Gambel Oak Ecology and Management in the Southern Rockies: The Status of Our Knowledge

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JOINT FIRE SCIENCE PROGRAM

SOUTHERN ROCKIES FIRE SCIENCE NETWORK

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Executive Summary

Gambel oak (*Quercus gambelii*) is one of the most widespread mountain shrub species through the Central Rockies region – found in most counties in Utah, Colorado, and portions of southern Wyoming and in Arizona and New Mexico. Although it is ubiquitous, in Colorado and Utah surprisingly little research has been devoted to understanding Gambel oak ecology, habitat management, or the dynamics of fire behavior in pure Gambel oak or mixed mountain shrub stands. This knowledge gap was identified as a significant regional research need in the early developmental stages of the Southern Rockies Fire Science Network.

This publication is an outcome of field discussions held between agency managers, researchers, and university scientists to bring together existing research and publications as well as current management knowledge, then combined with the authors' field and career observations. Subsequent collaboration between the Rocky Mountain Research Station, The Nature Conservancy, Utah State University, the U.S. Forest Service, Bureau of Land Management, and the Southern Rockies Fire Science Network resulted in literature searches, workshops, and research on the current body of knowledge regarding Gambel oak in the central Rockies, with a geographic focus on Colorado and Utah. This publication identifies nine key points summarizing the current status of our scientific understanding of Gambel oak in this region.

The need for in-depth research on Gambel oak as well as comprehensive understanding of current management strategies is underscored by changes in climate, increase in drought, changing forest conditions and health, and the dramatic spread of homes and structures in the wildland-urban interface in Gambel oak habitat. What are the ecological similarities and differences in various Gambel oak habitat compositions? What do we know about fire behavior in Gambel oak? What are the challenges and obstacles in landscape management? How do we successfully manage Gambel oak in the wildland-urban interface?

To provide answers to these and other questions, five general categories of research needs have been identified to frame research questions in support of further research efforts. The topics include a better understanding of community classifications and descriptions, increased understanding of oak ecology and associated tree and shrub communities, impacts and subsequent management options for climate change, and increased understanding of both fire behavior and ecological effects in these communities.

Greater knowledge and progress is needed in understanding treatment options and effectiveness for long-term management. The authors intend to use the Southern Rockies Fire Science Network as a platform for the exchange and dispersal of Gambel oak knowledge on www.southernrockiesfirescience.org.

For more information, or to order hard copies, contact the Southern Rockies Fire Science Network: www.southernrockiesfirescience.org.

Photo: Moderate intensity fire activity on the Yellow Jacket Prescribed Fire, 2015 (Photo courtesy Chris D. Tipton, Zone Fire Management Officer, San Juan National Forest).

Front cover photo: Gambel oak/conifer habitat in Northeast Utah (Photo courtesy Utah State University Forestry Extension).

Introduction

Gambel oak is a prominent and ecologically important component of natural vegetation in the Southern Rocky Mountains and Southwest. Woodland and shrub communities dominated by Gambel oak (*Quercus gambelii*) are widely distributed in Colorado, Utah, Arizona, and New Mexico. Gambel oak has long been recognized to have important benefits and uses such as supplying high-quality fuelwood and wildlife habitat, and has been managed for various benefits for a century or more. In Colorado and Utah, oak is generally found on moderate to steep slopes, and on a diverse range of soil types. With understory grasses, forbs, and other shrub species, oak provides primary protection against soil erosion over large areas.

Diverse wildlife species, both large and small, utilize oak for food and cover. Wildlife use often varies seasonally depending on migration patterns across both longitudes and elevations. Gambel oak is a preferred habitat type for elk and deer during winter months when snow limits accessibility to higher elevations and where oak is not too dense. Black bears and turkeys utilize Gambel oak for spring habitat, and acorns are an important fall food resource for a variety of species. In many areas, oak-dominated communities have provided herbaceous plants for domestic livestock grazing for well over a century.

Throughout their range, Gambel oak shrublands have been impacted extensively by both natural and human-caused disturbances, including fire, fire suppression, grazing, and mechanical treatments. A host of management practices have been implemented for a range of intended objectives and have focused more on pure or nearly pure Gambel oak communities instead of those dominated by other mountain shrubs. Yet the ecology of pure or nearly pure Gambel oak communities and effects of natural and human disturbances on them are not well understood. Furthermore, there is widespread recognition that management practices often fail to achieve desired benefits, or that benefits exist too briefly to justify treatment expense.

This report examines the status of our scientific knowledge about the ecology and concomitant management implications of Gambel oak and associated species, with a geographic focus on Colorado and Utah where published literature is notably limited. Through this effort we hope to set the stage for increased discussion and research that will provide land managers with a more complete understanding of the Gambel oak ecosysyems throughout the Southern Rockies region.

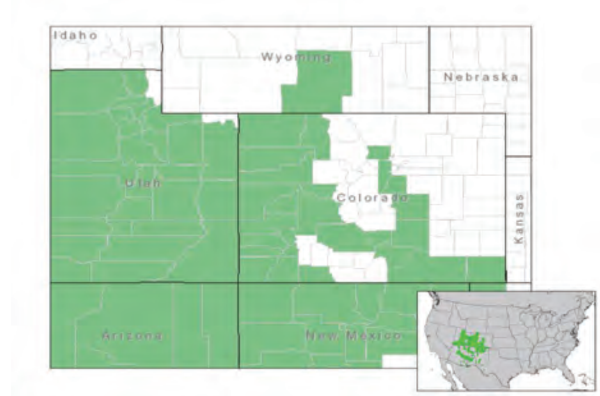


Figure 1. The geographic distribution of Gambel oak throughout the Southern Rockies region by county (Map data: USGS. 1971, USDA 2016)

General environment

Gambel oak and associated species in Colorado and Utah occur primarily at the lower forest ecotones and are frequently found in a band separating or overlapping with forest and grassland or sagebrush zones. Gambel oak may be the sole dominant in woodlands or shrublands covering extensive areas, or it may be associated with prairie grass communities, montane sagebrush steppe, mountain shrublands, piñon/juniper woodlands, or forests composed of various combinations of ponderosa pine, Douglas-fir, white fir, quaking aspen and big-tooth maple (See figure 4). For clarification of terminology used in this document, Gambel oak shrublands or simply oak or oak shrublands refer to Gambel oak communities including associated shrubland and tree species. Where Gambel oak occurs alone as pure stands or patches, terms such as pure Gambel oak or pure oak will be used.

Gambel oak tolerates a wide range of environmental and soil conditions. Furthermore, Gambel oak readily resprouts after fire, heavy grazing, or other disturbances, and in some parts of its range it may reproduce by prolific acorn production and germination. Thus oak remains one of the most persistent, stable, and common components in the landscape even after severe disturbance. Species-specific differences in environmental and soil requirements, response to disturbances, and reproductive processes contribute to the wide range of associations and community types that include Gambel oak.

Wildfire and Gambel oak

Under moderate burning conditions, Gambel oak is resistant to fire spread and can serve as a "greenbelt". However, Gambel oak communities often have heavy and continuous fuels, and under more severe burning conditions, wildland fires may be explosive and difficult to suppress. Even in complex, diverse landscapes natural fuel breaks may be relatively uncommon. Wildland fires in Gambel oak shrublands pose serious threats to firefighters and the public. Fast-moving fires can rapidly consume large areas of vegetation and in some cases carry intense fire into the wildland/urban interface where human life and property are at risk. The memorable 1994 South Canyon Fire in Gambel oak on Storm King Mountain near Glenwood Springs, Colorado was particularly devastating, killing 14 firefighters. In 2012, Gambel oak contributed to intense fire behavior reaching well into urban areas in Colorado Springs, Colorado, with the loss of more than 300 homes during the Waldo Canyon Fire. Understanding and managing both the spread of fire and subsequent impacts fires have on post-fire ecology are important considerations in oak management.

Figure 2. South Canyon fire, July 6, 1994 between 16:30 and 17:00 (Photo courtesy Wildfire Today, July 2014).

Previous Gambel oak research and current assessment

Considerable research has been done on Gambel oak vegetation (see suggested reading list), but because oak occurs over such a wide range of landscape settings and conditions throughout much of the southwestern US, generalizations about oak ecology and management have been elusive. This report reviews the status of our knowledge about oak ecology and management in Colorado and Utah, where research is notably incomplete. While many informal studies have been conducted in these two states, and numerous valuable experiences can be shared, few of these have adhered to sound scientific procedures or have been well documented and made available in published form.

While a significant portion of the content in this report reflects information found in published literature, a large amount of information was obtained through workshops and interactions with individuals having experience in Gambel oak ecology and management but whose findings have not been published. We have chosen not to cite references in the text as normally done for published scientific works, in part because this is an assessment of our knowledge including insights from unpublished studies and observations. Therefore, a suggested reading list has been provided that compiles known scientific research in the central and southern Rockies area. Additionally, readers may refer to a publication on Gambel oak by Simonin (2000) in the Fire Effects Information System (FEIS), a helpful resource for finding much of the literature that is available.

Our goal in this report is to assess the status of our knowledge (both published and unpublished) about oak ecology and management in Colorado and Utah. We examine the various types of stands and communities featuring Gambel oak in this geographic area. We review the knowledge available and gaps in our understanding, and summarize research needs for improving our ecological understanding and evaluating management objectives and practices.

Two stages of investigation were undertaken to develop a current assessment. First, a literature review was completed in 2013 searching for any available science in the central Rockies and Southwest regions. Second, a series of three small regional workshops was held in 2014, one in Utah and two in Colorado (west and east of the Continental Divide) in areas where Gambel oak management is a significant issue. At each of these workshops, discussion focused on developing a set of key points to determine our degree of understanding of Gambel oak ecology and management and any significant differences among the three regions. We welcomed insights based upon field experience as much as those found in published form. The following section presents these key points and reflections on the status of our knowledge. Numerous knowledge gaps were apparent, and a section on research needs summarizes the more important areas of uncertainty warranting attention.

Key Points

Key Point One: Not all Gambel oak communities are the same.

Gambel oak is adaptable to a wide range of environmental conditions, and thus may be associated with a wide variety of shrub and forest tree species. Furthermore, Gambel oak resprouts aggressively after fire or mechanical treatments kill back the above-ground parts, and because not all associated species resprout, this difference can affect the relative dominance of species in post-disturbance communities. Resprouting eliminates many of the reproductive difficulties associated with seed production, distribution, germination, and establishment that occur with non-sprouting species, thereby allowing oak to remain a stable plant community component. Not surprisingly then, descriptions of Gambel oak include a wide variety of growth forms and plant associations.

Numerous combinations of oak and its associated species occur, and it would be easy (but not necessarily helpful) to prepare an exhaustive list detailing these combinations. Workshop participants agreed on the most common Gambel oak ecosystems (See Figure 4).

Other tree species associated with Gambel oak may be important locally but less common regionally, including bigtooth maple, aspen, and white fir.

Key Point Two: Considerable uncertainty exists about the long-term ecology of Gambel oak ecosystems.

Gambel oak occurs not only across a range of community types, but also a range of growth forms and environmental conditions. Oak communities exist and survive as clones and rely on resprouting after severe disturbance that kills above-ground parts. Mature plants and sprouting root systems may have greater environmental tolerances than new regeneration from seeds.

Oak in Colorado and Utah has many more ramets or suckers per clone available for resprouting from the root system than oak in Arizona and New Mexico. Resprouting of oak after removal of the above ground parts comes primarily from lignotubers, and clonal spreading of oak occurs from rhizomes. Both lignotubers and rhizomes are abundant in the below-ground root system. Their dispersed occurrence both vertically and horizontally below the surface may provide protection from extreme fire events, and also from herbicide or mechanical treatments intended to suppress or kill the plants. Acorn production may be regular and even prolific in mesic sites especially in the southern two states, but acorn production, germination, and seedling establishment is less common in Colorado and Utah, especially on drier sites. A contributing factor is that oak in Colorado and Utah experiences less consistent summer monsoon precipitation.

Figure 3. Gambel oak in mature tree form in Southern Utah, taken by Kevin Heaton, Utah State University Forestry Extension.

Common Gambel Oak Ecosysyems

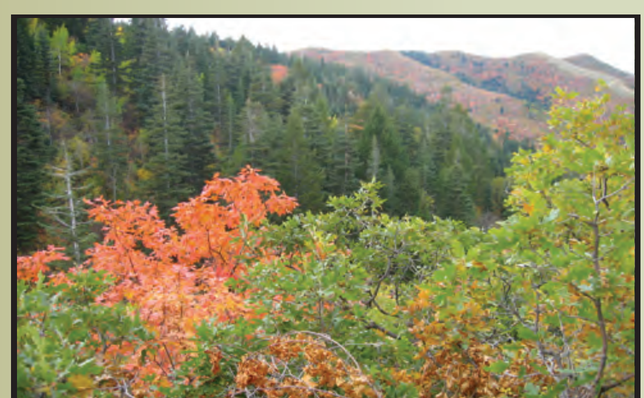
Gambel oak dominated: Gambel oak is commonly found in pure or nearly pure stands, with few other shrub or tree species present. Pure oak may be a savannah type with large stems, or it may exist as dense, shrubby stands with smaller stems (Photo courtesy Katie MacKnight).

Gambel oak/mountain shrub: Gambel oak is frequently associated with a variety of other mountain shrub species, including snowberry, serviceberry, chokecherry, bitterbrush, mountain-mahogany, and sagebrush (Photo courtesy Darren McAvoy).

Ponderosa pine/Gambel oak: Gambel oak is frequently associated with an overstory of ponderosa pine. The pine overstory varies widely in density, ranging from scattered trees and open canopy (sparse ponderosa pine/Gambel oak) to relatively closed canopies (dense ponderosa pine/Gambel oak). (Photo courtesy Katie MacKnight).

Piñon/juniper/ponderosa pine/Gambel oak: Gambel oak occurs with an overstory including piñon pine, juniper species, and ponderosa pine (Photo courtesy Rebecca Samulski).

Piñon/juniper/Gambel oak: Often found with scattered or dense piñon/juniper without ponderosa pine (Photo courtesy Rebecca Samulski).



Douglas-fir/Gambel oak: Some sites are vegetated with Douglas-fir in the overstory and Gambel oak in the understory (Photo courtesy Darren McAvoy).

Figure 4. Workshop participants agreed on the most common Gambel oak ecosystems.

Surviving the environment

Oak exhibits classic responses of many arid or semi-arid zone perennial woody species to long-term and short-term trends in precipitation and soil water supply. Some responses are evolutionary, involving the development of xeromorphic adaptations to relatively hot, dry climates. These drought resistance adaptations include both drought avoidance and drought tolerance mechanisms. Drought avoidance adaptations include the capacity for roots to extend deeply in the soil to absorb water, and the capacity for foliage to protect against lethal water loss through excessive evapotranspiration. In general, deep roots provide a margin of protection during droughts when upper layers of the soil profile dry out. And concurrently, relatively thick, small, and heavily cutinized leaves limit solar energy absorption and excessive evapotranspiration rates when high but sub-lethal levels of plant water stress develop.

In contrast, Gambel oak acclimation to drought involves plant adjustments to seasonal and annual differences in water availability. Acclimation occurs primarily through water absorption and water loss mechanisms. Plants constantly undergo checks and balances that lead to an acceptable (e.g. survivable) relationship between root water absorbing capacity, leaf evapotranspiration capacity and control, and photosynthesis for root and shoot maintenance and growth.

Drought adaptations and acclimation processes enable oak to reach a tree growth form in some settings (See figure 3). The tree form of Gambel oak is generally found on lower, more gentle slopes where soils are deeper and sites are more mesic. However, in more xeric sites oak remains small. Internal water stress develops on drier sites where soil water is limiting or where exposure favors high evapotranspiration, which in turn limits photosynthesis and growth. Thus over time internal feedbacks result in plants achieving a size best suited for site-specific environmental constraints that occur annually, especially during the growing season.

Gambel oak is found on a range of soil types. In Colorado and Utah, oak may tolerate heavy clay soils more readily than ponderosa pine and other tree species. Availability of moisture is a significant factor. Soils that are shallow and contain rock and gravel may support Gambel oak vegetation, but the oak is likely to develop only as low shrubs with no potential for reaching significant heights or densities. In addition, oak seedling establishment may occur more readily on coarse-textured soils having better drainage, a factor that may be important for species migration in the event of climate change (discussed later in this report).

Shrubby patches or thickets of oak are the predominant form of Gambel oak in Utah and Colorado. Patches range from three to 15 feet or more in height. Gambel oak in these two states also exists as patches in savannahs with small trees reaching 20 feet or more in height, but trees are generally shorter in Utah and Colorado than in Arizona or New Mexico. Patch sizes for shrubby clumps may be as small as a tenth acre or less (perhaps a single clone), but patches with relatively similar community types and growth forms may extend for hundreds of acres or more.

The diversity of sites and environmental conditions suitable for Gambel oak indicates a complex and diverse ecological range for oak and its associated species. Variations in natural (especially fire) and human-caused disturbances add additional variability to patch and stand structure across the landscape. This range results in part from recent patterns and differences in natural and human-caused disturbances, which affect current community structure and composition in oak landscapes. Genetic evolutionary adaptation and short-term acclimation to local environmental and climatic conditions both contribute to Gambel oak's complex ecology as well.

Gambel oak ecology

The ecology of Gambel oak involves a host of processes and responses, built upon and accommodating all the eco-physiological realities (see previous section) each shrub, tree, or clone must tolerate to survive and grow in a semi-arid and relatively warm environment. The ecology involves all the life cycle phases and processes, from germination or sprouting through to maturity. Gambel oak attains individual plant/clone longevity through vegetative reproduction in environments rarely favorable for new seedling establishment. Extensive root systems and re-sprouting facilitate rapid recovery of plants and clones not only in response to fire and drought, but also following other natural disturbances such as frost damage or insect attack, and they provide an advantage for oak over other species competing for limited resources.

The role of Gambel oak in successional trajectories varies widely depending in large part on the types of plant communities present and the life cycle and competitive interplays between oak and associated species. Oak may be a climax species in foothill ranges where sites are not suitable for forest trees. Where seed sources and suitable environments for tree species exists, oak may be a persistent subclimax species, provided that tree seedlings of other speciers are shade tolerant and can grow in the conditions found beneath an oak canopy before they overtop the oak. New site occupation by oak is rare under present climatic conditions, and it is unclear how rapidly and successfully colonization of new sites may occur under climate change scenarios.

We have only limited understanding of Gambel oak communities in their natural, pre-Euro-American settlement state. Unlike many other systems, we have few protected park or other lands where oak ecology has remained undisturbed by human-related influences. Furthermore, Gambel oak has low economic value compared with commercially valuable tree species, and historical records reflecting descriptions and inventories before significant management impact are rare.

These uncertainties about oak ecology do not suggest that Gambel oak is in peril. As a species, Gambel oak is nearly indestructible, and, in Colorado and Utah, it generally survives even aggressive attempts to manipulate or suppress it. The broad distribution of oak leads to multiple roles of oak in ecosystem conditions and processes across diverse landscapes, including benefits for countless animal species at various times in the annual and vegetative development cycles. Rather, oak survives and often thrives, with a strong resprouting response to many, if not most, attempts to suppress it. Nonetheless, with relatively little knowledge about historical oak ecology, it is unclear if oak communities and associations with other species are in a healthy, sustainable condition. For example, is ponderosa pine with an understory of thick shrubby oak at risk of elimination by catastrophic fire, or is sagebrush with oak sustainable or at risk of being overtaken by oak? Do ecosystems with an oak component provide historically appropriate benefits and conditions for local and migratory animals? Moreover, with other oak species in different regions already being afflicted or devastated by introduced pests, will a pest emerge that will similarly affect Gambel oak?

Key Point Three: Fire is the dominant natural disturbance agent causing changes in Gambel oak communities over time, with effects of drought, frost, insects, and diseases having additional long and short term effects.

Gambel oak is a fire-adapted species. Fire frequency prior to Euro-American settlement is not well understood, however, because physical evidence such as fire scars is nearly non-existent in oak. Patterns of fire behavior have been examined by

Figure 5. Gambel oak regrowth 8-10 years post-wildfire in a ponderosa pine/oak stand. Note raised crown base height in pine, dead oak stems in understory, and prolific re-sprouting of oak in the understory (Photo courtesy Dan Huisjen).

dating and mapping the ages of post-fire oak stems, though such assessments are difficult where other disturbances (natural or human) have also affected the oak community. Fire frequency is often assumed, in at least some cases, to be closely associated with patterns typical for overstory species that are present or nearby. Ignition by lightning may occur within oak-dominated communities, or fire started in nearby forests may burn into oak communities. It is generally believed that fires historically occurred more frequently in Gambel oak communities in Arizona and New Mexico than in Utah and Colorado, partly following differences in fire frequency in ponderosa pine forests in the two regions. Nonetheless, clear evidence supporting this conclusion is limited.

When Gambel oak reaches its maximum size and density (roughly 60-80 years), shoot mortality increases and adds fuel, which may lead to increased ease of fire ignition and spread, and higher burn severity. Since Euro-American settlement, mean fire return intervals have probably been well over 20 years and perhaps as long as a hundred years or more unless fire has been used for management purposes. Current fire suppression practices undoubtedly are extending the time between fires. However, because good historical fire data specific to oak are rare, it is not certain how current fire frequencies differ from historical patterns, especially given the wide range of plant communities that occur with a Gambel oak component.

Fire commonly kills the crowns of Gambel oak and any other shrub species that are present. The tree form of Gambel oak may survive low-severity surface fire if understory fuels are not excessive. Oak stands may burn more readily in the fall when fuels are dry and dead leaves remain on branches, but oak may burn any time in the growing season when fuel and weather conditions permit. Drought, spring frost, disease, and defoliating insects may alter Gambel oak productivity and vigor, but these disturbances are unlikely to eliminate oak from a site. The more significant effect is that these natural disturbances may affect fire behavior. Shoots killed by late spring frosts contribute to fuel loading, and occasionally insect damage to oak or associated species may also increase fuels (e.g. Ips beetles in piñon pine in southern Colorado and Utah).

Crown fires in Gambel oak communities have an immediate ecological effect: a resetting of the successional state back to openings with little or no above ground live woody biomass. Fire rarely if ever kills the root systems of Gambel oak, however. Vegetative resprouting from lignotubers and rhizomes produces new shoots and leaves, with time of emergence of new oak shoots largely depending on the seasonal timing of the fire in the annual growth cycle. Where oak exists with a sparse forest overstory, fire may kill the trees as well as top-killing oak. Oak woodlands with bigtooth maple in Utah may have lower combustibility than stands having conifers, which are more resinous and have more persistent litter.

Because Gambel oak resprouts, oak has a major post-fire competitive advantage over tree and other shrub species lacking resprouting capability. Oak stands emerging after lethal crown fire are often pure oak, and if overstory trees of other species were also killed, oak resprouting may result in a type conversion from oak with sparse forest trees to pure oak. Tree species such as ponderosa pine may not be reestablished after complete crown fire mortality. When intense fires occur in oak communities with a forest overstory, the resprouting oak may be the predominant species for decades or a century or more, depending on seed sources and conditions for germination and establishment for other shrub or tree species.

Key Point Four: Exclusion of fire from Gambel oak communities often but not always results in increased biomass and decreased landscape diversity, and may have variable effects on stand continuity.

Fire and decomposition processes are the only effective natural avenues by which living or dead biomass in Gambel oak communities is reduced. Fire and decomposition have very different effects on shrub communities, however. For all perennial plant communities, vegetative growth results in gradual accumulation of both above-ground and below-ground biomass. In mesic vegetation historically having only infrequent fire, live and dead biomass accumulates at rates dependent largely on plant age, stand density, and site productivity. After stand initiation, primary productivity (carbon gain) is generally much higher than decomposition, and net growth continues until stands mature. Eventually, offsetting processes (plant respiration and decay of organic matter) in perennial communities increase carbon loss as carbon gain from photosynthesis stagnates. In mesic environments where fire is uncommon and stands reach an advanced age (e.g. subalpine spruce/fir forests), rates of carbon gain and loss eventually match and net primary productivity falls to zero.

Fire-adapted species and communities, including Gambel oak, are unlikely to reach such an old-growth condition unless fire is successfully excluded for a very long time. But the absence of fire has other, more determinant effects on the structure and species composition of Gambel oak communities, particularly at larger spatial scales during fire supression. In recent decades, the ecological reset that historically was initiated when fire eliminated the above-ground live biomass no longer occurs. Thus the pattern of oak reestablishment after fire is replaced instead by persistence of later vegetative stages of the successional trajectory, and the elimination of new emergent patches of young Gambel oak. While shrub and tree species diversity is likely to remain high in the absence of fire, the spatial patterns of structural and age class diversity in the landscape caused by fire are lost, and landscapes become increasingly homogeneous because younger successional stages become less common.

Key Point Five: Past logging of ponderosa pine has increased oak stem count and patch density in the short term and in some cases stand continuity in the long term.

Where ponderosa pine co-exists with Gambel oak and reaches commercial size, heavy logging often leads to increased oak densities. The removal of overstory trees increases light transmission to the shrub canopy, and reduces tree competition for water and other resources. Logging also disturbs the soil and root systems and damages oak shoots. Ponderosa pine regeneration is often sporadic, limited both by infrequent years of good seed production and by unreliable seedbed conditions when seeds are produced. Even with adequate pine seed supplies in litter, rapid re-sprouting and growth of Gambel oak may limit pine regeneration and establishment for many years.

Protection of pine seedlings and saplings present at the time of logging may be critical for sustaining ponderosa pine after logging. Replanting may be desirable in areas where forest seedlings and saplings are understocked after fire. However, it is not clear that transplanted tree seedlings will survive and grow given strong oak competition. A strategy for determining how to protect or replace forest trees in Gambel oak communities is needed to assure an important forest component in the landscape is not lost.

Key Point Six: Gambel oak shrublands have been managed for several purposes, most of them designed to affect the structure, composition, or function of oak communities.

Figure 6: Treatment was comleted in July 2005 on the Dolores Ranger District, San Juan National Forest. Objectives were to break up continuous mountain shrub fuels and create multiple age/size classes in the oak; and to reduce ladder fuels around ponderosa pine in preparation from prescribed fire. This project was also designed to benefit deer and elk by providing palatable mountain shrub sprouts (Photo courtesy Todd Gardiner).

Figure 7. Before treament (Photo courtesy Todd Gardiner).

Figure 8. After treatment (Photo courtesy Todd Gardiner). Hydro-ax treatment was completed in May 2012 on the Dolores Ranger District, San Juan National Forest. Objectives were to break up continuous mountain shrub fuels and create multiple age/size classes in the oak; and to reduce ladder fuels around ponderosa pine in preparation for prescribed fire. This project was also designed to benefit deer and elk by providing palatable mountain shrub sprouts.

Gambel oak communities are extensive, and they provide many natural resource benefits for wildlife and domestic management purposes. Management goals include wildlife habitat enhancement, improved grazing conditions for livestock, improvement of age-class diversity, and wildfire hazard fuels reduction. Regional and local management objectives have differed and shifted in importance over the last century or more, often in response to needs or desires of local human populations. Most management objectives focus on Gambel oak, though other shrub species also have received some attention for natural resource benefits. While several of the associated mountain shrub species also have resprouting capability, oak's sprouting response is so strong that fire and other treatment options should be carefully evaluated if other species are desired in the subsequent shrub or forest community.

Large areas provide multiple opportunities for achieving management objectives, and treatments have often been implemented with multiple goals in mind. Most treatments in Gambel oak communities focus on removing or thinning the Gambel oak overstory and creating openings in the oak canopy. Openings provide access and movement corridors for animals. Creation of openings where they have been lost over the last century results in new young stands of oak, increasing overall stand age diversity and providing more variation in oak densities and sizes in the landscape. Treatments that reduce oak competition provide improved grass and forb production for grazing species (wildlife and livestock), and young oak shoots for wildlife browsing. Reducing canopy size, density, and continuity also may reduce fire intensity and rates of spread.

It is worth noting that treatments in Gambel oak communities in Colorado and Utah rarely qualify as "restoration" in the context of returning to pre-settlement conditions. Knowledge of the historical ecology of oak in Colorado and Utah, including historical stand composition, structure, and keystone processes such as fire, is too limited to determine the degree of departure of current oak communities from those present before Euro-American settlement. Without adequate knowledge of historical conditions to serve as a reference, nor availability of contemporary remnants free from manipulation (without past logging, livestock grazing, or fire suppression), it is difficult to develop true restoration treatments for Gambel oak. Rather, management activities may be justified more on the basis of current management goals such as those stated in the paragraphs above, including management toward improved ecological trajectories where disturbances have been extreme and historical ecological conditions have been disrupted.

Key Point Seven: Most management prac-

tices in Gambel oak communities that are intended to limit the spread or intensity of wildland fire, improve habitat for wildlife, or increase forage for domestic livestock grazing are successful for no more than a decade.

Treatment practices for the management of Gambel oak communities fall into four main categories: mechanical manipulation of vegetation structure, shoot browsing by goats, fire, and herbicides. Each type of treatment strives to reduce Gambel oak size, density, or biomass. Mechanical treatment methods have included chaining, roller chopping, mastication, raking, bull dozing, and root plowing, all intended to physically damage or remove above-ground biomass or disrupt below-ground structures. Browsing by goats is a limited practice effective in reducing oak canopy biomass in small areas for brief periods. Prescribed burning is used alone or in combination with mechanical or herbicide treatments. Herbicide use has focused on both top kill and complete kill including below-ground structures.

Many of these treatments result in rapid changes in the above-ground structure and density of Gambel oak communities. Biomass is either collected in piles, chopped or crushed and left on site, browsed, or consumed by fire, and the desired treatment benefits are reached in a short amount of time. Alas, few of these treatment effects last as long as a decade, or at most up to 15 years. Depending upon treatment objectives, a 10-15 year benefit may be acceptable, and in any case treatments add age-class diversity to the landscape. Regardless of the type of mechanical treatment used, or browsing or fire intensity achieved, resprouting is such a strong feature of Gambel oak ecology that most treatment effects do not persist, necessitating repeated treatments if effects are desired over the long term. Killing both the above-ground and below-ground structures is virtually impossible with any treatment other than possibly strong herbicides. Furthermore, subsequent retreatment with similar or modified treatment practices intended to further weaken plants and eliminate sprouting, even if economically feasible, also fail after a few years, again testimony to the strength of resprouting as a species survival mechanism.

Figure 9. Approximately 3 growing seasons post-prescribed burn in a ponderosa pine/pinyon-juniper/oak stand. Note dead juniper, raised crown base height in pine, and prolific re-sprouting of oak. The objectives of removing juniper and raising crown base height in pine were met; however the re-sprouting oak was not anticipated to this extent, significantly reducing the long-term effectiveness of the prescribed burn treatment (Photo courtesy Dan Huisjen).

Thus the goals of reducing fire intensity or severity, improving wildlife or livestock grazing habitats, or increasing structural diversity in the landscape at best can be achieved only for the short term of a few years, largely because they are counter to the natural ecology of Gambel oak. It is often stated that most disturbance treatments intended to reduce oak in fact cause such a strong recovery response that the final outcome can be even farther removed from the intended result than existed before treatment.

Key Point Eight: Careful use of herbicides that results in root mortality may be effective for a variety of management objectives benefiting from patchy elimination of oak.

Control of Gambel oak with herbicides is highly variable, depending on developmental stage, season, and type of herbicide. Herbicides may have little or no effect, or may even induce prolific sprouting, which reduces fire suppression effectiveness or forage production for wildlife and livestock. Herbicides providing some effectiveness in controlling or killing Gambel oak often cause collateral damage to understory herbs and grasses, and in some cases have a soil sterilizing effect. No herbicide treatment short of soil sterilization has been identified that effectively eliminates Gambel oak in one treatment, and even with follow-up treatment elimination of oak is rarely achieved.

Gambel oak in the Wildland Urban Interface

Even with the known limitations of Gambel oak control with herbicides, protection of properties in the wildland/urban interface may warrant the consideration of herbicide use at the urban fringe as a way to break up fuel continuity. Obviously concerns about environmental safety cannot be ignored. Yet risks are real for loss of property and human lives associated with rapid fire spread through oak communities. Wildfire in Gambel oak adjacent to housing in Colorado Springs, CO during the 2012 Waldo Canyon Fire illustrated how effectively fire in oak entered an urban development and destroyed many houses and other structures. This is complicated by the fact that oak is often highly valued and thus retained for landscaping.

Complete elimination of Gambel oak over large areas may not be necessary to reduce wildfire risk in the wildland/urban interface. Well-placed openings in oak canopies offer potential opportunities for arresting fire spread in a fuel break zone, provided the vegetated cover in openings lends itself to more effective fire suppression efforts. Thus herbicide use to control Gambel oak growth in suitably placed patches may be an effective urban interface protection strategy.

Key Point Nine: Climate change may affect Gambel oak in multiple ways, but the full extent of these effects is unclear.

Geological records, information obtained from studies of Gambel oak identified in packrat middens, and studies of hybridization within the *Quercus* genus suggest that the geographic distribution of Gambel oak has long been affected by climate, with migration of oak to present distributions in Colorado and Utah occurring in fairly recent millennia. Many questions remain regarding current patterns of distribution in relation to past and recent climate. For example, why is it found in some locations but not in others? What has governed migration to current locations or limited migration to other areas?

While social disputes about current climate uncertainties abound, evidence is clear that climate has become more variable and uncertain in the last several decades than generally seen since weather and climate records began. Rates of climate change appear to be greater than suggested in the geological history of the earth, an exception being temporary but rapid atmospheric cooling caused by large volcanic eruptions.

Dozens of models predicting climatic patterns in the decades ahead are available, and model predictions of regional temperature and precipitation patterns vary widely. Few models, however, predict no change. Thus a consideration of potential effects of climate variability is important, even if the direction and magnitude of change for climate variables is uncertain.

A growing number of biological observations, from local to global, suggest that various species, communities, and ecosystems are being affected by recent climatic conditions in ways not experienced since modern climatic data have been recorded. In certain cases, such as the possibility that past logging created landscape age structures unusually susceptible to damaging agents, climate change may interact synergistically with past land uses to amplify ecological change. Examples of recent and on-going large-scale biological effects in Colorado and Utah include mountain pine beetle mortality in lodgepole pine, spruce beetle in Engelmann spruce, and sudden aspen decline. Each of these is a type of natural disturbance often observed over the last century or more, but the intensity, frequency, rate of development, and spatial extent exceed expectations based upon earlier known disturbance patterns. It is not well understood if the Medieval warm period resulted in such extensive and intense biological effects.

Models of future climates enable the examination of spatial locations of suitable environment for plant species.

Environmental suitability for tree species has changed before, reflected in dendrochronological evidence of changes in tree species distribution as far back as the Medieval warm period a millennium ago and the Little Ice Age beginning several centuries ago. Recent trends in temperature and precipitation and climate model predictions for the rest of the 21st century suggest that the spatial distribution of suitable environments for major tree species in the Interior West are likely to be shifted upward to higher elevations and northward in latitude.

Species responses to temperature and precipitation are extremely complex, because they involve nearly all phases of the life cycle of individual species and the community ecology of ecosystems. In addition, species migrations may be limited or favored by soil suitability in newly available sites. Some species responses stem from physiological processes directly affected by temperature and moisture. But responses of species and plant communities also reflect influences of natural disturbances such as fires, insects, and pathogens. Some responses are gradual, for example migration of tree or shrub species into newly suitable environments. Others are sudden, such as mortality during severe insect epidemics or large crown fires.

As noted earlier, the ecology of Gambel oak and associated shrub species is complex. Oak's capacity to propagate by sprouting reduces the likelihood the species will disappear or even seriously decline from climate alone as temperature and precipitation conditions become marginal in a portion of its range of distribution. Heavy seeds produced by oak preclude rapid migration of Gambel oak into newly suitable environments at more northerly latitudes, though local acorn transport to higher elevations or other topographic aspects by birds may be somewhat quicker. It may be reasonable to expect Gambel oak to remain relatively unresponsive to climatic variability, at least over the next few decades. It is perhaps less clear that other mountain shrub communities and forest types will respond similarly. In any event, climate variability introduces many potential wildcards. We cannot be sure that natural disturbances such as insects, pathogens, fire, drought, and frost that have been relatively benign and harmless in the recent past may not become major influences in the future.

Research Needs

A wide array of research questions for Gambel oak and associated tree and shrub species were identified in the three workshops. Many topics are local and specific to current issues being addressed. Others are more broadly aimed toward better fundamental understanding of oak and its ecology now and into the future. There undoubtedly are opportunities to conduct research and treatment trials on many of these topics. For one example, the Western Area Power Administration has expressed interest in improving techniques for fuel management along transmission line rights-of-way on the western slope of Colorado. Potential research topics for several categories are listed below. At a minimum, these research efforts could aid managers specifying treatment options, and provide insights for planners examining future ecological effects and responses under a range of future conditions including climate scenarios.

1. Gambel oak community classifications and descriptions

- Improve oak community classifications in relation to functional and environmental similarities and differences as a basis for the assessment of management options and effectiveness.

- Assess associations of soil characteristics and landforms with oak community classifications, to provide insight into opportunities and constraints for vegetation treatment.

2. Fundamental ecology of oak and associated tree and mountain shrub communities

- Re-examine historical conditions and characteristics of Gambel oak/mountain shrub communities as a basis for clarifying departures of current communities from historical conditions, including the effects of human activities.

- Identify possible oak community restoration needs as well as options having greater potential for meeting management objectives.

- Assess the sustainability of forest tree species associations (especially ponderosa pine and Gambel oak) in relation to severe wildland fire, past logging, and other treatments.

- Develop strategies to protect or replace ponderosa pine in Gambel oak communities where fire may otherwise eliminate the tree component and convert communities to pure oak.

3. Consequences of climate change

- Improve vegetation models accounting for successional trajectories and natural disturbance effects of fire, drought, insects, disease, and frost, as a basis for assessing effects of climate variability.

- Assess Gambel oak and mountain shrub requirements for successful regeneration and establishment processes and responses to natural disturbances, especially for associated shrub species.

- Evaluate factors affecting the migration of individual shrub and tree species into newly suitable portions of the landscape, and the elimination of species from areas no longer suitable.

- Evaluate livestock and wildlife grazing and browsing on vegetative condition and sustainability for current and prospective future climatic conditions.

- Conduct a vulnerability assessment to understand whether introduced pests in other regions may be capable of afflicting Gambel oak in future climates.

4. Fire behavior and ecological effects of fire

- Improve our understanding of historical and current fire frequency and size, and fire effects in Gambel oak and mountain shrub vegetation.

- Examine how landscapes could be structured today to minimize threats of uncharacteristically large and intense wildfires and to improve the ecological condition of Gambel oak, mountain shrub, and forest tree communities.

5. Treatment effectiveness for meeting long-term management objectives

- Evaluate the compatibility of treatment objectives with ecological characteristics of Gambel oak, and clarify specifically which treatments have a realistic potential for achieving intended benefits consistent with the ecology of the vegetation where treatments are planned.

- Re-examine the effectiveness of Gambel oak treatments, including both longevity of treatment benefits and economic cost/benefit analyses.

- Assess how seasonal timing of alternative treatments or combinations of treatments such as prescribed fire, mechanical treatments, and herbicide application may improve treatment success and longevity of benefits.

- Identify treatments or treatment combinations providing adequate limitation or eradication of Gambel oak to create patchy disruption of fuel loading where wildfire poses threats in the wildland/urban interface.

- Consolidate and summarize the findings of tests and comparisons from recent local ad hoc studies that may have value for neighboring areas, capturing both positive and negative treatment outcomes.

- Establish a treatment assessment protocol or triage to determine best approaches for meeting specific management objectives, including the influence of treatment location, type, and timing in the landscape in relation to treatment objectives and expectations.

Conclusion

Gambel oak and its associated species and vegetation communities are very diverse, ranging from pure stands of oak to complex mixtures with various tree, shrub, and herbaceous species. The wide range of habitats and environments that include Gambel oak attest to the complex ecology of both oak and the associated mixtures with other species.

Gambel oak communities have been managed for multiple objectives, most of them related to providing suitable wildlife habitat and livestock grazing. Many treatments are implemented to reduce above-ground oak biomass or dominance and create openings in the oak landscape. While treatments often have been successful in meeting management objectives for a few years, a large body of evidence and experience in multiple environments across Colorado and Utah indicates that most benefits of treatments are lost within a decade. Gambel oak has a strong resprouting response, and nearly every treatment activates rapid sprouting and subsequent growth, quickly negating most treatment benefits.

There is a fundamental uncertainty about using oak management practices in almost any form. Treatments may be destined to fail because expectations are not compatible with key ecological realities about Gambel oak and associated species. At best there may be issues of timing and intensity of treatments that have been missed. Stability and persistence of oak communities may simply preclude success in achieving some management objectives where benefits are expected to be sustained for a significant length of time.

Control of oak vegetation may be important in certain critical situations regardless of the limited duration of treatment benefits. Protection of lives and property in the wildland/urban interface may warrant on-going investment in reducing vegetation density. Herbicides may have some potential for creating fuel discontinuity in oak vegetation, particularly in fuel break zones adjacent to urban development or in other infrastructure sites. Herbicides offer the only significant possibility for actually killing oak including root systems. Elimination of oak may have implications for erosion control in some situations. Replacing oak with grasses and forbs in patches of fuel breaks may enable fire suppression efforts to succeed where they otherwise would likely fail in intense wildfire situations.

Most of the recent focus on management of Gambel oak has been on reducing biomass or dominance of oak. Expanding research on the ecology of Gambel oak and its associated species and communities could provide better insight into the potential for treatment practices to meet management objectives, and to clarify which objectives can plausibly be met while remaining consistent with good oak ecology. Ecological research also could improve our understanding of potential climate change effects in future decades, particularly effects involving changes in natural disturbance impacts from fire, drought, insects, and pathogens.

Figure 11. South Canyon Fire showing severe burn conditions. Note oak in foreground already resprouting (Photo source City of Glenwood Springs official website).

Figure 10. Oak regeneration post fire in South Canyon (Photo source Magicvalley.com).

Suggested Reading

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