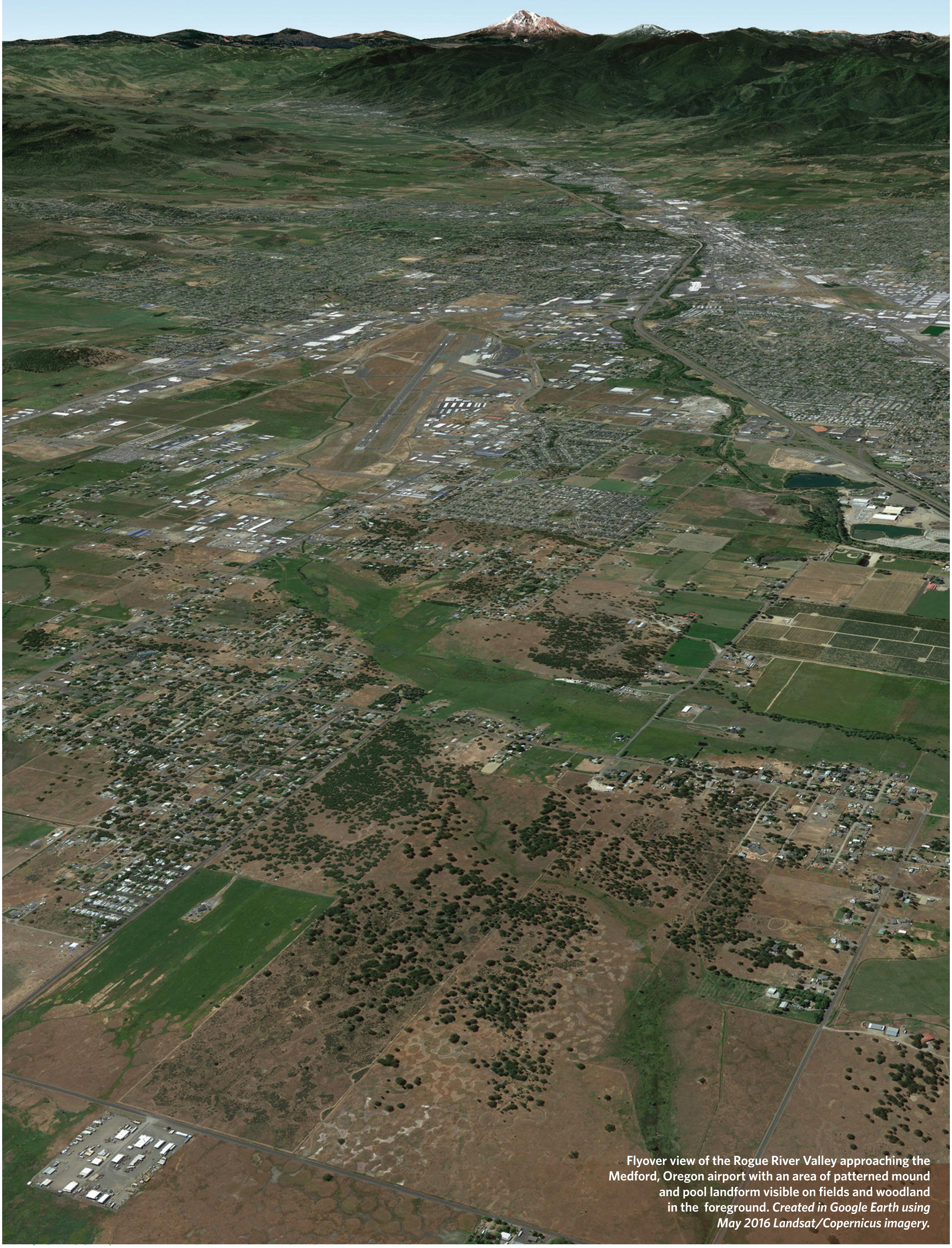
Southwest Oregon Vernal Pools

Flying into the Medford, Oregon airport on a clear spring day, your eye might be drawn to places on the landscape below where sunlight reflects from a multitude of tiny ponds scattered across open fields and woodlands. Looking closer, you would notice a distinctive pattern on the land: repeating circular forms, like small hills, in an array of sizes and configurations – with water filling the irregular spaces between. And then the curious scene is gone, lost from view and replaced by expansive tracts of farmland, neighborhoods, industrial areas, and the developed centers of Central Point, White City, and Medford. Even there, you still catch glimpses of standing water in odd places, backyards, pastures, and around the airport itself as you descend to land.

Those tiny ponds and hills you saw are the remnants of a vast mound and vernal pool landform that once covered a large portion of southwest Oregon's Rogue River Valley.[1] Most of the Rogue Valley's current land surface formed from river sediment deposited as flood plains and alluvial fan terraces during the ancient uplift and erosion of the surrounding mountains. Cut through by the Rogue River and its tributaries or interrupted by hills and mesas from a seven-million-year-old lava flow, these alluvial formations still define much of our valley-bottom terrain. Our mound and pool patterned ground developed on those ancient alluvial fan terraces. Characterized by shallow, gravelly, clay-loam soils filled with rounded cobblestones, fractured jasper, and bright agates, the landform is known locally as the Agate Desert.[2]

Beneath those soils, at a depth of just a few inches to a few feet, is an impermeable duripan layer resembling poured concrete. Formed by a natural process of dissolved minerals leaching down during the rainy season and solidifying as the soils dry back out in the arid summer, this duripan is what gives us our vernal pools. During the rainy season (October – April) the Rogue Valley receives an annual average of about 20 inches of precipitation, typically as a series of storm systems bringing heavy or persistent rain.[3] The duripan prevents that rain from soaking deep into the ground, resulting in a "perched" water table that quickly rises to the surface filling the low spaces in the mounded topography and creating a seasonal mosaic of vernal pool wetlands.[4]

The tiny ponds and hills of Oregon's Rogue River Valley mounded vernal pool landform. © *Keith Perchemlides/TNC*



Flyover view of the Rogue River Valley approaching the Medford, Oregon airport with an area of patterned mound and pool landform visible on fields and woodland in the foreground. *Created in Google Earth using May 2016 Landsat/Copernicus imagery.*

What is a vernal pool? Vernal pools are a distinctive type of wetland habitat found in a wide variety of forms all around the world. They are shallow ephemeral water bodies that seasonally inundate for relatively short spans of time, then dry out completely for extended periods before re-filling **(Figure 1)**. Alternately too wet for upland species and too dry for typical aquatic species, vernal pools host specialist plants and animals that are uniquely adapted to their profound cycles of inundation and desiccation.[5] Vernal pools are also important to more familiar species: as spawning habitat for frogs and salamanders, stopover and feeding grounds for migratory waterfowl and songbirds, or as a seasonal food and water source for a range of grazing and foraging mammals.

FIGURE 1. Three-photograph time series of seasonal transformation for a Rogue Valley vernal pool. Top: the pool fully inundated with rainwater during late winter. Middle: the same pool in the spring with surface water replaced by abundant wildflowers. Bottom: the pool in late summer, with soils and vegetation dry and dormant, waiting for rain. © *Evan Barrientos*

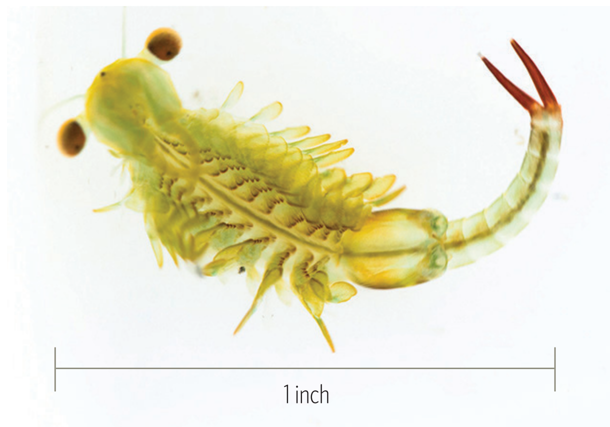
Vernal Pool Soils, Hydrology, and Ecology

Southwest Oregon's vernal pools are similar to those found in other Mediterranean-type climate regions around the world.[6] Filled only by precipitation, they inundate during the cool rainy season, transform into wildflower gardens in spring, then remain dry and dormant throughout the arid summer and fall **(Figure 1)**. The vernal pools in Oregon's Rogue River Valley are geographically and botanically unique outliers of the California Central Valley vernal pool system, sharing a characteristic mounded topography, similar soils and pool-adapted species or genera.[7] Southwest Oregon is at the northern extent of a large ecological zone known as the California Floristic Province, one of the continent's top biodiversity hotspots, and within this zone vernal pools are one of the rarest and most threatened plant communities.[8, 9, 10]

Rogue Valley vernal pools are relatively small and shallow, usually less than a foot deep and just a few yards across, but they make up a substantial portion of their landscape at a typical density of five or more pools per acre. They fill with rain during the fall or early winter (October – December) and may remain inundated until the weather changes in spring (March – April), or may repeatedly dry down and re-fill within the same wet season depending on rainfall patterns. Ephemeral surface and sub-surface flows connect vernal pools in complex drainage networks following the gentle slopes of the larger landform. Although individually small, at the landscape scale the water-retention capacity of vernal pools can play an important role in regulating and sustaining watershed flows to creeks and rivers.[11]

> Waiting for the rain is a specialty of vernal pool species. When the water finally returns, seeds and eggs burst into life after long periods of drought-induced dormancy that sometimes last for years.

Hydrology varies from pool to pool and over time; wetland characteristics may be strong or marginal, depending on the typical frequency and length of time that a pool holds water. Some pools inundate reliably and persistently every year, and some fill only briefly and dry quickly; others may go for years without any water unless conditions are just right. Differences in soils, duripan, drainage, topography, and vegetation interact to create landscape patterns of pool hydrology. And for each individual pool, weather-driven variations in hydrology cause dramatic transformation in plant and animal communities from one season to the next and from year-to-year.[12, 13, 14]



Mature male Oregon fairy shrimp with typical wide-set eyes, specialized antenna, and forked red tail. Fairy shrimp swim with undulating motions of their gill-fringed leg appendages oriented towards the water surface. © *Evan Barrientos*

Whenever pools do hold water for a span of weeks to months, they quickly fill with life. Waiting for the rain is a specialty of vernal pool species. When the water finally returns, seeds and eggs burst into life after long periods of drought-induced dormancy that sometimes last for years. Most vernal pool plants germinate in the fall and may spend months slowly growing underwater, then complete their growth and flowering after the pools dry out. Uninhabitable for fish, vernal pools are occupied by a host of unusual invertebrates, forming a miniature community of grazers and filter feeders, predators and prey.[15] Fairy shrimp, our largest vernal pool dependent invertebrates, are among the most complex and fascinating of these creatures.

The eggs of fairy shrimp can survive for decades in the soil in a state of near-lifeless dormancy until the presence of cold, fresh rainwater and sunlight cue them to hatch.[16] Fairy shrimp quickly grow into complex adult forms, mate and lay new eggs – sometimes in as little as two or three weeks.[17] Dense populations of fairy shrimp can fill vernal pools by the thousands, then disappear just as suddenly when the pools dry out. A little over an inch long at maturity, our local fairy shrimp feed on small particles in the pool water, and in turn provide food to waterfowl, songbirds, and amphibians.[18] Surprisingly, fairy shrimp eggs survive and hatch even more abundantly after passing through the digestive system of birds if the mother shrimp is eaten: an adaptation for dispersing to new pools.[19]

In southwest Oregon, native pocket-gophers and ground squirrels are abundant in vernal pool habitats. Incredibly, these types of burrowing animals seem to be the earth movers behind the formation of our characteristic mounded topography.[20] Over thousands of years of digging, foraging in moist ground and denning in drier ground, these burrowers can selectively transport large volumes of soil to create domed mounds of earth interspersed with low basins.[21, 22] The interaction of duripan, perched water table and persistent burrowing animals has resulted in a biologically created landform: a bio-geomorphology origin for our mounds and pools. And those animals are still digging today. Viewed over very long spans of time, these mound-and-pool soils are in motion, actively churning and forming under this constant burrowing disturbance or "bioturbation".

Upland mounds are elliptical in form and range in size from roughly 10 to 100 feet in diameter. The mounds often overlap in irregular clusters and chains, with pools filling the gaps between mounds. Interestingly, the contours of the sub-soil duripan layer typically follow the surface topography so that the duripan is higher under mounds and lower under pools **(Figure 2)**. This acts to channel both surface and sub-surface water to the vernal pool basins where a clay wetland soil develops as fine particles are transported downslope. These clays accumulate into a lens-shaped claypan above the duripan in most pool bottoms, adding to the water-holding capacity and providing a distinct soil substrate for our native vernal pool plants.[23]

Our mound-and-pool soils are a mosaic complex of two soil types known as Agate-Winlo **(Figure 2)**. Upland mound

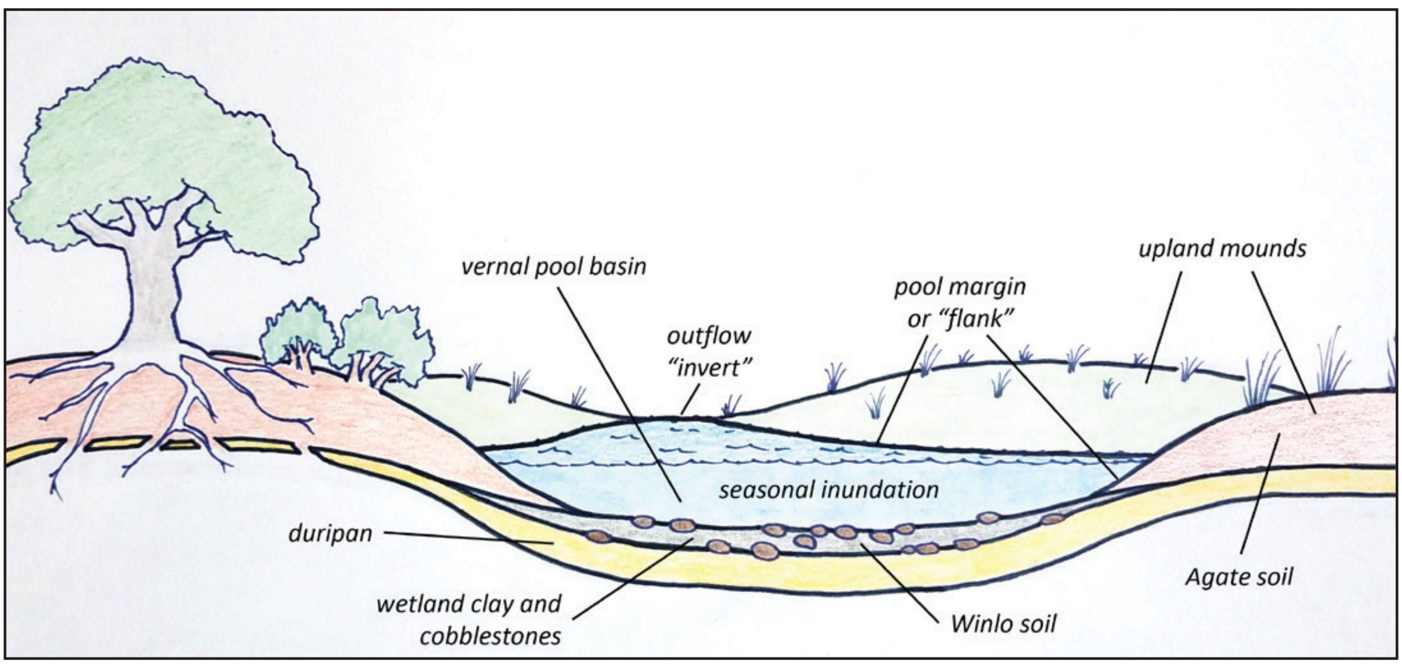


FIGURE 2. Characteristic landform features, soil types, and simplified cross-section profile for mounded vernal pool habitats on alluvial terraces in the Rogue Valley, Oregon. (Not drawn to scale.) © *Keith Perchemlides /TNC*

Rogue Valley mounded prairie, shrub, and oak woodland habitats in mid-winter with inundated vernal pools throughout. © *Keith Perchemlides/TNC*

Agate soils are a reddish, sandy clay-loam and may be two or more feet deep above the hardpan. Pool bottom Winlo soils are heavy gray clay, often dense with cobblestones, and are typically only inches deep.[24] These soils overlap and intergrade at the slope transition from pool to mound, the wetland margin or "flank". Each zone supports a different plant community that runs the full gradient from wetland aquatic species to dry prairie species in a span of just a few yards. This fine-scale topographic, soil, and hydrologic complexity is part of the reason why our vernal pools are known for their unique biodiversity.

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In the Rogue Valley, our mounded topography spans across open prairies and under Oregon white oak (*Quercus garryana*) and Ponderosa pine (*Pinus ponderosa*) woodland, with vernal pools throughout. Oak habitats typically occupy relatively higher ground, and the duripan appears to be thinner and less continuous in those areas, especially beneath the mounds **(Figure 2)**. By allowing root access to deeper sub-soil moisture, a discontinuous duripan may be why oak woodlands were able to develop in some areas. In prairies, we find the hardpan layer thicker and more continuous, likely excluding tree establishment. Shrub communities dominated by buckbrush (*Ceanothus cuneatus*) are found at the transition from prairie to oak habitat and can form expanses of "valley chaparral". These differences in duripan structure and permeability, landscape position, and plant community influence vernal pool hydrology, with pools in oak habitats generally inundating later and drying sooner than prairie pools.

Rogue Valley vernal pool habitats are a dynamic landscape filled with diverse species adapted to frequent change. Shallow soils, grassland and oak vegetation, plus summer drought lead to a short, intense growing season followed by a long fire season. In pool basins, wetland wildflowers burst forth in the brief weeks after emerging from the water and before their thin clay soils dry out – often forming concentric rings of bloom as the water recedes **(Figure 1, middle)**. Historically, grazing herds of deer, elk, and pronghorn roamed through our valley during the lush green months of April and May. By late June or July, the grasses and wildflowers have almost all set seed and dried to a crisp. Fires were common in this tinder-dry summer landscape before European colonization, including intentional burning by Native Americans who actively managed their land with fire for thousands of years.[25, 26] Native vernal pool plants are incredibly adapted to flood, fire, and natural grazing, typically responding with renewed vigor and population increase to these disturbances – and suffering in their absence.

Land Use History and Habitat Loss

Travel back in time to a spring day in the mid-1800s and most of the Rogue Valley, from foothills to river, would have been open grassland and oak woodlands, including large areas of intact vernal pool habitat. Ranchers would be turning out herds of cows or sheep to graze on the new growth. Their pasture would look very different from today's, with tall bunchgrasses and bright wildflowers still prominent instead of the near-uniform cover of non-native annual grasses that is typical now.[27, 28]

By 1853, the native Takelma people had been violently removed from their homeland to a temporary reservation at the nearby Table Rocks.[29, 30] A network of small farms, ranches, mining towns, military camps, roads, and railways marked the early stages of European colonization.[31, 32] Over time, these settlements continued to grow, and land use expanded and intensified until more than 75% of the Rogue Valley's mound and pool landform was permanently transformed or heavily impacted by residential and commercial development or agriculture.[33] Located in the valley bottom near rivers and irrigatable farmland, major roads, and expanding towns, our vernal pool habitats were, and are, at the epicenter of modern land development.

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The remaining vernal pool habitat in the Rogue Valley has been altered for well over a century by the impacts of that development: invasive weeds, overgrazing, fire exclusion, fragmentation, leveling, irrigation, removal of woodlands, and other changes. We have some high-functioning but no truly intact vernal pool habitat left.[34] The shallow, rocky soil and duripan associated with our vernal pools make them poor quality for farming, yet for many decades settlers attempted to grow both crops and orchards.[35] Local place-names like Agate Desert echo the early settlers' opinion of the land. Agricultural plowing or more intensive leveling re-arranged the natural topography and filled vernal pools with upland soil, profoundly changing wetland function. Agricultural development also included attempts to increase drainage or irrigate dry lands through a network of ditches to divert and re-distribute water, altering hydrology at a large scale. On vernal pool habitats these farming efforts were often abandoned because of the challenging soils, but the impacts remain.[36]

Grazing of both sheep and cattle has been a more economically viable use of the land, but shallow soils and summer drought made the native plant communities especially vulnerable to overgrazing. Grazing pressure combined with the spread of invasive plants, exclusion of beneficial fire and the intentional sowing of pasture grasses transformed the valley's native prairie and oak understory into communities dominated by exotic weeds, especially annual grasses.[37, 38] Even so, unlike farming and development, grazing did not typically require intensive changes to the natural topography or hydrology, and many of the Rogue Valley's best remaining vernal pool areas are former or active ranches.

Go back in time even further, over 300 years, to a summer afternoon before European colonization. Tall fire-scarred ponderosa pines towered above oaks laden with acorns and prairies filled with late-blooming wildflowers and ripening bunchgrasses. Native Takelma people could have been out harvesting camas bulbs from vernal pool wetlands or tending a fire set to aid in collecting edible seed.[39] Acorns, camas (*Camassia*), seed from tarweed (*Madia*) and native sunflower (*Helianthus*), wild parsnip (*Lomatium*) plants, meat from deer and elk, and salmon from the nearby river are examples of abundant and nutritious foods harvested by the Takelma living in the Rogue Valley.[40] Their traditional burning and land stewardship practices intentionally increased the health and abundance of preferred foods and shaped plant communities and habitats across the landscape.[41, 42]

At that time, you could have walked from one side of the valley to the other through rolling prairie and shaded woodlands, including the full expanse of over 32 square miles of intact vernal pool landscape divided by low hills and the riparian corridors of creeks and streams.[43] In addition to the diversity of wetland, prairie, and oak habitats, shifting patterns of fire and wildlife grazing created a mosiac of plant community succession on the land.[44, 45] It was a landscape where the people had a reciprocal relationship with the local ecosystems and species, and actively managed the land to maintain them. Our current vernal pool conservation areas provide a connection to this cultural and ecological history, an opportunity to return Native American traditional practices, and a responsibility to protect and restore what remains.

Habitat Conservation and Species Recovery

In the present-day developed landscape, one could easily assume that our relatively small and dispersed vernal pool natural areas are examples of a habitat type that was always rare and isolated. It is important to remember that these areas were once interconnected in a large and continuous landscape. Our surviving vernal pool sites may be small remnants, but this only increases their importance for preserving rare biodiversity and unique ecology.

Southwest Oregon's vernal pool habitats are important to conserve for both ecological and social values. Located near population centers, they provide accessible nature close to home for residents, outdoor classrooms for students from kindergarten through college, and discovery for nature-loving visitors. But this same proximity to people leaves vernal pool sites under continuing risk of loss and degradation. As a characteristic local wetland, vernal pools play a central role in our region's wetland protection regulations (see section II: Whetstone Savanna Conservation Area) as development continues to expand with the valley's steadily growing population. Medford and Central Point populations have more than doubled since 1980, accompanied by an expansion of housing, businesses, and roads into our remaining vernal pool areas at the edge of town and on adjacent rural lands.[46]

Many of our remaining high-quality vernal pool sites are now held in protected conservation ownership (or easement) by The Nature Conservancy (TNC), Bureau of Land Management (BLM), Oregon Department of Transportation

Elementary school students get outdoors to learn about their local ecology and wildlife habitat on a winter field trip at a Rogue Valley, Oregon vernal pool conservation area. © *Mike Potts*

Large-flowered woolly meadowfoam blooming in April along the edge of a still-inundated vernal pool. © *Evan Barrientos*

(ODOT), the Southern Oregon Land Conservancy (SOLC), Oregon Department of Fish and Wildlife (ODFW), the Bureau of Reclamation, local municipalities, or privately-operated wetland mitigation sites. These properties are relatively small, tens to hundreds of acres, compared to the historic habitat extent, and are widely separated by developed land. Other important habitat areas are not protected, and their fate remains uncertain. Both habitat loss and the active protection of new sites continue today.

Loss and degradation of our vernal pool habitat led the U.S. Fish and Wildlife Service (USFWS) to list three of our local vernal pool species under the federal Endangered Species Act (ESA): two endangered plants that grow on pool margins, the large-flowered woolly meadowfoam and Cook's desert parsley, and a threatened invertebrate, the vernal pool fairy shrimp. These "listed species" are protected by law and covered under a 2012 USFWS Recovery Plan for the Rogue and Illinois River Valleys with the goal of halting or reversing their decline and ensuring the long-term survival of these species.[47]

Large-flowered woolly meadowfoam

Limnanthes pumila ssp. *grandiflora* ("meadowfoam") is an annual wildflower native and endemic to the Rogue Valley. These small plants with bright white flowers and round, red-tinted seed heads are specialists at growing on the edges of vernal pools and similar ephemeral wetlands. They germinate in the fall and can be found underwater during the wet season, then quickly grow to maturity in the early spring, blooming and setting seed in April to May. As an annual, their population numbers vary widely from year-to-year, but their overall historic decline is unquestionable. Once a common and abundant species across the valley, our listed meadowfoam is now confirmed at only 17 sites that total less than 500 acres according to the USFWS.[48, 49] Direct loss of populations and habitat, competition from invasive weeds, altered wetland hydrology, and fragmentation that isolates small populations are the main threats to meadowfoam's survival

Cook's desert parsley

Lomatium cookii ("desert parsley") is a robust perennial when mature but is slow to establish, spending its first few years of life as a small fernlike plant. A distant relative of carrots, desert parsley grows along vernal pool margins in the Rogue Valley and in wet meadows of the neighboring Illinois Valley.[50, 51] Once mature, the plant produces clusters of cheerful yellow blooms and abundant seeds and is a favorite food of both native and domesticated herbivores. Desert parsley plants go dormant by mid-summer, retreating to their large below-ground taproot to survive drought, cold, or fire. In the Rogue Valley, desert parsley has been reduced to only 11 known populations on fewer than 150

Male vernal pool fairy shrimp, *Branchinecta lynchi* (left), with identifying tusk-like head appendages; and female Oregon fairy shrimp, *Eubranchipus oregonus* (right), with prominent egg pouch and forked red tail. © *Evan Barrientos*

total acres.[52, 53] Like meadowfoam, the main reasons for desert parsley's endangered status are widespread habitat loss, fragmentation into small isolated populations, unchecked herbivory, altered hydrology, and competition from invasive species – especially annual grasses that overwhelm mature plants and exclude new seedlings from establishing. Both desert parsley and meadowfoam respond to fire with increased growth, flowering and establishment of new plants. It is likely that fire exclusion is another central reason for the decline of both species.

Cook's desert parsley flowering in a dry vernal pool basin. © *Paul Benton/ODOT*

Vernal pool fairy shrimp

Branchinecta lynchi ("vernal pool fairy shrimp") are one of two species found in Rogue Valley pools, along with *Eubranchipus oregonus* ("Oregon fairy shrimp"). Vernal pool fairy shrimp are listed as a threatened species, while Oregon fairy shrimp are more regionally abundant and widespread. Southwest Oregon is the only location where these two species of fairy shrimp can be found swimming in the same pools. Interestingly, the vernal pool fairy shrimp's primary habitat area is California's Central Valley and Coast Range.[54] Our Rogue Valley population is a remarkable outlier for the species, found only in vernal pools of the Agate Desert landform or atop the Table Rocks volcanic mesas, and separated from its California relatives by over 100 miles of mountainous terrain. When they have functional habitat, fairy shrimp are impressively resilient and highly adapted vernal pool specialists. Habitat loss and fragmentation by development, insufficient pool hydrology from land alterations or invasion by exotic grasses, and degraded water quality are driving their decline.[55, 56]

Valuable and impressive on their own, fairy shrimp, meadowfoam, and desert parsley are equally important as indicators of habitat quality and the effectiveness of ecological land management. When these listed species can thrive on a site, we know their habitat is healthy and functioning well, providing a home for all vernal pool dependent species. Efforts to protect and recover these species appropriately focus on conservation or restoration of their habitat, to the benefit of all native species, rare or common – and the people who value these natural areas.

The Need for Vernal Pool Restoration

In the current context of land development, fire exclusion, invasive species, and climate change, our remaining Rogue Valley vernal pools, prairie, and oak woodland are under intense pressure. Altered by a long history of negative impacts and adapted to frequent natural disturbances that are often missing, survival of these habitats likely depends on how well we can reverse historic alterations and return beneficial ecological processes. Passive conservation management – simply protecting areas and letting them be – may not be enough at this point.

Efforts to control invasive weeds, encourage native plant communities, and protect rare species are essential to vernal pool conservation. But this work may fail or be severely limited in effectiveness when basic ecological functions have been undermined and populations of native species diminished to unstable small patches. In this context, conservation efforts remain at a persistent disadvantage.

Topography and hydrology are inextricably linked in vernal pool systems where even seemingly small alterations to the land surface have large impacts on wetland function. By limiting pool inundation and putting upland soils into pools, these changes diminish the habitat's capacity to support native species and shift conditions to favor invasive weeds.[57] Invasive species, especially annual grasses, can then further alter soil conditions and pool hydrology (by accumulating litter and increasing wet-season evapotranspiration) in a self-reinforcing cycle.[58, 59] Increasing variation in weather patterns from climate change pushes the limits for native species already living in an ephemeral habitat.[60] Combined with habitat degradation that reduces the function and resilience of wetland systems, this stress can lead to permanent losses.

On many sites, effective conservation and species recovery will first require active restoration of the landform and hydrology that allow these systems to function. Even then, the long-term persistence of restoration gains will rely on controlling invasive weeds and returning the natural disturbance processes these ecosystems evolved with. Restoration followed by a combination of prescribed fire, native seeding, and ecologically managed livestock grazing may be our best strategy for maintaining long-term vernal pool habitat quality in the Rogue Valley.[61]

Degraded vernal pools filled with upland soils and overrun by invasive weeds cannot provide functional habitat for dependent native species. © *Keith Perchemlides/TNC*

The Whetstone Savanna conservation area in springtime. New growth surrounds rain-filled pools in a rich mosaic of wetland and wildflowers, mounded prairie, oak, and shrubland. © *Keith Perchemlides/TNC*

SECTION TWO

Whetstone Savanna Conservation Area

The goal of this report is to share our methods and outcomes from a multi-year vernal pool restoration project led by ODOT and TNC on the Whetstone Savanna conservation area. Located outside of Central Point (north of Medford) in Jackson County, Oregon **(Map 1)**, the Whetstone Savanna conservation area includes 336 acres of mounded prairie and oak woodland/savanna habitat with vernal pools throughout. Part of the Agate Desert landform, the Whetstone Savanna is crossed by a seasonal swale that drains the surrounding vernal pool terrace into Whetstone Creek, a tributary to the Rogue River. Unofficially known as the Kincaid Swale, this slow-flowing low-gradient watercourse runs southeast to northwest across all three conservation properties, linking them hydrologically. Most of the surrounding landscape has been converted to rural-residential, commercial or agricultural uses, but neighboring ranch properties host additional surviving mounded terrain and vernal pool habitat.

The Whetstone Savanna is a wonderful conservation site to visit, with a clear view of the Rogue Valley's popular Table Rocks volcanic mesas to the north, a diversity of oak, prairie, and wetland habitats, wildflowers in the spring, vernal pools in winter, an impressive variety of birds year-round, and enough open space to create a real sense of being surrounded by nature. It is also an excellent example of the landform, ecology, land-use history, and conservation challenges of Rogue Valley vernal pools described above. Prior to being purchased for conservation, these properties were managed for grazing, with earlier histories of homesteading and agriculture, including active and abandoned irrigation ditches.

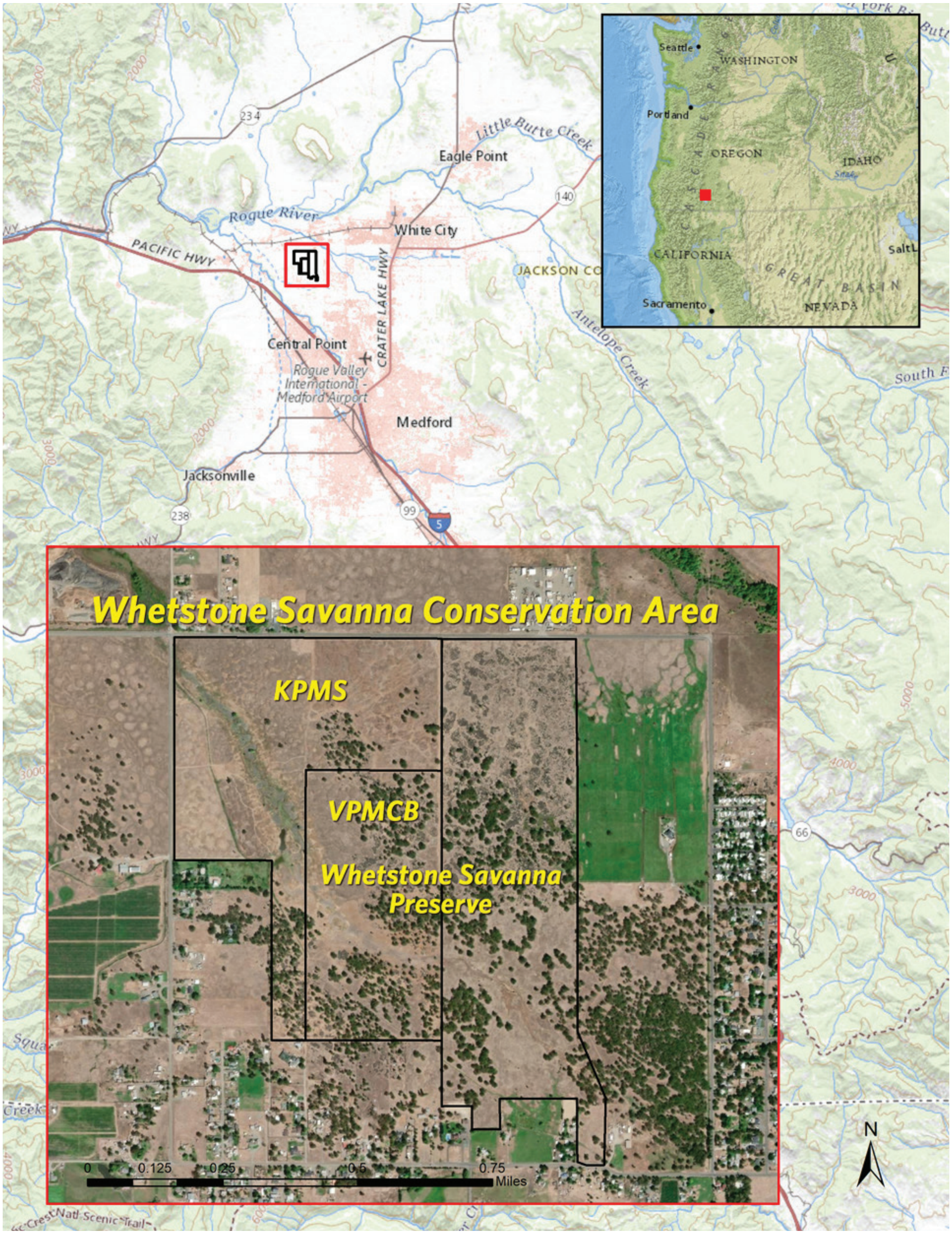
A Stronghold of Vernal Pool Habitat

The Whetstone Savanna conservation area is composed of three properties acquired by TNC and ODOT in a coordinated effort to secure a core block of high-quality vernal pool habitat **(Map 1)**. All three properties host populations of the endangered meadowfoam and desert parsley, as well as Oregon and vernal pool fairy shrimp. Whetstone Savanna's vernal pool habitat ranges from heavily impacted with little or no wetland function, to areas retaining most of their natural landform and hydrology.

In 1995, TNC acquired the original nature preserve in the area, the 140-acre Whetstone Savanna Preserve, mainly for conservation of mature valley-bottom Oregon white oak and ponderosa pine woodlands – a valuable and threatened Rogue Valley habitat type of its own. Vernal pools soon became an equal conservation priority for the preserve. TNC continues to protect and steward the preserve with invasive weed control and listed species monitoring.

In 2007, ODOT purchased 80 acres of adjacent vernal pool habitat west of the TNC preserve to meet the agency's need for compensatory mitigation (see below). Ownership of this new conservation property, named the Vernal Pool Mitigation and Conservation Bank (VPMCB), was then transferred to The Nature Conservancy, becoming part of the Whetstone Savanna Preserve. ODOT continues to fund and lead management of the VPMCB, with an agreement in place to transfer management to TNC when mitigation use

WHETSTONE SAVANNA CONSERVATION AREA



MAP 1. The Whetstone Savanna conservation area, 336 acres of protected vernal pool habitat in the Rogue River Valley north of Medford, Oregon; composed of three properties owned and managed by TNC and ODOT. *Basemaps and imagery: USGS National Map[62] , National Geographic World Map[63] (location inset), and ESRI World Imagery[64] (detail inset).*

is complete. This overlap of ownership and management, mitigation and conservation goals on the Whetstone Savanna catalyzed an effective long-term collaboration between ODOT and TNC in southwest Oregon.

Then in 2012, responding to additional compensatory mitigation needs, ODOT purchased another 116 acres north and west of the VPMCB and Whetstone Preserve. Named the Kincaid Property Mitigation Site (KPMS) for the remains of an 1800's homestead, ODOT retains ownership and actively manages the property.[65] The KPMS and VPMCB sites were intentionally established adjoining the original TNC preserve to expand conservation ownership and habitat continuity on the Whetstone Savanna and to allow for coordinated management.

Since 2008, TNC has worked under contract with ODOT to plan and monitor management of the VPMCB and KPMS. Over time, the network of partners, collaborators and contractors involved in these mitigation sites has grown to include private and Forest Service nurseries, the BLM and USFWS, the Natural Resources Conservation Service (NRCS), ODFW, the Oregon Department of Agriculture (ODA), and Oregon Department of Forestry (ODF), non-profit organizations like The Freshwater Trust, Bee Girl Organization, and Rogue Native Plant Partnership, and ecological consultants including Strauss Ecological Services and CC Patterson and Associates (CCPA). TNC has agreed to cover perpetual stewardship of the VPCMB, and ODOT will provide similar long-term management for KPMS, ensuring that these conservation investments will endure and be maintained into the future.

Together, these properties create an important stronghold of Rogue Valley vernal pool, prairie, and oak habitat. The conservation area is large enough to host stable populations of our listed species, creating a protected refuge for species recovery. It also provides valuable habitat for nesting and migratory birds, including songbirds, wood ducks, and Lewis's woodpecker, native mammals such as black-tailed jackrabbits, bobcat, and coyote, and several species of reptiles and amphibians, including blue-tailed skink and alligator lizards, Pacific chorus frogs and long-toed salamanders, that find their distinct niches in the site's wetland/upland mosaic.

Innovation in Compensatory Mitigation

ODOT's role in vernal pool conservation on sites like the Whetstone Savanna is determined by the State of Oregon's Removal-Fill Laws and Rules, and the federal Clean Water Act and Endangered Species Act (ESA), which require "compensatory mitigation" for wetlands and threatened or endangered species.[66, 67, 68] In the course of their work building and maintaining Oregon's public roads, ODOT projects can cause loss or damage "impacts" to wetlands or populations of ESA-listed species and their habitat. The guiding idea of compensatory mitigation is "no net loss" of these habitats or species. In practice, this establishes a system whereby negative impacts in one area are offset by actions to protect and increase or improve populations or habitat elsewhere. For ODOT, funding for compensatory mitigation is built into state and federal road project budgets whenever wetland or species impacts are involved.

Previously, compensatory mitigation was often achieved on a project by project basis resulting in multiple small mitigation sites scattered throughout the region. This piecemeal approach presents management challenges and limits site performance and sustainability. Small "postage stamp" wetlands are often ineffective at providing large-scale ecological functions and ecosystem services, and usually require continuous intensive management to support listed species and habitat quality. In some cases, these mitigation projects were established without a long-term habitat management strategy or relevance to regional conservation goals.

In the 1990's the concept of wetland mitigation "banking" gained in popularity and by the early 2000's became the preferred wetland mitigation strategy by the regulatory agencies. Mitigation banking combines the response to numerous dispersed small impacts onto one large wetland site that serves as compensatory mitigation for all the impacted wetlands. Efficiencies are gained in site management and monitoring, and large-scale ecological functions are preserved or restored. These banking sites typically have long-term stewards identified to ensure they are maintained in perpetuity. ODOT's local Region 3 office sought to expand on this concept by combining wetland and listed species compensatory mitigation banking in one site, the VPMCB.

ODOT's goal of creating the state's first combined wetland and species mitigation bank aligned with regional and local conservation planning efforts, in which TNC played a key role.

ODOT's goal of creating the state's first combined wetland and species mitigation bank aligned with regional and local conservation planning efforts, in which TNC played a key role.[69] In 2006, the Rogue Valley Council of Governments helped to lead an assessment of remaining Rogue Valley vernal pool habitat.[70] The intent was to allow for continued economic growth and development while planning for comprehensive protection of vernal pool wetlands and species. An initial step was to map and rank the size and quality of remaining habitats, identifying core areas for protection.[71] Along with earlier USFWS designation of vernal pool Critical Habitat areas, this planning sought to avoid development in the remaining areas of high-quality habitat.[72] Mitigation funding from impacts to lower-quality, fragmented habitat could then be channeled to conservation and restoration of larger core habitat areas.

In 2011, the USFWS published guidance to coordinate conservation, development, and mitigation of Jackson County vernal pool habitat under an overall strategy to protect these wetlands and their species.[73] This was followed by a 2012 USFWS recovery plan for rare, threatened, and endangered vernal pool species in the Rogue and Illinois Valleys, with the goal of stabilizing populations or reversing their decline.[74] The Whetstone Savanna mitigation properties exemplify the concepts of this conservation planning framework.

The currency of compensatory mitigation is the "mitigation credit." Credits are earned through meeting wetland protection, habitat quality, or listed species performance objectives. In mitigation banking, these credits are earned in advance of project impacts and "banked," held for later use as needed. Once a bank balance is established, projects with impacts can use the available bank credits. Being the first combination wetland and listed species bank in Oregon, the VPMCB provides both wetland mitigation credits and conservation credits for listed species. For projects that impact both resources, credits can be sold as "combination credits," offsetting impacts to both vernal pools and vernal pool listed species.

Mitigation banking creates a funding structure whereby multiple small negative impacts spread over time and space can be consolidated to cover focused conservation on a single larger site. Oversight for ODOT's mitigation work is provided by an Interagency Review Team (IRT) of regulatory agency staff from the USFWS, Army Corps of Engineers (Corps), and Oregon Department of State Lands (DSL). The IRT authorizes the release of mitigation credits when ODOT's mitigation work meets ecological performance standards established for the site.[75] Monitoring completed by TNC, ODOT, and CCPA informs the IRT's decisions on credit release.

Members of the Interagency Review Team on an ODOT-led tour of the Whetstone Savanna mitigation properties. © *Keith Perchemlides/TNC*

Baseline Habitat Condition

A set of mitigation performance standards for the KPMS and VPMCB sites define specific measures of habitat quality for vernal pools and upland mounds, and for the status of ESA-listed species.[76, 77, 78] For example, to meet performance, at least 70% of plant cover in vernal pools needs to be native species, and vernal pool fairy shrimp must be present in at least 40% of pools. **Table 1** provides a simplified summary of mitigation performance standards and thresholds for the VPMCB. Since 2008, TNC has conducted annual monitoring of vegetation and listed species to report on those standards. In the course of this routine performance monitoring, we have also assembled an important long-term dataset of site condition to inform restoration planning and assess effectiveness.

TABLE 1. Summary of mitigation standards for the VPMCB property with performance from pre-restoration baseline (2008 – 2011) and the most recent post-restoration monitoring (2019). Checkboxes indicate whether the standard is met/exceeded (checked) or failed (unchecked) for the monitoring period.

MITIGATION PERFORMANCE STANDARDS		BASELINE (2008-2011)	RESTORED (2019)
Vernal pools	**Threshold**		
native herbaceous relative cover	> 70%	☐	☑
invasive species relative cover	≤ 15%	☐	☑
key native vernal pool species	≥ 15	☑	☑
absolute cover of bare soil	< 75%	☑	☑
Listed species			
vernal pool fairy shrimp occupancy	> 40%	☐	☑
fairy shrimp occupancy relative to baseline	> 95%	–	☑
Cook's desert parsley flowering plants	> 200	☐	☑
large flowered woolly meadowfoam plants	> 2000	☐	☑
tree and shrub species relative cover	< 5%	☑	☑
Prairie uplands			
native herbaceous relative cover	≥ 25%	☐	☑
medusahead invasive grass relative cover	≤ 25%	☑	☑
other invasive species relative cover	≤ 25%	☑	☑
key native upland species	> 20	☑	☑
Oak uplands			
native herbaceous relative cover	≥ 25%	☐	☐
medusahead invasive grass relative cover	≤ 25%	☑	☑
other invasive species relative cover	≤ 25%	☑	☑
key native upland species	≥ 20	☑	☑
relative native cover including canopy species	≥ 50%	☐	☐
non-native tree and shrub abundance	< 5%	☑	☑
native tree density compared to reference	≥ 80%	☐	☑

Our baseline monitoring of the VPMCB property (2008-2011) revealed a struggling habitat. Native plants were getting overwhelmed by non-native invasive weeds. Before ODOT purchased the site, it was used for cattle grazing which likely kept many of the invasive plants in check, but also impacted native species.[79, 80] With grazing removed in 2008, both native and non-native plants were released to grow, but the invasive species had the upper hand. Invasive grasses, such as medusahead (*Taeniatherum caput-medusae*) on mounds and seaside barley (*Hordeum marinum*) in pools, were already widespread and well established.

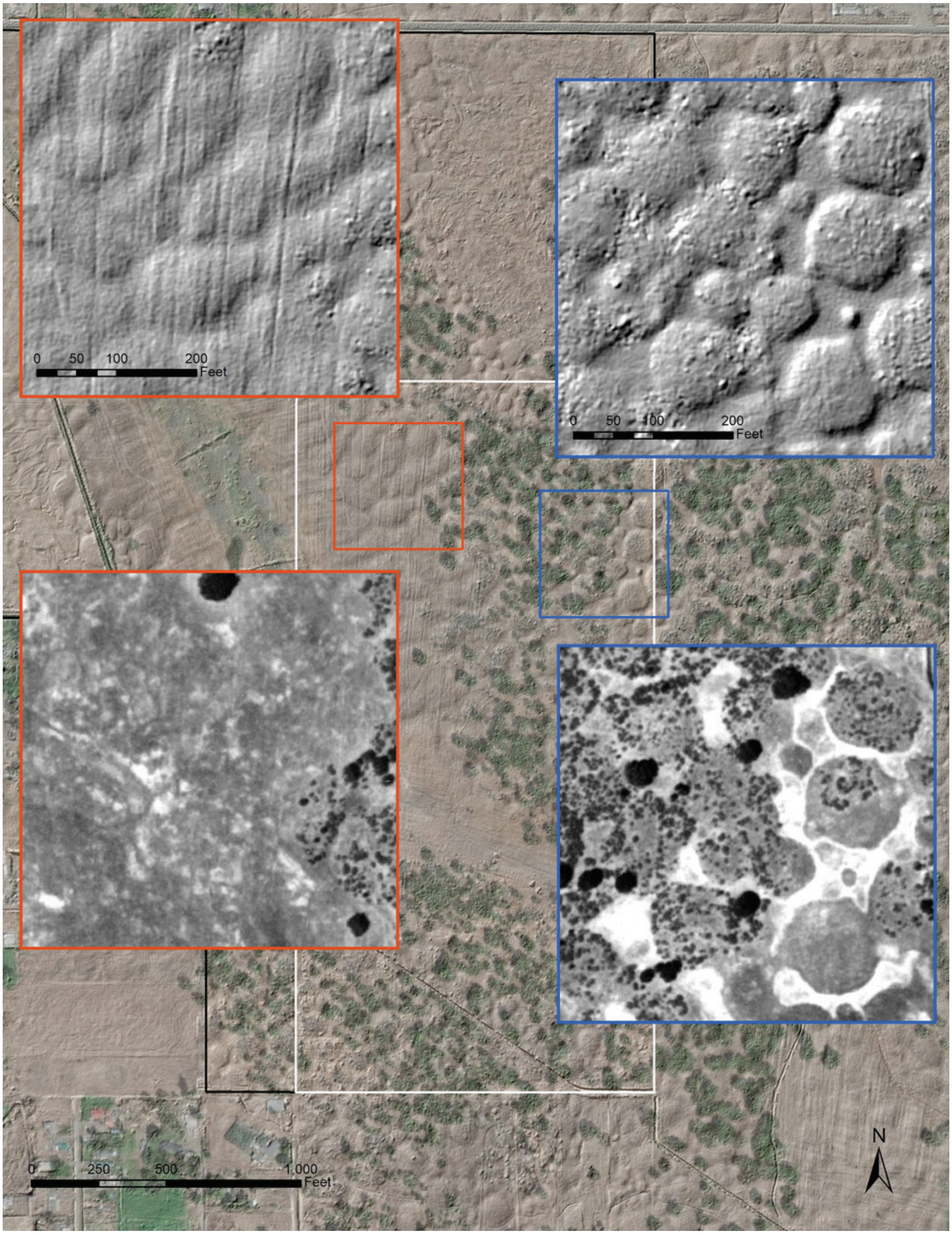
During the first seven years of management, we treated high-priority weeds and completed some initial restoration on the VPMCB. Even so, most of the site was essentially left to recover on its own – and its condition rapidly worsened. By the spring of 2015, native plants had declined precipitously while invasive species expanded aggressively. It seemed clear that after more than a century of ecological impacts, the site was not going to return to a high-functioning condition without intervention. ODOT was concerned about meeting standards for mitigation performance **(Table 1)**. We began to ask what was missing; what was limiting native species while allowing invasive plants to expand?

Our listed species were also struggling, or worse. Desert parsley was absent from both the VPMCB and KPMS, and meadowfoam was limited to small isolated patches. Vernal pool fairy shrimp were present, but few and far between. Baseline conditions on the KPMS property (2012-2014) were similar. Neither site was performing well, nor did they seem likely to improve without more active management.[81] Prescribed fire followed by native seeding is a strategy for improving native plant cover that has worked well on TNC's nearby Agate Desert Preserve. Returning grazing management was also an option. But we suspected that something more fundamental was limiting habitat quality and native species on the Whetstone Savanna mitigation sites.

Evidence of Habitat Degradation

During initial fairy shrimp monitoring surveys, we noticed that in some areas vernal pools were large and inundated well while on other parts of the Whetstone Savanna pools were small, shallow and didn't hold water long. The pools that inundated well had good native plant communities, and that's where we found most of the fairy shrimp. The other pools were filled with non-native grasses, and the few fairy shrimp we found often didn't manage to mature before the pools quickly dried out again. The surrounding topography was different too. Well-functioning pools were surrounded by distinctly mounded uplands. But where pools were weakly expressed, mound forms were irregular or absent. We found some scattered on-site evidence of past impacts: surface ruts, irregular piles of soil in pools, and both active and abandoned irrigation ditches. But we could not discern to what extent the differences in pool form and function were due to natural variation or a result of artificial disturbance.

New tools and evidence allowed us to see what was really going on. Perhaps the single most powerful tool was high-resolution "lidar" (light detection and ranging) mapping of the surface topography. Lidar uses pulses of infrared laser light reflected from a surface back to an airborne (or ground based) instrument to create a detailed elevation model of the ground surface – similar to how the more familiar radar (radio detection and ranging) measures the bounce-back of radio waves to detect objects. Viewed as a "bare-earth hillshade" image of the ground surface minus vegetation, lidar revealed what we suspected but were not able to see clearly on-site: widespread and systematic leveling and deep-tine plowing or "ripping" of the land, abandoned water ditches and dams along the seasonal swale channel, and heaps of fill dumped in pools.[82]



MAP 2. Evidence for past topographic disturbance on the VPMCB site: High-resolution pre-restoration lidar[83] topography of highly altered (top left inset) and relatively intact (top right inset) areas, paired with 1939 aerial photograph images[84] of the same two areas (bottom left and right insets); the disturbance predated 1939.

Comparing the current lidar topography with historic fly-over photographs of the Whetstone Savanna taught us even more **(Map 2)**. In time-steps roughly 10 years apart, dating back to 1939, these aerial photographs record early clearing, ripping, ditching, and more recent bulldozer leveling in the 1960s and 1970s.[85] Like doctors looking at an X-ray image, we could suddenly see the type and degree of damage. We returned to the site with new eyes,

> We returned to the site with new eyes, calibrated by the understanding gained from lidar and historic photographs, and the on-site signs of disturbance came into focus.

calibrated by the understanding gained from lidar and historic photographs, and the on-site signs of disturbance came into focus. A final step was digging soil pits to confirm our impressions. In shallow, grassy pools, we repeatedly found upland loam soil burying the distinctive wetland clay and cobbles of the native vernal pool bottom. The adjacent mounds showed scars from equipment used to move that soil. And we found charcoal buried in fill heaps in pools, likely from chaining and burning of trees and shrubs to clear woodlands for pasture nearly a century ago.

But we saw something else in the lidar maps, aerial photographs and soil pits that was just as important in building our understanding of past disturbance and restoration need: the shape of the natural landform **(Map 2)**. Here and there in the lidar images, we noticed areas of intact mound and pool forms that popped out clearly and distinctly. These lined up with areas on historic aerial photographs showing a consistent landform decade after decade. And that was where we found the pools with the most fairy shrimp and best native plant cover. Soil pits dug in those same pools turned up heavy wetland clay soils right at the surface. Just as the impacts of past disturbance were more obvious in the lidar images, so was the patterning of the natural mound and pool topography, allowing us to build a conceptual model of the intact landform. Surveys of other relatively intact vernal pool habitats elsewhere confirmed and refined our perception.[86] This understanding of intact mound and pool topography combined with the evidence of past disturbance formed the basis of our restoration plan and guided the work of our team.

Staff from ODOT and TNC examine soil in test pits. Soil pits in damaged pools revealed a layer of rust-red upland Agate soil (upper right) burying the gray wetland Winlo clay found at the surface of intact pools (lower right). © *Keith Perchemlides/TNC*

Restoration Framework and Goals

Native wildflowers crown upland mounds surrounded by strongly inundating pools in a restored landscape. © *Keith Perchemlides/TNC*

The central concept of our restoration plan was that human-caused changes to topography and hydrology had limited the ecological function of the Whetstone Savanna vernal pools. We knew from earlier work that vernal pool ecology is strongly determined by landform and hydrology, and that reversing topographic disturbance can be highly effective in restoring habitat quality.[87] Pools filled with upland soil have a diminished capacity to inundate and are more invadable by non-native plants. Earth-moving restoration would be necessary to restore functional hydrology and expose buried vernal pool soils. With soils and hydrology restored, conditions in vernal pools could shift to favor specially adapted native species, including our endangered plants. Restored hydrology would provide fairy shrimp with more consistent and prolonged inundation, allowing them to re-build stable populations. Returning essential ecological structure and function would then enable prescribed fire and native seeding, along with invasive weed control, to successfully maintain high-quality habitat. Based on this understanding, we developed the following goals.

Restoration goals:

1. **Restore vernal pool hydrology** by reversing topographic alterations.
2. **Enable native species recovery** by restoring wetland habitat and function.
3. **Increase desert parsley and meadowfoam populations** by seeding restored habitat.
4. **Increase fairy shrimp distribution and abundance** through egg-transfer and improved hydrology.
5. **Increase native plant cover and diversity in pools** by restoring soils and hydrology, and seeding.
6. **Increase native plant cover and diversity on uplands** through prescribed fire and seeding.
7. **Control invasive species with targeted treatments** and by altering conditions to favor natives.
8. **Improve ecological conditions** to meet wetland mitigation performance standards.
9. **Restore a natural-looking landform** typical of Rogue Valley vernal pool topography.
10. **Improve overall wildlife habitat** in Whetstone Savanna prairie, oak, and swale systems.

Precision excavation in action: restoring filled vernal pools in a cloud of dust and noise. © *Evan Barrientos/TNC*

SECTION THREE

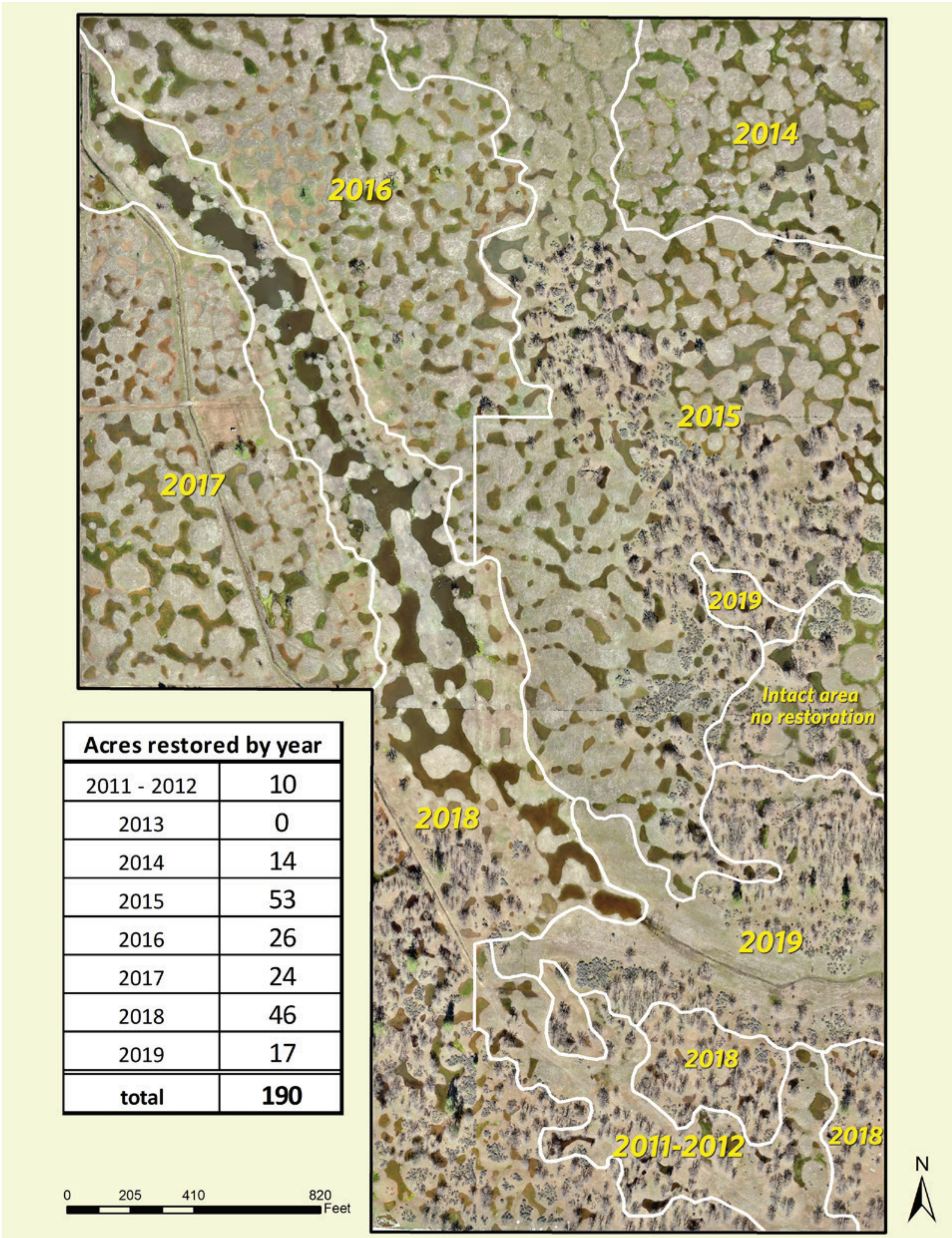
Vernal Pool Restoration Method

Over a span of nine years (2011 – 2019) and 190 acres, we have used excavators, bulldozers, and track loaders to carefully remove upland soil from impacted pools and rebuild mound and basin topography on the Whetstone Savanna. In each year of operation, we completely restored a project area ranging in size from about 10 to 50 acres (except no restoration work was done in 2013). The result is a multi-year patchwork of restored habitat with each successive year informed by and physically blended into adjacent earlier work **(Map 3)**. Adaptive management based on post-restoration monitoring and lessons learned in prior years' implementation has been integral to our process. By sharing our implementation methods, we hope to inform restoration of other degraded vernal pool and wetland sites, helping to expand habitat recovery across a larger landscape.

During each year of work, we ran through a full sequence of restoration actions on that season's project area, from plan development and site preparation, to grading implementation, and native seeding **(Figure 3)**. Grading check surveys were built into the workflow with precise elevation measurements informing the progression from first dig to final grade to ensure that the restored terrain would support proper hydrologic function. Planning and implementation occurred continuously over a months-long work season with the same team of individuals involved in all phases of work. The work is slow and intensive with every patch of ground in the project area studied, marked, excavated, measured, and adjusted to finished grade. Throughout the process, we continually adapted our work to achieve a best fit between plans, conditions revealed during excavation, and the hydrologic function of the finished topography – all balanced with project management logistics, timelines, staffing, and resources.

Within a project area, our stages of work proceeded in successive waves following drainage patterns and sub-areas of hydrologically interconnected basins. On any given day, one set of pools may have been getting marked-out for grading while other areas were being actively excavated, checked for correct form, or adjusted to final grade. With multiple stages in progress simultaneously, new information could be immediately applied to upstream steps during the same season. For example, soil observations during initial excavation in one area informed adaptations to the grading plan for other areas still in the layout and marking phase **(Figure 3)**. And with ecologists, equipment operators and contractors working closely together, all members of the team had a hand in shaping the final outcome.

The restoration method presented here has developed over the full span of our work from a process of year-to-year learning, trial and error, and cumulative experience. Each time we encountered new disturbance pattern, moved into a different habitat type or onto different topography, our operating assumptions were challenged, and our methods evolved. This included experimenting with new equipment or mapping tools, learning from co-workers or outside experts, broadening our concepts of landform and disturbance types, and returning to monitor and review our work in subsequent years. We are sharing the end result of a messy but essential multi-year process of method development. It is also important to note that despite past impacts, the duripan layer remained intact beneath our restoration area (except along the irrigation ditch) and there had been no major removal of native soils or dumping of off-site material. A far more intensive and costly restoration method would be needed to repair widespread duripan damage or haul large volumes of material onto or off site.



Acres restored by year	
2011 - 2012	10
2013	0
2014	14
2015	53
2016	26
2017	24
2018	46
2019	17
total	**190**

MAP 3. The Whetstone Savanna mitigation properties with our integrated patchwork of restoration project areas, year of completion, and acres restored from 2011 through 2019. Aerial imagery is CCPA drone orthophotography from March 2018, showing the restored landscape (except the 2019 project area) at high pool inundation.

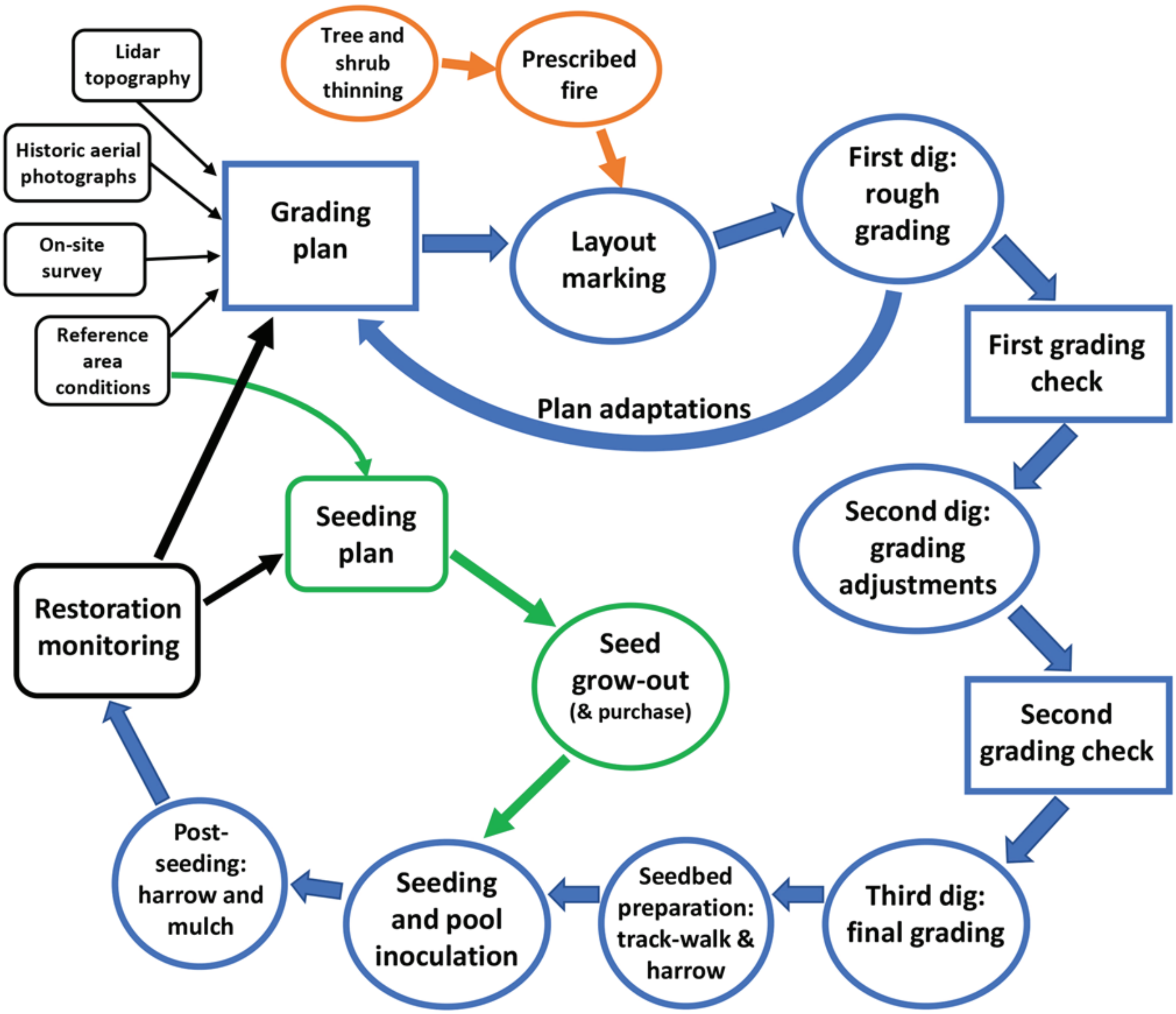
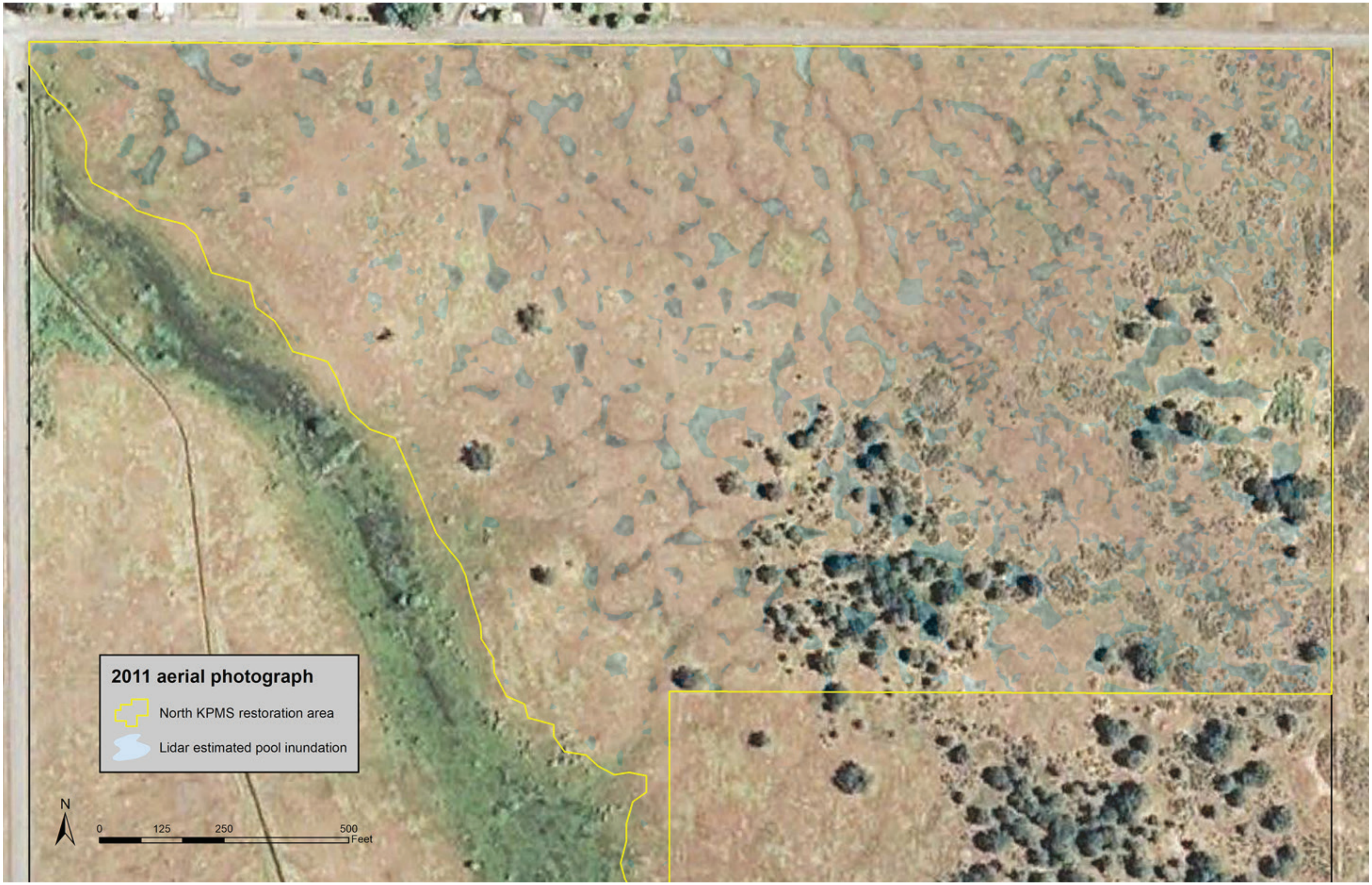
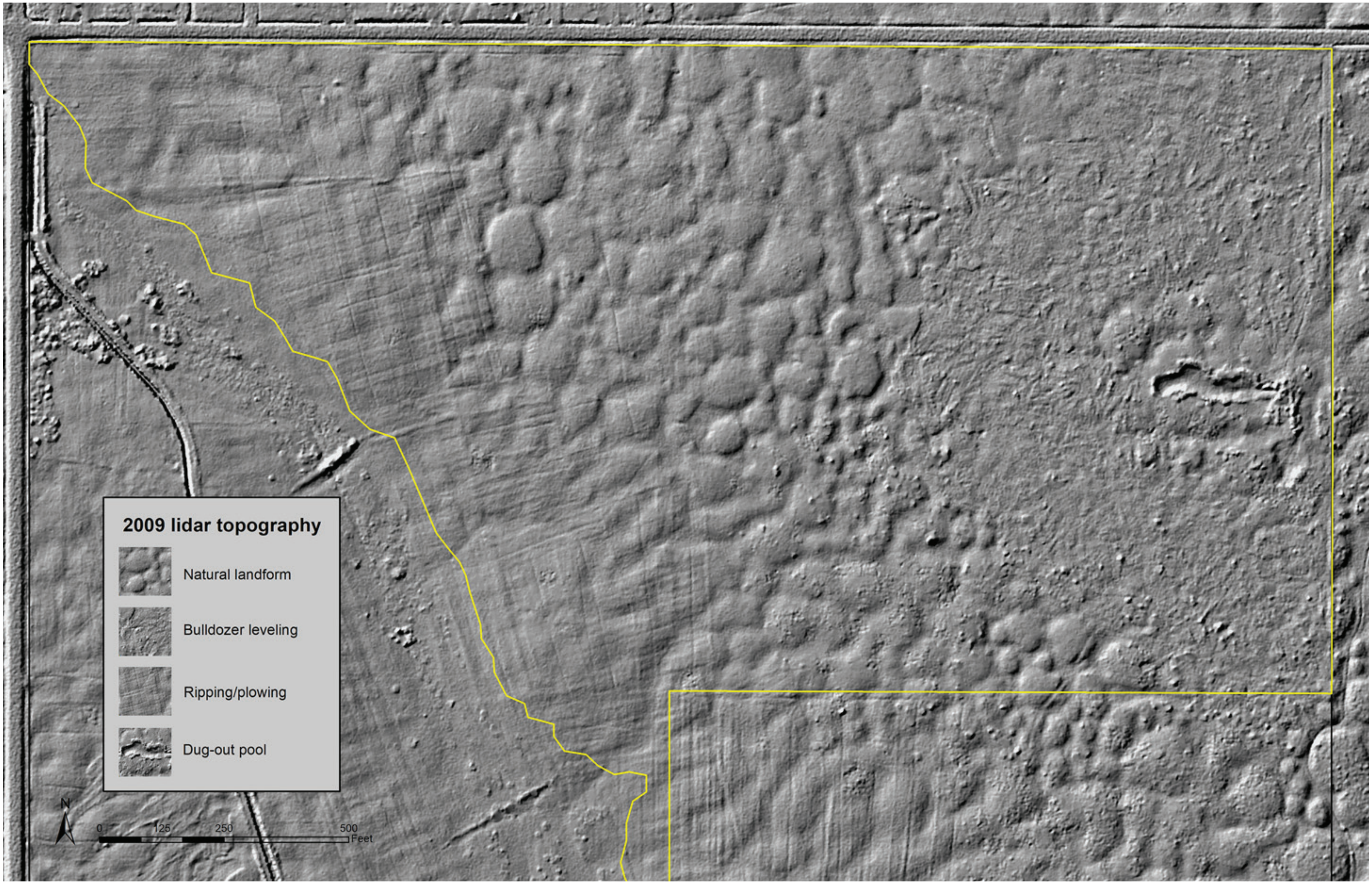


FIGURE 3. Restoration workflow diagram showing all information inputs (rectangles) and action steps (ellipses) involved in restoring a project area, including adaptive management and learning cycles. Tree and shrub thinning and seed increase grow-out were initiated one to three years in advance to meet the restoration timeline.

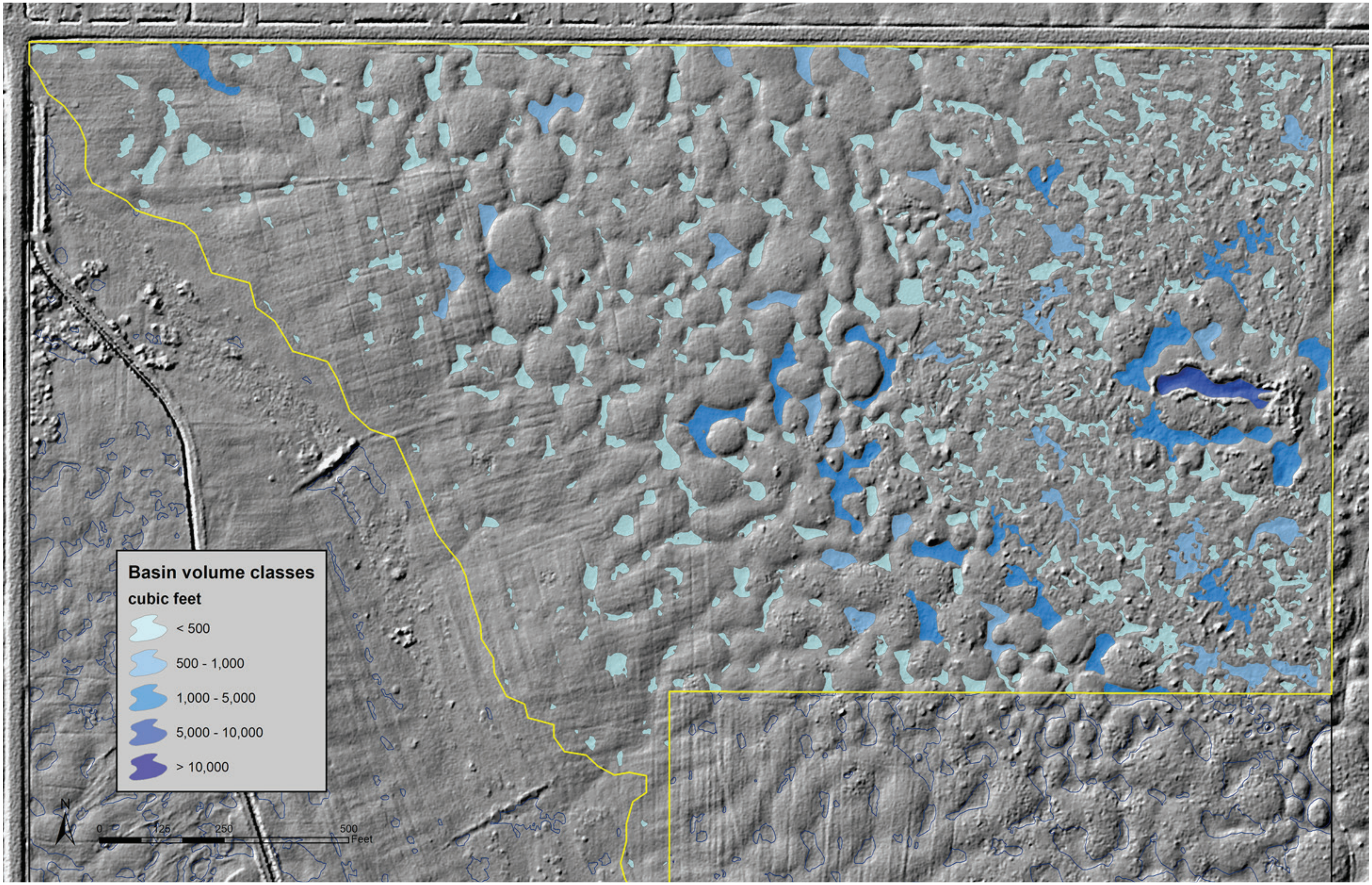
The following map series **(4a – 4j)** shows the progression from degraded to restored landscape across a range of disturbance types on a representative section of the KPMS site: 63 acres north of the VPMCB and east of the seasonal swale, restored from 2014 – 2016. This area had impacts ranging from light agricultural plowing (center) or intensive ripping and leveling (western side), to more recent bulldozer flattening of mounds and filling of pools (eastern side). The map series includes visual examples of different sources of evidence and analysis tools used to plan and guide the restoration and illustrates the resulting topography as lidar-based maps and aerial photographs. These maps are referenced throughout the description of our restoration methods (below) and results (section IV: Restoration Outcomes on Whetstone Savanna).



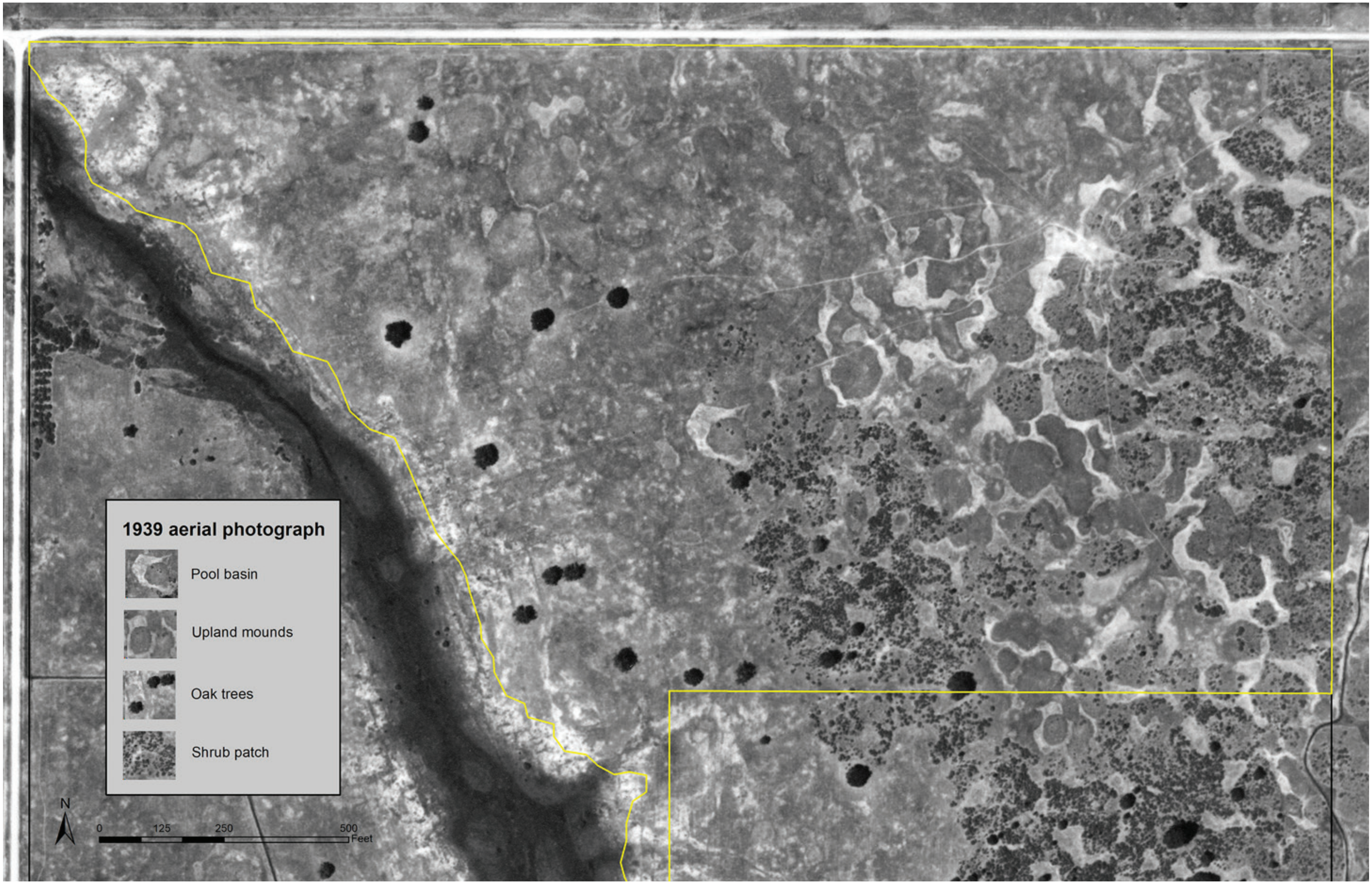
MAP 4a. Pre-restoration aerial image[88] of the 2014 – 2016 restoration area on north KPMS (yellow outline) with topographic basins mapped from 2009 lidar overlaid to represent potential inundating vernal pool habitat.



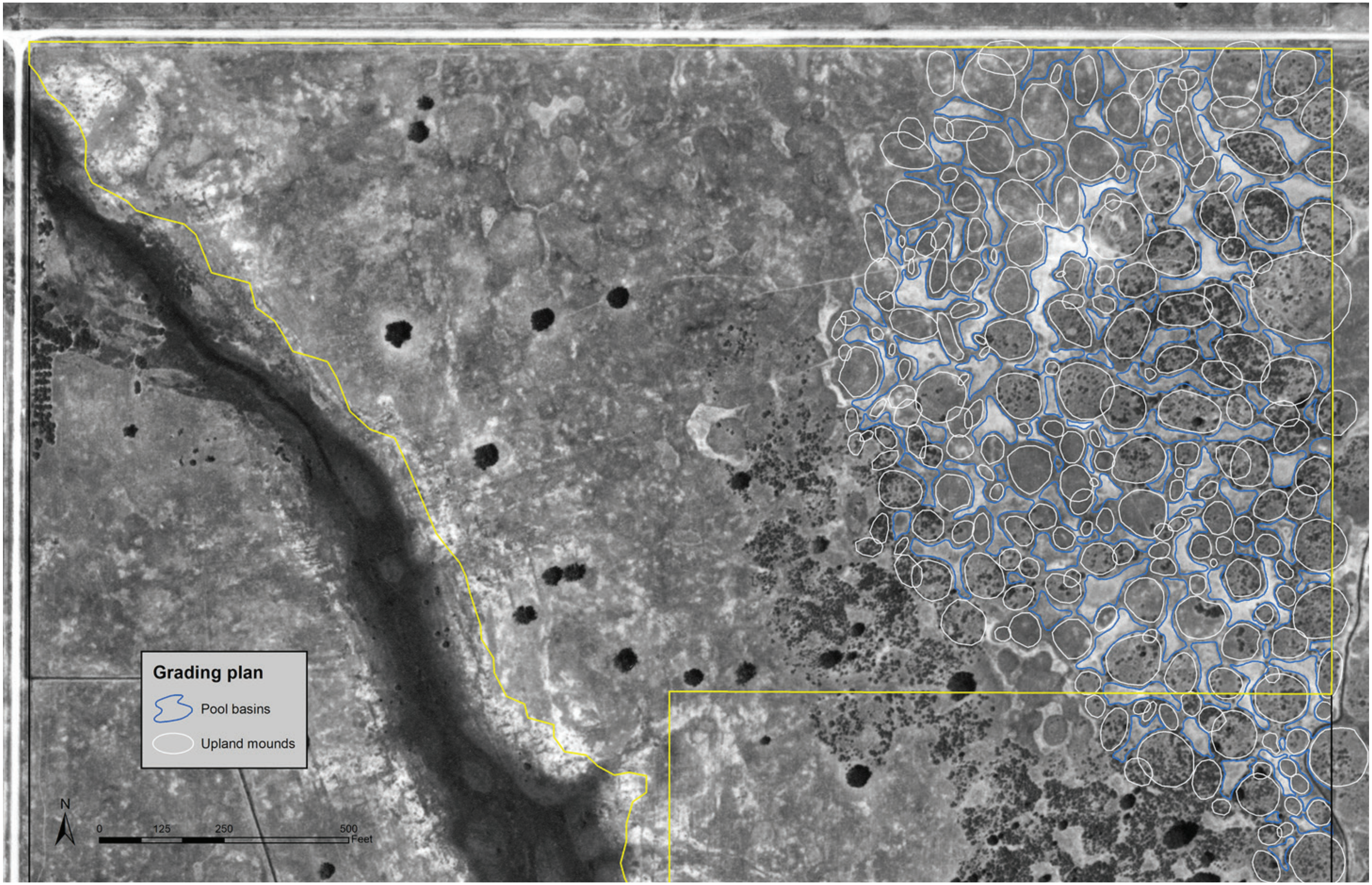
MAP 4b. 2009 bare-earth lidar[89] hillshade for the same area showing historic agricultural ripping impacts on the western side, more recent bulldozer leveling on the east, and less disturbed mound and pool landform at center.



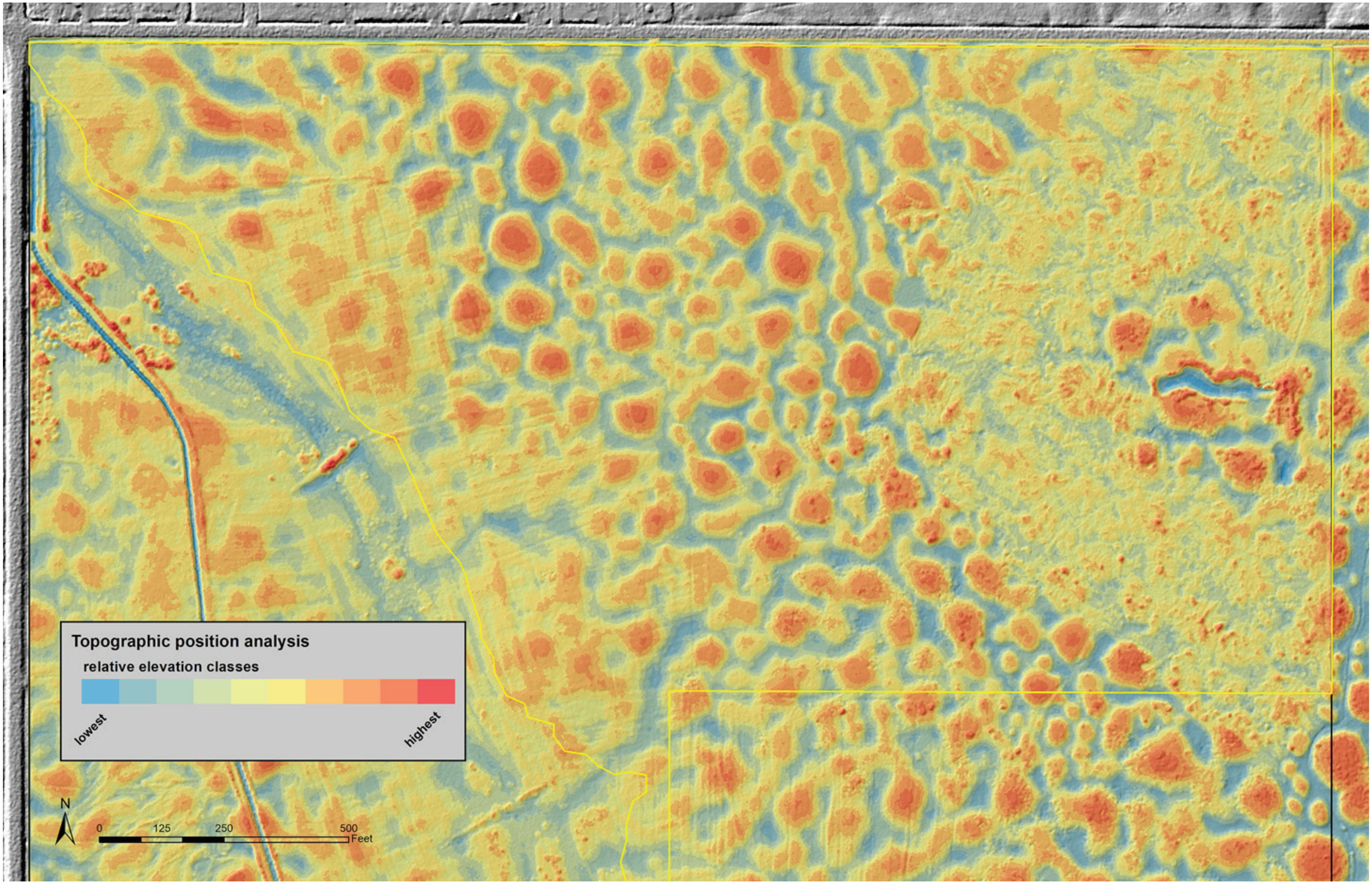
MAP 4c. Lidar-mapped vernal pool basins color-scaled by potential water volume capacity and overlaid on the pre-restoration hillshade. Impacted remnant pools are small or absent (west) or distorted and fragmented (east).



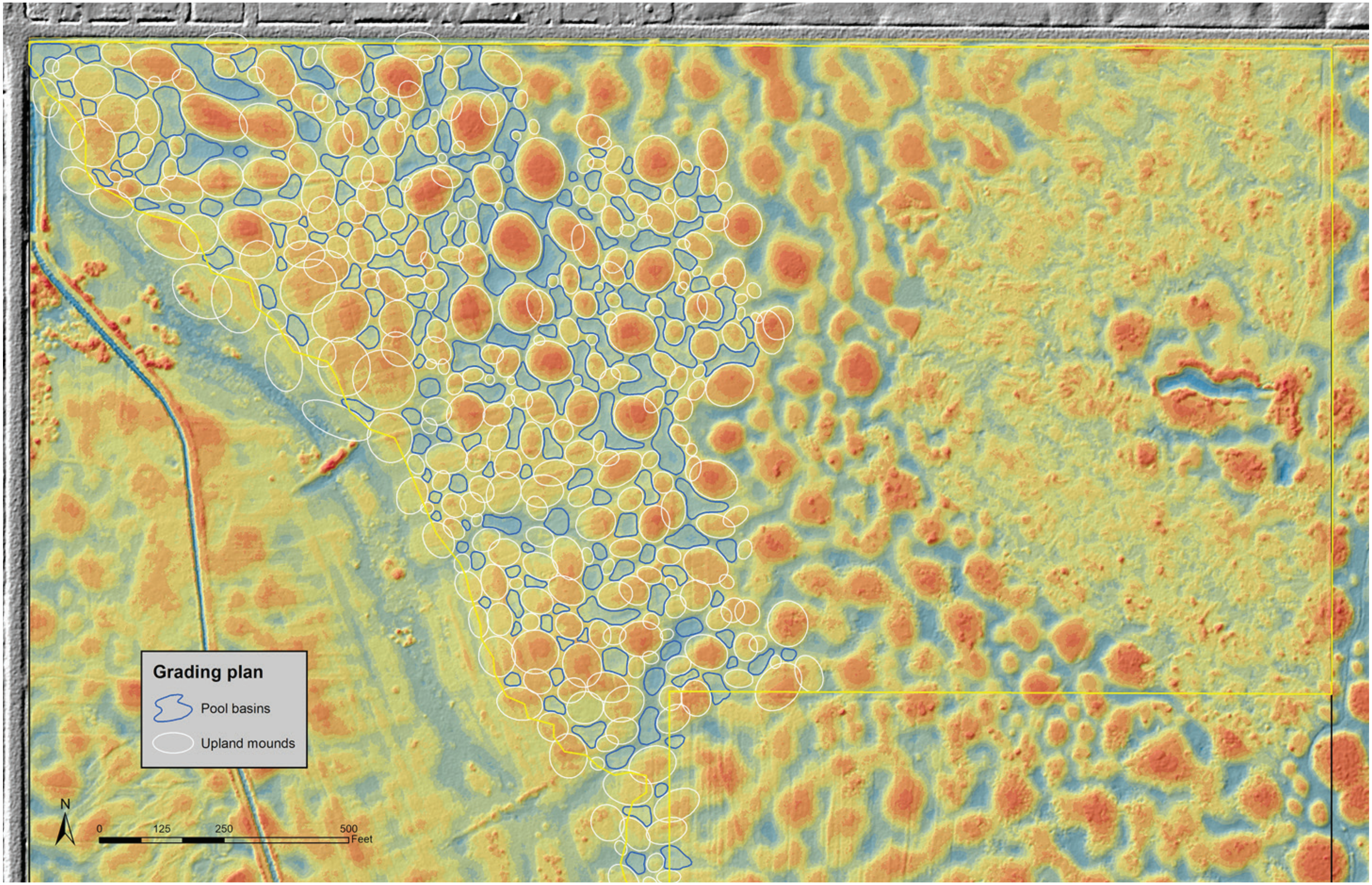
MAP 4d. 1939 flyover aerial photograph[90] of the project area. On the eastern side, pools (white) and mounds (gray) were largely intact, but heavy disturbance had already occurred on the western portion, erasing pools.



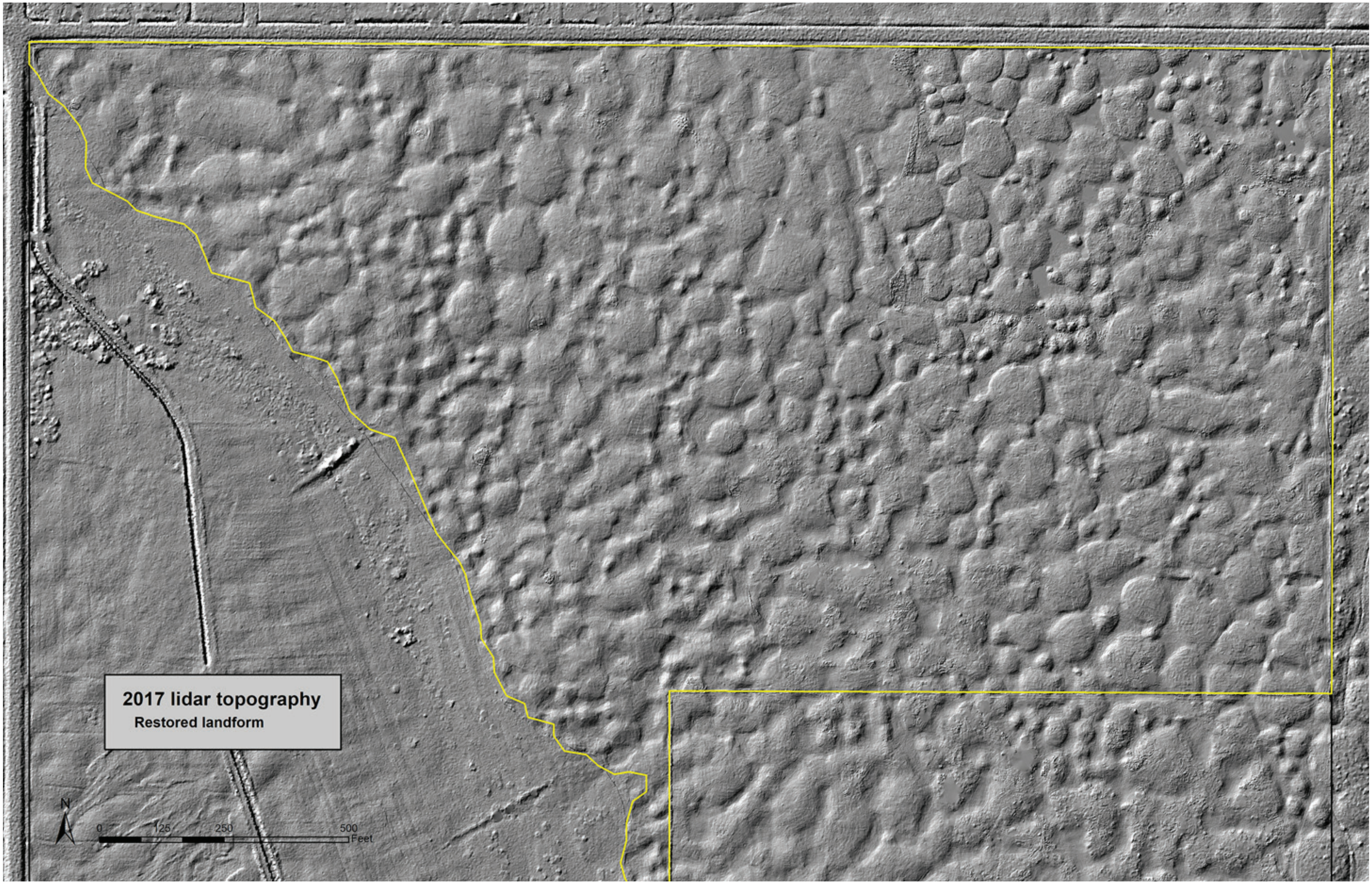
MAP 4e. Restoration grading plan map for the eastern section, with pools to excavate (blue) and mounds to build (white), overlaid on the 1939 aerial photograph that provided a template for the pre-disturbance landform.



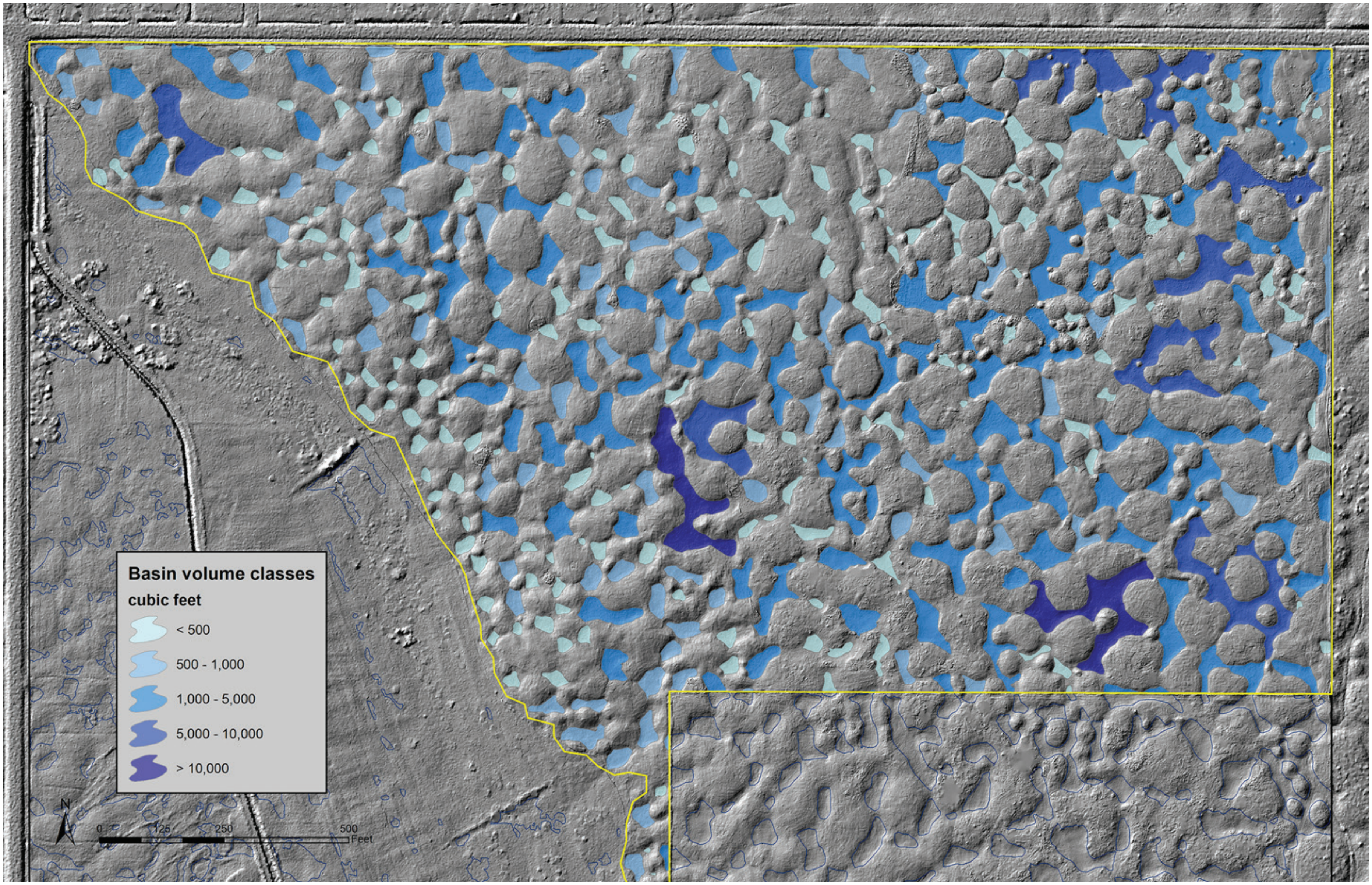
MAP 4f. Color-scaled relative elevation map from topographic position analysis of pre-disturbance lidar enhanced visual interpretation of remnant mound and pool topography. Blue areas are "valleys," red areas "hilltops."



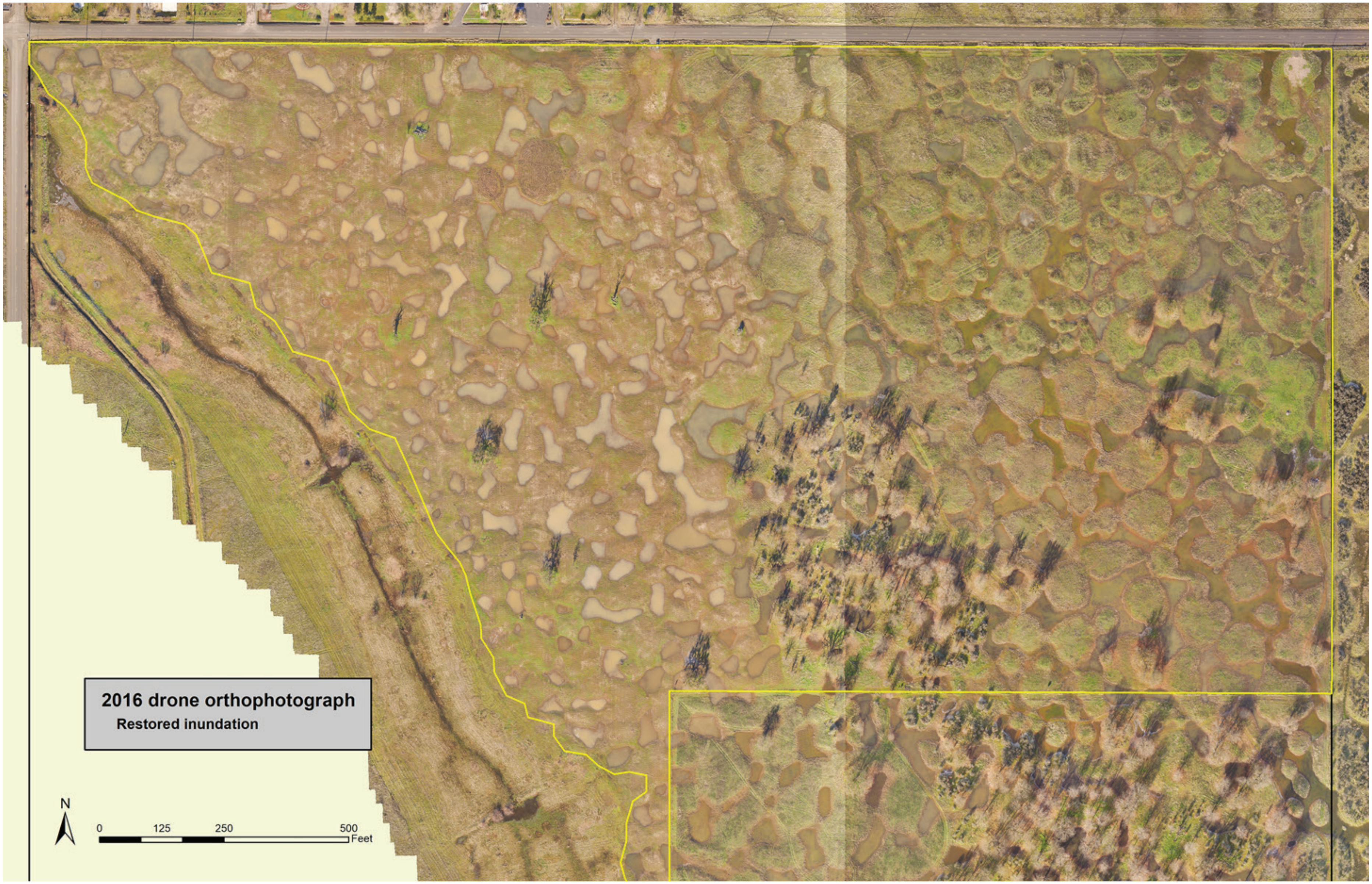
MAP 4g. Grading plan for the heavily impacted western section (pools blue, mounds white) overlaid on the relative elevation imagery used to estimate natural landform where no pre-disturbance aerial photograph was available.



MAP 4h. 2017 bare-earth lidar hillshade showing the newly restored landform. Leveling impacts were reversed and the mound and basin topography is again distinct across areas restored from 2014–2016. Compare to Map 4b.



MAP 4i. Post-restoration lidar-mapped vernal pool basins color-scaled by potential water volume capacity, overlaid on the restored terrain. Compare to Map 4c; pool size, connectivity, and landscape proportion were greatly increased.



MAP 4j. Post-restoration December 2016 CCPA drone aerial orthophotography showing strong inundation in restored pools. Note the tight correlation of surface water with lidar-mapped basins on Map 4i.

Grading Plan Development

Our grading plans mapped the estimated pre-disturbance location of each mound and pool to be restored within a project area **(Maps 4e and 4g)**. Project areas were defined by zones of similar landform, disturbance type, or hydrologic connectivity; boundaries often followed topographic breaks or the transition from oak to open prairie habitat **(Map 3)**. Annual project extents were also determined by workforce capacity, available funding, and the timeline of specific mitigation requirements for local transportation projects. The plans guided excavation and grading by mapping the intended shape and edges of pools to dig out, the configuration of upland mounds to rebuild, and expected surface flows between restored pools. Importantly, the quantity of fill to remove from pools or target basin depths were not defined by our grading plans. Depth of excavation was determined during the dig based on soil observations (distribution and thickness of fill, and depth to wetland clay/cobblestone layer or duripan), with water depth controlled by the relative elevation of the basin's outflow or "invert" **(Figure 2)**.

Mapping historic pools

Vernal pool hydrology is strongly determined by the structure and depth of the impermeable duripan and clay layers that perch the water table and channel sub-surface flows. On the Whetstone Savanna, these below-ground strata were mostly intact despite intensive soil disturbance, and their hidden topography mirrored the pre-disturbance land surface with vernal pools overlying low spots in the duripan. Surface run-off, overland flows, and sub-surface drainage all contribute to pool inundation.[91, 92] Because of this, we focused on restoring vernal pools to their original pre-disturbance locations to enable a return of strong hydrology and water quality.[93] This included restoring the topography of the surrounding upland "micro-watershed" so that both surface and sub-surface waters would collect in pool basins following the natural pattern of the landform.

Grading plans integrated historic aerial photographs, advanced mapping technology, and on the ground interpretation to build a best-estimate map of pre-disturbance pools and upland mounds:

Historic aerial photographs: Systematic fly-over photography of the Rogue Valley began in 1939 and has been repeated approximately every decade to present. Early black-and-white aerial photos of the Whetstone Savanna from 1939 and 1952 provided impressively clear images of pre-disturbance landform and an important time-series of impact events.[94] These historic photographs were aligned with their geographic location, "georeferenced," and overlaid on other map data, including lidar, using ESRI ArcGIS software (GIS).[95] Where the landform was mostly intact at the time of photography, the georeferenced image could be interpreted as a template for mapping historic pools **(Map 4e)**. But by 1939 development of the Rogue Valley was well underway, and large areas of the Whetstone Savanna were already heavily impacted in the earliest photographs **(Maps 4d)**.

Lidar topography: High-resolution ground-surface lidar provided a powerful tool to detect the type and extent of past disturbance **(Map 4b)**, and to map mound and pool forms from remnant natural topography. We reprocessed 2009 fly-over lidar data for the site to create a 1.0 ft^2 pixel resolution pre-restoration digital elevation model (DEM).[96] Using GIS analysis tools, we converted the lidar DEM into fine-scale contour lines at 0.1-foot intervals, highly detailed hill-shade imagery, or color-coded relative-elevation (topographic position index) maps that visually accentuated subtle features in the disturbed terrain **(Map 4f)**. These lidar maps greatly enhanced our ability to interpret the historic location of pools and mounds even in highly altered areas where the disturbance pre-dated the earliest aerial photographs **(Map 4g)**. Lidar data were also used to accurately map vernal pool basins and surface flows on existing topography before and after restoration **(Maps 4c, 4i)**. These maps informed our grading plans and allowed us to measure the change from restoration.

On-site survey: Mapped estimates of the pre-disturbance mound and pool landform based on historic aerial photographs and lidar were field-checked and fit to on-site conditions to create a finished grading plan. On-site observations of inundation, soils, and vegetation greatly improved our interpretation of the topography.

Even on highly impacted areas, soils in filled pools tend to retain moisture and support wetland plants; leveled mounds with subsoils exposed by disturbance have recognizably impoverished plant communities. Remnant shallow depressions at pre-disturbance pool locations may still pond surface water where similar low spots on historic upland mounds drain quickly and stay dry. Site surveys included examining the topography, hydrology, soils, and vegetation at minimally altered reference areas to better understand pre-disturbance conditions.

To create grading plans, we first mapped out the configuration of mounds, drawn as elliptical forms fit to evident upland areas. Pool basins to be restored were then drawn to fit the low areas between the mound ellipses **(Maps 4e, 4g)**. A set of guiding concepts and landform patterns informed our design. Pool edges follow distinct changes in elevation and slope at the transition to upland, and pinch-points between mounds align with breaks between pools. Consistent with reference sites, grading plans for flat terrace areas generally had large and highly networked pools, whereas pools on sloped ground were planned smaller, occurring in series along simple flow paths. We ran a stream network analysis in GIS to map the path and direction of flows between basins across the existing topography, then assessed current flows and disturbance patterns to determine the expected flow network for the restored landform. Draft plans were shared within our team for review before being finalized.

Site Preparation

Before we started earth-moving, we used prescribed burning (or mowing) to clear surface vegetation and litter from the project area to allow for effective grading. Accumulations of plant material in the soil would otherwise interfere with equipment, leaving an irregular restored surface, limiting stabilizing soil compaction and causing excessive post-grading settling. Thinning and pile-burning of small trees and shrubs has been important in oak woodlands for both habitat restoration and preparation for grading.

Grassland ignitions during an Oregon Department of Forestry training on the KPMS property. Burning removes surface vegetation and litter accumulations to facilitate grading restoration of the area. © *Keith Perchemlides/TNC*

Prescribed fire

Burning in early summer, before grading, has been ideal for vegetation removal and provides multiple ecological benefits. In addition to consuming surface material, a well-timed burn helps control invasive weeds by killing standing plants and stopping new seed production. Fire-adapted native plants benefitted from burns with increased germination, growth, or flowering the following year. And fire-adapted native trees and shrubs were highly resistant to fire damage, especially during early-season burns. Burning off surface vegetation greatly improved visibility of important fine-scale topography, disturbance scars, and variation in soils – and allowed for clear layout marking. When a burn was not possible, close mowing was the next-best alternative. Burning or mowing also improved the accuracy of new lidar (or drone orthophotography) surface mapping by removing obscuring vegetation.

ODF training burns: In a great example of state agency collaboration, ODOT and the Oregon Department of Forestry (ODF) coordinated to achieve site-prep burning by opening the KPMS property for fire training exercises. Local ODF crews were able to practice grassland fire suppression tactics by lighting and extinguishing fires in restoration project areas. In this way ODF achieved valuable training while supporting restoration work. And by removing surface fuels, these burns provided important fire safety. The risk of sparks from equipment igniting dry vegetation during summer grading would otherwise have limited or shut-down our work during wildfire season.

Prescribed fire devours invasive medusahead grass, killing its seed and preparing the ground for restoration. © *Keith Perchemlides/TNC*

Cutting down to rebuild

Historically, frequent fires (wildfire and traditional Native American burning) maintained open conditions in Rogue Valley oak habitats. In the absence of fire, unchecked in-fill of trees and shrubs has led to uncharacteristically dense stands that benefit from thinning restoration.[97, 98]

> Burning in early summer, before grading, has been ideal for surface vegetation removal and provides multiple ecological benefits.

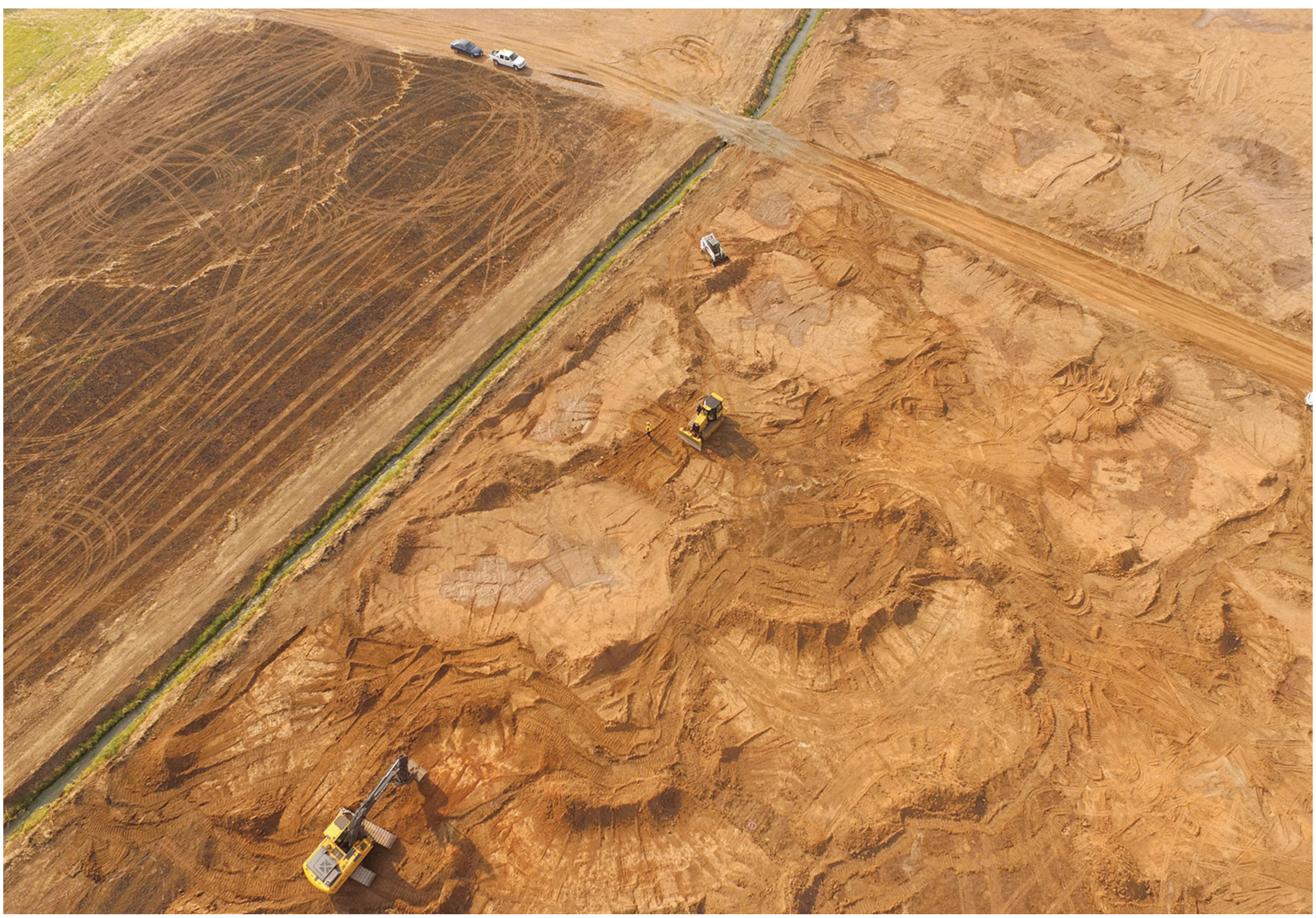
In some cases, shrub patches or dense oak stands were also thinned to enable restoration grading. In areas of intense disturbance, where basins were buried under a deep burden of upland soil, recently established shrubs and oaks were sometimes growing inside former vernal pools. And for major recontouring, when large volumes of soil needed to be relocated from pools to mounds, upland shrub patches were sometimes removed to allow for mound forming. In less impacted areas, shrubs were strategically thinned or retained to allow for grading while keeping valuable habitat structure.

Tree or shrub felling was generally done during the fall and winter one to two years prior to grading. Tree felling was limited to small diameter, overly dense trees as appropriate for oak restoration. Thinning of shrubs is also consistent with oak restoration and enables prescribed fire by reducing fuel continuity and accumulations under large old legacy oak trees. As site preparation for grading, more intensive clearing of native buckbrush patches was sometimes necessary; this represents a temporary loss of shrub habitat to enable the restoration of essential landform. These disturbance-adapted shrubs are resilient and are already reestablishing unassisted from their seedbank in areas cleared in 2014.

Restoration Grading Workflow

Reshaping a landscape takes a lot of time and work. The disturbance was heavy-handed and widespread – reversing it required an equally intensive effort. But unlike simple leveling, we were carefully rebuilding a complex surface that had to be correctly formed in order to function. It was precision grading done at-scale, and so needed to be both aggressive and carefully detailed. Our restoration work required coordination of resources, personnel, and timelines that had much in common with operations on large construction projects. Because of this, our work greatly benefitted from project management and equipment operation skills that ODOT brought from their road maintenance and construction work.

On the Whetstone Savanna, grading work began as early as May and ran as late as November with soil moisture as the main constraint. Soils needed to have dried out enough after the rainy season to allow for grading without clumping, over-compaction or rutting by equipment – and all work needed to be timed to finish before the first soaking rains of fall. Grading spanned the arid summer months: working conditions were hot, dry, and dusty. During our wildfire season (typically June – September), Industrial Fire Precaution Level (IFPL) restrictions could halt or limit the daily duration and type of work allowed.[99] Hazards such as smoke from frequent summer wildfires and the presence of heavy equipment required continuous attention to worker safety.



Drone flyover view of restoration grading in progress. The excavator operator (lower left) completes a rough first dig of pool basins, staging the soil for the bulldozer and track loader operators (center) to re-form upland mounds. Blackened ground from prescribed burning earlier in the season awaits grading (left) on the other side of an irrigation ditch. © *Cam Patterson*

Marking out a vernal pool basin perimeter for excavation using construction marking paint, guided by the restoration grading plan on a survey-grade GNSS tablet. The area was burned earlier in the season to clear vegetation. © *Evan Barrientos/TNC*

During grading we worked as a core team of two heavy-equipment operators (excavator and bulldozer) and three restoration ecologists. Typically, one ecologist worked directly with the excavator or bulldozer operator, guiding the removal of soil from pools and the rebuilding of mounds. A second ecologist marked out the grading plan and performed follow-up grading check measurements. The ODOT ecologist acted as project manager, guided equipment operators, or operated a track loader for lighter precision grading. Project management included administering contracts, acquiring permits and consultation from regulatory agencies, coordinating schedules, equipment and supplies, and assuring that work was completed on-time and in-budget.

In developing our restoration team, we learned that it is essential to include substantial time for training, on-the-job skill building, and developing effective communication between members. Effort and patience invested at the start of the season paid off in quality, efficiency, and safety later on. This skill building required patience and commitment by all members of the team. It was a mutual learning exchange between operators and ecologists to develop a shared understanding of methods, workflow, capabilities, and goals – and to build respect for the all of the work stages and skillsets involved.

The mark - plan layout

Before we started digging, we marked out the grading plan directly on the ground to guide the initial excavation **(Figure 3)**. We loaded the plan maps onto rugged survey-grade field tablets equipped with highly accurate RTK (real-time kinematic) GNSS (global navigation satellite system) location technology, allowing us to align our plan with the on-site topography at 0.1-foot accuracy. Like the more familiar GPS (global positioning system), GNSS uses satellite signals to determine location on the ground but accesses a larger array of international satellites for more accurate and consistent navigation. Following the plan, we used construction-marking spray paint to outline the perimeter of each vernal pool basin to be restored. This line represented the outer extent of ponded water for the restored pool at its fullest inundation and provided a basic "cut-and-fill" grading guide. Inside the line soil was removed (cut) to restore the basin depression, and the excavated soil was deposited (fill) on the surrounding uplands to restore the mound forms.

We used a set of painted symbols to indicate the location of essential basin grading features such as pool outflow inverts, surviving areas of native basin soil to leave as-is, or artificial fill heaps to remove. The upland mound forms were not directly marked, but their reliably elliptical forms were indicated by the inverse arcs and coves of pool margins. Special marks around basin boundaries pointed to "valleys" between overlapping mounds or the sloped "ephemeral swale" flow-paths between pools through upland bottlenecks. Once fully marked out, the grading plan was effectively displayed for all members of the team, including the equipment operators, to review before the dig began.

The marking process was not a simple mechanical transfer of the plan onto the ground. During marking, the grading plan was adapted to fit the actual terrain at a finer level of detail than in GIS mapping – responding to subtle cues of landform, soils, vegetation, knowledge gained during prior excavation, and an intuitive sense of pre-disturbance conditions. Restoration practitioners often acknowledge that artistry in addition to science guides our work. In layout and grading, our aesthetic sense of natural landform helped to create a more authentic restored habitat. Marking also involved practical plan adjustments to incorporate or avoid valuable native plant patches, remnant undisturbed areas, or permanent site infrastructure.

First dig – rough grading

Marking and digging moved in stages along landform drainage networks, working through sub-areas of hydrologically interconnected basins or "micro-drainages." Once a micro-drainage was marked out, a two-person team of excavator operator and ecologist worked to remove fill from each pool basin, establishing initial form and depth. The excavated soil was proportionally distributed to surrounding uplands where the bulldozer operator rough-graded the configuration and domed shape of the mounds. Including the mound forms and inverts in this

Working together, an equipment operator and ecologist remove upland soil from a filled vernal pool basin, using hand-signals and radio communication to adjust the depth and extent of excavation. © *Evan Barrientos/TNC*

A buried surface of gray wetland Winlo soil is revealed as excavation removes several inches of rust-red upland Agate soil fill from a vernal pool basin during restoration grading. Insets: horseshoe artifact (left) and buried charcoal (right) uncovered at the wetland soil surface provide further evidence of the historic terrain. © *Keith Perchemlides/TNC*

initial grading was essential for establishing the catchment area, ponding depths, and the network of flows between pools.

At first impression, a full-size excavator parked in the middle of sensitive wetland habitat, gouging soil out of vernal pools with a massive scoop-bucket looks like destruction, not restoration. But in fact, this was a careful and systematic process guided in equal parts by the grading plan marks, observations of soil type and structure, and precise elevation measurements. Both ecologist and operator interpreted soils and topography, actively communicating and adjusting while digging. Much was learned, and immediately applied, about the historic soil structure, hydrology, and disturbance during the dig. Our restoration grading relied heavily on the skill and insights of the equipment operators, and their understanding of the landform and restoration goals developed over multiple years as part of the team.

On the Whetstone Savanna, fill soil in pools generally came from the adjacent upland mounds and was transported only a short distance to be deposited in basin or flow-path lowlands. Upland fill soils were typically a reddish Agate clay-loam in contrast to the usually heavy "massive" gray Winlo clay of the underlying original basin **(Figure 2)**. Rounded cobblestones were a characteristic part of the basin clay soil and served to mark the interface between upland fill and historic pool bottom. The depth of excavation matched this transition from upland loam to the clay and cobblestone of the buried pool.

Starting from the center of the marked basin and working out to the edges, the operator and ecologist used hand-signals and radio communication to excavate inch by inch while monitoring soil composition and depth. Once the historic pool surface was found, excavation proceeded by maintaining that depth and following the wetland soil out towards the edge of the pool. Basin bottoms are typically nearly flat until ramping up to a slope inflection at the pool margin **(Figure 2)**. As needed, the ecologist guiding the excavator also used a surveyor's level or tripod mounted GNSS tablet to maintain a consistent grade across larger basin bottoms. Operators were often able to feel the difference in density and resistance between fill and native soil while digging, and at times could "peel" off the fill as a physically distinct layer that separated from the original surface along a horizontal plane. Durable historic artifacts such as pieces of glass, horseshoes, and charcoal were sometimes found on the newly re-exposed pool bottom surface.[100, 101]

> At first impression, a full-size excavator parked in the middle of sensitive wetland habitat, gouging soil out of vernal pools with a massive scoop-bucket looks like destruction, not restoration.

An understanding of the mechanisms and patterns of the historic disturbance impacts further informed our excavation process. Agricultural plowing tended to add a relatively thin, uniform layer of upland soil to pools that otherwise remain distinct topographic basins **(Map 4b, center)**. Larger pools in these areas often retained an exposed area of native soil at the basin center. Ripping or furrow-plowing with agricultural implements before 1939 (likely horse-drawn or steam powered) left deep, systematic linear scars across both mounds and pools, a deeper but variable depth of fill, and an irregular, rutted wetland clay horizon **(Map 4b, west side)**. More recent bulldozer leveling moved large volumes of upland soil into pools, transported over greater distances. In some bulldozed areas, mounds were so deeply cut, and pools so heavily filled that their elevations were reversed with pool bottoms buried under a foot or more of fill **(Map 4b, east side)**. As pool excavation revealed these soil patterns, we were able to confirm or adapt our disturbance model and grading work accordingly. In some areas, multiple rounds and types of disturbance were overlaid, making for a complex puzzle to unravel.

Method adaptation – the right tool for the job: Our process of figuring out the best equipment for grading in different disturbance or habitat types provides an example of our adaptive learning and method development. With excavators, we started small in an attempt to minimize impacts, but realized that a bigger machine actually produced better results. Especially in large prairie pools with a lot of fill to remove, a full-size excavator with a five-foot-wide smooth bucket (no tines on the cutting edge) gave operators a long reach and left a smooth cut surface. This allowed us to remove fill from pools while parked on adjacent uplands and minimize disturbance of the native pool soils. The power of a larger machine was needed to make clean and level cuts through heavy fill, and a smooth bucket was best for staying on-grade in flat-bottomed basins while precisely peeling off the fill layer. But in oak woodlands we returned to a smaller excavator for access and maneuverability beneath the low-branching trees. In areas of lighter disturbance, with shallow fill in pools, a large track loader was enough to skim off relatively loose fill and invasive grass sod. In contrast, areas of intense bulldozer leveling sometimes had large volumes of mound soil displaced into pools hundreds of feet away, requiring a front-end loader to transport upland soils back to their origin.

First check – measuring for function

Once the first dig was completed across a micro-drainage area, we systematically checked each basin, inflow, and outflow to ensure that we were on-track to restore hydrologic function. Because the basins are hydrologically linked, these grading checks could not have been done pool-by-pool as the first dig progressed. It was essential for initial grading to be completed across all the basins, mounds, and inverts in a micro-drainage before checking the grading; this allowed us to evaluate the inundation potential of each pool and the pattern of flow linkages between basins.

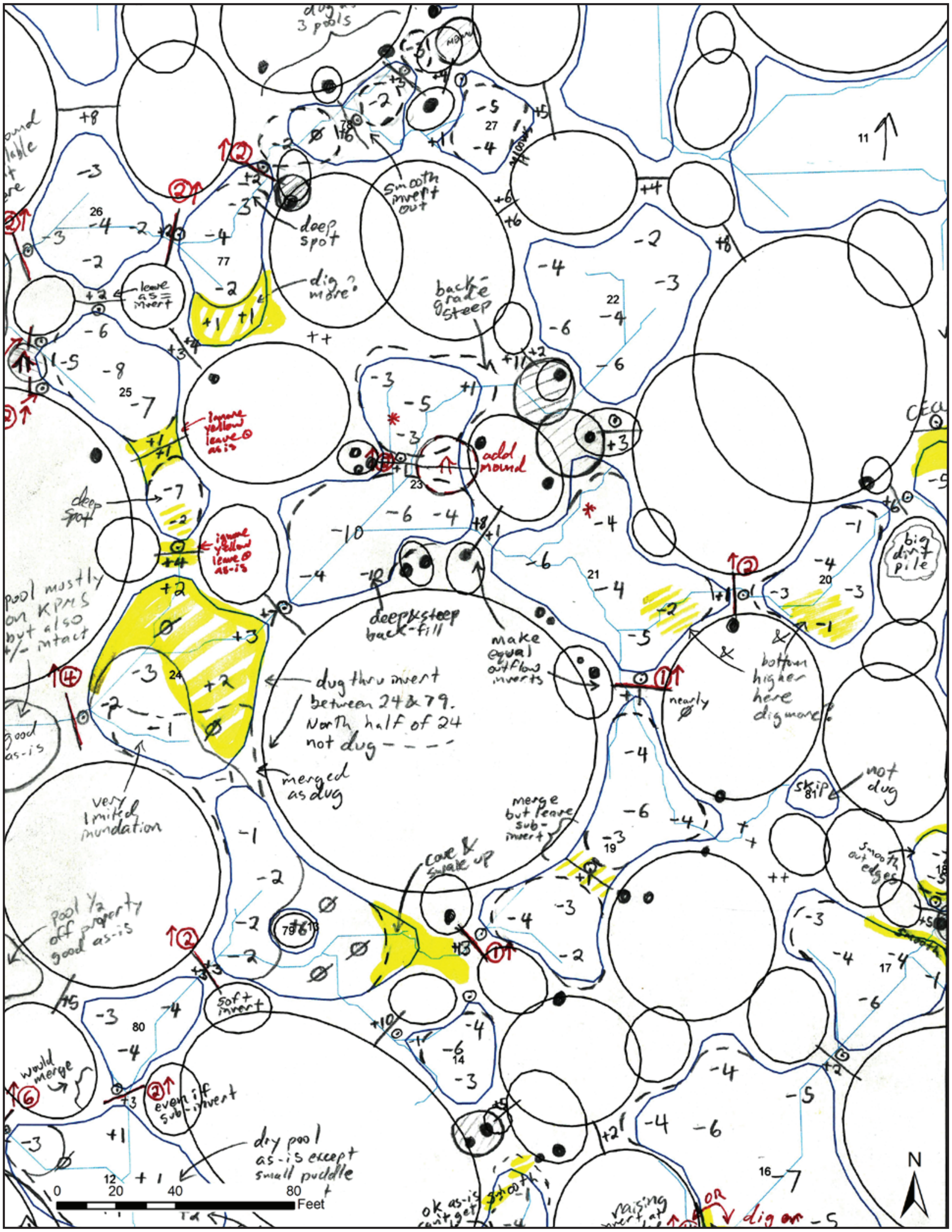
Using a surveyor's laser-level or RTK GNSS elevation readings on a tripod-mounted tablet, we measured relative elevations and depths at key points in and around each basin to 0.1-foot accuracy. We also reviewed the exposed soils and rough-graded landform. These measurements and observations were combined to create annotated field maps of the new topography, with estimated pool inundation and recommendations for further grading **(Map 5)**. Our first-round grading checks focused on five questions:

1. **Was all initial excavation completed?** The check highlighted remaining areas of fill to remove or overlooked features to excavate.
2. **Will the basins hold water?** Elevation measurements determined the potential water depth and extent for each newly excavated basin at maximum inundation.
3. **Is the restored hydrology appropriate?** We assessed whether the ponding depths in basins and flows between basins fit with our understanding of pre-disturbance hydrology.
4. **Was too much material removed?** Irregular deep spots, or patches of exposed duripan or subsoil were signs that over-digging may have removed native wetland basin soils.
5. **Do the mounds fit the pools?** Pools and mounds align like puzzle pieces. We identified needed changes to upland mounds to achieve natural landform and support pool hydrology.

At each basin we first located the hydrologic invert (the lowest point in the basin's perimeter where ponded water spills out of the pool at full inundation) and checked that water would outflow in a pattern that fit the landform. On flatter terrace areas, basins might have two or more equal outflow inverts and more complex hydrologic networks. Surface water flows out of the pool invert(s) to the next lower basin(s). We then measured the potential inundation extent and depth of the excavated basin. All elevation measurements for the basin were recorded relative to the invert elevation set at zero, with potential water depths as negative numbers and dry ground as positive values **(Map 5)**. Adjacent basins with the same or nearly equal invert elevations could potentially be merged into a single larger basin.

Based on relatively intact reference pool hydrology, we expected the maximum depth of typical restored pools to range from about 2 to 12 inches (rarely to 18 in.), roughly proportional to basin area. For habitat function, the duration of inundation is generally more important than water depth – but in most cases deeper ponding leads to

Surveyor's laser level in use for precise relative elevation measurements across a series of newly excavated vernal pool basins during grading checks. Background: a track loader builds up an outflow invert to increase basin depth. © *Karen Hussey/TNC*



MAP 5. Example of one of our first-check field maps for a series of micro-drainages. Elevation measurements are recorded in 0.1-foot increments relative to the invert zero-elevation for each basin. Specialized symbols, drawn lines, color-coding, and notes communicate recommendations for the next round of restoration grading.

longer-lasting inundation. (Because of sub-surface flows and larger catchment areas, pools on the downslope end of drainage networks can have exceptionally long inundation periods relative to size or depth.) Our grading checks usually recommended deepening basins that would not inundate across their entire extent or when large pools were uncharacteristically shallow (< 4 in.). If upland fill soil remained, the basin could simply be dug deeper. If hydrology was still limited even after fill removal, the invert may have been altered by disturbance, in effect draining the pool. In those cases, we intentionally built-up the invert elevation to raise the water level.

Small basins that were uncharacteristically deep (> 10 in.) may have been over-dug, or past disturbance may have added fill to the pool's outflow creating an artificial dam. Over-excavation usually exposed distinctive subsoil layers or even the underlying duripan, requiring backfill with pool soil. Because large natural basins typically have a nearly flat-bottomed profile, we expected similar restored basins to have the same form, with minimal depth variation. If we found two distinct depth zones in excavated basins, these may have originally been two separate pools; in these cases, we would usually adapt our grading plan and re-shape the surrounding mounds as needed to create an appropriate hydrologic break.

Grading recommendations were added to the elevation measurement maps using a standard set of color codes, symbols, and notes **(Map 5)**. These hand-drawn maps were then scanned and converted to georeferenced images in GIS to load onto our field-tablets – or shared as geotagged PDF files for convenient navigation with the Avenza Maps app on smart-phones when high-accuracy location was not required.[102] This technology allowed the grading crew to navigate across the site following a hand-drawn map to the location of specific recommendations when completing subsequent rounds of grading.

Second dig and second check – getting it right

The second round of grading work progressed from rough to finished grade while implementing the recommendations mapped during the first check. The grading crew added their own review and judgment to best fit the adjustments to the soils and conditions in each basin. Additional major fill removal or mound re-configurations required an excavator or bulldozer. Simply maneuvering these heavy machines back across the work area caused soil disturbance, so we learned to intentionally leave the first grading rough until the second dig was completed. Adjustment of depth-controlling invert heights, removal of shallow fill,

Equipment operator and ecologist review and discuss final grading adjustments on-site. Photo. © *Evan Barrientos/TNC* backfilling over-dug basins, or rebuilding small mounds could all be done with a lighter and more maneuverable track loader.

Our second round of grading checks used the same tools and concepts as the first round. The main task of the second check was to confirm that the second round of grading had effectively adjusted the terrain. Where basins were further excavated, merged, separated, or had their invert elevations adjusted, we re-measured and mapped the new depths and flow patterns. The second check added an emphasis on finish-grading for a natural appearance, noting areas that remained rough, irregular, or artificial-looking. The new measurements and final-grading recommendations were again transferred to tablets (or phones) as maps for the grading crew, or sometimes simply marked directly on the ground.

> Incremental grading with measurement, learning, and review incorporated at every step was how we arrived at a successful restoration when so much was unknown about the pre-disturbance topography.

Final grading – the restored terrain

The third and final round of grading work implemented any second-check adjustments while smoothing and blending the restored surface to achieve a natural-looking landscape. This was spot-specific work for the skid-steer in pools or bulldozer on the upland mounds, with most of the terrain already successfully graded and left as-is.

Once finish-graded, the entire project area was "track-walked," using the weight and cleated treads of the bulldozer to smooth and compact the graded soils. Typically soil compaction is something to avoid in natural areas, but our intensive earth-moving would otherwise leave the ground too loose and aerated on uplands and re-built inverts – soil conditions that can favor invasive species. Intentional compaction mimicked the slow natural settling of soils, creating soil density and moisture retention conditions more compatible with native plants. Importantly, this compaction also reduces soil erosion and excessive settling during the first rainy season after grading.

In excavated pools, track walking provided an opposite benefit, breaking-up the surface of native pool bottom soils compacted by being long buried under fill. This loosening of the surface in already-compacted basin soils created microsites and root access for native seed germination and establishment. Finally, a chain-harrow or spiked roller implement was drawn across the entire project area to smooth the surface, erase equipment track marks, and prepare a fine-textured seedbed.

By the end of the grading process, the restored pools were visited up to eight times: marked, dug, checked, adjusted, re-checked, finish graded, track-walked, and harrow-smoothed **(Figure 3)**. This stepwise approach may appear repetitive or inefficient but was essential for our adaptive process. Incremental grading with measurement, learning, and review incorporated at every step was how we arrived at a successful restoration when so much was unknown about the pre-disturbance topography.

Track-walking imprints from a bulldozer's cleated treads line the restored terrain. The operator uses the weight of the machine to stabilize and settle the soil after final grading. © *Keith Perchemlides/TNC*

Native Seeding Window of Opportunity

The newly graded surface presented an excellent bare-ground, fine-textured seedbed for reestablishing native plant communities. The final step in our restoration workflow was comprehensive seeding of pool basins, upland mounds, and the flank and flow transitional wetlands between. Our restoration process created a unique window for seeding success during the first fall after grading. Prescribed burning followed by earth-moving removed standing vegetation and accumulated litter, killed non-native plants and much of their seed, and diluted the remaining seed bank, reducing competition during the crucial establishment period for native plants. These conditions, combined with loosening and nutrient release from soil disturbance, favored strong establishment from seed and bulb. The crux was to ensure that native species, not detrimental invasive species, benefitted most from this opportunity.[103, 104, 105]

Despite their empty appearance, the freshly graded soils still contained a substantial seed bank of both native and non-native plants. This created benefits and challenges for re-establishing native plant communities. Some native species rebounded so strongly from their seed (or bulb) bank, even after all the earth-moving disturbance, that there was often no need to seed them. These included upland popcorn-flower (*Plagiobothrys*), native lily (*Dichelostemma, Triteleia, Camas*), and owl-clover (*Castilleja*). At the same time, invasive species in the seed bank were also poised to flourish on the newly disturbed bare ground – especially disturbance-adapted annual forbs like storks-bill (*Erodium*) or more fire-resistant grasses such as bulbous bluegrass (*Poa bulbosa*).

Our restoration seeding aimed to establish abundant native cover as soon as possible after grading. This was itself a primary goal, as well as a strategy to directly compete with the non-native and invasive species that were also racing to re-assert themselves. To date, we have been largely successful in achieving this without the use of broadcast herbicide treatments. Prescribed fire combined with grading gave results similar to non-selective herbicide application: reduced weed competition and open ground for seedling establishment.[106] For particularly persistent invasive species, targeted treatment of patches before and after restoration has so-far been effective for controlling outbreaks following grading.

Seeding by habitat and for species recovery

Our seeding goals were to shift the plant communities in each habitat zone from non-native and invasive cover to diverse native species while simultaneously re-establishing abundant populations of ESA recovery species. We combined broadcast native seed sowing across the project areas with targeted seeding of meadowfoam and desert parsley on pool margins. This was a comprehensive strategy for species recovery, restoring habitat function and the entire native plant community while directly increasing listed species populations on a protected conservation site.

Newly restored terrain in late summer just after final grading. Track-walking followed by chain-harrowing stabilizes soils and provides an ideal fine-textured seedbed for fall sowing of native plant seed. © *Keith Perchemlides/TNC*

Harvesting the success of collaboration: agricultural grow-out of native plants yields abundant seed for recovery of endangered species. *© Molly Morison/TNC*

Whetstone Savanna's mosaic of habitat types, each with its own array of specialized native species, made it important to carefully target our seeding. Working with native seed specialists at the BLM (Medford District), Forest Service (J. Herbert Stone Nursery), NRCS, ODA, the Rogue Native Plant Partnership (RNPP) and commercial seed growers, we assembled multi-species seed mixes for each habitat type:

1. prairie uplands
2. oak understory uplands
3. wetland margins (flanks and flow paths)
4. vernal pool basin bottoms
5. seasonal swale wetlands

The exact species and quantities varied by year and project area based on need, availability, and lessons learned in prior seeding – including post-restoration vegetation monitoring results **(Figure 3)**. Each sown mix contained a diversity of grasses and forbs, annual and perennial species, and ecological functional groups to provide a range of early vigorous growth, long-term native cover, and habitat for native pollinators, birds, and other wildlife.[107, 108, 109, 110] Native bunchgrasses provide persistent structure and forage in upland and pool margin habitats. Rapidly establishing annual forbs directly compete with invasive species with similar growth strategies.[111] Late-blooming and perennial wildflowers add long-lasting pollinator benefits and consistent competitive pressure on invasive species. **Tables 2a** and **2b** list the typical species, sowing rates, and target habitats for our Whetstone Savanna upland and wetland restoration seeding.

Obtaining the seed for this was challenging. When available, we purchased appropriate native seed already in commercial nursery or agency production, but this was a limited list, especially for vernal pools, and did not include our two listed species. As a result, much of the seed we used had to be sustainably harvested from local wild populations and increased in special agricultural grow-outs. Through this restoration project, ODOT, the BLM, and TNC initiated the collection and seed-production of numerous Rogue Valley native species not otherwise available. This had benefits for our local farm and nursery economy as well as increasing species availability for other organizations and agencies doing similar seeding. It is essential to note that planning and production work for agricultural seed increase must begin years in advance of restoration sowing to allow time for collection of wild foundation seed stock and one to three years of growth before seed is ready for harvest. This is especially important for slow-maturing perennials or for species with very limited foundation stock, which may need a year or more of grow-out simply to have enough seed for production sowing.

Importantly, our seed-increase work put special effort into Cook's desert parsley and large-flowered woolly meadowfoam, creating an unprecedented source for the recovery of these seed-limited listed species. In agricultural grow-out at the J. Herbert Stone Nursery, both species have yielded hundreds of pounds of precious seed over several years in small-lot (0.10 to 0.25-acre) plantings. Seed foundation stock was harvested following minimum-impact practices from Rogue Valley wild populations on nearby TNC preserves and public lands.[112] To avoid genetic drift in agricultural production, seed harvest of desert parsley has continued from our original 2011 sowing, which began producing in 2014; meadowfoam has been sown annually with seed saved from the first-year grow-out in 2013.

TABLE 2a. Upland species used or planned for restoration seeding on the Whetstone Savanna mitigation sites from 2011 – 2020 with typical sowing rates (pounds per acre) and target habitat(s).

COMMON NAME	SPECIES NAME	LBS/AC	HABITAT
common yarrow	*Achillea millefolium*	0.25	prairie/oak upland
Lemmon's needlegrass	*Achnatherum lemmonii*	5.50	prairie/oak upland
big flowered agoseris	*Agoseris grandiflora*	0.50	prairie/oak upland
common fiddleneck	*Amsinckia menziesii*	1.00	prairie/oak upland
California brome	*Bromus carinatus*	4.00	oak upland
winecup clarkia	*Clarkia purpurea*	3.00	prairie upland
diamond-petal clarkia	*Clarkia rhomboidea*	0.10	prairie/oak upland*
giant blue-eyed Mary	*Collinsia grandiflora*	1.50	prairie/oak upland
American wild carrot	*Daucus pusillus*	2.00	prairie/oak upland*
blue wild rye	*Elymus glaucus*	4.50	prairie/oak upland*
Oregon sunshine	*Eriophyllum lanatum*	0.50	prairie/oak upland
Roemer's fescue	*Festuca roemeri*	4.00	prairie/oak upland
prairie June grass	*Koeleria macrantha*	5.00	prairie/oak upland
showy tarweed	*Madia elegans*	1.00	prairie upland
slender tarweed	*Madia gracilis*	2.00	prairie/oak upland
downy pincushion	*Navarretia pubescens*	0.25	prairie/oak upland
common popcorn flower	*Plagiobothrys fulvus*	2.00	prairie/oak upland
shortspur seablush	*Plectritis congesta*	0.25	prairie upland
sticky cinquefoil	*Potentilla glandulosa*	0.25	prairie/oak upland*
bluebunch wheatgrass	*Pseudoroegneria spicata*	3.00	prairie upland
southern Oregon buttercup	*Ranunculus austro-oreganus*	0.10	oak upland
pacific snakeroot	*Sanicula crassicaulis*	0.50	oak upland
narrowleaf mule-ears	*Wyethia angustifolia*	0.25	prairie upland

** seeded in both prairie and oak habitats but best suited to and most successful in oak or shrub uplands*

This abundance of seed from agricultural increase has allowed us to broadcast-sow meadowfoam and desert parsley across pool margins and flow paths throughout the restoration area. To our knowledge, our restoration is the first project to sow these species at such a scale, and the results have been well worth the effort. Through our partnerships, excess meadowfoam and desert parsley seed has also become available for other species recovery and mitigation projects in the Rogue Valley.

Soil inoculum for diversity

Even with funding and a network of partners, many unique vernal pool species simply could not be agriculturally grown for seed increase. To provide important cover and diversity in restored vernal pools, we used a strategy of transferring soil-inoculum collected from intact or previously restored pools with strong native plant communities. During the late summer or early fall, when basins are dry and dormant, we harvested inoculum by carefully skimming off surface litter and about ¼-inch of soil from basin bottoms outside the project area. This layer is rich in propagules of both native plants and invertebrates. We limited collection to less than half of the harvest basin bottom to minimize impacts. The underlying soil still had an abundant native seed and bulb bank, and the surrounding basin surface was spread over the harvest area after collection. Inoculum harvested from

VERNAL POOL RESTORATION METHOD

TABLE 2b. Wetland species used or planned for restoration seeding on the Whetstone Savanna mitigation sites from 2011 – 2020 with typical sowing rates (pounds per acre) and target habitat(s) for sowing.

COMMON NAME	SPECIES NAME	LBS/AC	HABITAT
blow wives	*Achyrachaena mollis*	1.00	wetland margin
American bird's foot trefoil	*Acmispon americanus*	0.75	wetland margin
narrow-leafed milkweed	*Asclepias fascicularis*	0.25	wetland margin/upland
camas	*Camassia quamash*	0.50	wetland margin/swale
California oatgrass	*Danthonia californica*	6.50	wetland margin
slender hairgrass	*Deschampsia elongata*	0.50	wetland margin
Bolander's sunflower	*Helianthus bolanderi*	0.50	wetland margin
toad rush	*Juncus bufonius*	0.10	wetland margin
poverty rush	*Juncus tenuis*	0.10	wetland margin
California goldfields	*Lasthenia californica*	0.50	wetland margin
large flowered meadowfoam	*Limnanthes pumila ssp. grandiflora*	3.50	wetland margin
Cook's desert parsley	*Lomatium cookii*	1.00	wetland margin
monkey flower	*Mimulus guttatus*	0.10	wetland margin
Sandberg bluegrass	*Poa secunda*	3.00	wetland margin/upland
Nutall's fescue	*Vulpia microstachys*	0.75	wetland margin
Pacific foxtail	*Alopecurus saccatus*	0.10	pool basin
annual hairgrass	*Deschampsia danthonioides*	2.50	pool basin/margin
Cascade calicoflower	*Downingia yina*	0.25	pool basin
coyote thistle	*Eryngium petiolatum*	2.00	pool basin
smooth goldfields	*Lasthenia glaberrima*	0.50	pool basin
sculpted popcorn flower	*Plagiobothrys glyptocarpus*	0.50	pool basin
stalked popcorn flower	*Plagiobothrys stipitatus*	1.00	pool basin
white brodiaea	*Triteleia hyacinthina*	0.10	pool basin/margin
water foxtail	*Alopecurus geniculatus*	3.00	swale wetland
American sloughgrass	*Beckmannia syzigachne*	12.00	swale wetland
dense sedge	*Carex densa*	0.50	swale wetland
tufted hairgrass	*Deschampsia cespitosa*	2.00	swale wetland
creeping spike rush	*Eleocharis palustris*	0.75	swale wetland
western mannagrass	*Glyceria occidentalis*	7.50	swale wetland
meadow barely	*Hordeum brachyantherum*	15.00	swale wetland
soft rush	*Juncus effusus*	0.10	swale wetland
spreading rush	*Juncus patens*	0.10	swale wetland
fragrant popcorn flower	*Plagiobothrys figuratus*	2.00	swale wetland

multiple pools was mixed together to maximize diversity and dispersal of species and distributed by hand in the bottoms of newly restored pools. A little inoculum went a long way – distributed at a rate of just a few shovels per basin, propagule-dense inoculum from a small number of collection pools could supply an entire annual project area.

This soil-inoculum also had the important benefit of reintroducing a wide range of aquatic invertebrates found in high-functioning pools as dormant eggs or cysts. Inoculation jump-started a miniature community of grazers and predators essential to nutrient-cycling, and a food source to larger animals.[113, 114, 115] Importantly, we used the inoculum to intentionally "seed" restored pools with fairy shrimp by collecting from pools known to have

> Inoculation jump-started a miniature community of grazers and predators essential to nutrient-cycling, and a food source to larger animals.

abundant populations of both Oregon fairy shrimp and our target recovery species, the vernal pool fairy shrimp. Although difficult to document with certainty, we are confident that many of our restored pools now host fairy shrimp where none were found before restoration because of the egg-containing soil transferred with the inoculum. We also expect that some incredibly long-lived fairy shrimp eggs simply remained viable in the buried wetland soils of filled pools and hatched out after decades of dormancy when uncovered by our restoration.[116] Both scenarios likely contributed founder populations of fairy shrimp to our restored pools.

Sowing seed and covering the soil

Seeding and inoculum transfer were completed as soon as possible after final grading and before soil-wetting rains. Sowing early allowed for seed exposure to important on-site germination cues of temperature and moisture, setting the native seed on a competitive timeline relative to non-native species – an important factor in this first-come-first-serve growing environment.[117] Each habitat zone was sown separately to ensure specialist species went where they would thrive, and to make the most efficient use of valuable and limited native seed. Upland seeding mixes were broadcast sown, often with a tractor-driven seed-spreader to cover large areas. Flank and basin mixes were generally hand-sown to target their relatively limited and narrow habitat. Meadowfoam and desert parsley seed were included in the flank mix or sown independently to target the specific microsites where they

Spreading dry soil inoculum by hand adds essential diversity to restored and seeded vernal pool basins. © *Evan Barrientos/TNC*

Hand sowing endangered large flowered woolly meadowfoam seed (and chaff) from agricultural grow-out along the winding flanks and flow paths of restored vernal pool wetlands in early fall. © *Evan Barrientos/TNC*

would best establish and persist. We usually dragged a flexible chain-harrow across the seeded area again after sowing to improve seed-soil contact and germination success.

Seeded uplands and flanks were lightly mulched with straw from native grass-seed production to ensure seed cover and protect against erosion; basin bottoms were not intentionally mulched, but some straw would often blow in. Because the restored topography is gently sloped and quickly revegetates, soil erosion risk from flowing water was minimal. In areas with sloping drainages, erosion at pool inverts and along flow paths was controlled by installing jute or coir netting. This commercially available netting is designed to hold soils in place while allowing vegetation to grow through, then naturally decomposes within a few years – after which plant cover, roots, and soil-settling prevent further erosion.

Even before we had completed these final stages of the restoration, the gophers and ground-squirrels of Whetstone Savanna were at work churning the newly graded terrain. Their tunnels and digging spoils quickly added fine-scale topographic complexity and below-ground structure to the restored mounds and flanks, and impressively demonstrate their own bioturbation earth-moving ability.

Restoration Cost and Future Stewardship

With restoration completed, we allowed the area to rest, revegetate, and reassert a hydrologic cycle much closer to its natural range. We will return annually to spot-treat invasive weeds, and to monitor vegetation and fairy shrimp for the next several years. To maintain habitat quality, we plan to return beneficial fire through prescribed burning on a three- to five-year cycle; ecological grazing, mowing, or additional native seeding can also be used as needed. The 2019 season saw the completion of all major mitigation-funded vernal pool restoration across the VPMCB and KPMS sites – and our first success with post-restoration burning and seeding on KPMS areas restored in 2014–2015.

The cost of this intensive earth-moving restoration was relatively high. We estimated our typical project budget at roughly $7,500 per acre to cover planning, site preparation, materials, and on the ground work, including staff and equipment **(Table 3)**. For ODOT, these restoration costs were an acceptable mitigation expense and within budget for our vernal pool landscapes and their listed species. This type of restoration is only necessary on topographically altered areas where hydrologic function has been lost or degraded, not as a general treatment for vernal pool habitats. And the intensity of grading can and should be scaled to the level of disturbance, so that less altered areas will be less costly to restore. Our costs likely represent the upper end of expense for sites that still have an intact duripan and no need for hauling material onto or off of the site. Areas with extensive damage to the duripan layer, or where a large amount of native soil has been removed or off-site material dumped on the site, are generally not practical choices for restoration: many more acres and pools could be restored elsewhere with the same budget.

By restoring the Whetstone Savanna sites, ODOT has been able to establish ecological conditions that are on-track to fulfill mitigation requirements on land that could not meet performance standards when purchased. The VPMCB now has a 90% success rate in meeting mitigation performance standards, compared to only 50% before investing in restoration **(Table 1)**. Part of that success is due to our robust seeding program which covered both upland and wetland habitat and contributed substantially to per acre cost **(Table 3)**. On sites where mitigation performance is not a driving requirement, upland seeding could be reduced or deferred to lower costs or expand the area of restoration grading.

TABLE 3. Summary of typical per-acre costs for earth-moving restoration on the Whetstone Savanna.

	COST PER ACRE
Prescribed burn (site preparation)	$ 250
Ecologist staff time (x3)	$ 2,000
Equipment rental and fuel	$ 1,400
Operator staff time (x2)	$ 1,600
Native seed and mulch	$ 2,000
Other operational expenses	$ 250
Total cost per acre	**$ 7,500**

Earth-moving restoration is a one-time reset, not a process to be repeated. It returns essential habitat quality and stability to degraded pools that would otherwise remain in a persistent low-functioning state. Restored inundation should stabilize and maintain high-quality habitat in vernal pool basins, minimizing future management needs. Maintaining restoration gains on flank and upland habitats will require ongoing work to control invasive species and perpetuate conditions that favor a strong native plant community. In the absence of natural fire and large native herbivores, ecological grazing (or mowing) combined with intentional burning are our most promising tools. Returning those processes can be a real challenge given small management areas, limited funding, economic disincentives for ecological cattle management, and increasing cost and risk concerns with prescribed fire. In this context, it is important to create conditions that allow these management actions to be as effective as possible when used. Investing in one-time intensive grading restoration, when needed, can greatly increase the success of these management tools and of long-term conservation stewardship.

Endangered Cook's desert parsley blooms glow on the springtime margin of a restored vernal pool three years after seeding. © *Lyndsey Lascheck/TNC*

SECTION FOUR

Restoration Outcomes on Whetstone Savanna

The net result of our restoration has been a transformation of the landscape. The rebuilt topography was most visible in the fall right after grading, when the freshly contoured terrain was still bare ground. What may have looked that spring like a vacant field of irregular lumps, gouges, and shallow puddles had returned to the gently rolling patterned ground, undulating mounds, and smooth arcs of native vernal pool prairie. But the most striking transformation came after the first heavy rains of the wet season, when the previous year's scattered grassy puddles were replaced by hundreds of tiny blue ponds reflecting the winter sun and, on a closer look, teeming with new life. When spring returned and the pools dried down, the weedy grasses that once clogged buried basins were replaced by bands of native wildflowers encircling each restored pool. These transformations, both seasonal and from restoration, were captured by repeat photo-monitoring (both ground-based and drone orthophotography) of pools during peak inundation and spring bloom, before and after restoration **(Figure 4)**.

A distinctive feature of the Whetstone Savanna restoration has been the scale and continuity of this transformation. The work would have been beneficial for the habitat and demonstrated effective restoration methods even if completed on only a few acres and pools. But our goal was to accomplish comprehensive restoration across the entire conservation area. As of 2019, we have restored over 1,200 vernal pool basins on the Whetstone Savanna, including the complex network of flow paths and uplands that interconnect and surround these pools across 190 acres of conservation land **(Map 3)**. The mandate for compensatory wetland and endangered species mitigation was a driving force in scaling-up our restoration in proportion to the impacts of our region's transportation system. This push to restore vernal pools at scale catalyzed us to reach for more efficient tools and methods.

As of 2019, we have restored over 1,200 vernal pool basins on the Whetstone Savanna, including the complex network of flow paths and uplands that interconnect and surround these pools across 190 acres of conservation land.


A bright winter sky reflected in restored vernal pools during their first inundation cycle after grading. © *Keith Perchemlides/TNC*

FIGURE 4. Repeat photography of a grassland vernal pool on the VPMCB at maximum wet-season inundation, before restoration (2009), top, and after restoration (2017), bottom. Restored in 2015, this pool demonstrates a typical increase in inundation after removal of fill. © *before, Keith Perchemlides/TNC; after, Evan Barrientos/TNC*

FIGURE 4. (continued). The same vernal pool during peak spring growth, before restoration (2009), top, and after restoration (2017), bottom. Restored in 2015, this pool illustrates the strong establishment of native plants with restored hydrology, seeding and inoculum. © *before, Keith Perchemlide /TNC; after, Evan Barrientos/TNC*

Mapping the Transformation

Lidar-derived topographic mapping was essential to our restoration planning and allowed us to create detailed models of the pre- and post-restoration landform. Our before-restoration lidar data came from publicly available 2009 airborne scans of the Rogue Valley, which we reprocessed to maximize resolution.[118] Our topographic modeling following restoration was a composite of ground-based lidar scans and photogrammetrically derived data from high resolution drone imagery. These survey methods create a three-dimensional point-cloud of data that can be processed into a bare-earth surface terrain digital elevation model (DEM). The DEM is a fine-scale GIS "raster" (data matrix) of 1.0 or 0.5-foot pixels, each with an X – Y geographic position location and a Z-axis elevation.

Viewed as a hillshade image, the lidar DEM reveals surface topography and features with far more definition than a comparable aerial photograph. In the pre-restoration hillshade image on **Map 4b**, the leveling and pool-filling disturbances stand out clearly and had obviously obscured (west) or obliterated (east) the more natural mound-and-pool landform seen near the center of the image. The post-restoration hillshade for the same area **(Map 4h)** displays a complex pattern of elliptical mound uplands and networked basins that are dramatically different from the pre-restoration surface.

Hydrologic analysis of lidar DEMs in GIS allowed us to create precise maps of vernal pools that are highly consistent with on the ground inundation and wetland expression **(Maps 4i and 4j)**. For our restoration and fairy shrimp monitoring, we mapped vernal pools as closed topographic depressions (basins) at least 53.8 ft^2 (5 m^2) in area and 0.1 foot (3 cm) deep occupying the low ground between mound forms.[119, 120] (Smaller "pothole" basins were sometimes included if they had regular, persistent inundation.) The basin perimeter marks the maximum potential inundation level before pooled water flows out downslope; actual inundation at any given time is determined by complex interactions of weather, soils, and drainage patterns. Mapped this way, pre-restoration vernal pools are seen to be reduced, distorted, and fragmented, reflecting the patterns of disturbance **(Map 4c)**; depth, inundation period, and habitat quality are also diminished. Vernal pool mapping on the restored topography reveals an abundance of large and well-defined pools covering a much greater proportion of the landscape **(Map 4i)**.

Measuring the restored landscape

Mapping of pool basins from lidar allowed us to quantify change from restoration in simple metrics relevant to habitat and hydrologic function **(Table 4)**.[121] As seen in the before-and-after maps above **(4c and 4i)**, the distribution and size of vernal pools markedly increased with restoration. Restoration doubled the area of pool habitat on the VPMCB and KPMS sites, and more than tripled the water holding capacity of pool basins. At the same time, the number of distinct vernal pools was *reduced* by 16% as small fragmented basins were rejoined.

Catching a drone at the end of an orthophotography flight sequence.
© *Keith Perchemlides/TNC*

TABLE 4. Summary of vernal pool basin area, depth and volume before and after restoration from lidar DEM analysis in GIS. Landscape proportion, total basin area, and water storage capacity (total volume) are summarized for all pools combined (upper sub-table). Basin-level metrics are summarized separately for terrace pools and pools within the seasonal swale (lower sub-table) because of differences in landform and pool size.

	ALL POOLS	
	Before restoration	After restoration
Number of vernal pool basins	**1,505**	**1,271**
Proportion of landscape in basins	**14%**	**28%**
Total area of vernal pool basins	**28.1** acres	**54.5** acres
Surface water storage capacity*	**7.7** acre-feet	**27.0** acre-feet

	TERRACE POOLS		SWALE POOLS	
	Before restoration	After restoration	Before restoration	After restoration
Number of vernal pool basins	**1,469**	**1,244**	**36**	**27**
Average basin area	**800** ft^2	**1,631** ft^2	**1,404** ft^2	**12,726** ft^2
Average maximum depth	**3.9** in.	**8.3** in.	**3.9** in.	**13.5** in.
Average basin volume	**220** ft^3	**769** ft^3	**357** ft^3	**8,151** ft^3

** An acre-foot is a measure of volume equal to the amount of water needed to cover one acre of land surface to a depth of one foot; one acre-foot = 43,560 cubic feet.*

For our typical alluvial terrace vernal pools covering most of the Whetstone Savanna, average basin area and depth doubled with restoration as diminished basins were returned to their historic extent **(Table 4)**. Pools in the seasonal Kincaid Swale represent a different geomorphology and changed even more dramatically. Formed on a more recent fluvial landform and underlain by a thick claypan instead of duripan, swale pools and mounds are larger and elongated as a result of a higher water table and active seasonal flow. The swale area had been heavily impacted, with pools nearly erased by ripping, leveling, plowing and channelizing. Maximum depth more than tripled following restoration, while the average basin area increased almost ten-times in these broad but relatively shallow swale pools **(Table 4)**.

We did not achieve these gains by creating a homogenous landscape of big deep pools. In fact, the increase in pool area and depth was accompanied by an expansion of the size range and hydrologic diversity of the pool basins **(Figure 5)**. Before restoration, the distribution of basin size and hydrology was heavily skewed with most pools at the small, shallow, and briefly inundating end of the range.

Restoration resulted in a much more even distribution of pool basin sizes that includes substantially larger and longer inundating pools without omitting the relatively small pools that are part of the natural habitat range.

This increase in pool size and diversity provides a greater variety of wetland habitat over a longer range of time and more resilience to variation in weather cycles from climate change. The greater depth, area, and interconnectedness of restored pools provides better wetland function and habitat stability for aquatic invertebrates, amphibians, birds, and wetland plants. Flow paths between pools now have stronger wetland expression and receive more sustained flows from longer-inundating upstream pools, providing stable niches for our ESA-listed wetland margin plants.

At the landscape scale, the increased volume of restored pools adds up to greater water retention and storage capacity **(Table 4)**.[122] This boost in water storage capacity holds rainwater on site longer, benefitting the larger watershed by slowing runoff and helping to lower downstream flood risks, as well as contributing to higher base flows in the Rogue River and tributaries during our arid summers.[123]

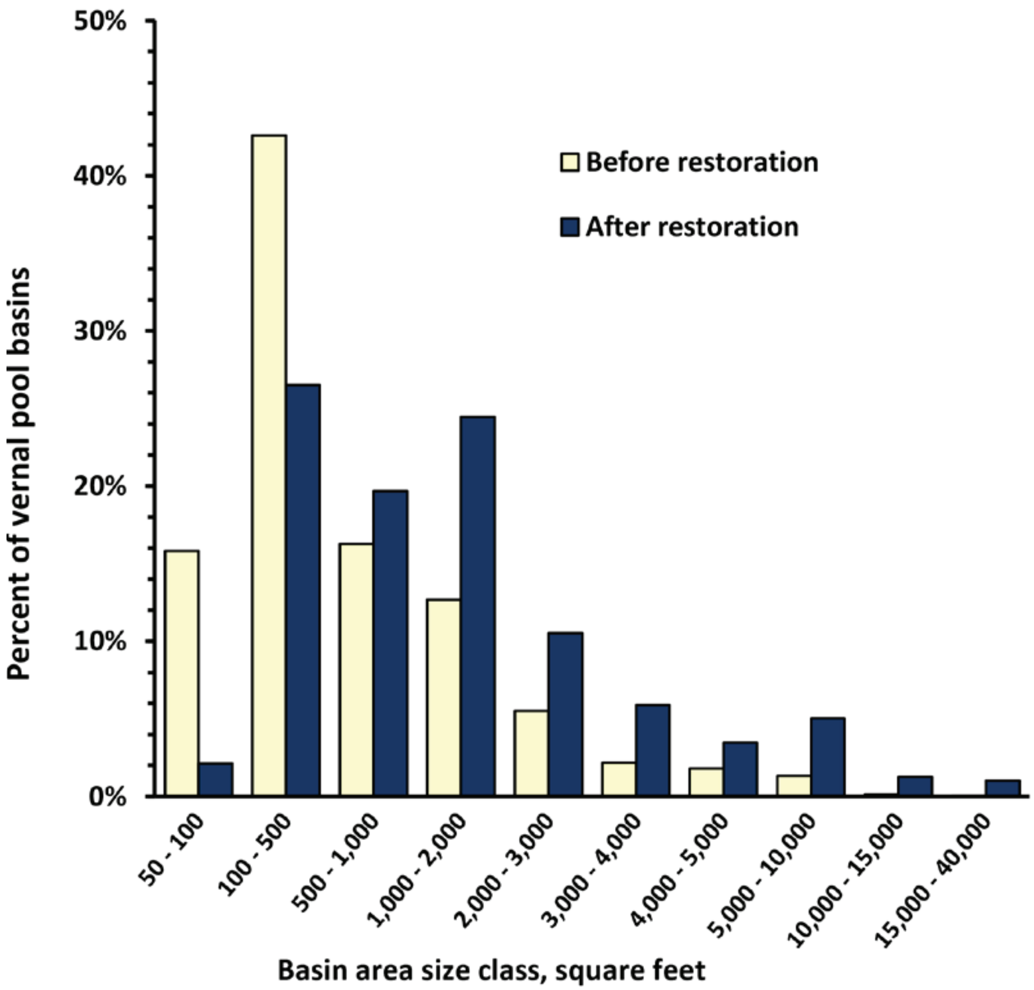


FIGURE 5. Size distribution of vernal pool basins before and after restoration. Pools are grouped into size-class categories by basin area (square feet). Size-class ranges are unequal and scaled to relevant breaks in pre- and post-restoration basin area distribution. Pool counts in each size class are displayed as percent of the total number of pools before or after restoration.

Restoration Monitoring

In scaling up and increasing the efficiency of our restoration, we raised the risk of lowering quality. Countering this, our restoration objectives and ODOT's mitigation requirements are only met when the restored areas achieve high standards of habitat function and abundance of native species. Our on the ground restoration has been accompanied by rigorous annual monitoring of vernal pools and uplands across restored and unrestored areas. Starting in 2008 on the VPMCB, we have monitored a range of conservation targets and habitat quality indicators including vernal pool fairy shrimp, desert parsley, meadowfoam, and plant community cover and species composition **(Table 1)**. When ODOT acquired the KPMS site in 2012, we expanded our monitoring program to cover both properties. This monitoring established accountability for mitigation performance, informed our restoration methods **(Figure 3)**, and directly addressed the core question of any restoration practitioner: "Is it working?"

Re-tasking a long-term dataset

Viewed from a restoration perspective, our annual mitigation performance monitoring provided a robust long-term dataset recording before and after conditions and change. It included a multi-year baseline of data collected before the start of restoration work, which was especially important because we did not have parallel data from a control site. With a dataset spanning 12 years (2008 – 2019), hundreds of pools, and multiple indicators, collected with consistent methods and observers, we had a wealth of information on-hand to assess our restoration effectiveness.

But there were challenges when using these data to evaluate restoration effectiveness. Simply put, our monitoring was not designed for it. Performance monitoring was intended to track annual conditions at the property scale on a timeline linked to agency reporting requirements. In contrast, our restoration work has been completed in a shifting patchwork of variably sized projects over the course of nine years, spanning both properties. Re-tasking our monitoring data to track restoration results required combining samples from different years and sample-sets into new analysis groups. This introduced irregularities in sample size and density, timing and distribution, and uneven influence from overlapping habitat and disturbance types that we did not control for. Recognizing this, we present results here that are quantitative but not based on statistical tests; our data have limited power for statistical inference.

Fortunately, all our monitoring samples were tracked with a specific GPS location and date. This allowed us to retroactively assign each data point to a specific restoration project-area as a pre- or post-restoration record. To focus on change from restoration, we limited our analysis to restored areas with both pre- and post-restoration data; samples from unrestored areas or portions of the site that lack either before or after data were excluded. And by using area-weighted averaging, we could minimize distortion from unequal sample sizes or project areas. Despite limitations, our data reveal obvious trends and large before-and-after differences strongly indicating successful restoration. Time-series summaries show leaps in habitat indicators aligned with each round of restoration and a consistent pattern of sustained improvement well above the baseline.

Springtime vegetation monitoring requires species-level botanical identification skills and careful observation to accurately record plant cover and diversity within sample frames. © *Evan Barrientos/TNC*

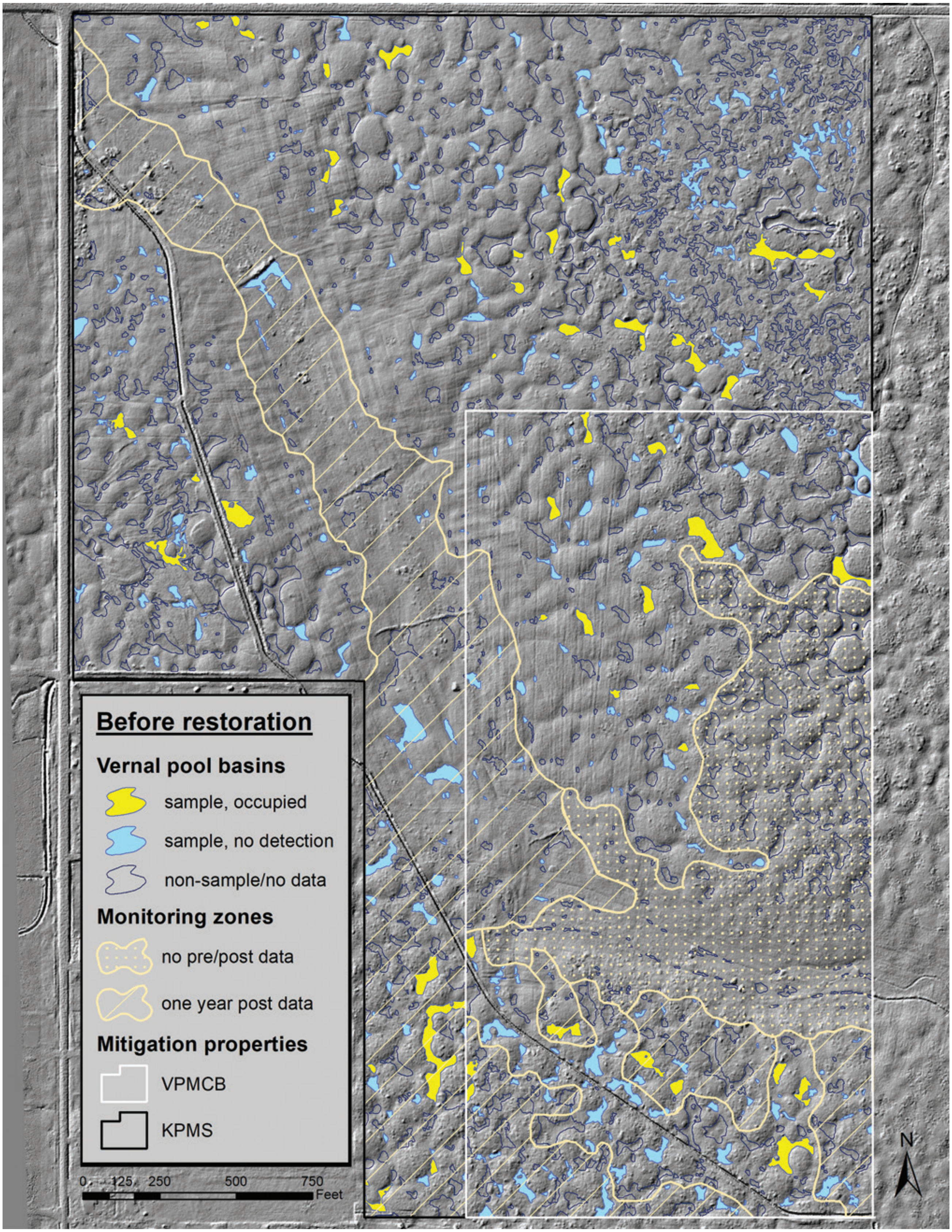
Vernal Pool Fairy Shrimp

Fairy shrimp have benefitted tremendously from restoration of their habitat on the Whetstone Savanna. Far more of our vernal pools – at least three times as many – now host fairy shrimp, compared to before restoration. Both species of fairy shrimp, the Oregon fairy shrimp (*Eubranchipus oregonus*) and vernal pool fairy shrimp (*Branchinecta lynchi*), are important indicators of habitat quality. In general, the more pools that can support fairy shrimp populations, the better the overall habitat quality on a site. When the amount or duration of inundation, or the water chemistry of pools is adversely changed, fairy shrimp populations diminish or disappear.[124, 125] And as a federally threatened species, maintaining a large and stable population of vernal pool fairy shrimp is its own conservation priority. Our monitoring tracked the simple metric of fairy shrimp occupancy, which is the proportion of pools with fairy shrimp present. Occupancy rates are expressed as a percentage of either the number of pools or the area of pool basins.

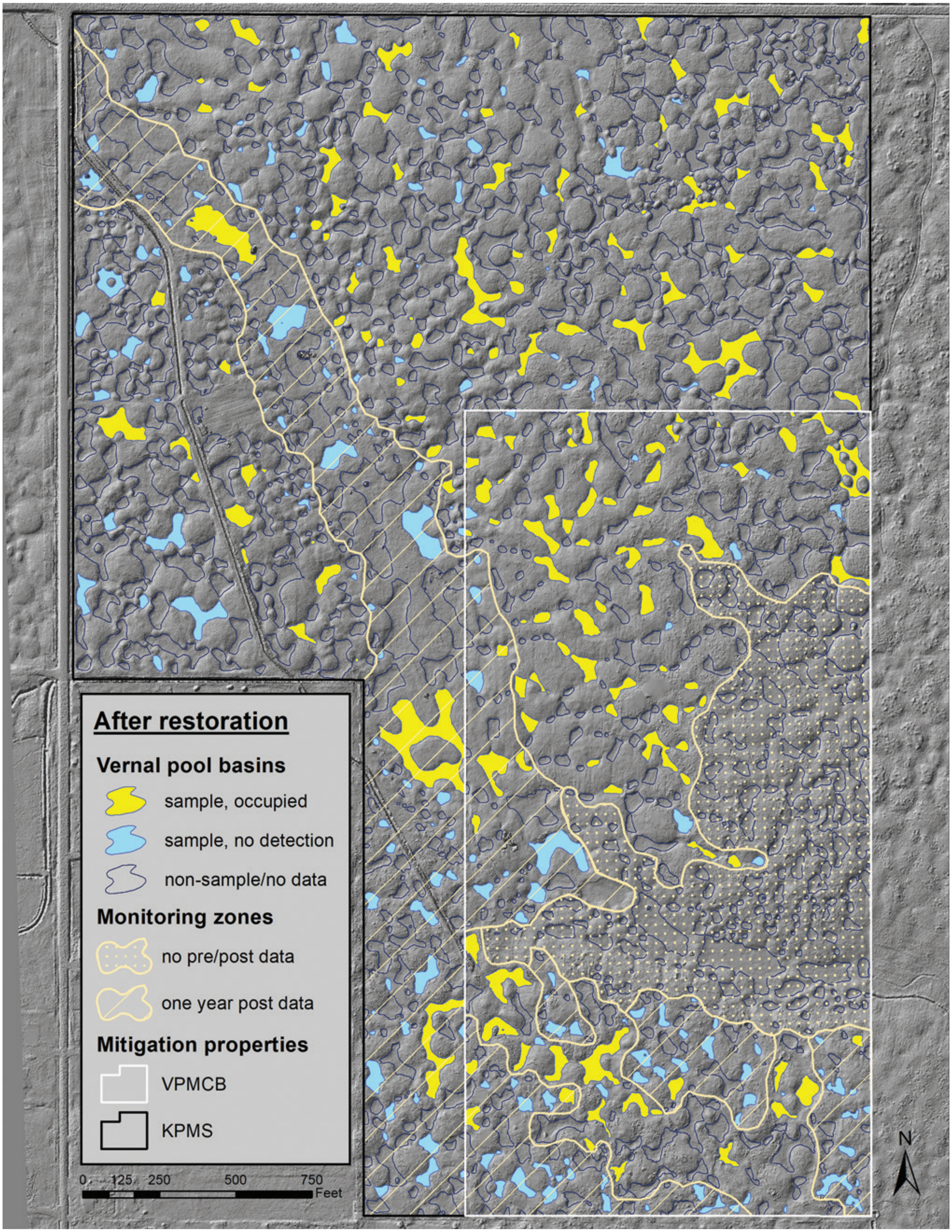
Count occupancy = number of occupied basins / total count of vernal pool basins
Area occupancy = area of occupied basins / total vernal pool basin area

Fairy shrimp are active creatures and fascinating to find gliding or darting fish-like through the chilly pool water on a clear day. Our monitoring fieldwork spanned from fall (as early as October), through winter, when pools could ice over, into early spring (March), when the fairy shrimp were joined by Pacific chorus frog tadpoles. Working under USFWS listed-species recovery permits, we sampled by carefully netting a representative selection of pool basins one to four times every season, depending on weather patterns and hatch cycles.[126, 127, 128] Fairy shrimp hatch in response to new inundation and commonly do so multiple times each wet season as pools inundate, dry down (fully or partially), and then refill. Our sampling targeted the peak period(s) of occupancy and fairy shrimp maturity by tracking hatch and development following each major cycle of rainfall. Once netted, the fairy shrimp were field-identified and released live back into their home pool. As with any wildlife monitoring, our ability to detect fairy shrimp was not perfect; even with good technique, we did not always find them, especially in pools with sparse populations. And the size and timing of shrimp populations can vary widely from year to year. By combining data over multiple years, we get a more reliable picture of their actual presence.

Catch-and-release: monitoring vernal pool fairy shrimp in mid-winter. Fairy shrimp were captured by sweeping the pools with fine-mesh nets, then field-identified in observation trays before being returned to their pool. © *Keith Perchemlides/TNC*



MAP 6a. Vernal pool fairy shrimp occupancy *before* restoration. Sample basins are yellow if vernal pool fairy shrimp were present, blue if none detected; outline-only basins were not included in restoration monitoring. Pools in the stippled area did not have pre- and post-restoration data and were excluded from this summary. Crosshatch areas had only year-1 post-restoration data and were dropped from the year-2 summary.



MAP 6b. Vernal pool fairy shrimp occupancy *after* restoration. Sample basins are yellow if vernal pool fairy shrimp were present, blue if none detected; outline-only basins were not included in restoration monitoring. Pools in the stippled area did not have pre- and post-restoration data and were excluded from this summary. Crosshatch areas had only year-1 post-restoration data and were dropped from the year-2 summary.

Restoration response

To focus on restoration results, we looked at fairy shrimp occupancy specifically in our completed work areas where we have monitoring data from both before and after restoration **(Maps 6a & 6b)**. To measure change, we compared all sample detections of fairy shrimp during pre-restoration monitoring to all detections in restored pools for the same area. Because restoration changed the vernal pool landscape, we could not maintain the same monitoring sample of pools before and after restoration. Our before and after samples were each representative of the vernal pool habitat at the time, but not identical; the pre-restoration sample size and pool locations had to be adjusted to remain representative of the new number, size, and distribution of restored vernal pools. For most of the restoration area, our monitoring timeline gave us substantially more opportunities to detect fairy shrimp *before* restoration. Despite this, far more fairy shrimp occupied pools could be found in a single post-restoration survey than in all pre-restoration years combined.

Before restoration, vernal pool fairy shrimp were sparsely scattered across the site, found in only 13% of sample pools **(Map 6a)**. Many of the degraded pools rarely inundated or simply did not hold water long enough for the shrimp to hatch or mature, even after substantial rainfall. Surviving fairy shrimp populations were generally restricted to the largest or least disturbed pools. Following restoration, count occupancy of vernal pool fairy shrimp jumped to 44% in restored pools, more than three times their pre-restoration presence **(Map 6b)**. Existing fairy shrimp populations remained, and new populations established in a multitude of pools where they were simply not found before restoration.

More fairy shrimp next year

Over eight years of monitoring restored pools, we noticed that fairy shrimp populations were usually very sparse during the first rainy season after restoration. This was especially true in pools without pre-restoration occupancy, where fairy shrimp were establishing from a small founder population. These low levels of year-one post-restoration shrimp abundance caused detection error in our sampling; with so few fairy shrimp present we did not consistently find them in occupied pools that first year. By the second or third year after restoration, shrimp abundance in restored pools was generally higher and more stable. This indicates that the actual increase in fairy shrimp occupancy from our most recent restoration work may be larger than what we have seen so far.

If we zoom in on fairy shrimp occupancy data from areas where at least two years had passed since restoration **(Map 6a & 6b)**, the results are more impressive – and likely more meaningful. For these areas, vernal pool fairy shrimp count occupancy was more than four and a half times higher for restored pools than before restoration **(Figure 6)**. Expressed as area occupancy, the proportion of pool habitat hosting vernal pool fairy shrimp doubled with restoration. To put this area occupancy gain in perspective, recall that restoration also doubled the physical area of vernal pool basins **(Table 3)**. With greater occupancy of a larger set of basins, the actual area of vernal pool habitat occupied by vernal pool fairy shrimp more than tripled, increasing 265% by year-two after restoration. Fairy shrimp are now in many more pools and occupying a much higher proportion of a much larger habitat area.

Fairy shrimp have adapted to persist over long periods, then increase dramatically when conditions are favorable. It seems our restoration has provided them favorable conditions. Importantly, our post-restoration monitoring

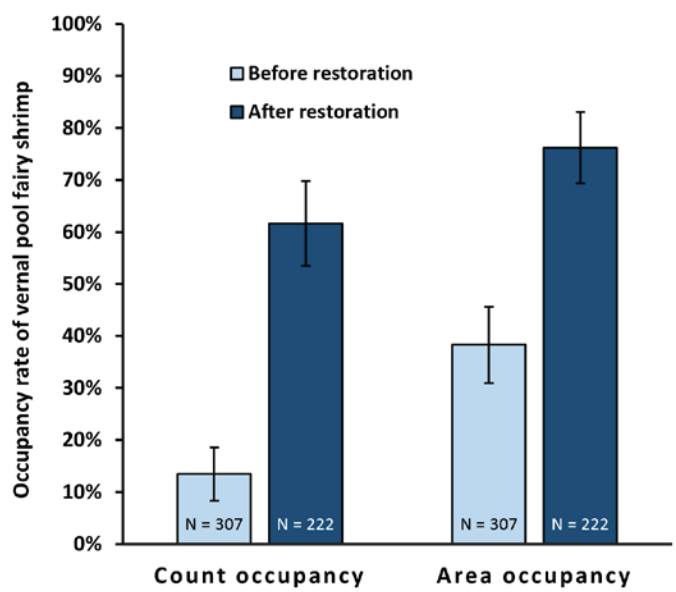


FIGURE 6. Cumulative vernal pool fairy shrimp occupancy rates before and after restoration summarized as count and area-based percent occupancy. Data are from restored areas with monitoring completed at least two years after restoration. Error bars are Wilson's interval for binomial data, calculated at a 95% confidence level.[129] Sample size (number of pools) is at the base of each bar.

Mature male (right) and female (left) vernal vernal pool fairy shrimp circle in an observation tray. © *Keith Perchemlides/TNC*

has also confirmed that the intensive disturbance from our grading work did not cause the loss of fairy shrimp populations, even at the individual pool scale; over 95% of pools with fairy shrimp present before restoration were found to still host fairy shrimp by year-two after restoration.

In addition to higher occupancy rates, restored pools seemed to host more abundant populations of fairy shrimp. Although difficult to accurately measure in the field, we observed that by year-two, population density of fairy shrimp in restored pools was typically much higher than in unrestored occupied pools. One explanation for this is the hydrologic stability of the restored pools which inundate earlier and hold water longer, increasing the survival and longevity of each fairy shrimp hatch. Longer-lived shrimp reproduce more; female vernal pool fairy shrimp continue to produce eggs throughout their lifespan. That increase in shrimp survival and reproduction means greater abundance of eggs deposited in the pool, leading to larger hatches next time. And the larger pools can maintain these increases by providing more food and space for a bigger population of fairy shrimp.

Another explanation for increased post-restoration shrimp abundance may be the greater range and complexity of restored pool hydrology. Large pools with multiple coves and sub-basins across a range of depths respond more variably and dynamically to short-term rain and drying cycles during the wet season. Instead of simply filling and drying out as smaller, uniform pools tend to, large complex pools partially dry, then re-fill in portions creating pulses of new recruitment. Deeper areas of the same pool stay inundated, maintaining earlier-hatched cohorts and adding up to a large age-diverse population.

A rising tide of shrimp

Tracking the trend of fairy shrimp occupancy over time provides more evidence that their expansion was a direct result of habitat restoration **(Figure 7)**. On the VPMCB property, we have been monitoring fairy shrimp annually since 2008. By focusing in on the area of the VPMCB where grading and monitoring have been completed **(Map 6a & 6b)**, we can track the increase in fairy shrimp occupancy relative to restoration progress with annual survey results over a 12-year span. **Figure 7** shows a strong trend of increasing annual occupancy (dotted line) with jumps following restoration activity. During the pre-restoration baseline from 2008-2011, annual occupancy rates were persistently low. With the completion of the first restoration project area in 2012, fairy shrimp detections rose noticeably. In 2015 our restoration expanded to cover two-thirds of the area and fairy shrimp occupancy climbed steeply to over 40% in a single survey year (2017), far above any previous rate.

The percent of occupied pools declined somewhat in 2019 following completion of the final round of restoration in this area – apparently breaking the pattern of occupancy jumps following restoration **(Figure 7)**. Some unique aspects of the 2018 restoration area help to explain this. The 2018 restoration reversed a heavy disturbance that had effectively erased vernal pools from most of the project area. As such, our 2018 work had the atypical result of *increasing* the number of vernal pools. Combined with sparse fairy shrimp populations in year-one pools, we had more pools to net and fewer shrimp to find in 2019. In effect, our short-term occupancy was diluted by a sudden expansion of habitat.

Fluctuations in rainfall and inundation caused variation in our results unrelated to restoration, accentuating high or low occupancy on wet or dry years. Inundation was so limited in 2009 and 2018 that no monitoring was done on those years. By averaging fairy shrimp occupancy over a three-year moving window (solid line on **Figure 7**) we smooth out some of this year-to-year fluctuation and can see a clear trend of increasing and sustained occupancy aligned with restoration.

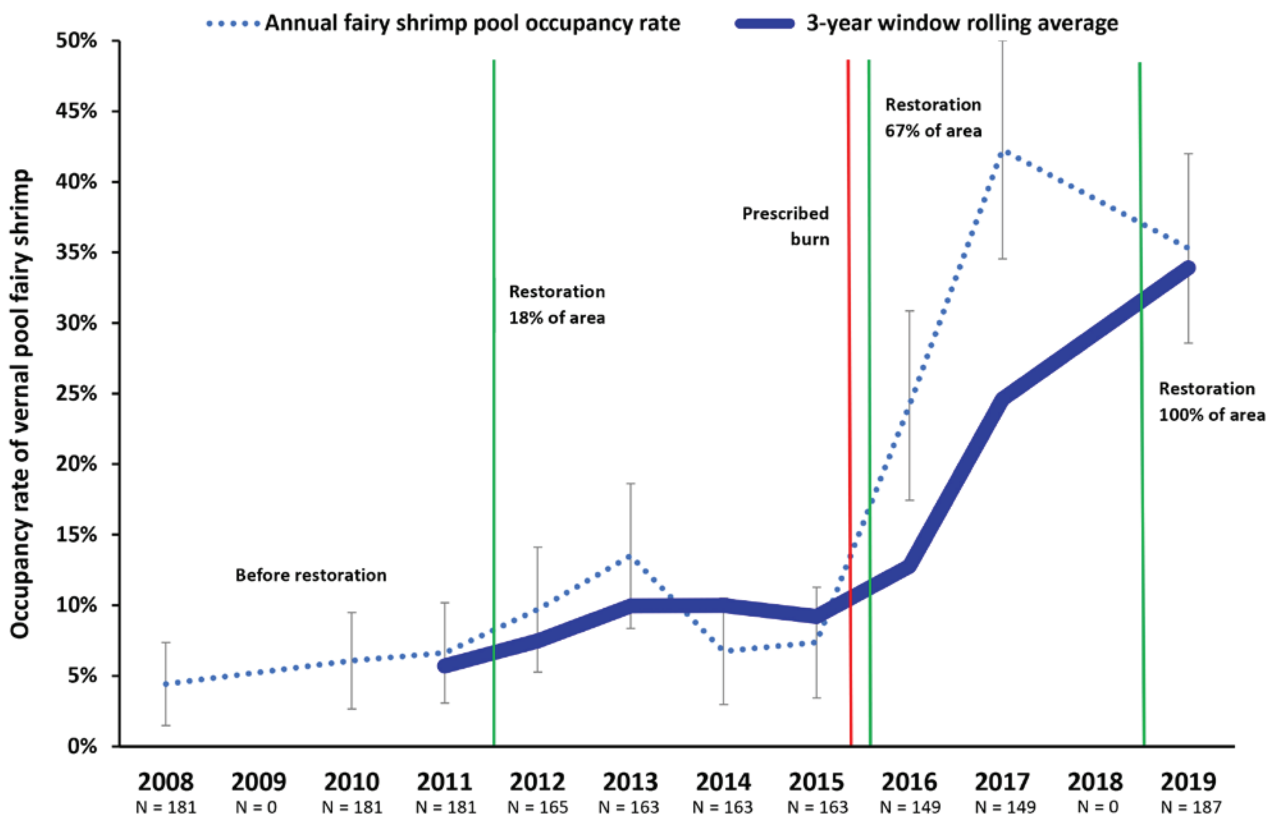


FIGURE 7. Annual trend in vernal pool fairy shrimp count occupancy rate (dotted blue line) for the portion of the VPMCB restored from 2011 – 2018, with a summary trend line (solid blue) based on average occupancy within a three-year rolling window. Vertical lines mark timing and extent of major restoration actions: topographic restoration in green, red for prescribed burning. Annual data include both pre- and post-restoration samples as work progressed across the area. Sample size (number of pools) is below year on the x-axis; no monitoring was done in 2009 and 2018. Error bars are Wilson's interval for binomial data, calculated at a 95% confidence level.[130]

Fairy shrimp of oak woodlands

The results presented so far have covered the threatened vernal pool fairy shrimp, our target species for recovery and monitoring. But our restoration has also benefited the co-occurring and ecologically important Oregon fairy shrimp. Although not federally listed, Oregon fairy shrimp are far less abundant than vernal pool fairy shrimp on the Whetstone Savanna. This seems to be due mainly to natural limits of their preferred habitat. We have found Oregon fairy shrimp almost exclusively in oak woodland pools and the large pools of the seasonal swale bottom. Typical open prairie pools seem to be outside their habitat range; Oregon fairy shrimp were nearly absent from terrace grassland pools. The biological reasons for this are unknown, but the pattern of distribution is clear.

In our area, vernal pool fairy shrimp appear to have a wider habitat tolerance than Oregon fairy shrimp and are found in both prairie and oak pools, and in restored swale pools. Southwest Oregon is the only area where both these fairy shrimp species are known to inhabit the same pools; in our oak and restored swale habitats, vernal pool and Oregon fairy shrimp swim together.[131] Only heavily oak-influenced pools, with tea-colored water from leached oak leaf tannins, seem outside the range for vernal pool fairy shrimp.

Our landscape-scale restoration spanned oak, prairie, and swale habitats and strongly benefitted vernal pool fairy shrimp in all these settings. By comprehensively including oak and swale pools in the restoration, we have also seen a doubling of Oregon fairy shrimp occupancy across the site. But it is more relevant to look at the Oregon fairy shrimp's response to restoration of their preferred habitat. In oak and swale habitats, Oregon fairy shrimp count occupancy tripled from 7% of pools before restoration to 21% after restoration.

Endangered Plant Recovery

Populations of our two endangered plants, large-flowered woolly meadowfoam (*Limnanthes pumila* ssp. *grandiflora*) and Cook's desert parsley (*Lomatium cookii*), have exploded across the site with restoration, setting a hopeful example for species recovery **(Figure 8)**. Before restoration, our standard monitoring method for both species was a simple, intensive annual inventory. We mapped all patches and counted all plants, a method appropriate to small populations of rare species. But as of 2018, the restored population of desert parsley on the KPMS property had expanded far beyond what could be reasonably mapped and censused. For meadowfoam, this overwhelming (from a monitoring perspective) increase happened in 2016, the first year after our initial large-scale sowing of the species. With both species widespread and common around restored pools across the site, monitoring by full census inventory became unnecessary and impractical.

Importantly, this increase in meadowfoam and desert parsley has been unique to our restoration area and seems due entirely to our work; monitoring on adjacent unrestored areas and other local vernal pool conservation sites has not recorded a similar jump.[132]

Lomatium cookii comeback

Before restoration, desert parsley was absent, extirpated from both the VPMCB and KPMS properties and found on the Whetstone Savanna only as a small and struggling remnant population on the original TNC Preserve. Restoration changed that. As of 2019, the desert parsley population across our restoration area contained well over 10,000 mature flowering plants. And this impressive new population was only an initial result from areas restored and sown in 2016 or earlier – about half of the total restored area.

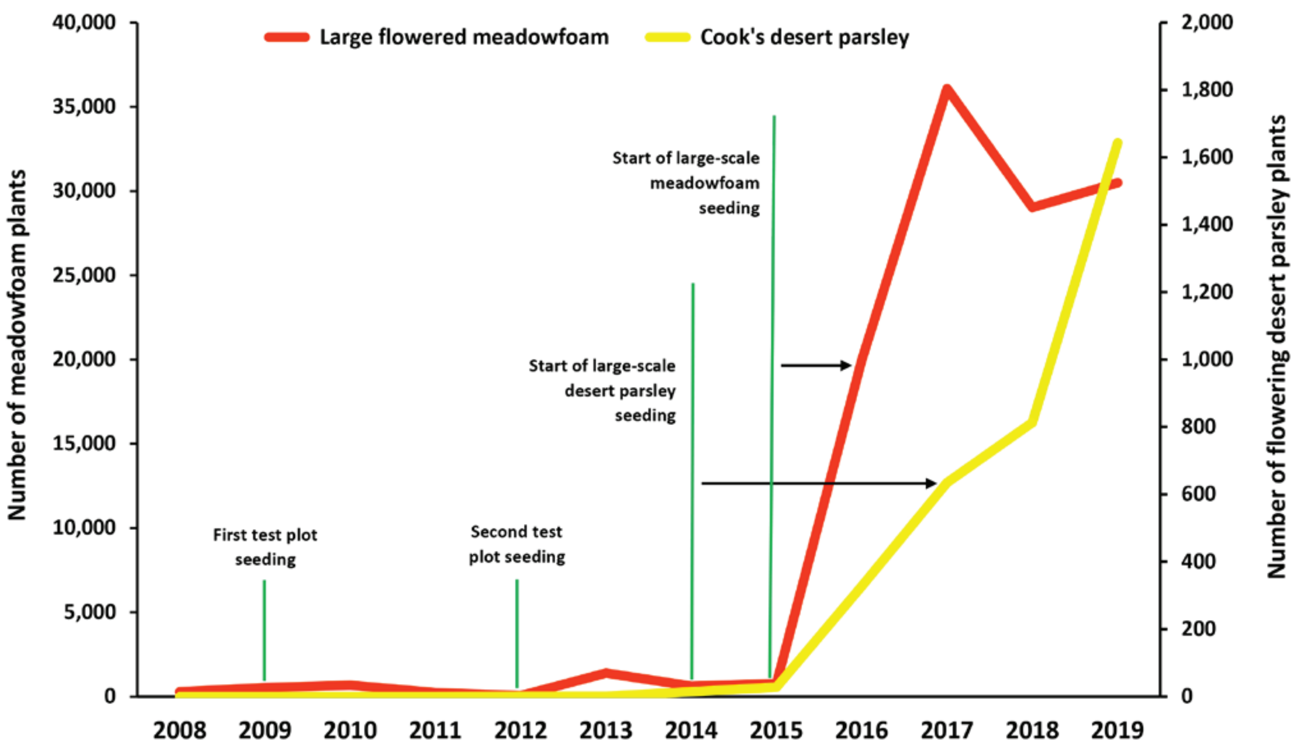


FIGURE 8. Annual trend in population size of large-flowered woolly meadowfoam (red line, left axis) and mature Cook's desert parsley (yellow line, right axis) on the VPMCB site, aligned with timing of restoration seeding (vertical green lines). Population data are from full census counts, except meadowfoam populations from 2016 – 2019 are assumed to be 10x the total from trend monitoring plots. Horizontal arrows from the 2014 desert parsley and 2015 meadowfoam seeding indicate three-year and one-year time lags, respectively, for establishment from seed.

Red-tinged seed heads of meadowfoam along the margin of a restored pool. The woolly flower structures of meadowfoam close up tightly once pollinated, protecting their ripening seed. © *Evan Barrientos*

As a slow-growing perennial, desert parsley takes at least three years to reach flowering maturity with the proportion of flowering plants continuing to increase in year four and five. Once established, these patches of cheerful yellow spring blossoms and sturdy fern-leaved plants are remarkably persistent. Our monitoring tracked only mature, flowering desert parsley plants because mortality of immature plants is high, and they do not yet contribute seed to long-term population stability. The number of immature plants from restoration seeding far exceeds the flowering population, so the increase in mature desert parsley should continue for years to come. For example, the flowering population of desert parsley on the VPMCB doubled from 2018 to 2019, from seeding done in 2015 or earlier **(Figure 8)**. At present, desert parsley has not yet begun to flower on the additional 87 acres of the VPMCB and KPMS restored and seeded from 2017-2019 **(Map 3)**. And the established plants are already producing new seed and seedlings on-site. We expect the flowering population of desert parsley to continue increasing for another three to five years before stabilizing as mortality and new recruitment balance.

Fields of meadowfoam

Prior to restoration, meadowfoam was present only in small remnant patches on both the VPMCB and KPMS sites. These were outliers of a larger persistent population on the northern portion of the neighboring TNC preserve. As an annual species, meadowfoam numbers can fluctuate dramatically from year-to-year in response to weather, inundation patterns, and competition. Annual pre-restoration meadowfoam counts for the entire VPMCB and KPMS population ranged from about 200 to 4,000 plants total in our baseline monitoring.

After restoration and seeding, our total meadowfoam population expanded to tens of thousands – no longer practical to count **(Figure 8)**. In response, we adapted our monitoring method to track population trend for meadowfoam in a small set of permanent plots distributed across restored areas on both sites.[133] These plots provided trend information on a representative sub-population of meadowfoam but do not give us statistical estimates of the total population count. Even so, a simple comparison of scale puts the dramatic population increase in perspective. After restoration, meadowfoam were counted in 35 plots, each 108 ft^2 (10 m^2) – mere dots on the map amounting to less than a tenth-acre of combined area. Yet our plant counts in these plots consistently exceeded the pre-restoration full-census totals across the entire 196 acres of the KPMS and VPMCB properties. With abundant meadowfoam flowers brightening pool margins and flow paths across most of the surrounding habitat outside our plots, the total restored population has likely been ten to one-hundred times larger than our annual plot counts **(Figure 8)**.

A window for successful reintroduction

Although the long-term size and stability of these populations remains to be seen, this has been by far the most successful and large-scale reintroduction of desert parsley and meadowfoam in the Rogue Valley to date and an important step towards species recovery. The lemon-lime yellow of desert parsley flowers and the carpeting white blooms and red-blush seed-heads of meadowfoam are now a familiar springtime sight throughout the restored Whetstone Savanna. An obvious reason for this success has been the seed increase work of ODOT and the BLM that provided hundreds of thousands of locally sourced seeds for both species. But there seems to be a deeper explanation for this success tied to a specific window of post-restoration conditions.

Desert parsley and meadowfoam are niche-specific vernal pool species occupying pool margins and ephemeral flow-paths in the Rogue Valley. Both species seem to prefer wetland soils that are regularly saturated but not persistently submerged during the wet season. The broad, relatively flat areas on the outer edge of pool coves or at pool inflow and outflow points generally provide the largest and most hydrologically stable microsites. When pools are filled with upland soil or leveled, these microtopography features are lost, because pool margins are abrupt or covered by faster-drying upland soils. Degraded pools simply have less suitable and less reliable desert parsley and meadowfoam habitat.

Invasive grasses make this situation worse. When upland soils cover the wetland surface in impacted pools, conditions shift to favor non-native species, especially opportunistic invasive grasses like seaside barley (*Hordeum marinum*) and perennial ryegrass (*Lolium perenne*). Competition from these species and the physical barrier of their accumulated litter suppress meadowfoam and desert parsley growth and can exclude seedling establishment. Past attempts by TNC to directly sow desert parsley and meadowfoam on pool margins occupied by invasive grasses were unsuccessful. Seedling monitoring of the remnant desert parsley population on the Whetstone Savanna Preserve has found that plants under this type of competitive stress can fail to successfully reproduce for years. And long-term monitoring on TNC's nearby Agate Desert and Rogue River Plains Preserves has consistently found an increase in meadowfoam and desert parsley following prescribed burns that cleared invasive grasses and litter.

> Post-restoration conditions seem to create an important window of opportunity for reintroduction of desert parsley and meadowfoam immediately following earth-moving restoration.

From 2009 to 2015, we conducted small-scale field trials for desert parsley and meadowfoam reintroduction on the VPMCB, and similar reintroduction trials were done by the Institute for Applied Ecology from 2008 to 2015 on the nearby Agate Desert Preserve.[134, 135] In our trials, seeds were sown in plots that were either simply cleared of vegetation (2009), with no soil disturbance, or tractor-tilled (2012), an intensive soil-disturbance. We closely monitored how well plants established (percent of seeds that grew into surviving plants) in these plots through 2015. In plots prepared with just vegetation removal, we found very limited desert parsley establishment: 6% by year-three after sowing. Plots prepared with tractor-tilling of the soil were more successful with 14% average desert parsley establishment by year-three. But tractor-tilled plots installed in recently restored areas were even more successful: by year-three, desert parsley plants had established at 19% in post-restoration tilled plots. Patterns for meadowfoam were similar. First-year meadowfoam plants in tilled plots were far larger and flowered more abundantly than plants in cleared no-till plots or wild patches – an average of 22 flowers per plant for tilled-plots compared to four flowers per plant for no-till or wild meadowfoam.

Together, these results suggest that desert parsley and meadowfoam are adapted to natural disturbance and may have historically relied on favorable disturbance events (including fire and soil bioturbation by burrowing animals) for cycles of intensive recruitment or abundant flowering to replenish patch populations and seed banks. Long-term monitoring of meadowfoam on TNC preserves indicates that its seed can remain dormant and viable in the soil for years, allowing populations to surge when conditions are right. In our restoration work, the combination of prescribed fire and soil disturbance from grading appear to have provided a beneficial disturbance opportunity for desert parsley and meadowfoam. Both fire and grading greatly reduced herbaceous competition and left a relatively loose bare-soil seedbed. Combined with the restored microtopography and hydrology of their habitat niche, this provided a greatly expanded growing area and favorable conditions. These post-restoration conditions seem to create an important window of opportunity for reintroduction of desert parsley and meadowfoam immediately following earth-moving restoration.

Native Plant Community

Beyond the recovery of individual species, our overarching restoration goal is to support the full range of plants and animals native to the Whetstone Savanna. One of our best perspectives on the overall ecological health of a site comes from tracking the composition of the herbaceous plant community. Herbaceous plants are the grasses and forbs, wildflowers, and weeds that cover the ground surface. They are practical to monitor, form the foundation of the food-web for herbivores and pollinators, and provide essential habitat for small mammals and birds. In vernal pools, herbaceous plants can strongly influence hydrology and wetland function, and on uplands they determine patterns of grazing and fire behavior. Mitigation performance standards recognize this by including native herbaceous plants as important indicators of habitat quality for both pools and uplands.

Native plants are thriving in our restored areas. The abundance and diversity of native herbaceous plants have greatly benefited from restoration, especially in vernal pools, while non-native invasive weeds have been dramatically reduced. In this section we present our native plant restoration results going from general to specific: starting with overall trends, then looking closer within distinct habitat types of pool and upland, oak and prairie, and finally examining dynamics at the species level.

Herbaceous community monitoring

Starting in 2008, we have monitored herbaceous plants every spring by recording all species present and their contribution to surface cover (“percent cover”) in a set of representative sample plots.[136] These 2.7 ft^2 (0.25 m^2) plots were randomly dispersed each year across the VPMCB and KPMS properties, in restored and unrestored areas, at a

Native vernal pool plants, including bright blue and yellow Cascade calicoflower and the odd, fuzzy short woollyheads, fill a monitoring sample frame in a restored vernal pool basin. © *Evan Barrientos/TNC* density of about one plot for every one to two acres. To accurately represent the natural diversity of the Whetstone Savanna, we assigned separate groups of samples to the four distinct habitat types (strata) on site: vernal pools and uplands in oak and prairie settings. Our 12 years of vegetation data from this effort provide a detailed botanical record of before-and-after species composition and abundance, tracking change year-by-year. To focus on change from restoration, the results presented here are specifically from vegetation data collected within our restoration area where both before and after monitoring were completed.

With herbaceous plants, growth and cover change year-to-year and month-to-month depending on weather, soil conditions, herbivory, and the life cycles of each species. Because of this, we recorded plant species cover during the same seasonal window of peak growth and flowering every year for consistent data and meaningful comparisons over time. To track important changes in the plant community, we analyzed our data using the *relative* cover of species. Relative cover is the proportion of the total plant cover that each species contributes. Plants may be sparse or abundant, large or small on any given piece of ground, but if half of what's there comes from one species, it has 50% relative cover.

Using relative cover focused our analysis on the balance between different species or groups of plants and how that changes over time. A key distinction in plant ecology is between native vs. non-native or invasive species. Invasive species are not simply non-native; for Rogue Valley vernal pool habitats they are a short list of particularly aggressive exotic species capable of taking over, excluding native plants and undermining habitat quality. The classification of invasive species used here follows the mitigation performance standards for the VPMCB and KPMS sites and the Oregon Department of Agriculture (ODA) list of noxious weeds.[137, 138]

From weeds to wildflowers

Springtime visitors to the restored area of the Whetstone Savanna miss a lot. They see just what you would expect on a vernal pool conservation site: a rolling grassland thick with wildflowers, and between the mounds, lowland basins filled like bowls with native wetland plants in bloom. What they miss is what it used to look like. Our before-and-after vegetation monitoring tells the story.

Across our restoration area, native species have gone from troubling decline to dramatic increase while invasive species have dropped down to satisfyingly low levels. This transformation to a mostly native plant community and its link to site management and restoration is captured by long-term annual trend data from the restored area of the VPMCB property. **Figure 9** tracks the relative cover of native and invasive plants during baseline monitoring, and then as restoration progressed across the sample area. At the start of conservation management (2008), native cover was reasonably good and invasive weeds were limited. Recent grazing had likely kept invasive grasses in check, and removal of grazing (in 2007) allowed native species a chance to recover. But after a long history of negative impacts and without beneficial disturbance, our native species were soon overcome by invasive plants.

The bright white blooms of native popcorn flower outline the basin of a restored vernal pool in springtime. © *Keith Perchemlides/TNC*

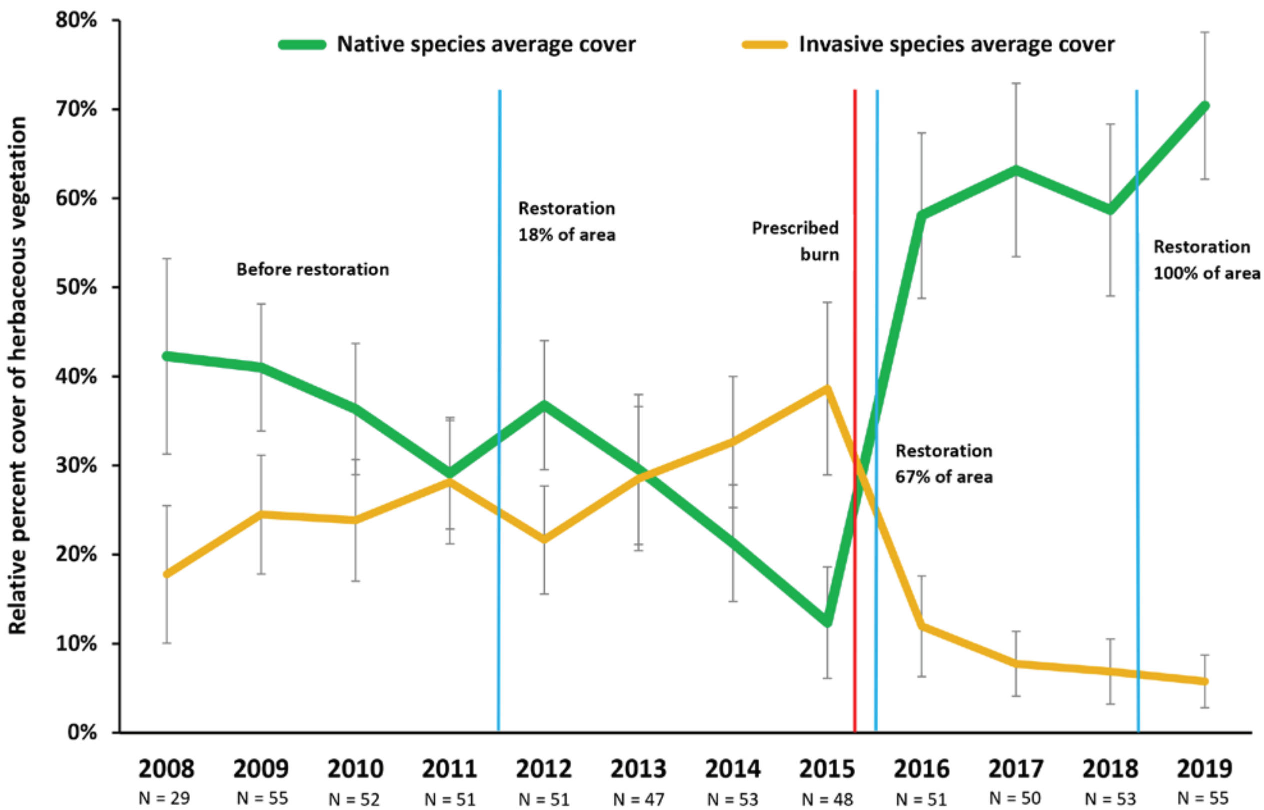


FIGURE 9. Annual trend in average relative cover of native and invasive herbaceous species from vegetation monitoring in the VPMCB restoration area from 2008 – 2019. Vertical lines mark timing of major restoration actions: topographic restoration in blue, red for prescribed burning. Annual data include both pre- and post-restoration samples as work progressed across the area. Error bars are 2x standard error, with sample size noted below year on the x-axis.

Our first round of partial restoration helped native plants rebound somewhat in 2012, but their overall decline continued. By 2015, invasive species were three times more abundant than native plants, which had dropped to their lowest recorded level **(Figure 9)**. Prescribed burning followed by large-scale restoration later that same year dramatically reversed the trend. Native and invasive species traded places as native plants became far more abundant and the invaders receded. With restoration completed across the entire sample area in 2018, native plant cover rose even higher, far above the pre-restoration baseline, and invasive species dropped to their lowest level since the start of conservation management. Positive change of this magnitude has not been observed at any comparable local sites and seems compellingly linked to our restoration work.

Restoration response in pools and uplands

This pattern of positive change in the plant community holds true across the entire Whetstone Savanna restoration area, but with interesting differences between vernal pool and upland habitats. **Figure 10** compares the abundance of native plants before and after restoration in pool and upland habitats for all restored areas with pre- and post-restoration monitoring. Both vernal pool and upland herbaceous communities have strongly benefitted from restoration, but we have achieved far greater success in pool habitats to date.

Wetland soils and seasonal inundation tend to make vernal pool habitat more resistant to non-native plants and more responsive to restoration than uplands.[139] Excavation of fill removed much of the non-native seed bank from pools, re-exposed wetland clay soil and returned hydrology that strongly favors specially adapted native plants. Native plant cover in vernal pools nearly tripled with restoration, from less than one-third to almost 90% **(Figure 10)**. The remaining non-native species are usually restricted to pool margins; restored basin bottom plant communities are almost entirely native.

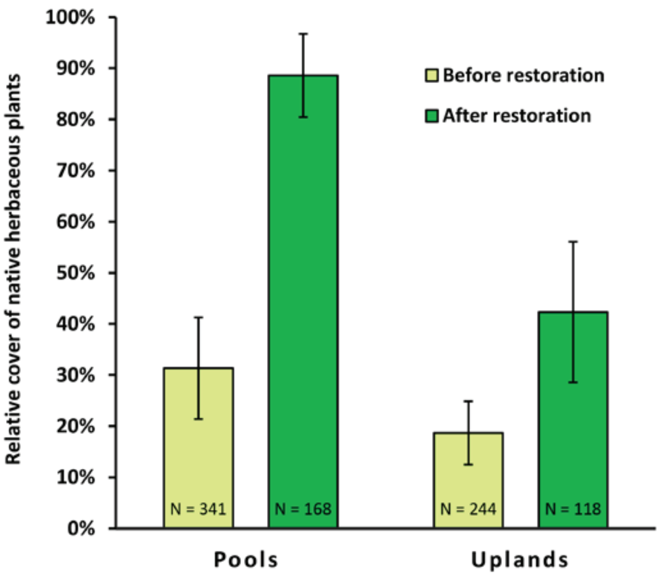


FIGURE 10. Average relative cover of native herbaceous plants before and after restoration in pool and upland habitats. Data are combined across years from project areas on the KPMS and VPMCB sites with both pre- and post-restoration samples. Error bars are 2x standard error, with cumulative sample size at the base of each bar.

Upland conditions are more challenging. Before restoration, native cover on mounds was even lower than in pools. After burning, grading, and seeding restoration, upland native cover more than doubled; this was an impressive increase, but of far less magnitude than in pools **(Figure 10)**. Compared to pools, these prairie and oak understory upland habitats are more invadable and had lost more of their native plant community during their long history of impacts. Abundant non-native species built up a dense seed bank on uplands, while the native seed bank was depleted by attrition.

In pools, cycles of inundation and drying benefit native species and impede most non-native plants; the comparable dynamic for uplands is fire. Prescribed fire is our single best tool for controlling non-native plants and encouraging native species on uplands but requires precise timing and conditions to succeed. Issues of risk, cost, and public concern have made the use of prescribed fire at a frequency and timing needed for upland restoration difficult in our area. And some of our most challenging upland weeds have their own fire adaptations, setting seed before burning is possible or surviving as below-ground roots or bulbs.

Effective upland restoration requires combining prescribed burning with other complementary treatments and native seeding – an ongoing process on the Whetstone Savanna.

Vernal pools and uplands also differed in their total amount of actual plant cover ("absolute cover") after restoration **(Figure 11)**. Before restoration, uplands and pools were very similar with about half of the ground surface covered by live plants (both native and non-native). After restoration, absolute cover in pools diminished, leaving a sparser plant community with more bare ground, while total plant cover on uplands increased substantially. Short-term post-restoration conditions on mounds favor lush plant growth, with removal of litter accumulations and increased nutrient availability from soil disturbance.

In restored pools, naturally shallow clay soils and stronger cycles of inundation and drying tended to limit plant growth. Restored inundation that persists later into spring can result in a shorter growing season and smaller size for wetland plants that must wait for pools to dry down before maturing. Excavation of fill reduced the density of upland and non-native plants and seed in pools, and those that

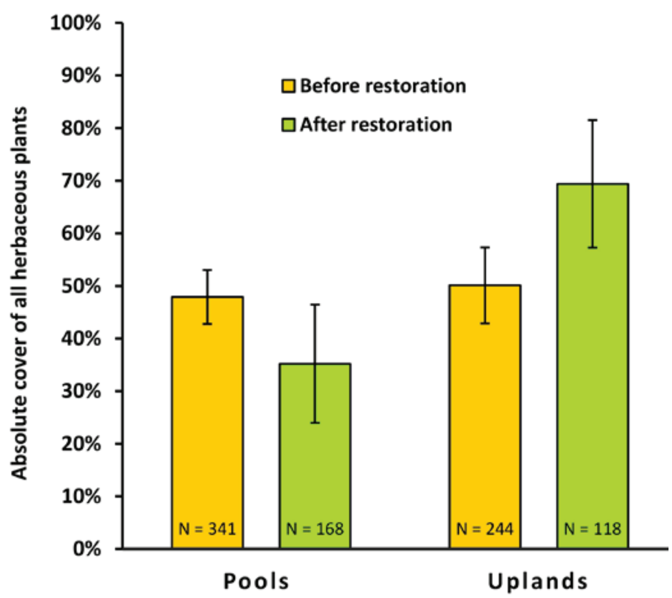


FIGURE 11. Average absolute cover of all herbaceous plants (native and non-native) before and after restoration in pool and upland habitats. Data are combined across years from project areas with both pre- and post-restoration samples. Error bars are 2x standard error, with cumulative sample size at the base of each bar.

remained usually could not tolerate the longer inundation. Time is also an important factor, with newly restored and seeded pools often taking years to attain full vegetation cover. All of this contributed to a relatively sparse native-dominated, small-stature plant community in most restored pools.

The sparseness of some restored pools may also have been due to removal of more productive soils, including unintentional over-excavation that left a very thin covering above the duripan or exposed sub-soils. As careful as we were to dig only to the original wetland soil horizon, that layer was not always intact or apparent enough to fine-tune our depth. Avoiding over-excavation was a consistent focus in reviewing and adapting our work: any impacts have been limited and do not overshadow the wider benefits of the restoration. As wetlands and natural sinks in the landscape, restored vernal pools can be expected to rebuild soil and nutrients over time now that their hydrology is functioning.

Native plants of oak and prairie

A mosaic of prairie and oak habitats is part of the Whetstone Savanna's appeal and exerts a strong influence on growing conditions for herbaceous species. For native plants, our restoration was more successful in vernal pools than on uplands, and more successful in prairie than in oak habitat **(Figure 12)**. Restored prairie pools had a higher proportion of native cover than restored oak pools. Differences in hydrology, soils, and shading in oak pools may make them less conducive to native revegetation or more invadable by non-native weeds. Oak pools generally inundate later in the season and for shorter periods than prairie pools because of landscape patterns in drainage and duripan permeability. Strong and persistent inundation tends to favor native species in vernal pools and may do so less effectively in oak woodland basins.

Similarly, prairie uplands made larger gains in native cover than oak uplands **(Figure 12)**. After restoration, over half of all plants in prairie uplands were native, a tremendous accomplishment for highly invaded valley-bottom grasslands. Native species on oak uplands made a substantial but lesser gain. After restoration, oak uplands had lower native cover than prairie uplands. This is notable because oak uplands started with higher native cover than prairie uplands before restoration.

Much of this apparent difference in oak and prairie upland response is likely due to patterns of historic disturbance and practical limitations on restoration work. Oak habitats were, on average, less topographically altered than prairie or swale areas on the Whetstone Savanna. The machinery used at the time to level and fill pools may not have been

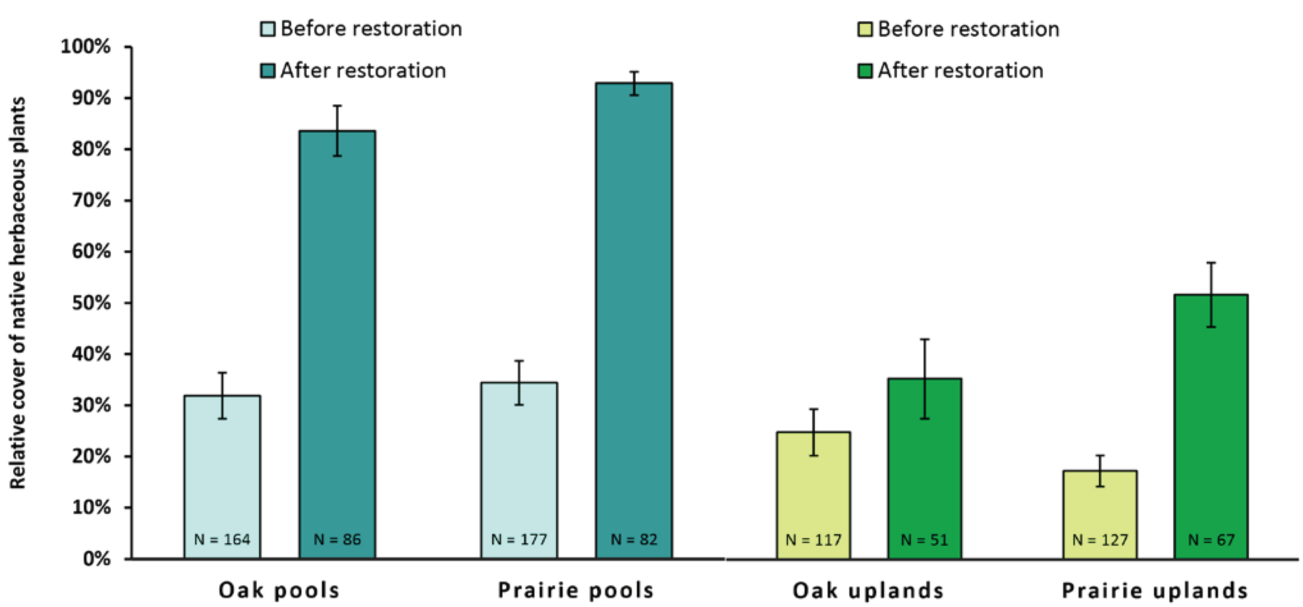


FIGURE 12. Average relative cover of native herbaceous plants before and after restoration in pools (left side) and uplands (right side) within prairie and oak habitat settings. Data are combined across years from project areas on the KPMS and VPMCB sites with both pre- and post-restoration samples. Error bars are 2x standard error, with cumulative sample size at the base of each bar.

able to operate in oak woodlands, and clearing the trees may have often been too effortful. Whatever the reason, there was generally less fill for us to remove from oak pools and thus less soil to cover upland mounds during grading. Our equipment operators were also limited in how thoroughly they could re-form mounds while maneuvering around tree and shrub cover. The result was a less clear and continuous seedbed in oak uplands.

In addition, our use of fire for restoration has been far less effective in oak woodlands. To date, we have not succeeded in getting prescribed fire to carry and consume well under oak canopy during the available prescribed burn season.[140] Shade and thicker litter accumulations under oaks support plant communities that remain green later into the season and allow surface fuels to retain moisture longer. Local oak habitats generally do not dry down enough for fire to burn off litter and vegetation until well into wildfire season, at which point the risk of prescribed burning is prohibitive. Waiting to burn in the fall is an option but does not provide the same ground-clearing site preparation or invasive grass control benefits as early-season burning.

> Increasing native plant cover is essential for restoration, but to effectively bring back habitat quality and preserve local biodiversity we must also protect and restore the *diversity* of native species.

Without fire and grading to clear a seedbed, we have not completed native seeding on oak uplands, and they are less transformed because our restoration is incomplete. In some oak areas we have even seen an *initial* drop in upland native cover following restoration. This was a predictable response in areas under invasive species pressure when there is soil disturbance that is not combined with prescribed fire or native seeding. Importantly, these examples of negative upland results seem to confirm by omission the effectiveness of our usual sequence of complementary restoration actions: burning, grading, and seeding. Our oak areas are unfinished work. We have adapted our prescribed burning plans to safely meet the objectives of bringing restorative fire (and seeding) to oak uplands at the first opportunity.[141]

Species diversity for effective restoration

Increasing native plant cover is essential for restoration, but to effectively bring back habitat quality and preserve local biodiversity we must also protect and restore the *diversity* of native species. Each plant species plays a different role in the ecosystem and the absence of species leaves gaps in ecosystem functions. These roles can be defined in many ways, as forage for grazers, cover for prey species, or nectar source for pollinators; species with similar ecological roles are often categorized into functional groups.

The simplest metric of species diversity is "richness," the number of different species present on a site or in a sample. Native richness increased by over 50% in our restoration area (from an average of six native species per sample before restoration to nine after restoration). Species diversity was highest in restored vernal pools, while the greatest increase in native diversity was achieved in prairie uplands. These increases in diversity came from both reintroduction of absent species by seeding and from increases in the abundance of native species that were already present. Upland diversity had a stronger response to restoration in part because uplands had lost more native diversity and had more to gain.

Perennial bunchgrass and wildflower species are a key component of native plant diversity that was lacking in degraded habitats on the Whetstone Savanna. Opportunistic native annuals such as popcorn flower (*Plagiobothrys*) or tarweed (*Madia*) species can often survive amidst intense competition from non-native species or on low quality sites and rebound quickly from seed when conditions allow. Bunchgrasses and perennial forbs tend to rely more on persistent live plants rather than abundant annual seed production or long-lasting seed banks; they are generally slower to establish and are more vulnerable while doing so. When conditions that enable their survival or reproduction are interrupted, or when competitive stress or grazing pressure cause excessive mortality, native perennials fade away.

Because of this, our restoration seeding emphasized re-establishing perennial forbs and grasses in addition to abundant annual species **(Table 2a and 2b)**. Sown perennials included Oregon sunshine (*Eriophyllum lanatum*), cinquefoil (*Potentilla glandulosa*), and yarrow (*Achillea millefolium*), as well as perennial grasses such as California oatgrass (*Danthonia californica*), Lemmon's needlegrass (*Achnatherum lemmonii*), and June grass (*Koeleria macrantha*). This effort led to important gains in native perennial cover in pools (40% increase), and a satisfying doubling of native perennial cover on uplands – hopefully with more increase to come as these long-lived species establish and self-seed under more favorable conditions.

The restoration story at the species level

Summary metrics, such as relative native cover or species richness, help us understand big-picture patterns of change and restoration response. But at that level, we can sometimes lose sight of the many individual species that make up the plant community and their dynamic interactions. **Table 5** brings us back to the species level with a summary comparison of the main actors in this botanical power struggle and the rise of native species following restoration. The table presents the ten most abundant species before and after restoration for pools and uplands. In each situation, the top-three species made up about one third of the relative plant cover for the habitat.

In pre-restoration pools, the top-three species were all aggressive non-native annual grasses, led by invasive seaside barley (*Hordeum marinum*), a dense colonizer of wetland margins. Only three native species were present in the pre-restoration top-ten, each with minimal cover. After restoration, all of the vernal pool top-ten were native wetland species, including a native species typical of California pools and only recently recognized as occurring

Summertime native perennial cover on restored Whetstone Savanna uplands five years after burning, grading, and seeding: bright yellow blooms of Oregon sunshine rise in a field of ripening native bunchgrasses. © *Keith Perchemlides/TNC* in Oregon, vernal pool buttercup (*Ranunculus bonariensis*). Invasive grasses were absent from the top-ten for restored pool cover, with seaside barley relegated to a meager 2% of cover in restored pools.

In uplands, the victory was not so decisive for native species, but still encouraging. Before restoration, three non-native grasses again dominated, with a combined cover of over 40%. Invasive medusahead grass (*Taeniatherum caput-medusa*) ruled the uplands, maintaining control by laying down a thick barrier of accumulated litter. Only one native species persisted in the pre-restoration top-ten, the hardy showy tarweed (*Madia elegans*). Restoration has not yet reversed the roles of native and non-native species in uplands but has established four native species in the top-ten, including another tarweed (*Madia gracilis*) in the top-three along with perennial Oregon sunshine (*Eriophyllum lanatum*). As for invasive medusahead grass, it is gone from the restored upland top-ten and, like seaside barley, reduced to a mere 2% relative cover.

TABLE 5. The top-ten most abundant species before (left) and after (right) restoration for pools (top) and uplands (bottom). In each box, species are ranked in order of average relative cover across all pre- or post-restoration samples for the strata. Species are color-coded as native (green), non-native (gray) or invasive (orange). Data are from restored areas that had both before and after monitoring completed between 2008 - 2019. Species that were included in our restoration seeding are marked with an asterisk.

POOLS BEFORE RESTORATION

COMMON NAME	SPECIES NAME	RELATIVE COVER
seaside barley	*Hordeum marinum*	20%
rat tail fescue	*Vulpia myuros*	9%
perennial ryegrass	*Lolium perenne*	8%
field brome	*Bromus arvensis*	8%
white brodiaea	*Triteleia hyacinthina*	4%
California goldfields	*Lasthenia californica*	4%
soft brome	*Bromus hordeaceus*	4%
annual hairgrass	*Deschampsia danthonioides*	3%
teasel clover	*Trifolium retusum*	2%
cutleaf geranium	*Geranium dissectum*	2%

POOLS AFTER RESTORATION

COMMON NAME	SPECIES NAME	RELATIVE COVER
stalked popcorn flower *	*Plagiobothrys stipitatus**	11%
vernal pool buttercup	*Ranunculus bonariensis*	11%
Cascade calicoflower *	*Downingia yina**	10%
whitehead pincushion plant	*Navarretia leucocephala*	8%
short woollyheads	*Psilocarphus brevissimus*	7%
toad rush	*Juncus bufonius*	4%
bracted popcorn flower	*Plagiobothrys bracteatus*	3%
annual hairgrass*	*Deschampsia danthonioides**	3%
Orcutt's quillwort	*Isoetes orcuttii*	3%
Fitch's tarweed *	*Centromadia fitchii**	2%

** species included in restoration seeding*

UPLANDS BEFORE RESTORATION

COMMON NAME	SPECIES NAME	RELATIVE COVER
medusahead grass	*Taeniatherum caput-medusae*	16%
bulbous bluegrass	*Poa bulbosa*	14%
soft brome	*Bromus hordeaceus*	12%
longbeak stork's bill	*Erodium botrys*	7%
rat tail fescue	*Vulpia myuros*	6%
little hop clover	*Trifolium dubium*	4%
showy tarweed	*Madia elegans*	3%
smooth cat's ear	*Hypochaeris glabra*	2%
ripgut brome	*Bromus diandrus*	2%
bur chervil	*Anthriscus caucalis*	2%

UPLANDS AFTER RESTORATION

COMMON NAME	SPECIES NAME	RELATIVE COVER
bulbous bluegrass	*Poa bulbosa*	12%
soft brome	*Bromus hordeaceus*	12%
slender tarweed *	*Madia gracilis**	8%
rat tail fescue	*Vulpia myuros*	8%
longbeak stork's bill	*Erodium botrys*	6%
showy tarweed	*Madia elegans*	4%
toad rush	*Juncus bufonius*	3%
little hop clover	*Trifolium dubium*	3%
Oregon sunshine *	*Eriophyllum lanatum**	2%
cutleaf geranium	*Geranium dissectum*	2%

** species included in restoration seeding*

Native camas lily blooms rise above a field of fragrant popcorn flower filling the basin of recently restored swale-bottom vernal pool. © *Keith Perchemlides/TNC*

SECTION FIVE

Demonstration Restoration

Our restoration demonstrates that precision earth-moving, combined with prescribed burning and seeding, can succeed in bringing back lost vernal pool hydrology, native species abundance, and natural landform on sites impacted by topographic alterations and invasive weeds. Our long-term ecological monitoring has documented both the need for restoration and the gains achieved. This restoration has reestablished conditions for a resilient native ecosystem to persist on the Whetstone Savanna – and developed a method that can do so elsewhere.

With vernal pool soils and hydrology restored, native wetland species were able to rebound under conditions that once again fit their specialized adaptations. Integrated with fire and seeding, soil disturbance from grading created an opportunity to push back invasive weeds and reestablish native plant communities on prairie and oak uplands. By actively augmenting threatened and endangered species on restored habitat during a window of beneficial disturbance, we have turned the tide for populations on this site, setting a hopeful example for recovery on a larger scale.

On sites where human impacts have undermined basic ecological structure and process, habitat quality can remain limited or deteriorate further, even under conservation protection. Left as-is, this type of degraded condition does not self-correct and favors invasive species over native ones, perpetuating a treadmill of rare-species intensive care and annual weed control for land stewards. Although the cost of earth-moving restoration is high, as a one-time investment to re-set ecological form and function it may be more cost effective in the long term than continuous maintenance of highly altered sites. If our conservation goal is to keep functional examples of the Rogue Valley's native vernal pool ecosystem in the modern landscape, then habitat quality is as important as acres. Holding degraded sites in conservation status falls short for the land and species we seek to protect and for the public we hope to engage.

The Rogue Valley's vernal pool habitats are a natural legacy worth protecting and restoring. Different in every season, they are a source of wonder and education, providing accessible natural areas with deep roots in local history and culture. The mound-and-pool landform creates a rich mosaic of wetland, prairie and woodland habitat, essential to a wide diversity of plants and animals, large and small, rare and common. And vernal pools can play an important role in our watershed, retaining winter rains to create seasonal wetlands, then slowly releasing the water to moderate and sustain downstream flows. Most of our local vernal pool habitat has already been lost; what remains is at risk of collapsing under intense pressure from land development, incompatible management, invasive weeds, and climate change, unless we take an active role.

> Bringing this type of transformative restoration to other degraded sites may be what it takes to achieve lasting conservation at a landscape scale and effective recovery of listed species.

Bringing this type of transformative restoration to other degraded sites may be what it takes to achieve lasting conservation at a landscape scale and effective recovery of listed species. The Oregon State Land Board has recognized the value and potential of our restoration with the 2020 Wetland Award.[142] Land Board Awards honor exceptional projects for their contribution to protecting and enhancing Oregon's natural areas. Our work was recognized for innovation, collaboration, and on-the-ground results, "setting a new standard for how habitat restoration can be done."[143] This report shares the methods we have developed, our monitoring results, and the lessons we learned as an example of repeatable success in vernal pool restoration. We hope to have set a precedent that allows others to invest in this type of intensive restoration with confidence in its ability to succeed.

Lessons Learned

Although every site, team, and project are different, there are some core restoration practices we recommend:

1. Put the pools back where they were. Vernal pool function is linked to underlying landform patterns. Pools work best at their historic location where wetland soils and drainage support strong hydrology. Building a site-specific understanding of the pre-disturbance landform and how it was altered allows for effective reversal of past disturbances. Careful restoration planning increases the efficiency and success of operations. The time invested in developing a detailed grading plan is worth it.

2. Be ready to continuously adapt. Restoration planning and grading must be able to flexibly adapt to achieve a best fit between site conditions and goals. Active learning and communication are key. Soil structures and disturbance patterns revealed during pool excavation provide essential information to confirm or adjust plans. Integrating cycles of topographic measurement and review into the workflow enables fine-tuned grading to achieve strong hydrologic function and a natural landform.

3. There's no substitute for a skilled team. The success of earth-moving restoration depends heavily on the ability and commitment of the equipment operators. When skilled operators and knowledgeable ecologists work together, sharing what they know, the outcomes consistently benefit. Coordination by an effective project manager is the foundation of a solid team. Investing time in operator training develops essential understanding, communication, and mutual respect – and when the same team members return year after year, these strengths continue to grow.

4. Combine complementary restoration actions. Certain restoration actions create enabling conditions that increase the effectiveness of subsequent steps. Project workflows that intentionally combine complementary actions increase success. For example, prescribed fire increases grading effectiveness, reduces weed seed, and stimulates native species germination. Grading then restores habitat conditions that favor native species and creates an ideal opportunity for establishment from seed. Seeding immediately after grading limits the establishment of invasive weeds and holds disturbed soils in place against erosion.

Members of our restoration team pause to examine and discuss soils and disturbance patterns, adapting grading to new information. © *Keith Perchemlides/TNC*

The Rogue Valley Vernal Pool Information Network[144], including state and federal agencies, local government, contractors, non-profit organizations, and interested members of the public discuss vernal pool ecology and restoration on a field-tour of a newly restored area of Whetstone Savanna. © *Karen Hussey*

5. Encourage evolution of methods. There is no set prescription for this type of restoration. Method development needs to be an active process based on trial and error while striving for the best results and most efficient workflow. Each project differs by landform, disturbance history, habitat type, and opportunities or constraints on operations. By letting go of assumptions, trying out new tools and approaches, and learning from all sources, restoration methods evolve to meet the needs of each site. Cumulative experience is a strength for multi-year projects.

6. Monitoring is integral to restoration. Ecological and topographic monitoring that is directly linked to project objectives is well worth the effort. Monitoring before, during, and after restoration, provides critical information for planning, adapting methods, evaluating success, and communicating results. Monitoring data reveal important patterns that could otherwise be overlooked. Through on-site monitoring, ecologists build a deeper relationship with the land and understanding of site conditions essential to restoration success.

7. Leverage available funding sources. Earth-moving restoration on highly impacted sites is costly. Compensatory mitigation can be a powerful force for achieving this type of intensive restoration. ODOT's commitment to this work sets a strong example for wetland mitigation and listed species recovery. Integral to transportation budgets, mitigation can provide a large one-time infusion of funding to purchase lands and restore basic ecological function. This initial investment can enable effective long-term management with lower-level funding such as conservation endowments.

8. Collaboration benefits go beyond the project. Bringing together multiple organizations, agencies, and contractors allows all parties to pool strengths, share resources, and learn from each other. This collaboration improves the quality of the restoration while developing a foundation of local capacity and expertise for future work. The relationships and learning built around the work live on and create local networks capable of accomplishing the next restoration.

Reflected canopies ripple on the surface of restored pools in a rain soaked oak woodland. *© Keith Perchemlides/TNC*

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