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# Ecology, Biodiversity, Management, and Restoration of Aspen in the Sierra Nevada

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**Abstract—**This report was commissioned by the USDA Forest Service Lake Tahoe Basin Management Unit to synthesize existing information on the ecology and management of aspen (*Populus tremuloides*) in the Sierra Nevada of California and surrounding environs. It summarizes available information on aspen throughout North America from published literature, internal government agency reports, and experienced scientists and managers. The historic distribution, abundance, and ecologic role of aspen in the Sierra Nevada are discussed, along with the reproductive physiology of aspen. Issues that affect aspen health and vigor in the Sierra Nevada and elsewhere are covered, along with methodology for assessing the condition of aspen and monitoring the effects of management activities to restore and maintain aspen. Descriptions of the types of aspen that occur in the Sierra Nevada are presented along with alternative techniques to manage and restore aspen that are applicable wherever aspen is found.

***Key words:*** aspen, *Populus tremuloides*, ecology, management, disturbance, Sierra Nevada, Lake Tahoe basin, monitoring, and assessment

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# Preface

This publication was undertaken through a cooperative work agreement between the USDA Forest Service Lake Tahoe Basin Management Unit. Printing costs were covered by the USDA Forest Service Pacific Southwest Region. We thank them for their generous support. Much of the information contained in this publication appeared in an internal report submitted to the Lake Tahoe Basin Management Unit in January, 2006. It has since been subjected to additional peer and policy review and has been revised to include additional sources of information and clarify statements made in the earlier report.

The purpose of this effort is to assemble the best information available about the ecology, biodiversity, and management of aspen (*Populus tremuloides*) within the Sierra Nevada ecosystem and nearby environs. However, we feel that much of the information contained in this document is applicable outside the Sierra Nevada proper and will be useful to managers elsewhere. To meet our goal, we scoured published literature, internal agency reports, and captured local expertise through personal contacts with the intent of finding the best and most pertinent information available about aspen. Because aspen is a minor component of landscapes in the Sierra Nevada, the body of published literature is somewhat limited. Therefore, we have interpreted results of research published elsewhere in North America and extrapolated that knowledge to the biophysical setting of the Sierra Nevada within the limits of our accumulated experience and knowledge of aspen ecology. In all instances, we have endeavored to separate fact from opinion, and knowledge from assumption. We feel that what we have presented here is the state of the art of what is currently known about aspen, but remind readers that local knowledge and experience gained from trial and observation through an adaptive approach to management is as valuable as anything we have included in this document.

# Acknowledgments

We would like to thank the many people who contributed their expertise to this General Technical Report.

Particular thanks are due to Bobette Jones, Ecologist, Eagle Lake RD, Lassen NF; Coye Robbins, Wildlife Biologist, Almanor RD, Lassen NF; Paul Schmidt, Wildlife Biologist, Alturas Field Office, BLM; Victor Lyon, Wildlife Biologist, LTBMU; and Beth Brenneman, Ecologist, LTBMU who provided us with important aspen assessment data.

We would also like to acknowledge the contributions of George Gruell, Carson City, Nevada; David Goin, Reno, Nevada; and Tom Rickman, Wildlife Biologist, Eagle Lake RD, Lassen NF for their repeat photography sets that helped capture some extensive changes that have occurred to aspen habitats in California.

We are very grateful for the work of Bruce Davidson, GIS Specialist, LTBMU, Jessica Iles, Wildlife Biologist, Pacific RD, Eldorado NF for their many hours in designing and revising the maps that are found in this General Technical Report, and Kay Glowes, Penryn CA, for her countless hours of editing early drafts of this document.

Finally, we would like to thank Ken Tate, Rangeland Watershed Specialist, UC Davis; Walt Mueggler, Rocky Mountain Research Station (retired); Hugh Safford, Regional Ecologist, USFS, Pacific Southwest Region; Shane Romsos, Wildlife Biologist, LTBMU; Mollie Hurt, Wildlife Biologist, LTBMU; David Fournier, Vegetation Management Planer, LTBMU; and Linda Joyce, Project Leader, RMRS for their diligent review of this synthesis.

# Contents

# Chapter 1.

# Introduction

Quaking aspen (*Populus tremuloides*) is the most widespread tree species in North America (Baker 1925; Preston 1976; Lieffers and others 2001), and thought to be second in worldwide range only to Eurasian aspen (*Populus tremula*) (Jones 1985a). Aspen is found in most of eastern Canada and the U.S. (except the Southeast), throughout the upper Midwest and Lake States, across sub-boreal Canada and Alaska, in the Rocky Mountains from Canada through the U.S. and into northern Mexico, and in mountain ranges paralleling the west coast from Alaska through British Columbia, Washington, Oregon, California, and Mexico's northern Baja California (Preston 1976). The species is most abundant in Canada's central provinces and the U.S. states of Colorado and Utah (Jones 1985a; Lieffers and others 2001). In much of the western U.S., aspen is a mid-elevation shade-intolerant species that is a relatively minor component of more widespread conifer forests.

Aspen is an important tree species throughout the western United States. One of the few broad-leaved hardwood trees in many western forests, it is a valuable ecological component of many landscapes, occurring in pure forests as well as growing in association with many conifer and other hardwood species. While aspen provides desirable scenic value, the diversity of understory plants that occur in the filtered light under aspen trees supply critical wildlife habitat, valuable grazing resources, and protection for soil and water. Though aspen is a crucial component of many Western landscapes, it may be even more valuable in the Sierra Nevada, where it is less common or extensive than elsewhere.

To that end, this publication presents a broad-based synthesis of aspen ecology and management for the Sierra Nevada Range of California and Nevada. We use the same geographic criteria applied in the Sierra Nevada Ecosystem Project (SNEP 1996) and the Forest Service's Sierra Nevada Forest Plan Amendment (SNFPA FSEIS) (USDA Forest Service 2004c) to define our area of interest (fig. 1-1). In short, these documents focus primarily on the entire Sierra Nevada ecoregion section—hence called "ecoregion" (Bailey 1995; Miles and Goudey 1997)—as well as portions of the Southern Cascade and Modoc Plateau ecoregions (fig. 1-2). These ecoregions contain aspen on lands administered by the United States Forest Service, Bureau of Land Management, National Park Service, Nevada and California State Park Systems, California Tahoe Conservancy, California Department of Fish and Game, and private ownership (fig. 1-3). We believe the Lake Tahoe basin can serve as a barometer of aspen issues found throughout the Sierra Nevada, and we will therefore use the basin and adjacent environs for case studies to illustrate issues at finer scales. A base map of the Lake Tahoe basin is provided as a reference for those less familiar with the area (fig. 1-4).

Within this framework, the primary objectives of this publication are to provide resource managers with the knowledge and tools to:

- Understand contemporary aspen ecology and resource issues.
- Develop management direction and goals.
- Work toward desired conditions for aspen.
- Apply regulatory standards and guidelines to aspen situations.
- Map out strategies for monitoring that will support adaptive management.

To meet these objectives, pertinent information on aspen ecology and management was synthesized for the Sierra Nevada. Aspen-specific research from the Sierra Nevada region is limited. Throughout this publication we use research produced elsewhere to address this geographic shortcoming in aspen knowledge. Sources used include published and unpublished literature, as well as administrative records.

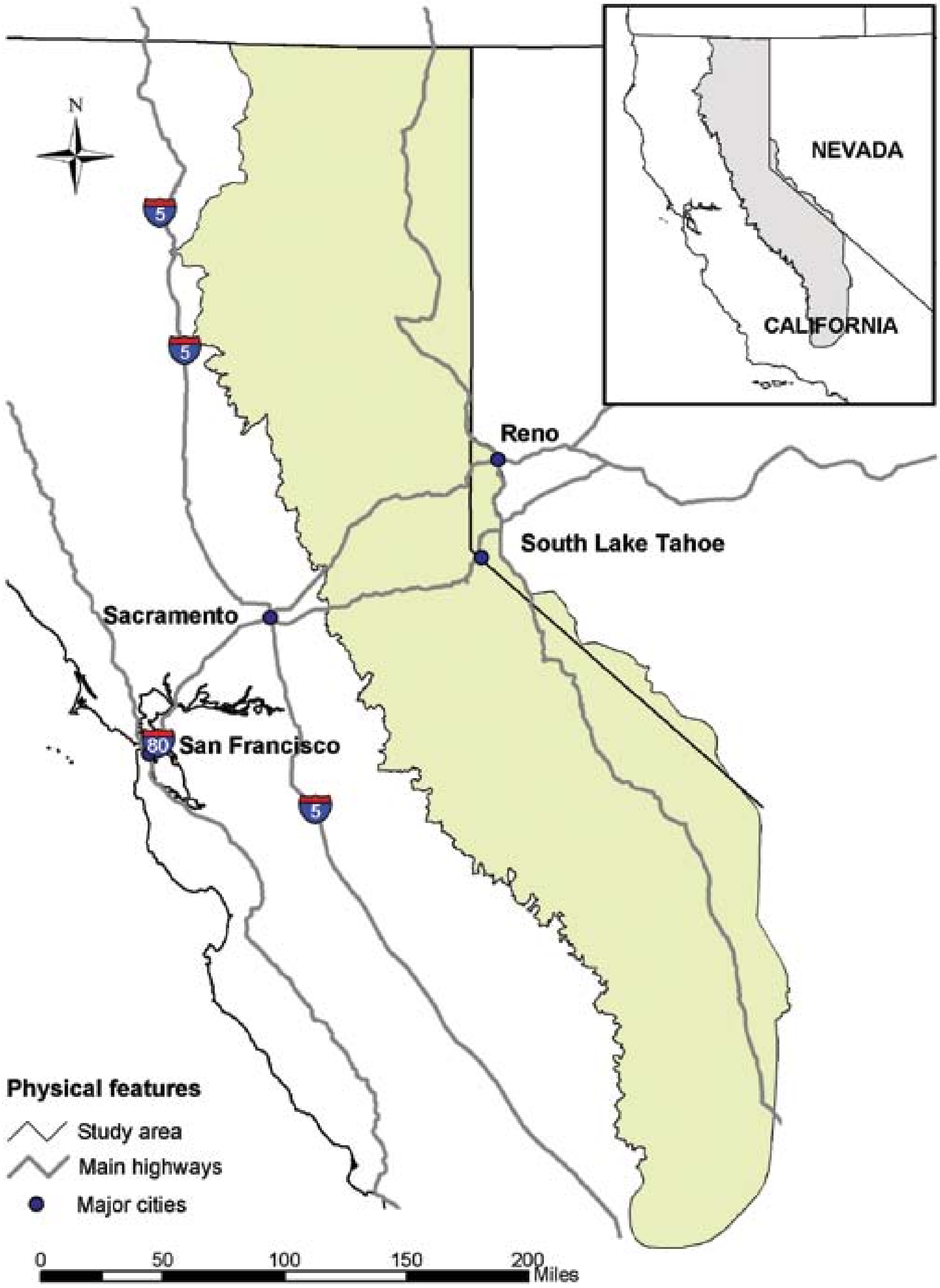



**Figure 1-1.** The geographic area covered by this report. It is the same as that in the Sierra Nevada Ecosystem Project (1996) and Forest Service Sierra Nevada Forest Plan Amendment (2004).

In order to provide a scientific framework for the implementation of aspen-related management, we rely heavily on the related concepts of "range of natural variability" (RNV) (Landres and others 1999) and "properly functioning conditions" (PFC) (Campbell and Bartos 2001). At their core, these concepts can be used to implement management practices based on the best available understanding of ecosystem dynamics in a context of changing physical and social environments. It is proper to discuss aspen ecology and management in this framework because it is closely related to standards and guidelines of the government agencies that administer public lands in the Sierra Nevada. For example, in the U.S. Forest Service's Final Supplemental

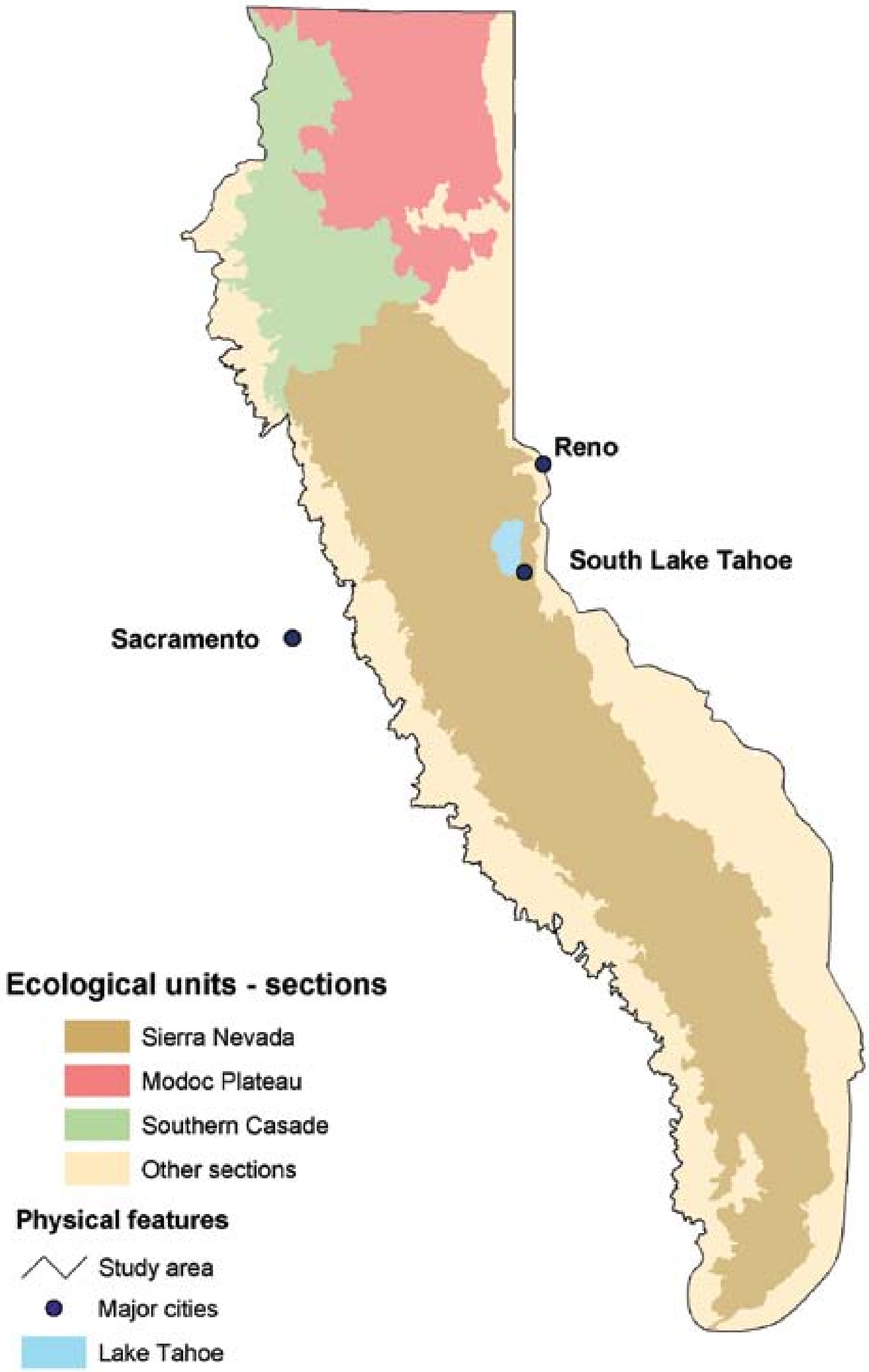



**Figure 1-2.** The portions of the Sierra Nevada, Southern Cascade, and Modoc Plateau ecoregion sections (Miles and Goudey 1997) that are within the geographic area covered by this report.

Environmental Impact Statement of the Sierra Nevada Forest Plan Amendment (USDA Forest Service 2004c) the Record of Decision states:

> At either the landscape or project scale, determine if the age class, structural diversity, composition, and cover of riparian vegetation are within the range of natural variability of the vegetative community. If outside the range of natural variability, consider implementing mitigation and/or restoration actions that will result in an upward trend. Actions could include restoration of aspen or other riparian vegetation where conifer encroachment is identified as a problem.

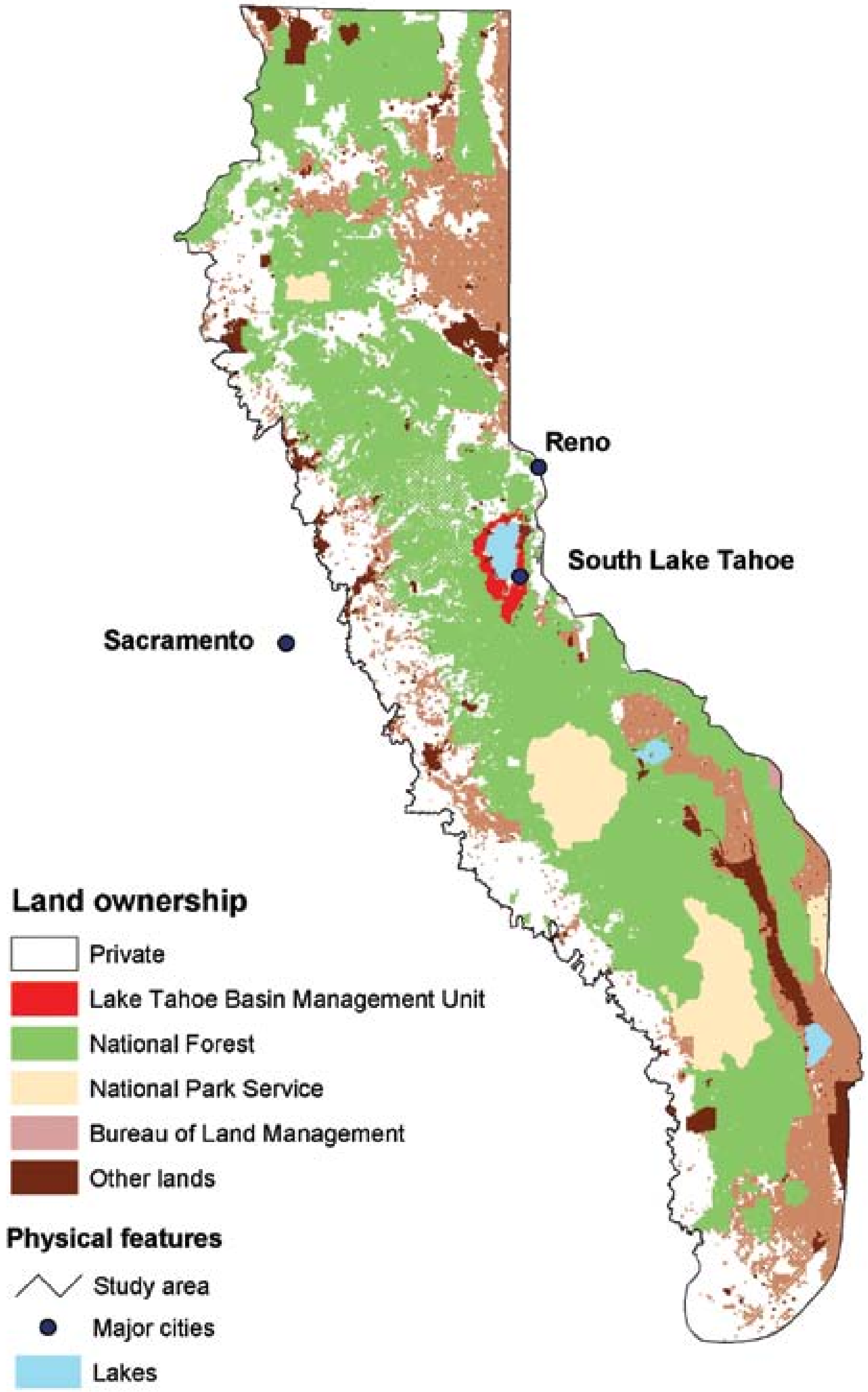



**Figure 1-3.** Land ownership within the geographic area covered by this report. The "Other" category includes State, County, City, and Tribal Trust administered lands, as well as lands under private ownership.

The Bureau of Land Management and the National Park Service call for similar attention to properly functioning natural conditions in vegetative communities (USDI NPS 1999; USDI BLM 1999a; USDI BLM 1999b). Since these directives call for vegetative communities to be managed within a range of natural variability or in a properly functioning condition, a short review of the concepts will provide a foundation for much of the discussion that follows.

Landres and others (1999) define natural variability as "the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people." The authors illustrate how management's use of natural variability relies on

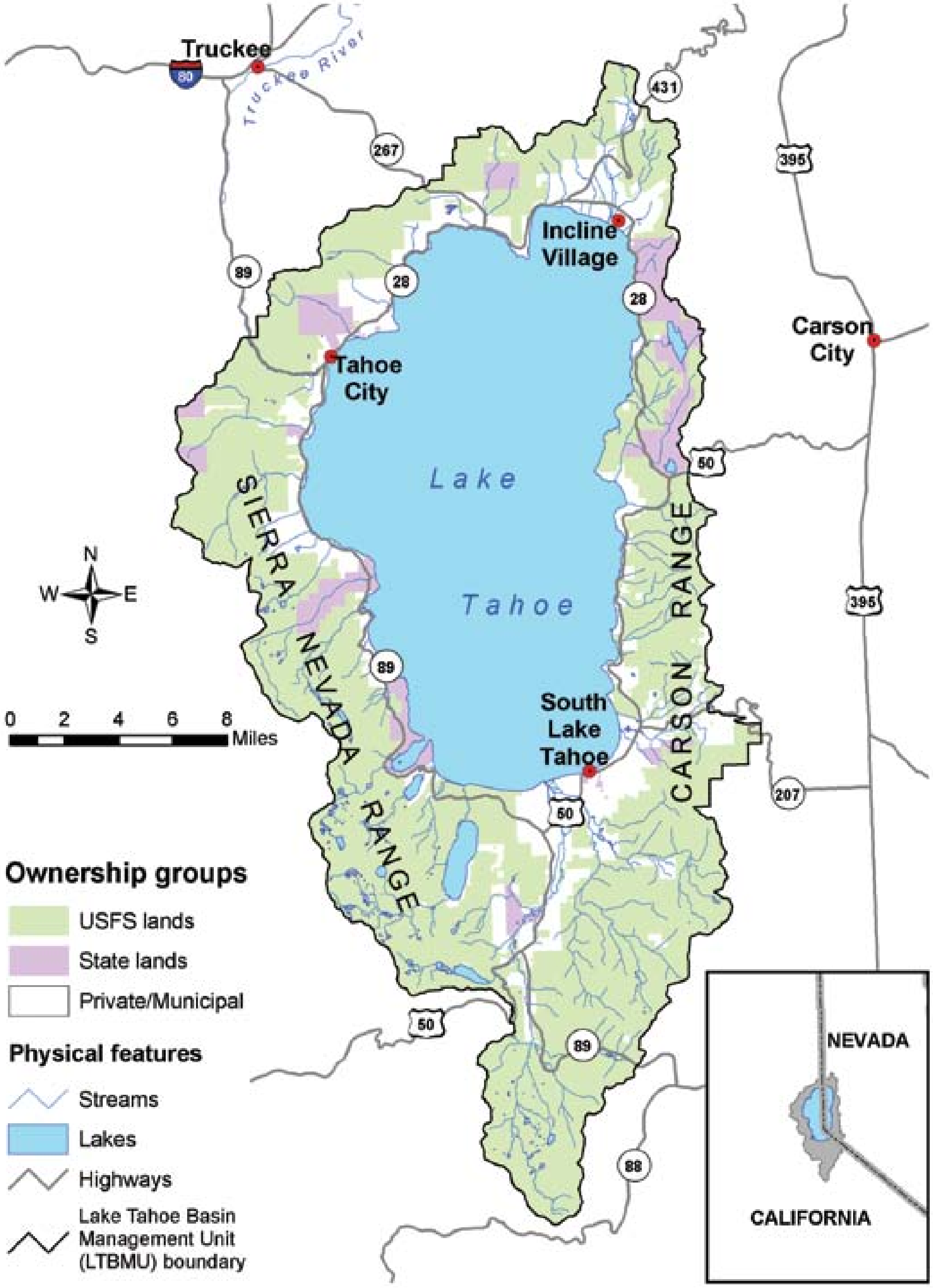



**Figure 1-4.** Land ownership and physical features in the Lake Tahoe basin.

two concepts: understanding ecological processes and recognizing that those processes are constantly in flux. We would like to emphasize the importance of avoiding defining the variability of a plant community in too wide a spatial scale or too exact a temporal point. Regarding spatial variables, Fule and others (2002) point out that changes in site specific characteristics, like geography, soils, precipitation, aspect, and slope are spatial variations that may cause shifts in natural variability. Likewise, regarding temporal variables, Millar (1997) indicates that temporal variation caused by short and long term climate changes requires consideration of ecosystem relationships and climatic factors rather than natural variability tied to one pre-anthropogenic reference point. The primary difference between the two concepts is that natural variability is used to identify variation in a vegetative community, and functioning condition is used to describe where the current community is in relationship to overall variation.

For our purposes, we consider a vegetative community to be in a properly functioning condition if it is within the range of conditions known to have existed historically in the area where it is found (Barrett and others 1993; USDA Forest Service 1997; Campbell and Bartos 2001).

This publication is based on the concept of managing aspen within its natural variability. To better understand historic variability, we begin in Chapter 2 by looking at pertinent spatial and temporal factors found in the Sierra Nevada, such as climate and human-caused disturbance, which have strongly influenced contemporary aspen communities. Next, we examine current knowledge of aspen ecology (Chapter 3). This discussion begins with aspen physiology and evolves toward a broader look at aspen's role in ecosystems. The relationship of aspen to a range of modern land management issues is discussed in Chapter 4. Then we review current conditions in aspen communities in the Sierra Nevada through the use of historical records and existing aspen stand assessments (Chapter 5). A review of research on aspen management and discussion of applications to specific conditions found in the Sierra Nevada follows (Chapter 6). Chapter 7 details the history of stand assessment and monitoring techniques for evaluating aspen management. We conclude by discussing the use of adaptive management techniques to meet aspen-oriented objectives. Finally, a brief summary chapter will review the important messages presented in this document (Chapter 8).

# Chapter 2.

# Natural and Historical Setting

## Physical Environment

### *Defining the Area of Concern*

The same criteria applied by previous regional examinations published under the title "Sierra Nevada" (SNEP 1996; USDA Forest Service 2004c), are being used here, acknowledging similar ecological and social concerns as the previous efforts (fig. 1-1). We will emphasize the core Sierra Nevada range, but on occasion will use adjacent ecoregions for related discussions.

Three ecoregions (sections) define and describe this area: Sierra Nevada, Southern Cascades, and Modoc Plateau (fig. 1-2). The Sierra Nevada Foothills section has been excluded for the practical reason that there are very limited aspen in this region (Potter 1998). Likewise, there are other areas adjacent to the Sierra Nevada ecoregion that contain aspen populations. Several features are common to these three ecoregions (table 2-1). All have warm, dry summers and cool to cold, moist winters. Likewise, soils of granitic or volcanic parent material that commonly support aspen forests (Potter 1998) are abundant in all three sections. Finally, these ecoregions occur in higher elevation mountain landscapes (as opposed to interspersed valleys). Regional precipitation patterns are presented in figure 2-1. Because temperature and precipitation data were only available for certain locations, climate in mountainous terrain may deviate considerably from the averages presented.

### *Ecoregion Sections*

The Sierra Nevada ecoregion (fig. 1-2) is a block-fault range trending northwest along the eastern edge of California. Elevations vary from 1,000 to 14,495 ft (305 to 4,418 m). The range is tilted to the west meaning there are generally much longer, gradual slopes to the west than to the east. The west side is generally wetter, with the steep east slope lying in a classic rain shadow. Deeply incised canyons flow to the west eventually joining the central valley, while to the east drainages are relatively short, flowing over bedrock into the Great Basin (Miles and Goudey 1997). Precipitation generally increases from south to north and from low to high elevation in the Sierra Nevada (fig. 2-1). The west slope receives more precipitation than the east slope and most moisture comes in the form of snow. The western foothills get 20 to 30 inches (50 to 76 cm) of rain annually; the mixed conifer forest belt gets between 30 and 60 inches (76 and 152 cm); and the highest elevations can receive up to 100 inches (254 cm) (Hornbeck and Kane 1983). Dryer east side slopes tend to have similar precipitation zones, although they are narrower and occur at slightly higher elevations. The Lake Tahoe basin contains elements of both moist western slope and rain shadow eastern slope precipitation regimes (fig. 2-2).

Local mountains and ridges may alter the general precipitation and temperature trends stated above. Boca, California is an example from the northern part of the range (east side). This town rests at 5,575 ft (1,699 m), to the north of Lake Tahoe, and on the lower edge of the forested belt. Boca receives an average of 22 inches (56 cm) of moisture annually (60 percent as snow), with an average temperature of 42° F (5.5° C) (Hornbeck and Kane 1983).

The Southern Cascades occupy the northwest portion of our area of interest, extending northwest to a point near Mt. Shasta, then due north to Oregon. This ecoregion is comprised mainly of volcanic highlands dissected by broad valleys. Elevations range from 2,000 feet (610 m) on the western side of the range to

**Table 2-1.** Physical and climate features of the three prominent ecoregion sections discussed in this report.

| | Elevation (ft) | Köppen climate zone (Hornbeck p. 24) | Precipitation: Avg. annual range | Precipitation: Percent snow | Temperature: Avg. annual | Temperature: Avg. annual high | Temperature: Avg. annual low | Geo-morphology | Dominant parent material | Common soils |
|---|---|---|---|---|---|---|---|---|---|---|
| Sierra Nevada* | 1,000-14,495 | Mediterranean highland | 30-60" | >60% $42^{0}$ | $62^{0}$ | $25^{0}$ | | westward tilted block | granite | entisols/ inceptisols |
| Southern Cascades** | 2,000-14,162 | Mediterranean highland/Mediterranean warm summer | 20-70" | not available | $42/60^{0}$ | $62/72^{0}$ | $25/47^{0}$ | volcanic andesite | basalt/ /alfisols | inceptisols |
| Modoc Plateau*** | 3,700-9,892 | Mediterranean | 8-30" | 30% | $48^{0}$ | $68^{0}$ | $32^{0}$ | block faults | basalt | aridosols/ mollicsols |

* Precipitation and temperature data taken from weather station at Boca.
** Precipitation and temperature data taken from composite information of climate zones and weather stations at high/low elevations.
*** Precipitatioin and temperature data taken from weather station at Fort Bidwell.
Sources: Hornbeck, David. California patterns: a geographical and historical atlas. Palo Alto, CA: Mayfield Publishing Company; 1983. 117p.
Miles, Scott R. and Goudey, Charles B., compilers. Ecological subregions of California: section and subsection descriptions. San Francisco, CA: USDA Forest Service, Pacific Southwest Region; 1997; R5-EM-TP-005.

14,162 feet (4,316 m) at Mt. Shasta (Miles and Goudey 1997). This range is deceptive, however, because unlike the numerous 14,000 foot (4,267 m) peaks in the Sierra Nevada, Mt. Shasta towers above much of the surrounding Southern Cascades.

The primary watersheds within the Southern Cascades proper are the Klamath and Sacramento Rivers on the west slope, while lesser waterways drain to the east into the Modoc Plateau ecoregion. There is generally greater precipitation in the western parts of the Southern Cascades. Average annual moisture for the section is 20 to 70 inches (50 to 178 cm) (Miles and Goudey 1997), though some areas near Mt. Shasta receive as much as 90 inches (228 cm) (Hornbeck and Kane 1983). This ecoregion is characterized as being a mix of two climate zones in California: the Mediterranean highland and Mediterranean warm summer. The upshot of this mix is that most of the area follows similar temperature and precipitation patterns as the Sierra Nevada section. An exception is the southwest portion of this section, centered between Mt. Shasta and Lassen Peak, which more closely follows the higher annual rainfall and warmer winters of the Mediterranean warm summer climate zone. This area often receives more moisture than the Modoc Plateau to the east (Hornbeck and Kane 1983).

The Modoc Plateau ecoregion encompasses the area to the north of the Sierra Nevada and much of the northeast corner of California. Geomorphologically the Modoc Plateau is comprised of blocks and faults similar to the Basin and Range formations of the Great Basin. These northward trending mountains and valleys are infused with volcanic remnants such as craters, cones, and lava flows. The elevations range from 3,700 to 9,892 ft (1,128 to 3,015 m) in the Warner Mountains (Miles and Goudey 1997). While some rivers flow to the western drainages of the Southern Cascades, many drain internally to catchments or to the east toward the Great Basin. Average rainfall for Fort Bidwell, California (4,500 ft [1,371 m]), in the Mediterranean highland climatic zone, is 16.1 inches (40.9 cm) (section-wide range of 8 to 30 inches/20 to 76 cm). Average summer high temperatures are about 68° F (20° C) (about 7° F/4° C warmer than Boca in the Sierra Nevada). The Modoc Plateau receives only 30 percent of its annual moisture from snow, whereas the Sierra Nevada receives at least 60 percent from snow (Hornbeck and Kane 1983).

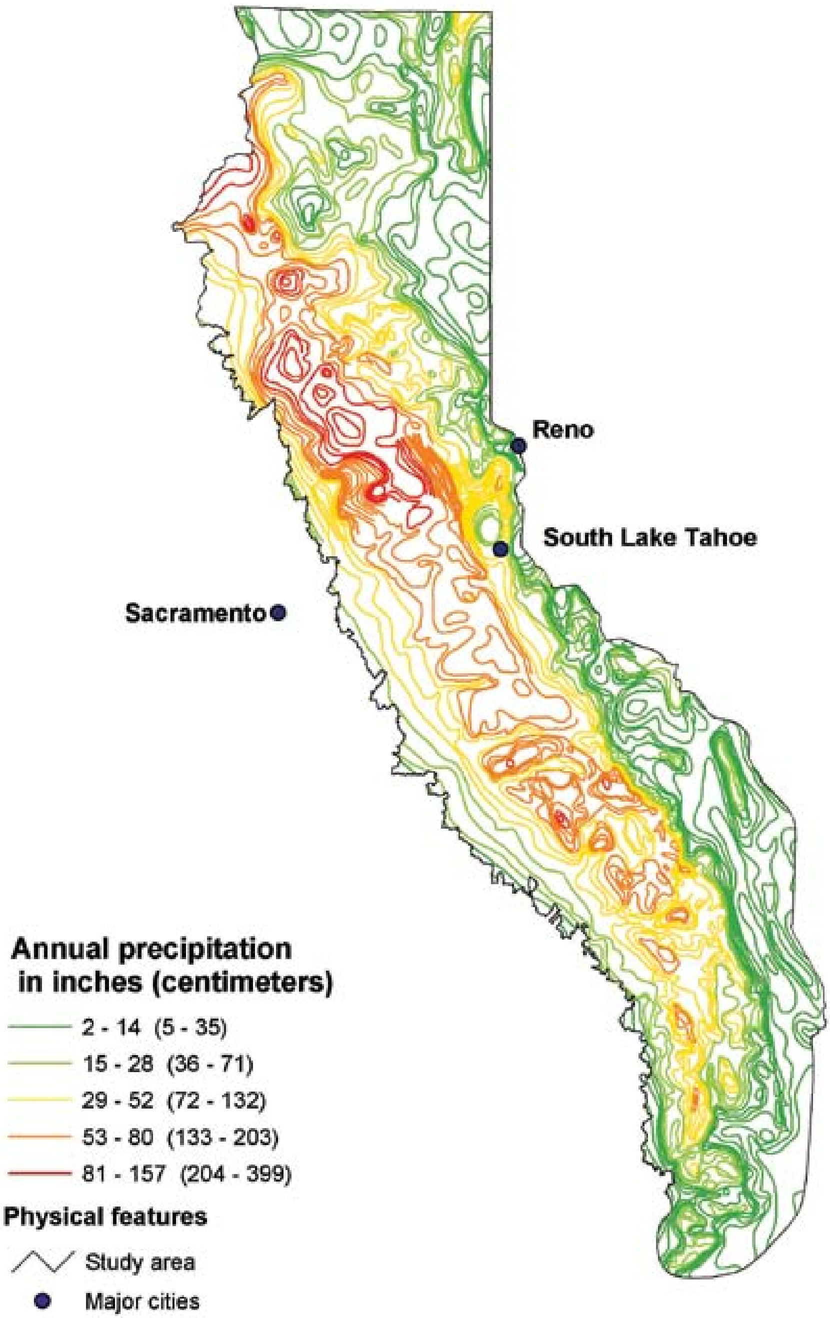



**Figure 2-1.** Precipitation patterns across the Sierra Nevada region. Moisture generally increases with elevation and latitude. The east side of the range is drier than the west side.

## *Aspen Distribution*

Aspen is located throughout the three ecoregions of our area of interest and spills into adjacent provinces (fig. 2-3). In the Sierra Nevada, aspen is found in stands from the Kern Plateau in the Sequoia National Forest in the south to Diamond Peak in the Lassen National Forest on the north. Aspen stands are located on both east and west sides of the Sierra, though they tend to be larger and more abundant on the east slope. Stands can be found along a west-to-east transect through the Eldorado and Humboldt-Toiyabe National Forests in the central Sierra from 5,310 ft (1,618 m) on the western slope, to 8,800 ft (2,682 m) at the crest of the Sierra Range, descending to 5,640 ft (1,719 m) to the east where the Sierra Nevada meets the Great Basin. Aspen can also be found in abundant numbers in the Carson and Monitor Ranges located east and south of Lake Tahoe, in the Sweetwater Mountains north of Mono Lake, and in the White Mountains east of Bishop.

In the Southern Cascades, aspen is located on both sides of the range and, as is the case in the Sierra Nevada, is more abundant on the eastern slope of the range. In the area of Lassen National Forest and Lassen National Park, aspen ranges from 5,500 ft (1,676 m) on the western slope to 8,000 ft (2,438 m) in Lassen

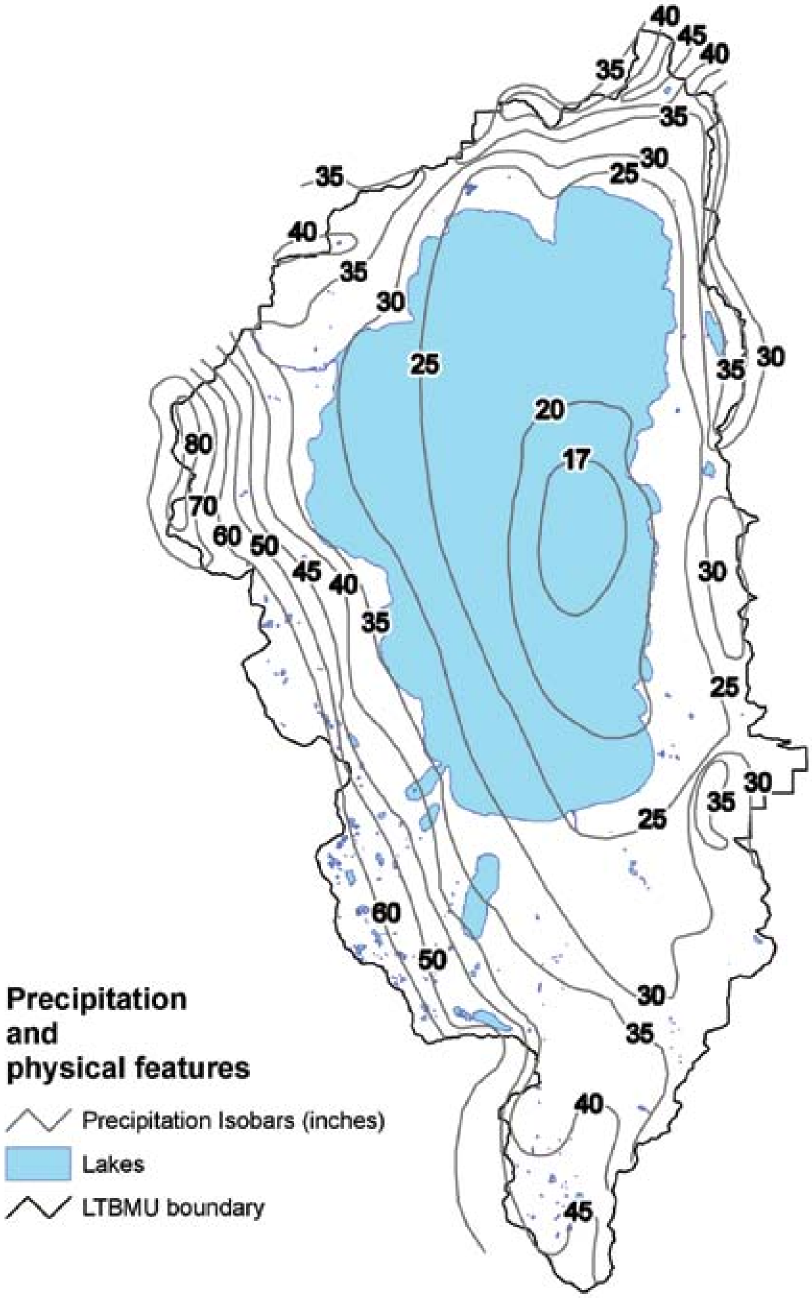



**Figure 2-2.** Precipitation patterns within the Lake Tahoe basin.

National Park to 6,000 ft (1,828 m) on the eastern slope of the range, where the Southern Cascades join the Modoc Plateau.

In the Modoc Plateau, aspen is found extensively in the Warner Mountains as well as in nearly all the mountains at elevations above the broad valley floors. Aspen is also located in small isolated sites in the expansive Devils Garden plateau, near Alturas, California.

## *Geology and Glaciation*

The modern Sierra Nevada owes its form to geologic forces created by the collisions of tectonic plates over the last 200 million years (Hill 1975). The Sierra Nevada range originated during the Mesozoic Era from 150 to 200 million years ago. The range is a product of continental shifting and folding, which forced a buckling along block fault lines on the present east slope, when the North American continental plate collided with the Pacific Ocean plate. At the core of the mountain range, very large metamorphic granite intrusions of Jurassic (135 to 180 million years BP) and Cretaceous (70 to 135 million years BP) origin were uplifted during this mountain forming period (Hornbeck and Kane 1983). As mountains rose, a combination of fluvial and glaciofluvial processes began to incise deep canyons along

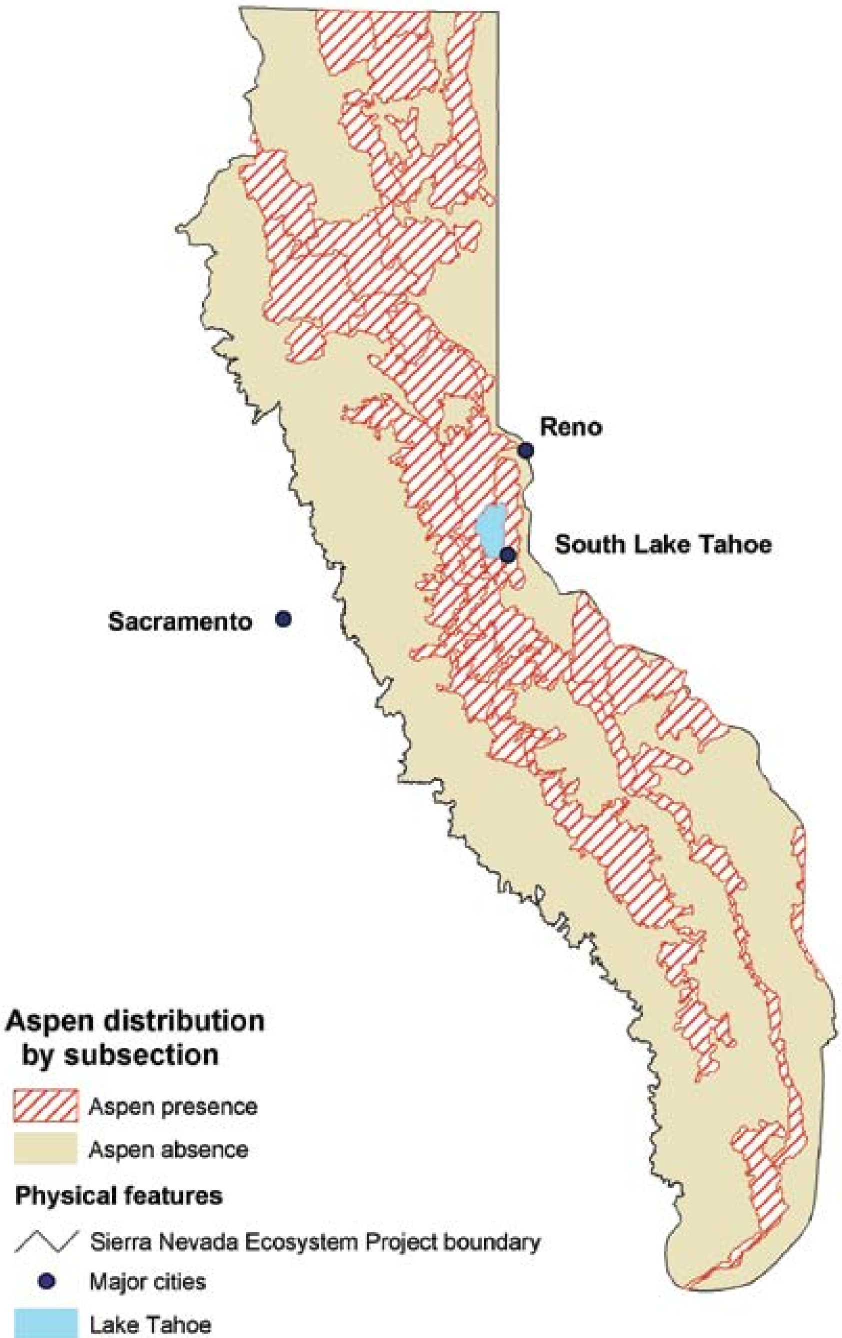



**Figure 2-3.** Subsections of the Ecological Units of California (Miles and Goudey 1997), where aspen is known to occur. No inference should be drawn as to the number and size of stands in each subsection.

prominent waterways, notably those on the western slope. Today volcanic rocks that originated during the Tertiary Period (26 to 66 million years BP) are common in the northern and central Sierra Nevada, although small outcrops can be seen throughout the range (Hill 1975; Clark and others 2005).

Active fault zones dominate the Sierra Nevada landscape. Lake Tahoe was formed by uplifting along fault lines followed by a series of volcanic dams on the upper Truckee River that periodically raised the level of the lake. During subsequent glacial epochs, additional glacial dams were formed and later breached, causing catastrophic flooding downstream (Schweickert and others 2000). The present Lake Tahoe basin is in an active earthquake zone. The Sierra Nevada fault block is currently inching west to northwest. A major fault bisects the lake itself, forming a boundary between the Basin and Range province to the east and the Sierra Nevada proper. By geologists reckoning, the same continental shifts along fault lines that helped shape the Sierra could spawn a magnitude 7.0 earthquake in the Lake Tahoe basin today. Evidence of tsunamis—large destructive waves generated by earthquakes—is also found in the contemporary geology of Lake Tahoe's western shoreline (Schweickert and others 2000).

Subsequent to mountain formation, the Sierra Nevada experienced significant glacial periods that carved out prominent canyons, while moving large volumes of parent material downslope. Abundant landforms left by past glaciers define some of the Sierra Nevada's most prominent scenery, including National Parks, alpine peaks, and scenic mountain lakes. Major glaciation took place in the Sierra Nevada during the Pleistocene Epoch (10,000 to 1.5 million BP). Birman (1964) notes at least seven glacial periods during the Quaternary: six in the Pleistocene and one in the Holocene. The latter occurred specifically during the Little Ice Age (1350 to 1850 A.D.). Numerous researchers have investigated the close link between climate and glacial advances and retreats of the Holocene and their subsequent effects on vegetation (see Climate Effects on Vegetation, this chapter). In terms of ongoing glaciation, there are presently 108 active, mostly small glaciers and 401 glacierettes (large over-summer snowfields) in the Sierra Nevada (Guyton 1998).

In the previous eras of larger glaciers, it is likely that aspen was among the first species to colonize recently vacated outwash plains. Recently glaciated landscapes are free of other vegetation, have deep soil deposits, and have a ready source of moisture in glacial melt (Muller and Richard 2001). All of these landscapes would favor the establishment of aspen seedlings (McDonough 1979). It has been hypothesized that new genetic varieties of aspen have not been introduced to the Sierra Nevada since the last major glaciation when climate may have been more conducive to true seedling establishment (Strain 1964). However, recent documentation of seedling establishment in Yellowstone National Park (Romme and others 1997), and research in the Sierra Nevada documenting genetic diversity among small isolated aspen stands (Hipkins and Kitzmiller 2004), raises the possibility that more recent seedling establishment has occurred here.

## Water and Hydrology

The Sierra Nevada contains some of the most intensively used and managed watersheds anywhere on earth. Nearly every drop of moisture that hits the range is allocated for some downstream human use. Between 75 and 90 percent of the runoff goes to agricultural uses. Every major drainage in the range has been significantly altered, either by historic uses or contemporary dams. Currently, there are hundreds of large dams in the Sierras and thousands of minor dams (Hornbeck and Kane 1983; Kattelmann 1996).

In the latter half of the 19th century, mining had enormous effects on Sierra Nevada watersheds. Early surveys documented seasonal drying up of both major and minor rivers in the area from mining activities (Sudworth 1900). Though surface erosion is naturally low in granitic soils because of high infiltration rates, intensive use and redistribution of water during the mining era dramatically affected soil and vegetation. As a result of large-scale mining, waterways were dammed, diverted, polluted, excavated, and filled with debris. Hydraulic mining—redirection of water using gravity into flumes, down steep slopes, and eventually through high pressure nozzles directed at river banks and hillsides to remove gold-bearing sediments—was the most egregious form of riparian destruction. Kattelmann (1996) asserts there were over 400 hydraulic mining operations in the Sierra Nevada during peak use, most of these being located on the west slope between the North Fork of the American and Feather rivers. While much of the hydraulic mining took place at lower elevations, water was diverted and timber was cut to support these activities in areas where aspen occurred.

Clearing of near-stream forest vegetation, including timber cutting for flumes, sluices, mine timbers, and construction materials was also related to mining operations. This activity led to further sedimentation of streams and significant alteration of surrounding vegetation. However, clearing of vegetation adjacent to streams may have created openings with abundant water, allowing established riparian aspen clones to expand onto disturbed sites. Such mining activities, like other disturbances of this era, likely contributed to the creation of riparian aspen stands found on the landscape today (Potter 1998). Like mining and logging, excessive livestock grazing in the late 19th century was also responsible for removing meadow vegetation that increased sedimentation and led to downstream gullying (Kattelmann 1996).

The 20th century brought new large-scale impacts to California's waterways. In the Sierra Nevada, fire suppression was fully instituted (after some debate) by the 1920s. In terms of riparian systems, it was thought that suppressing fires would reduce erosion. While it is true that a pulse of erosion generally occurs after fires, periodic fires also contribute important organic matter to stream systems (Kattelmann 1996). Suppression of frequent surface fires can eventually lead to denser forest canopies that burn as larger crown fires which, in turn may contribute bigger sediment loads to lakes and rivers. Increased logging and development later in

**Figure 2-4.** Aspen growing on the shoreline of Caples Lake, formerly known as Twin Lakes, in the Eldorado National Forest. Aspen habitats, as well as part of the Mormon Emigrant Trail, were flooded when this lake was increased in size as part of a hydroelectric development.

the century led to large-scale road building. Improperly constructed forest roads can divert streams, increase sedimentation, and occasionally lead to slope failure. In Kattelmann's opinion, roads built during the period from the 1950s to the 1970s were the greatest disturbance to healthy watersheds since the 19th century mining era.

Although many large dams were built at lower elevations during the early- to mid-20th century, numerous small dams were also constructed throughout the range (Kattelmann 1996). Dams may effectively simulate localized drought on downstream riparian vegetation, allowing tolerant plants to invade formerly active stream channels. This conversion can cause downstream water tables to drop, leading to stream incision, reduced overbank flooding, and eventual die-off of adjacent woody vegetation (Kondolf and others 1996). In one documented case around 1940, water was diverted from Rush Creek, near Mono Lake, to supply water to Los Angeles, drying-up the creek downstream of the diversion and causing die-off of aspen and related riparian communities (Stine and others 1984). Water backing up behind dams has also flooded aspen habitat at numerous reservoirs in the Sierra Nevada. Thin strips of aspen remain along reservoir shorelines today where larger stands may previously have existed (fig. 2-4).

Cumulative effects on adjacent forest communities of major and minor hydrologic alterations throughout the region are not well understood. Although we have reason to speculate that aspen forests were unintentionally changed by past riparian manipulations, further investigation is needed to verify this hypothesis. We do know from other regions that forest succession alone may have lasting impacts on water balances. Gradual succession from seral aspen stands to longer-lived conifer forests is evident in the absence of fire and with unchecked browsing of aspen regeneration (Mueggler 1985; Bartos and Campbell 1998; Rogers 2002).

It is thought that forests dominated by conifers will use more water than those dominated by aspen (Kaufmann 1985), given the greater transpiring surface area of conifers and their ability to transpire moisture from the soil anytime that temperatures are above freezing. In Utah, researchers measured net water changes between stands of aspen, subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*), and combined spruce-fir stands. They found that there was a net reduction in runoff in all the conifer stands when compared to aspen (Gifford and others 1983a). A similar study in Colorado examined seasonal water use and available moisture by aspen, spruce, and grassland ecosystems (Brown and Thompson 1965). Results from this study suggest that aspen use more water during the summer season, although more water is available from aspen forests (presumably due to retention in deep clay/organic soils) than from either spruce or grassland types. These authors caution that they did not closely examine year-round use and that interception of snow by spruce, for example, may alter annual use and moisture projections. They go on to speculate that aspen use more water during the growing season; conifers likely use more water over the entire year. Previous studies of forest composition and water retention imply that aspen stands can potentially increase hydrologic flows if they are retained on the landscape, but further research is needed to confirm these theories.

# Climate Effects on Vegetation

Recent advances in the field of disturbance ecology—the study of long-term and large-scale catastrophic events on ecosystem change—have become more reliant on understanding climate patterns and their effects on vegetation (Millar and Woolfenden 1999a; Veblen and others 2000; Dale and others 2001; Whitlock and Knox 2002; Whitlock 2004; Pierce and others 2004). Estimations of natural variability in ecosystems are based on knowledge of disturbance regimes that are largely dependent on climatic fluctuations (see Historical Disturbance Ecology, this chapter). The overarching message from these studies is that climate, and therefore natural systems, are not static. The Sierra Nevada is no exception to this rule. A full appreciation of the role that climate has had on the occurrence and distribution of aspen in Sierra Nevada ecosystems requires a brief review of climatic variability over long-term, millennial, and recent time scales. This will also allow some speculation as to the effect of future climate projections on aspen in the region.

## *Long-Term Climate Variability*

On the scale of millions of years, geologic evidence of gross change may reflect continental shifting and large climate flux. In the realm of centuries—closer to our own lifespan—finer-scale disturbance cycles, such as flood, fire, insect and disease infestations, and human interventions, seem of more importance. Where short-term drought events seem important within human life spans, they have less standing at millennial scales. In general, pre-Holocene climate favored long glacial periods over brief regional warming. Thus, glacial fluxes affected the spatial distribution of vegetation in dramatic ways. For instance, around Owens Lake, vegetation alternated between spruce-fir (*Picea-Abies* spp.) and juniper (*Juniperous* spp.) forests from 800,000 to 650,000 B.P. (Woolfenden 1996). Not only does this point to wide elevational fluctuations of forest cover, but to changes in spatial distribution as well. For example, the closest contemporary stands of spruce are in Arizona.

The Holocene (10,000 years to the present) marked the end of the last true glacial advance. During the Holocene, longer warm periods in the Sierra were generally punctuated by a few prominent cooler epochs lasting several hundred years. These did not include significant glaciation, and occurred around 11,000; 8,000; and 3,000 B.P. (Woolfenden 1996). Aspen, as well as other species, likely resided in different locations during these times.

## *A 1000-Year Record*

Multiple authors have documented a warmer climate in the Sierra Nevada, known as the Medieval Warm Period, occurring from approximately 1000 to 1400 A.D. (Swetnam 1993; Scuderi 1993; Woolfenden 1996; Millar and Woolfenden 1999a; Millar and Woolfenden 1999b; Millar and others 2004). Several lines of evidence, including increases in tree ring growth, fire scars, tree line elevations, pollen records for fire-dependent species, and decreased Mono lake levels indicate consistent patterns of prolonged drought and large-scale disturbance during this time. Millar and Woolfenden (1999a) speculate that volcanic vents erupted later in this period in the Glass Creek watershed and played a role in igniting fires in the region. Regardless of ignition source, the warmer and dryer conditions prominent during the Medieval Warm Period appear to have encouraged more frequent fires at low elevations (Swetnam 1993), as well as in montane forests (Millar and Woolfenden 1999a). This climate and disturbance pattern probably encouraged growth of species more resistant to low intensity fire, such as Jeffrey pine (*Pinus jeffreyii*) and Ponderosa pine (*P. ponderosa*).

The Little Ice Age (1400 to 1850 A.D.), as the name suggests, was characterized by cool temperatures and increased precipitation. Although the later portion of this period was moderately dry, the overall cool and wet conditions spawned minor glacial advances in the Sierras (Stine 1996). In terms of vegetation, much of the current "old growth" red fir forest in the Sierra Nevada originated during this era when fires were generally infrequent, though more intense (fig. 2-5) (Millar and Woolfenden 1999a). Swetnam (1993) documented the lowest fire return intervals of the past 2000 years during the Little Ice Age (except for the 1860 to present fire exclusion period). Generally, the longer the fire return interval, the easier it is for shade tolerant species such

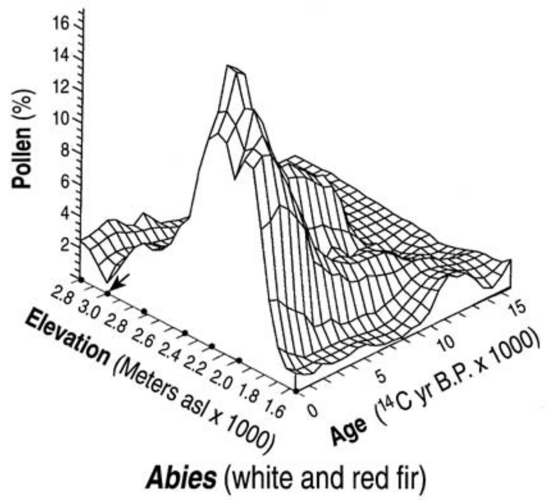



**Figure 2-5.** Pollen records of Abies (white fir and red fir) from the central Sierra Nevada show an increasing abundance since the last major glaciation in the elevation range where aspen is present today (Anderson and Smith 1994).

as red fir, white fir (*Abies concolor*), and mountain hemlock (*Tsuga mertensiana*) to colonize particular sites. However, lodgepole pine (*Pinus contorta*) and quaking aspen can thrive immediately after crown fires at upper elevations because of their need for full sunlight and ability to regenerate quickly after disturbance. Millar and Woolfenden (1999a) describe cycling shifts between red fir and lodgepole pine forest as climate changed over the past several centuries. The first fir originated during the cool/wet early Little Ice Age period, followed by a pulse of pine as cool/moderately dry conditions prevailed around the turn of the 19th century. A final understory layer of fir regeneration is found in present stands reflecting a 20th century that was relatively fire free and moist (Millar and others 2004). We presume that aspen "pulses" parallel those of lodgepole pine, given the two species' similar response to climate and disturbance (Skinner and Chang 1996). This would result in greater aspen abundance toward the end of the Little Ice Age (based on climate conditions) and toward the end of the 19th century (resulting from human-caused disturbances).

As previously mentioned, the transition from Little Ice Age to a warm and moist 20th century was coincident with widespread impacts of human settlement (see Historical Disturbance Ecology, this chapter). Other authors have noted the difficulty in separating the effects of these factors on modern vegetation (Millar and Woolfenden 1999a); however, Swetnam (1993) does note a clear decline in the fire frequency after 1860 in lower montane west-side sequoia groves in the central Sierras. Conversely, other studies cite frequent burning in upper montane sites that was documented by early settlers and forest surveyors (Sudworth 1900; Leiberg 1902; Cermak 1988). Beaty and Taylor (2001) attribute frequent fires that proliferated into the early 20th century in the northern part of our area to a combination of grazing practices (post-season burning) and drought conditions. Increased fire starts in the upper montane zone during the latter half of the 19th century were likely brought on by natural climate fluctuations (Millar and others 2004) in conjunction with intentional and unintentional burning by settlers. Based on current aspen stand ages (Potter 1998), we think that these late 19th century climate and disturbance patterns favored a widespread pulse of aspen regeneration.

## *Recent Climates and Future Directions*

Observations of annual branch growth of treeline conifers, snowfield invasion, vertical branch growth in krümmholz, meadow invasion, and climate records have all indicated some decadal climatic generalities based on synchrony across methods and sites in the range, which characterize the 100-year record for the region (Millar and others 2004). Overall, the past century was warmer and wetter than several previous centuries; relatively warm periods occurred from 1920 to 1940 and 1976 to 2000. The second half of the century was wetter than the first half, and the relatively dry periods occurred from 1910 to 1935 and 1945 to 1970.

Many scientists now speculate that we are on the brink of another climatic shift fueled primarily by human industrialization that will lead to accumulation of greenhouse gasses in the atmosphere (Overpeck and others 1990; Dettinger and others 2004). Specific effects of such a climate shift on aspen are not known, but we could expect that aspen growing in ecotones near the limits of its growing conditions would be affected. There may be far-reaching consequences for aspen where exotic species act in tandem with rapid climate shifts. A recent study in Utah used conservative (1 percent/year increase) $CO_2$-based estimates of climate warming to model potential impacts of gypsy moth (*Lymanteria dispar*) on quaking aspen in the coming century (Logan and others 2006). Their results suggest incremental temperature increases in the next century will facilitate widespread introductions of gypsy moth into previously temperature-limited elevation zones containing Gambel oak (*Quercus gambelii*), bigtooth maple (*Acer grandidentatum*), and aspen. Where these hardwoods have no previous exposure to gypsy moth, large contiguous stands without natural defense mechanisms may be destroyed. Similar potential host situations occur throughout western mountain ranges where temperature modification will have more pronounced effects by elevation than by latitude.

In the Sierra Nevada, projections are for a warming of about 5.4° F (3° C) during the 21st century (Dettinger and others 2004). While these authors are less confident in the direction of precipitation change, they do expect warming to have significant affects on the timing and amount of spring runoff. Where snowmelt occurs earlier in the spring, longer and warmer summers will likely result in drying forest fuels, facilitating wildfire ignition and expansion. This will also result in soils drying out sooner which could lead to greater moisture stress in aspen. If this predicted climate trend materializes, a practical approach toward natural range of variability management in aspen may be to emulate patterns and processes favored during the Medieval Warm Period, rather than those found during the Little Ice Age just prior to Euro-American settlement. After all, a warm/dry summer weather pattern facilitating increased frequency of fires may be one more favorable to aspen expansion, or at least more favorable to greater renewal of aspen and regular culling of competing conifers. However, unpredictable consequences of artificial warming, such as exotic pest introductions, cannot be overemphasized. To add further caution, most studies cited in this section have stressed a high degree of variability within broad climate patterns and especially during periods of climatic shift (Millar and others 2004; Dettinger and others 2004). The unprecedented nature of human-induced climate change, though not intentional, introduces further variability to natural change where future vegetation, including aspen, and human health are concerned.

## Historical Disturbance Ecology

We have previously discussed aspen's great ability to adapt to varying environments as evidenced by its wide contemporary range (see Physical Environment, this chapter). For example, aspen is apparently one of the first colonizers following glacial retreat in Canada (Muller and Richard 2001). Modern literature suggests that some aspen have been in the Sierra Nevada for at least the last 8,000 years (Strain 1964), although some estimates of clonal persistence for Interior West locales date to the Pleistecene (Baker 1925; Grant 1993; Mitton and Grant 1996). Mobility of clones over long periods is not well understood; however, it is conceivable that particular clones could migrate to adapt to changing conditions. A study in eastern Oregon found two sections of a genetically identical clone over 800 ft apart (Personal Comm., Valerie Hipkins, Geneticist, USDA Forest Service, National Forest Genetics Laboratory). Alternatively, specific climatic conditions, such as those following the Yellowstone fires of 1988, may facilitate episodic seedling establishment, thereby greatly increasing local aspen range and abundance (Romme and others 1997). Potentially, these two strategies work in tandem to effect both slow and rapid advancement that is dependent on climate pattern.

The role of disturbance in Sierra Nevada forests, and specifically in aspen's place in those forests, is largely a study of 19th and 20th century environmental history. Region-wide, this 200-year period witnessed a human impact on vegetation transformed from relatively benign, to very intense, to scientifically "managed." This transformation was based not only on great changes in population, but on changes (in orders of magnitude) in the scale and intensity of landscape modification. Native cultures exploited the mountain range at a subsistence level; Euro-Americans extracted resources and converted land at an industrial level. Cermak (1988) echoes this sentiment in relation to magnitude of Native American versus Euro-American burning:

> It is likely that Indian burning affected this natural balance in some places and not others. At any rate, Indian burning had little effect upon California's forests compared to the repeated, widespread burning of forests and brushlands practiced by settlers during the last half of the nineteenth century.

There is no doubt that natural disturbance cycles have been disrupted over the past 200 years. Our intent here is to discuss the impacts and interactions of natural- and human-caused disturbance (or, in the case of fire suppression, lack of disturbance) on aspen. In addition, parallel and sometimes coincident changes in regional climate have strongly influenced disturbance and vegetative patterns.

To unravel the effect of these impacts on the limited cover of aspen forests in the region we must examine pre-settlement, Euro-American settlement, and modern era patterns of forest disturbance. Disturbance commonly affects more than a single vegetation community, often benefiting one vegetation type to the detriment of another (Rogers 1996). Thus, interplay between aspen and its successional associates is an important component of our historical assessment.

## *Pre-Settlement*

Prior to Native American migration to the Sierra Nevada region, vegetation was largely influenced by climate and natural disturbance. During the Holocene, California witnessed dramatic climate change that resulted in broad elevational shifts in vegetation (Woolfenden 1996). From this long-term perspective, disturbances—volcanoes, earthquakes, glaciation, floods, land slides, snow avalanches, insect and disease epidemics, and wildfires—were commonplace. As a pioneer species, aspen was likely the first tree species on site after most of these disturbances. For example, aspen was the most effective colonizer after continental glaciation in Canada (Muller and Richard 2001).

Although all of these disturbances have occurred in the Sierra Nevada, fire stands out as possibly having the most consistent long-term influence on aspen communities. We know more about fire's influence, compared to other disturbances, on aspen from a large body of research in this subject area predominantly conducted in the Interior West (Gruell 1983; Jones and DeByle 1985b; Bartos and others 1994; Floyd and others 1997; Romme and others 2001; Rogers 2002).

Aspen in the Sierra Nevada is found primarily in the upper montane zone (Potter 1998), so we will confine our brief review of fire ecology to that vegetation zone. In general, aspen regenerate best after stand-replacing fires given their root sprouting habit and need for open sunlight unhindered by competing overstory species (Jones and DeByle 1985b). However, montane fire regimes are not uniform. The most common aspen associates in the high Sierra—red fir (*Abies magnifica*) and white fir (*A. concolor*)—tend to have fire return intervals between 50 and 150 years (Skinner and Chang 1996; Potter 1998). In contrast, the slightly lower elevation mixed conifer zone tends to have fire return intervals between 30 and 90 years, and the lowest elevation west slope and drier east slope forests have very short fire return intervals between 5 and 30 years (Skinner and Chang 1996; Taylor 2004). Thus, the structure and composition of aspen's vegetative associates can be expected to vary considerably under varying fire regimes.

These are broad generalizations. Species composition and microhabitat will more directly affect the fire ecology at a given locale (Brown and Simmerman 1986). For example, aspen associates such as lodgepole pine, Jeffrey pine, sugar pine (*P. labertiana*), western white pine (*P. monticola*), and whitebark pine (*P. albicaulis*) include widely varying fire characteristics, from frequent underburning (Jeffrey pine) to infrequent crown fires (lodgepole and whitebark pine). Pure aspen stands in Colorado have been described as nearly fire resistant because of their high density of moist forbs and higher stand humidity (Fechner and Barrows 1976). However, under very dry conditions even this dense forb layer becomes flammable (Jones and DeByle 1985b). Aspen trees also have thin bark that is extremely sensitive to fire. Even low intensity fire will often lead to high aspen mortality where flammable vegetation is found in the understory of aspen stands (Jones and DeByle 1985b). Where aspen commonly occurs in the Sierra Nevada in riparian and other moist areas (Potter 1998), we would expect a somewhat longer fire cycle. Though little research specific to aspen forests has been done here, Skinner and Chang (1996) speculate that "Fire return intervals in these locations are likely to be quite variable and long." The natural fire cycle may be shortened where conifers are readily invading aspen sites. In terms of fire size, most fires in this zone are relatively small, often limited by discontinuous fuels or natural fire breaks.

Anthropological evidence suggests that Native Americans have lived in the Sierra Nevada for the past 10,000 years (Anderson and Moratto 1996; Parker 2002). At least six major tribes and countless smaller bands lived in and around this range with a total estimated population of about 90,000 to 100,000 prior to European settlement (Cook 1978; Parker 2002). Several authors have attempted to piece together the environmental use and vegetative impacts—primarily intentional burning of forests—of Native Americans (Denevan 1992; Anderson and Moratto 1996; Vale 1998; Parker 2002; Vale 2002). These assessments run the range from Native Americans having widespread regional impacts to having very little impact at all on vegetation. An exhaustive synthesis of demographics, physical environment, lightning strikes, climate patterns, tree ring records, and anthropological land uses conducted by Parker (2002) concludes that aboriginal populations did modify landscapes intensively near permanent settlements, but effectively left most of the Sierra Nevada range to processes of natural disturbance and succession.

Native Americans also modified landscapes in other ways, including land clearing for settlement, planting for agricultural practices, and harvesting products such as nuts, berries, pruned limbs, and other plants for food and tools (Anderson and Moratto 1996; Vale 1998). However, these activities were generally at very local scales, and not common where aspen occurred in the upper montane zone. Although modifications may have been substantial in places like the Yosemite Valley, where large Miwok villages were located, the high elevation hinterland was used only on a seasonal basis, and mainly for transitory hunting purposes (Vale 1998). In sum, there was minimal human alteration of vegetation during the pre-settlement period at upper montane locations where most aspen occurs.

The end of the pre-settlement era (1780 to 1850) witnessed minor European exploration from the east (American traders and explorers) and west (Spanish missionaries and military), and only limited settlement in the area. Euro-American contact had swift and devastating impacts on Native American demography. From 1800 to 1830, Native American mortality originated primarily from coastal Spanish missions via three mechanisms: Native Americans returning from mission trading brought disease into their villages; interior Spanish military excursions brought disease to foothill settlements, which in turn spread epidemics to Sierra tribes; and occasional violence upon arrival of military treks in Indian Territory (Cook 1978). After 1830, as Euro-American contact from the east began in earnest, Native mortality increased exponentially resulting in an estimated 60 percent of all mortality taking place during the period from 1830 to 1848 (Castillo 1978). Beesley (1996) estimates that 80 percent of pre-contact Sierra Nevada Indian populations died as a result of Euro-American contact, mostly from disease and, to a lesser degree, violent confrontation. He calculated that although some settlers were killed in conflicts, the ratio was nearly 50 Native Americans dying for every white settler. To the extent that Native Americans impacted vegetation prior to contact, whether locally or regionally, the drastically reduced populations of these tribes effectively nullified their impacts by 1850. Based on low indigenous population densities and a subsistence-scale of land use, vegetation impacts, on the whole, were driven primarily by natural factors.

A recent pre-settlement fire history near Lake Tahoe attributes 90 percent of fire starts to climatic conditions that were common during the period from 1650 to 1850. Essentially, late summer weather, including dry conditions during La Niña years and periods of peak lightning strikes, seems to be sufficient to account for the number and seasonality of pre-settlement fire regimes (Taylor and Beaty 2005). Van Wagtendonk (2004) pinpointed the highest levels of lightning strikes to be east of the Sierra crest and between 8,500 and 9,000 ft elevation, with the northern half of the range receiving slightly more lightning strikes than the southern half. This zone favors frequent historical fire ignitions within aspen growing elevations (Potter 1998).

## Euro-American Settlement

It is well known that the mid-19th century Gold Rush brought prospectors and settlers into California's high country in large numbers. Initial settlement was followed by successive waves of resource extraction-driven development. For this reason the settlement era in the Sierra Nevada is best characterized by intensive use and abuse of natural resources, beginning with mining and followed by small-scale water diversion, logging, and grazing. These efforts were not necessarily mutually exclusive. For example, hydraulic mining diverted streams to extract gold-bearing sediments along major Sierra tributaries. Palmer (1992) estimates use in northern Sierra watersheds alone as being 36 million gallons (136 million liters) of water in a single 24-hour period, some three times the use of San Francisco during that era. These operations, spread throughout the range, but more commonly on the west slope, completely cleared adjacent hillsides of vegetation and sent millions of tons of sediment downstream to the Sacramento valley. Eventually hydraulic mining was stopped, not because of its impact on the immediate landscape, but because sedimentation severely limited valley farmers' use of water for irrigation. Construction of local sluices not only diverted substantial amounts of water from streams and increased erosion near prospecting sites, but often involved denuding surrounding hillsides for building materials (Beesley 1996). Such disturbances could not only have favored aspen with the removal of competing conifers, but been detrimental to aspen where roots were washed away or buried under heavy sediment.

Logging had both local and widespread impacts on the central Sierra Nevada. In the Lake Tahoe basin, logging to support the Comstock mining district in Nevada nearly denuded the Carson range (east of Lake Tahoe) and impacted most forests surrounding the lake to some degree (Jackson and others 1982; Strong 1984; Kim and Rejmánková 2001; Taylor 2004). Pollen analysis of sediment cores at three marsh sites near Lake Tahoe show a distinct signature of increased sedimentation and decreased pine pollens during the late 19th and early 20th centuries (Kim and Rejmánková 2001). Historic photos from this period show barren hillsides behind logging decks stacked high with locally harvested timber (Strong 1984) (fig. 2-6). Near Truckee, huge volumes of logs were extracted to supply mines, construct giant V-shaped flumes for transporting logs, and for use on

**Figure 2-6.** Intense logging during the Comstock era denuded much of the Carson range. This photo was taken at Spooner Summit in 1876. © Reproduced by permission (Goin and Blesse 1992).

the Union Pacific rail line (Jackson and others 1982). Beesley (1996) estimated that 300 million board feet of timber were harvested to construct snow sheds for the railroad and an additional 20 million board feet per year to maintain the sheds. In Comstock, mining efforts consumed an additional 70 million board feet per year, for about 10 years, for flume construction, mine ties, fuel wood, home building, and construction of a narrow-gauge rail line from Virginia City to Spooner Summit (and eventually Lake Tahoe itself). Of course, this rail line allowed massive exploitation of lumber, which was towed by boom from various points across the lake (Strong 1984; Beesley 1996). Strong (1984) further explains that logging practices at this time often involved post-harvest burning, which contributed to large fires in 1889, 1898, 1902, and 1903, and resulted in expanses of brush fields in the following decades. In 1900, the government agent George Sudworth made an extensive survey of the Stanislaus Forest Reserve on the west slope of the Sierra Nevada. He encountered small mills in the headwaters of each major and many minor west slope drainages and found evidence that mills had moved several times after exhausting the entire supply of lumber within a 2.5 to 3 mile radius (Sudworth 1900). This massive clearing of forests in the Sierra Nevada, although not directed at aspen as a species, nevertheless had great residual effects by stimulating aspen growth in large newly created forest openings.

Even though mining and logging activities were widespread during the late 19th century, they probably affected less total land than sheep (*Ovis* spp.) grazing. Grazing, especially by sheep, leaves a near-continuous impact on the landscape, whereas both mining and logging activities tend to leave a "patchy" disturbance footprint. Noting that some of these later "patches" could be quite large, their impact in terms of acres could not compare to grazing during this period. During the "sheep boom" (1870 to 1890) there were no restrictions on the number of sheep or the timing and movement of herds. Although accurate estimates of sheep use during this period are not available, Beesley (1996) says that they numbered in "the millions" and Cermak (1988) noted 7 million for the state, a substantial portion of which likely used this prime high elevation rangeland. Although foraging and trampling by sheep can devastate meadows (fig. 2-7), both meadow and forest alike were affected by the common and widespread practice of burning pasturage upon leaving the mountains in the fall. In general, aspen persistence thrives in frequent

**Figure 2-7.** In 1905, Grove Karl Gilbert photographed and noted the extensive sheep grazing and browsing on lands near Bowman Lake in what is now the Tahoe National Forest. Source: U.S. Geological Survey, Denver, Colorado.

fire environments (Brown and DeByle 1989; Bartos and others 1991; Skinner and Chang 1996; Rogers 2002). Numerous authors detailed these burning practices (Sudworth 1900; Leiberg 1902; Jackson and others 1982; Cermak 1988; Kinney 1996; Beesley 1996) typified in a quote from P.Y. Lewis (Cermak 1988): "We started setting fires and continued setting them until we reached the foothills. We burned everything that would burn."

Burning, sheep grazing, logging, mining, and water diversion had major effects on Sierra Nevada vegetation during the latter half of the 19th century. Some areas, such as the Carson range on Lake Tahoe's east side, were completely transformed (Strong 1984; Taylor 2004). Potter (1998) aptly relates this human-caused disturbance of over a hundred years ago to contemporary aspen cover:

> In general, the ages of the current aspen component in many stands corresponds relatively well with the end of intensive grazing pressures in the late 1800s and the institution of fire suppression policies in the early 1900s.

## Modern Era

In large part, the establishment of Forest Reserves, and eventually the Forest Service in the Department of Agriculture, were a reaction to the west-wide abuses of the land resources during the late 1800s. The modern period therefore is characterized by implementation of much needed regulation of forest lands, both nationally and in the high Sierra. The age of scientific land management began to take hold after documentation of natural resource abuses by the likes of Sudworth (1900), Leiburg (1902), and preservationists such as John Muir (Muir 1982). Grazing was limited and monitored to some degree, logging was planned and inspected, and mining and water use were closely regulated. In hindsight, this approach to implementing emerging management practices was fraught with scientific weakness and personnel shortages, but *esprit de corps* and sheer bravado often carried the day in the newfound agencies. The Forest Service in California's newly formed Region 5 confronted fire in an all out attack, not only on wildfire, but on the burning practices of the settlement era and those of Native Americans.

After the big fires of the 1890s and early 1900s, forest managers began discussing the idea of fire suppression as a means of bringing the former situation under control. Established forest use practices of that time were largely ignored in the effort to control wildfire. This included Native American use of fire and other resource users who intentionally set fires to improve forage for livestock, clear brush and logging slash (although this often led to more brush), clear land for settlement, and improve game forage and hunting visibility. In 1910, extreme fire conditions in the northern Rockies (Pyne 2001) brought the national debate—fire suppression versus "light burning"—to the forefront (Hoxie 1910). Eventually, Stuart Bevier Show, a Region 5 forester, played a national role in advancing the fire suppression policy agency-wide (Show and Kotok 1930). This policy of suppressing all fire, especially following the heavy burning and extraction of the previous era, is likely a key factor in the development of contemporary aspen forests.

The legacy of early 20th century scientific forestry, epitomized by Gifford Pinchot and Henry Graves at the national level and S.B. Show in California, was the establishment of practices designed to bring both nature (even if it was rebounding from large-scale human abuse) and resource extraction into alignment with management objectives that conserved and sustained forest resource outputs. Hence, fire would be suppressed with military fervor; rivers would be controlled with dams and diversions; forests would be "managed" for highest yields; and game animals would be regulated by elimination of large predators and optimization of game species' numbers. The economic engine driving forest management in the Sierra Nevada, as in much of the nation through this period, was timber harvest. More specifically, this meant the intensive management of high value, fast growing conifer species. Secondarily, forage for livestock and forage for wild ungulates were considered forest "products" to be favored in management plans.

Resource extraction did not cease around 1900; it was only controlled and managed by the resource agencies established at that time. For instance, in the Truckee basin, several waves of industrial logging continued until about 1940, when "virgin timber" was eventually exhausted (Knowles 1942). In water engineering, the scale of resource use may have been larger than previously occurred. To some degree, twentieth century water diversion on both large- and small-scales probably affected riparian uplands where aspen reside through the flooding of small meadows and the diversion of water from streams. In the Mono Lake drainage, for example, diversion of water for Los Angeles led to a loss of riparian vegetation, notably large stands of aspen, along Rush Creek (Stine and others 1984). Similar impacts on aspen communities may have taken place throughout the range as a result of politically driven, and scientifically engineered, solutions to economic development. To some extent, riparian-associated vegetation like aspen is accustomed to frequent fluvial events that accompany wet and dry periods. However, dams and diversions effectively mimic continuous downstream drought conditions, ultimately leaving deeply incised channels and lowering local water tables that support moist site trees such as aspen (Mount 1995).

Management philosophy around the middle of the 20th century began to shift from control of nature to understanding, and eventually to working with natural processes. This movement was evident in management reactions to disturbances, notably wildfire and floods. The "multiple use" management approach began with the U.S. Forest Service and was eventually adopted by many land use agencies. Essentially, multiple use meant that agencies were transforming from single use missions, such as cutting timber or capturing streams with dams, to a variety of "outputs," often led by the same dominant uses.

On the heels of multiple use management came the increased environmental and planning requirements of the 1970s meant to bolster protection for multiple resources. This transformation from a production mode, primed by California's rapid population growth, to a stewardship mode, was not easy (Beesley 1996). However, the evolution of resource management is ongoing nationally, with greater recognition of disturbance processes having become more accepted in today's management decisions (Rogers 1996).

The modern era, especially in response to settlement practices, has had a great impact on the Sierra Nevada landscape. The extent of aspen was certainly influenced by the combined effects of fire suppression, management favoring conifers (cutting and replanting commercial species), and grazing of aspen sprouts by livestock and unfettered wild ungulates. To a lesser extent, a relatively moist 20th century may have helped boost the confidence of managers in their quest to suppress most wildfires. The impact on aspen communities in this 100-year period, beginning with widespread disturbance that favored regeneration, has been a general trend toward advancing succession in the absence of fire, where many stands have "a few remnant aspen below an almost closed canopy of conifers" (Potter 1998).

Whether or not the absence of fire is the result of successful fire suppression, wetter climate, or combined effects, the end result is a century of relatively low fire occurrence on the heels of elevated levels of disturbance (in the latter part of the 19th century). However, a fire suppression management strategy may not be sustainable under warmer and dryer years, which could lead to more intense fire activity at the start of the current century.

Aspen forests have probably never covered large areas of the Sierra Nevada. Additionally, aspen ecosystems (as well as other vegetation) have been grossly disrupted by human activities over the past 200 years. The challenge for today's managers, in light of today's intense human development and use of Sierra forests, is to return aspen communities to some semblance of their natural range of variability.

# Chapter 3.

# Aspen Ecology

## Physiology of Aspen

Many years of ecological research have revealed a great deal about how aspen thrive on the landscape. We believe the basic physiological research—cited here primarily from the Interior West of the U.S. and Canada—is equally valid in Sierra Nevada aspen stands. A key prerequisite to managing aspen community health is understanding the basics of aspen's growth habit, ecology, and its reproductive physiology that emphasizes vegetative rather than sexual reproduction. Further discussion related to seed dispersal and sexual reproduction can be found in the Aspen Genetics section later in this chapter.

### *Aspen's Ecological Amplitude and Habitat*

Although aspen occurs throughout the western United States, in California aspen is found in the Sierra Nevada, southern Cascades, Modoc Plateau, Transverse and Peninsular Ranges, and select highlands of the Basin and Range province (Strain 1964; Barry 1971; Thorne 1977; Di Orio and others 2005). California aspen is generally more limited in range, most often confining itself to areas of above average soil moisture, such as stream banks, meadows, springs, and subsurface water sources (Barry and Sachs 1968; Potter 1998; Smith and Davidson 2003). However, in the Southern Cascades and Modoc Plateau ecoregions, as well as parts of the eastern Sierra Nevada, aspen may also be found outside of riparian settings.

At the continental scale, aspen has several physiological characteristics that permit it to attain great geographic amplitude. Lieffers and others (2001) outline the following important adaptive traits of aspen: 1) Among the wide ranging genus *Populus* spp. (cottonwoods, poplars, aspen), aspen seems to have a very high stress tolerance. Usually, high stress tolerance is associated with slow growing species and those with a limited reproduction strategy; 2) Aspen appears to rely on vegetative reproduction via root suckering more than other *Populus* spp. These authors assert that the passing of extensive root systems between generations enhances tolerance to absorb climate stress (DesRochers and Lieffers 2001); 3) Aspen also has the ability to adapt leaf size to xeric and mesic conditions (that is, smaller leaves for drier sites). Its smaller leaf size could keep the leaf surface slightly cooler, allowing earlier shut down of stomata, thus tempering water stress during drought; 4) Aspen seems to tolerate cold temperature and short growing seasons better than most hardwoods (Pearson and Lawrence 1958); 5) Leaf fluttering may be an adaptive advantage in cooling leaf surfaces of many *Populus*; and 6) Aspen appears to have a higher photosynthesis capability than other *Populus* spp., which is comparable to that of high yield poplar hybrids. Aspen photosynthesizes well in low light (for example, competitive situations) and its bark is also capable of photosynthesis, which helps to ameliorate respiration during periods of high insolation (before spring leaf-out) (Pearson and Lawrence 1958). Photosynthesizing bark may help aspen recover from injuries and infestations (Jones and Schier 1985; Lieffers and others 2001) and may allow aspen to photosynthesize at low levels during the winter giving the tree a photosynthetic "boost" prior to leaf-out (Pearson and Lawrence 1958; Shepperd and others 2004). As leaf chlorophyll increases during the summer, bark chlorophyll decreases causing bark to become whiter (Strain 1964).

Most aspen stands are composed of one to several clones that may persist along a continuum of successional stages, from sparsely growing individuals to apparently stable pure or near-pure groves. Although clones are often separate and distinct from one another, studies have demonstrated spatial intermingling where multiple clones are co-located (DeByle 1964; Mitton and Grant 1980; Wyman and others 2003; Hipkins and Kitzmiller 2004). In eastern North America, clones tend to be smaller in size (less than 5 acres [2.02 ha]) and tree establishment from seed is not uncommon. In the Interior West, clone sizes are generally larger (from 20 to 100 acres [8.09 to 40.47 ha]) and seedling events are rare (Kemperman and Barnes 1976). Compared to conifers, aspen ramets—individual stems, or suckers, of the same genotype from a parent root system—are relatively short lived. This is due to succession (replacement of aspen by more shade tolerant species) and/or a typical onslaught of mortality related to stem decays and diseases from ages 80 to 100 years (Baker 1925; Hinds 1985; Potter 1998; Rogers 2002). Aspen thrive where somewhat regular and frequent disturbance promotes regeneration (DeByle and Winokur 1985). Occasionally, aspen stands appear to perpetuate themselves with regular low-level regeneration in multilayer, stable stands (Mueggler 1988; Cryer and Murray 1992). Healthy ramets (trees) can live over 300 years (Personal Comm., John Shaw, Forester, USDA Forest Service, Rocky Mountain Research Station) and attain diameters of at least 38 inches (96.5 cm) diameter at breast height (dbh). Aspen in the western U.S. are longer lived than elsewhere. Many mature stands in Colorado are currently over 120 years of age (Shepperd 1990). Tree form varies from shrubby at upper and lower forest margins to over 100 ft (30.5 m in height) in prime locations with average heights of 50 to 60 ft (15 to 18 m) (Baker 1925).

It should be noted that variation in physical traits of aspen is often determined by genotype and therefore expressed on a clonal basis by all stems within a particular clone. For example, in Colorado the timing of spring leaf development, color during growing season and during senescence, size, bark color, and leaf fall may be used to distinguish separate clones (Shepperd 1982). The following characteristics are common to aspen: leaves are 1.5 to 2 inches (3.8 to 5.1 cm) long, with serrate margins, semiorbicular shape, ending in a distinct point (similar to the "spade" in a deck of playing cards). New sprouts will often have considerably larger leaves allowing increased photosynthesis and quick growth. Flattened petioles allow leaves to flip or "quake" in a breeze. Aspen bark may vary from green-white, yellow-white, pure white, to deeply furrowed black on the lower trunk of older specimens (Shepperd 1982, 1990). Quaking aspen is characteristically dioecious, meaning there are separate male and female plants. However, perfect flowers, containing staminate and pistillate flowers, seem to occur in 5 to 20 percent of ramets (McDonough 1985). Catkins containing the developed pistillate seeds are from 2 to 4 inches (5.1 to 10.2 cm) long and can readily be seen dangling from aspen twigs in the late spring. As the tiny seeds mature, tufts of white cotton protrude from catkins. These tufts will hold seeds aloft as they are dispersed in the wind (fig. 3-1).

**Figure 3-1.** Aspen seed dispersing from pods on a branch.

## *Clonal Habit and Root Systems*

Though the topic is touched on elsewhere in this publication (see Aspen Genetics, this chapter), here we focus more on the physiology of aspen clones and their associated root systems. Aspen generally sprout profusely (up to 500,000 stems per acre) following disturbance, although there is some continuous low-level regeneration even in shaded stands. High initial numbers of aspen suckers in post-disturbance stands typically self-thin following a negative exponential decay model, with most losses occurring in the first few years (fig. 3-2) (Shepperd 1993). Young trees studied in Canada and the U.S. Rocky Mountains grow an average of 3 to 6 ft (0.9 to 1.8 m) the first 2 years and a total of 9 to 15 ft (2.7 to 4.6 m) in 5 years (Shepperd 1993; Miller 1996).

Lateral aspen roots are found generally within a foot of the soil surface. These roots are mostly 0.25 to 3 inches (0.6 to 7.6 cm) in diameter and have very little taper at distances out to 100 ft (30.5 m) from

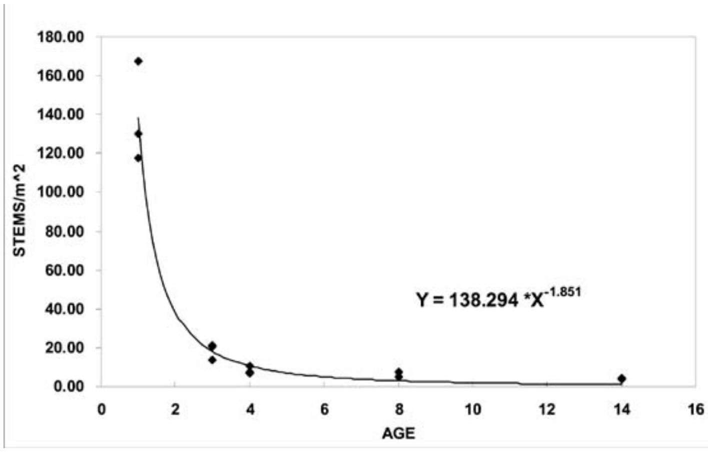



**Figure 3-2.** Self thinning of young aspen sucker populations follow a negative exponential decay model. Data from a study of aspen regeneration in the Rocky Mountains (Shepperd 1993).

**Figure 3-3.** Lateral roots of aspen form a dense mat just under the soil surface. Fine roots descend from the lateral roots to access moisture deep in the soil.

the parent tree. Fine "sinker roots" may develop anywhere along the lateral roots, with about 30 percent originating beneath developing ramets (Baker 1925; Jones and DeByle 1985b). The primary role of these vertical roots is to tap into soil nutrients and water while increasing stem and root system stability (fig. 3-3). A key ingredient of healthy lateral root systems is their ability to store carbohydrates as "fuel" for shoot growth in the event of a regeneration pulse. Aspen stands in Colorado between the ages of 20 to 80 years have been shown to have higher rates of carbohydrate storage in their roots than older or younger stands (Shepperd and Smith 1993). It has been demonstrated that carbohydrate levels vary throughout the year (Shepperd and others 2004). In addition to carbohydrate storage, overall root mass may be related to clone vigor. Shepperd and others (2001) found greater root masses in aspen stands that were actively regenerating versus those that were not.

Most root suckers arise on roots within 6 inches (15 cm) of the soil surface and on roots from 0.15 to 0.79 inches (4 to 20 mm) in diameter (Schier and Campbell 1978). Suckers initially depend on parent roots for nutrients and water (Jones and DeByle 1985b) and stored assimilates (Tew 1970), but later develop discrete root systems (Shepperd and Smith 1993). As a sucker grows, the distal parent root enlarges and new branch roots arise from the base of the shoot itself (Baker 1925; Brown 1935). Dependence on parent root support is thought to decrease as suckers develop their own roots (Zahner and DeByle 1965) and connected roots die or break (Gifford 1966). The parent root system no longer offers a competitive advantage to the new suckers after a few years (Shepperd 1993), although functional root connections between small groups of stems arising from the same parent root may exist throughout the life of a stand (DeByle 1964; Maini 1968; Tew and others 1969).

The mechanism driving the suckering process is the ratio of cytokinin to auxin hormones in the roots and apical meristem (Schier 1976, 1981; Frey and others 2003). Auxins translocated from the apical meristem are thought to suppress suckering, while cytokinins in the root tips are believed to induce new shoot growth (Schier 1981). When aspen crowns are receiving ample sunlight, auxins are sent to the root system, effectively curbing new shoot development. In the event of increased aboveground mortality, such as from fire or land clearing, auxin production is sharply reduced allowing cytokinins to stimulate bud primordia on roots to develop into a proliferation of new suckers. In less extreme events, increased soil temperature alone can stimulate cytokinins to the point of developing new suckers (Schier 1976; Frey and others 2003). This factor is probably instrumental in low-level suckering in partially shaded stands. Apparently, soil temperatures are critical only where roots are near the surface. Deeper roots are less affected by thermal heating of the forest floor. In a post-burn study in Arizona, the soil temperature of the blackened surface increased down to 15 cm and induced greater suckering compared to the unburned treatments (Shepperd 2004). These deeper roots seem to be capable of producing suckers when auxins are suppressed after stand replacing disturbance (Frey and others 2003).

Although aspen ramets are relatively short-lived, aspen genotypes may persist for a very long time (Schier 1981; Mitton and Grant 1996). Clone longevity, especially in very large clones, has been attributed to the interconnected nature of their extensive root systems (Mitton and Grant 1996; DesRochers and Lieffers 2001). This does not necessarily mean that individual roots persist for hundreds or thousands of years. Changes in root biomass as ramets age suggest that belowground biomass rejuvenates each ramet generation as well (Shepperd and Smith 1993). Past work noted that young ramets became progressively less dependent on their parental root system after 25 years of age, eventually cutting underground ties completely (Barnes 1966). Other researchers have demonstrated that portions of root systems appear to remain functionally interconnected for more than one generation (DeByle 1964; Jones and DeByle 1985b; DesRochers and Lieffers 2001).

Although all stems in a clone may not be connected, connections between stems may act as a vital survival mechanism where decaying stands must support young trees. Desrochers and Lieffers (2001) found that young trees in southern Canada connected to a parent root system could utilize the pre-existing root network when parent stems died. They found that even dead parent trees had portions of their root network living. Interestingly, these researchers did not find that stem decays aboveground were transferred into the still living belowground root network. Physically disconnecting aspen roots from parent trees can also stimulate the suckering process. From studies conducted in Arizona, Shepperd (2001, 2004) found that separating lateral roots from parent trees resulted in greater sprouting density and subsequently demonstrated that root ripping can be an effective way of expanding existing aspen clones.

Aspen can grow in a large variety of soils, although it prefers relatively deep and nutrient rich soils with ample moisture found most often on moderate slope angles. Aspen favor deeper soils on flood plains, benches, slope bottoms, and concave landforms because they retain soil moisture and have fewer subsurface rocks that can inhibit lateral root extension (Baker 1925; Jones and DeByle 1985c). Exceptions may be found where aspen grows in avalanche chutes, near ridge lines, or on talus slopes. In much of the West, aspen is commonly found on mollisol soil types (Cryer and Murray 1992; Bartos and Amacher 1998) containing a well-developed organic layer. Soils associated with aspen stands in the Sierra Nevada include mostly inceptisols, followed in prominence by alfisols and mollisols (Potter 1998). Soil richness under aspen has been attributed in part to organic matter accumulation from annual leaf fall from aspen. Where conifers are invading aspen stands, needle litter can alter soil properties over time (Cryer and Murray 1992). However, it is believed that this change is not extreme enough to limit aspen regeneration in the event of fire (Bartos and Amacher 1998).

Much of the regeneration "strategy" of aspen involves quickly producing suckers following disturbance in order to out-compete rival plants. Elevated levels of nitrogen in post-fire soils afford greater nutrient availability for developing aspen regeneration for 1 to 3 years following fire (Amacher and others 2001; DesRochers and others 2003). Increased soil temperatures work in tandem with elevated nutrient levels after fire to give aspen an apparent edge in early growth following disturbance (Shepperd 2001, 2004; Fraser and others 2002). Shepperd (2004) presented data from an experimental burning study in Arizona that indicates increased temperature and nutrients associated with burned soils led to more numerous aspen stems and greater growth in individual stems in the early post-fire years. However, DesRochers and others (2003) provide a note of caution. They found different responses to post-fire nutrient use in Alberta among clones in the same area.

# Damaging Agents Affecting Aspen

A number of insects, diseases, and other damaging agents can affect the health and vigor of aspen. Complete and extensive discussions of these factors have been presented elsewhere (Walters and others 1982; Hinds 1985; Ostry and others 1988), so we will only briefly review them here.

## *Stem Canker Diseases*

Aspen's living bark makes it susceptible to a number of fungal canker diseases that can attack, girdle, and ultimately kill the trees by blocking the transport of photosynthates to the roots. Some, such as *Ceratosystis* spp., or target cankers are slow growing and can take years to girdle a tree (fig. 3-4). Others, such as Encoelia pruinosa (*Cenangium* spp.), or sooty-bark canker (fig. 3-5) can kill a tree in just a few years. Yet others, such as *Cryptosphaeria* canker (fig. 3-6) can kill aspen trees

**Figure 3-4.** Ceratosystis stem canker on aspen. Note the target-like compact concentric growth rings.

**Figure 3-5.** Sooty-bark canker (*Encoelia pruinosa*) on aspen. The large concentric bands indicate annual growth progression.

in a single year. All are fungal organisms that infect the living bark phloem tissue through wounds, some as insignificant as that caused by the staple holding the card on the tree in figure 3-6. Once a canker fungi spore infects phloem tissue, the fungus grows, feeding off nutrients in the living cells and killing them as it spreads through the surrounding bark. Although not all wounds get infected, any wound is a potential entry site for a canker infection. If the fungus is a slow-growing species, the tree reacts to the infection by producing callous tissue to seal-off the fungus and eventually heal the wound by growing new tissue over it, similar to what happens when fire scars a tree. Usually, canker organisms spread again the next growing season, resulting in an annual infection and callus production that creates the characteristic concentric wounds on aspen that will eventually girdle and kill the tree.

Trunk rot fungus, *Phellinus tremulae* (fig. 3-7), affects wood quality if aspen is grown for commercial wood products. It also weakens live trees, making them susceptible to wind breakage. Trees near houses or in developed recreation areas that have hoof-shaped

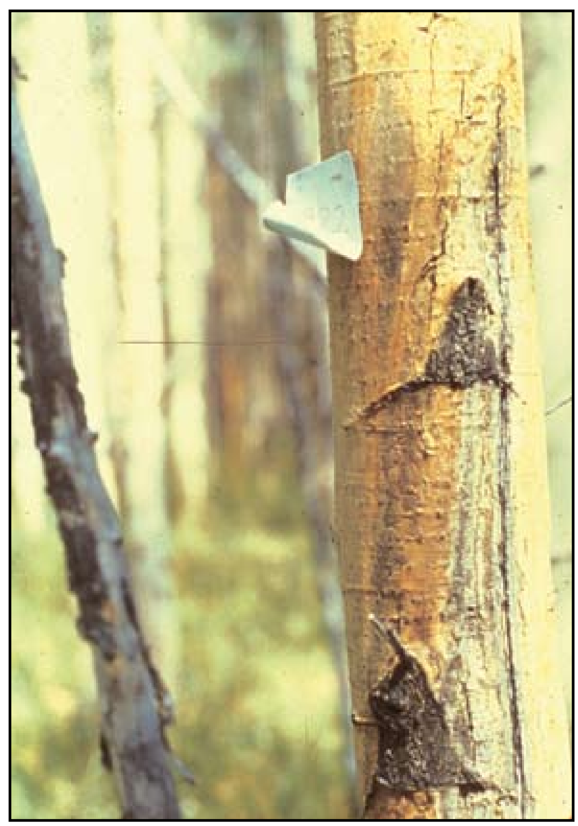


**Figure 3-6.** Cryptosphaeria stem canker on aspen. This fast growing canker can kill a tree in a single year.

**Figure 3-7.** *Phellinus tremulae*, trunk rot fungus in aspen.

"conks" or fruiting bodies of this fungus should be considered for removal to reduce potential hazard and spread of disease to adjacent stems.

## *Root Diseases*

Aspen is subject to root diseases such as *Armillaria* spp., which can cause significant localized mortality within aspen stands, but usually does not kill entire stands. Root diseases kill the roots and spread to the stems causing them to topple over in light winds. Since the disease can spread through the soil, all roots in an epicenter usually die, preventing any aspen suckering from occurring. While root diseases may contribute to clonal decline, they have not been a major cause of aspen mortality in our experience.

## *Boring Insects*

Aspen is not susceptible to bark beetles, such as Mountain Pine beetle (*Dendroctonus ponderosae*), or spruce beetle (*Dendroctonus rufipennis*). However, wood boring insects and beetles such as Agrilus planipennis (fig. 3-8), do attack aspen, boring directly into the wood and affecting wood quality. Although wood borers usually do not directly kill the tree, their wounds can be entry points for canker infections, which can kill trees.

**Figure 3-8.** Large galleries of *Agrilus planipennis* wood borer under aspen bark.

## *Foliage Diseases*

Other fungal diseases, such as ink-spot (*Ciborina whetzelii*) (fig. 3-9), attack aspen leaves, killing cells and creating characteristic patterns of leaf mortality that can stress trees, but usually don't directly kill them. Such diseases are periodic, not occurring every year or in every genotype, but can create distinct color patterns in pure aspen forests when viewed from a distance.

## *Defoliating Insects*

Insects such as aspen tortrix (*Choristoneura conflictana*) and western tent caterpillar (*Malacosoma californicum*) (fig. 3-10) can defoliate large areas of aspen. Single defoliation events usually do not kill many trees, but can trigger suckering events in aspen clones. Repeated defoliations for a number of years can result in widespread mortality. However, clones can naturally regenerate after such events, if growing conditions permit.

**Figure 3-9.** Foliage disease on aspen caused by *Ciborina whetzelii*, ink-spot fungus.

**Figure 3-10.** Western tent caterpillar (*Malacosoma californicum*) can be a serious aspen damage agent.

**Figure 3-11.** Deep snowpacks can settle and severely deform young aspen suckers (note ski pole in foreground).

## *Physical Damage*

A number of physical factors can damage aspen and affect stem form and tree longevity. Snow can bend or break mature aspen stems and deform young suckers into grotesque shapes (fig. 3-11). Aspen's shallow rooting habit makes it susceptible to windthrow, especially if protected trees are exposed by partial harvests of trees of similar age. Animals that can physically harm aspen include large animals such as elk (*Cervus elaphus*), moose (*Alces alces*), and deer (*Odocoileus* spp.) (fig. 3-12) that may feed on bark because of its high food value in winter (Shepperd and others 2004). Small mammals, such as beaver (*Castor* spp.) (see Terrestrial Biota, this chapter) or voles, also feed on aspen bark (fig. 3-13). The degree to which animals harm aspen is dependent upon the size of both the animal and aspen populations in a given area.

As a disturbance dependent species, aspen has evolved to deal with damaging physical agents by absorbing the effects through the sheer number of stems in a clone, or by rapidly reproducing new stems to replace those killed. In properly functioning ecosystems, an uneasy balance is struck between aspen and its damaging agents. Recognizing when this balance has been disturbed and

**Figure 3-12.** Infected wounds caused by elk on aspen.

**Figure 3-13.** Voles have gnawed bark from the stem of this aspen sucker and girdled it.

taking steps to correct it is a basic tenet of contemporary aspen management.

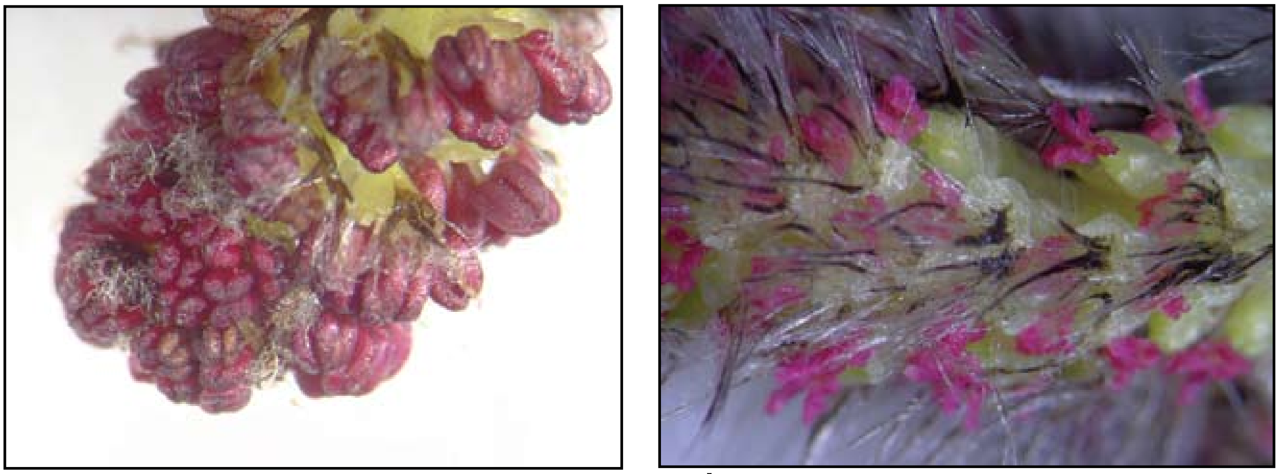
## Aspen Genetics

In recent years, the subfield of aspen genetics has begun to question previous assumptions about aspen life histories. For instance, researchers generally considered aspen "stands" to be synonymous with individual clones, and that clones could be easily discerned based on phenotypic characteristics. Also, it has long been assumed that rare seedling establishment in the West "…is of no importance in the management of aspen stands…" (Baker 1925). More recently, researchers are pondering the relationship between unusual events in time and their impact on species genetic diversity on the landscape. Could rare seedling establishment be related to aspen's limited spatial extent in the Sierra Nevada? Or, do rare seedling pulses occurring over time play a crucial genetic role in maintaining the limited extent of aspen on the landscape that is so important to vegetation and wildlife diversity in the Sierra Nevada? And finally, what role does somatic mutation play in maintaining diversity under the regime of asexual (clonal) reproduction? Before addressing these topics, a basic understanding is needed of reproductive strategies in aspen.

### *Asexual and Sexual Reproduction*

It has long been held that quaking aspen in western North America reproduce primarily from suckers arising out of a common root system (Baker 1925) (see Physiology of Aspen, this chapter). A network of lateral roots exists near the soil surface and may produce vertical suckers or shoots (fig. 3-3). Mature ramets (stems) produce auxins that suppress development of adventitious shoots. When a stem loses apical dominance, auxin levels decrease and pre-existing meristems and buds can develop into full-fledged shoots (Schier and others 1985). Over time, clones may expand as regeneration takes place on the perimeter of an open grown stand, when disturbance eliminates apical dominance of the existing clone, or when there is competition from other tree species. Depending on light availability and the preponderance of disturbance, clones may vegetatively expand or contract over time, or physically migrate across a landscape.

Could vegetative reproduction alone account for the huge range of aspen (Baker 1925; Strain 1964)?



a b

**Figure 3-14a,b.** Micro-photographs of male (a) and female (b) catkins of aspen. The staminate (male) flowers are distinguished by the four-lobed stamens and the pistillate (female) flowers by their frill-edged style and pear-shaped ovaries. Source: Andrew Groover, Instiute of Forest Genetics, USDA Forest Service.

**Figure 3-15.** Profuse aspen seeding along a roadside in southern Colorado (note radio for scale). Source: Larry Johnson, U.S. Forest Service.

Baker (1925) estimated that lateral roots in Utah could expand out 15 to 50 ft (4.6 to 15.2 m) over a 20 year period. Other researchers have found maximum root lengths to be around 100 ft (30.5 m) (Buell and Buell 1959; Jones and DeByle 1985b). We have personally observed a sucker growing 150 ft (46 m) from the edge of an isolated clone in a Utah meadow. Although these spread rates are impressive, it seems unlikely that they can explain the vast expanse of aspen coverage on the continent. Furthermore, physical barriers to root expansion, such as bedrock and riparian areas, in combination with soil and climatic restrictions, would seem to further inhibit purely clonal explanations for widespread distribution.

Sexual regeneration results in the production of new genets from seed. In the West, recruitment from seed is rare in many clonal species and adverse conditions may hinder sexual reproduction, such as when plants are near their geographic limit or climates are changing (Eriksson 1992). Although aspen do produce viable seed, many authors have attested to the rarity of seedling establishment in comparison to vegetative reproduction (Baker 1925; Barnes 1966; Einspahr and Winton 1976; Schier and others 1985; Romme and others 1997). Aspen is characteristically dioecious, having separate female and male plants, which develop in catkins on twigs prior to leaf-out in the spring (fig. 3-14a,b). Ratios of male to female clones can vary widely. Researchers in Colorado, for example, found a decreasing proportion of female aspen with increasing elevation (Grant and Mitton 1979). Tiny aspen seeds (about 0.04 inches/1 mm) are dispersed by wind with the aid of a placental cotton-like hair that keeps them aloft for up to 200 miles (322 km) (Einspahr and Winton 1976) (fig. 3-1). Seed production is profuse, with mature trees generating millions of seeds in a good seed year (fig. 3-15) (Maini 1968; Schreiner 1974).

Aspen seedling establishment across regions of North America appears limited by a narrow range of conditions for germination (Barnes 1966; Barry and Sachs 1968; McDonough 1979; Jelinski and Cheliak 1992). Seeds are only viable between 2 and 4 weeks *in situ* and need exposed mineral soil for bedding (Barry and Sachs 1968). Also, temperatures must be above freezing and in near-constant moisture to promote seed germination and facilitate seedling establishment through the first full growing season (McDonough

**Figure 3-16.** In this exceptional situation, an aspen seedling takes advantage of moisture availability and lack of competition to establish, if only temporarily, in a street gutter.

1979) (fig. 3-16). Since seedling growth is dependent on minimum competition from other vegetation, recently burned surfaces facilitate this requirement. Some authors in the western U.S. feel that these requirements are rare enough that seedling "events" introducing new genes into aspen populations may occur only at a given locale on a scale of hundreds (Barnes 1966; Romme and others 1997) or even thousands of years (Strain 1964). In the rare case where quaking aspen seeds do germinate, herbivory from large ungulates can severely impact the newly established seedlings (Turner and others 2003). While occasional aspen seedlings do establish, the events are so rare that we cannot depend upon seedling establishment to manage aspen in the western U.S.

## Clonal Intermixing

It is a common perception that individual aspen clones dominate specific sites, and where clones come in contact with each other, they can be easily distinguished by phenotypic characteristics, such as timing and color of spring leaf out and autumn senescence (Baker 1925; Jones and DeByle 1985a; Miller 1996). However, studies have shown that intermixing of clones on the landscape is common (Barnes 1966) and that relying on morphological characteristics alone may be misleading (Mitton and Grant 1980). In the Sierra Nevada, Hipkins and Kitzmiller (2004) used genetic information to identify the number of genotypes per stand, assess levels of genetic diversity, and detect geographic patterns of variation. They found stands in close proximity can be genetically quite distinct, with nearly 50 percent of individual west slope stands on the Eldorado National Forest each containing only a single genotype.

These monoclonal stands in the Sierra Nevada tend to be smaller in average size (0.8 acres [0.32 ha]) than multiclonal stands (3.1 acres [1.25 ha]) (Hipkins and Kitzmiller 2004). All clone sizes in this study were more similar to those in the eastern U.S. than in the Interior West (Barnes 1966; Miller 1996). For comparison, Interior West clones sizes ranging up to 200 acres (80.94 ha) (based on phenotypic characteristics) were found to be common in south-central Utah. It has been hypothesized that clone sizes in semi-arid regions are larger because seed germination is rare, thereby promoting longer lasting and larger clones bolstered by vegetative sprouting following repeated disturbance (Kemperman and Barnes 1976). If this hypothesis holds, then a possible explanation for smaller Sierra Nevada aspen stands may be their general proximity to favorable growing conditions. Alternatively, small stand size in this region may be due to a lack of recent disturbance, or the compromise notion that a paucity of disturbance has forced aspen stands to contract toward the relative stability provided by increased soil moisture availability. Regardless of mechanism, the monoclonal nature of stands in conjunction with the spread of some genotypes between stands suggests a broader, more extensive occurrence of aspen in the Sierra Nevada in the past than what we find now.

Hipkins and Kitzmiller (2004) also found a very high level of genetic variability throughout their Sierra Nevada study area. Overall, they found 82 percent genetic variation as measured by polymorphic loci. This same high level of genetic variation has been confirmed in Canada (Cheliak and Dancik 1982; Jelinski and Cheliak 1992) and has led researchers to proclaim aspen one of the most genetically diverse plant species (Mitton and Grant 1996). Using the same method, enzyme electrophoresis, Hipkins (Personal Comm., Geneticist, USDA Forest Service, National Forest Genetics Laboratory) found 88 percent polymorphic loci in a similar unpublished study conducted in eastern Oregon. Multiple clones were documented in many stands in both the Oregon and California studies (fig. 3-17). In Oregon, results suggest that aspen stands in one drainage were on average small, monoclonal, and less diverse—in terms of genetics and male/female clone ratios—while the opposite was true in another watershed. She hypothesized that greater numbers of

**Figure 3-17.** Often there may be multiple aspen clones within a contiguous stand. Here, separate clones can easily be distinguished by their early summer leaf development and color.

disturbances over long periods in the latter watershed created more seedling opportunities and therefore greater genetic diversity. Likewise, greater equality in clone sex ratios affords more and better chances of viable seed crops following disturbance (Personal Comm., Valerie Hipkins, Geneticist, USDA Forest Service, National Forest Genetics Laboratory). The sexual distribution of clones was not established in the Sierra Nevada genetic study. However, male and female clones were identified in a separate study on the Eldorado National Forest on the Western Slope of the Sierra Nevada (Burton 2004b). These findings establish sexual duality in aspen on the western slope of the Sierra Nevada, contrary to the postulations of previous researchers that only male clones were present here (Hutchinson and Stebbins 1986; Johnston 1994).

In Quebec, Wyman and others (2003) used a newer technique, microsatellite (loci) analysis, to examine clonal intermixing in stands. They discovered that suckers from different genotypes are likely to be highly intermixed after disturbance with ramets of different genotypes located within 6 to 9 ft (2 to 3 m) of a central trunk. In their words, "No clear relationship was found between the mean distance of the potential ramet to the central trunk and whether or not the central trunk and ramet were the same genotype." They conclude that it was not possible to distinguish between clones based purely on morphological features at their study site. However, they also found more genetic variability within stands than between stands, suggesting a very different stand make up in eastern forests versus western forests (Wyman and others 2003; Hipkins and Kitzmiller 2004).

A byproduct of clonal intermixing is a potential for natural root grafting. Barnes (1966) found only a single root grafted to another ramet in his study of clonal root systems in Michigan. Though he did acknowledge intergrowth of clones following disturbance, he apparently did not give consideration to the possibility of intermixed clones grafting. However, DesRochers and Leiffers (2001) found a much higher rate of root grafting, most commonly directly under the stems of both live and dead mature aspen. Their main conclusions focus on the long-term health of clones maintained by adoption of established root systems of mature ramets within a clone; however, there could be implications for genetic fitness in combination with root-associated physiological adaptations among intermixed clones that graft.

## *Long-Term Heterozygosity*

Genetic diversity, or heterozygosity, can be viewed at the broadest scale as a measure of aspen's reproductive health. Though many aspen stands are made up of single clones, we have seen that there is considerable genetic diversity within local populations and, at least in some places, within stands. This high level of heterozygosity seems counter-intuitive in a species so dependent on vegetative reproduction from clones. Two known mechanisms may account for high levels of genetic diversity in aspen: clonal mutation and rare seedling establishment.

Somatic mutations occur when random "mistakes" happen in the creation of DNA in the process of vegetative reproduction. These chance happenings that result in favorable morphological traits are "selected for" in the evolutionary process of adaptation to local environments. A prerequisite for successful somatic mutation in long-lived species like quaking aspen is that clones be relatively stable on a landscape for many generations—commonly estimated to be several thousand years or since the last glacial epoch (Baker 1925; Strain 1964; Barnes 1966; Jelinski and Cheliak 1992; Mitton and Grant 1996). Some authors have further hypothesized that dry climatic conditions in the West are more conducive to clonal permanence (on the landscape) and therefore somatic mutation, whereas genetic variability in eastern North American forests is more reliant on greater frequency of successful seedling events (Kemperman and Barnes 1976; Jelinski and

Cheliak 1992; Mitton and Grant 1996). Interestingly, both asexual and sexual genetic variances are dependent on regular disturbance.

As previously established, successful seedling events, notably in western locations, are rare due to very specific conditions required for germination (Maini 1968; McDonough 1979). We found no reports of seedling establishment in the Sierra Nevada. However, recent documentation of large-scale seedling establishment following the Yellowstone National Park fires of 1988 questions the notion that sexual reproduction plays a limited role in genetic diversity of quaking aspen (Kay 1993; Hargrove 1993; Tuskan and others 1996; Romme and others 1997; Turner and others 2003). In Alberta, Jelinski and Cheliak (1992) found genetic variability high among aspen and pointed to mutation as the most likely contemporary explanation. Even though they have no immediate evidence of seedling establishment, Jelinski and Cheliak speculate that uncommon "windows of opportunity" are a likely explanation for high rates of genetic variability in their populations. Yellowstone researchers take this proposition a step further with clear evidence of increased genetic variability after the landmark seedling establishments in those environments (Tuskan and others 1996; Stevens and others 1999; Romme and Turner 2004). However, these authors caution that long-term survival of the recent seedling crop will be crucial and they have thus far been monitoring new gamets for about 15 years. Romme and Turner (2004) have reported large-scale losses of new seedlings due to elk herbivory, but they and Ripple and Larsen (2001) note that "islands" of protected seedlings occur when downed wood, predominantly falling dead trees from the wildfire, act as natural barriers to ungulates. In addition to increased population heterozygosity, Yellowstone studies have demonstrated clear range expansions into areas previously unoccupied by aspen (Romme and others 1997; Romme and Turner 2004). These findings could point to a larger regional or continental model for long-term genetic variability and fitness, as well as a punctuated equilibrium explanation for range expansion. We may yet witness "windows of opportunity" in aspen genetic variance, depending on survivorship in the Yellowstone situation, and possible new seedling events elsewhere under a warmer climate and increased large-scale fire scenario.

What might we expect with changing climates in terms of aspen regeneration generally and sexual reproduction (genetic fitness) more specifically? In general, we have seen that over the millennia, aspen may be one of the most highly adapted tree species in North America. This may be shown by its genetic variability, the large size and grand age of some regional clones, or its wide habitat and climate range across the continent (Barnes 1966; Kemperman and Barnes 1976; Jones 1985b; Lieffers and others 2001). Westfall and Millar (2004) discuss how tree species have adapted to climatic shifts in the past. Though they do not discuss aspen specifically, they do reflect on survival strategies during shifting climatic epochs. Foremost among these characteristics is high genetic variability to cope with what they see as inevitable climatic shifts. They state that "greater genetic variation results in a higher proportion of individuals that are adapted to the changed environment." However, the models they used were highly dependent on seed dispersal as a mechanism for adaptation. In mountainous landscapes, shifts in a species' range can be elevational as well as latitudinal. Of course, with shifts in temperature and precipitation there are accompanying changes in disturbance frequencies. For example, cooler and wetter periods accompany longer cycles, but more intense fire events (Pierce and others 2004). If rare seedling events are brought on by epoch climatic shifts accompanied by large disturbance (cool/moist scenario), then aspen seems well positioned to move over long distances with its small seeds to colonize favorable environments, provided adequate seed beds and moisture are available (Romme and others 1997). We speculate that where more frequent disturbance dominates (warm/dry scenario), we might expect short-cycle disturbance regimes that are more favorable to clonal reproduction, mutation, and creeping migration. In either case, models presented by Westfall and Millar (2004) emphasize "sufficient plasticity" in species in terms of genetic variation and dispersal mechanisms as the key to long-term population survival. These are the same traits that have been reviewed here for quaking aspen.

## *Frontiers in Aspen Genetics*

Investigations in aspen genetics have used a range of established and developing techniques. In the past 10 to 15 years, new molecular techniques have been made available that increase the resolution of genetic studies (Parker and others 1998). The most commonly used method for aspen studies has been enzyme electrophoresis (Jelinski and Cheliak 1992; Hipkins and Kitzmiller 2004). Advantages of this technique include low cost, relative simplicity, and dependability in discerning degrees of polymorphism.

New techniques revolve around different ways of examining DNA tissue at higher resolution than established enzyme analysis. Though more expensive, these approaches give a more detailed "DNA fingerprint" of individual sections of the much larger genetic sequence of an organism. For example, Tuskan and others (1996) used a procedure called randomly amplified polymorphic DNA (RAPD) to isolate desired sections of the aspen genome, thereby eliminating nonheritable segments of the genome. In essence, RAPD allows researchers to focus more quickly on specific sequences with the DNA structure that distinguish clones.

Wyman and others (2003) were most interested in the clonal intermixing question addressed above. They worked with microsatellite DNA specifically because of its strong applications in population studies. Microsatellite genetics is an especially rewarding technique where all or most of a particular organism's total genetic make-up, or genome, can be catalogued. Fortunately for aspen researchers, the *Populus* genome was released for public use in September of 2004 (International Populus Genome Consortium 2005). Published work has already resulted from this breakthrough (Moreau and others 2005) and geneticists will likely gain considerable mileage from the *Populus* genome as it relates specifically to aspen—the most widely distributed tree of this genus—using a broader variety of DNA sequencing techniques and applications.

Recent work using this technique on European aspen (*Populus tremula*) in Finland was able to demonstrate that very small clone sizes (average 2.3 ramets per clone) appear to be the rule, rather than the exception, in this region (Suvanto and Latva-Karjanmaa 2005). Microsatellites allow investigators to more easily discern up to 30 to 50 alleles at a given DNA loci of interest, making positive individual identifications within populations possible and allowing for possibilities in tracing clonal heredity (Parker and others 1998).

In summary, aspen genetics provide many avenues for study and conservation of the species. We have seen how a variety of methods have been used to investigate population heterozygosity and clonal intermixing. Aspen genetics studies may also aid us in understanding explanatory mechanisms for the species' great adaptability to varying environments, as well as its high rate of polymorphism. While geneticists and ecologists are still unraveling the role of rare seedling events in long-term species genetics, recent developments in DNA sequencing techniques have made investigation of fine-scale population heredity possible. The interdisciplinary nature of this final point should not be overlooked; genetic knowledge should not be viewed in isolation from basic ecology. If addressed jointly, genetics and ecology provide a powerful analytical approach to understanding and managing aspen.

From a local conservation perspective, further research is needed to increase understanding of range-wide and stand-level diversity of aspen. Depending on the outcome of further investigation, we may find that population isolation in the Sierra Nevada has led to a limited genetic resource in aspen. In this case, greater effort will need to be placed on a strict conservation course of action. However, if we find that genetic diversity is strong, then we can feel more confident in aspen's local adaptability to changing climates. Of course, the unknown in these speculations is the amount or probability of future seedling events. Thus far, there has not been documentation of recent genotype establishment in the Sierra Nevada. Whether reproducing from seed or suckering, aspen still must have adequate moisture, deep soils, and relatively unhindered disturbance regimes. In the absence of these basic requirements, it will be difficult to maintain even the small populations that currently exist in our area of interest.

# Plant Associations

## *Vegetation Classification in California*

On a statewide scale, California's vegetation is very diverse, from desert to coastal scrub to rainforest to alpine. The size of the state and diversity of plant types is not conducive to mapping (or even classifying) aspen forests at this scale. Aspen is considered a "minor" hardwood forest type with about 1 percent of the total forest cover in the state (Bolsinger 1988). Previous classification efforts in California illustrate the difficulty of elevating an uncommon species to regional prominence via systematic land typing at a large scale.

Mapping and habitat classification efforts in the state have been piecemeal (regional) or incomplete through the mid 20th century (Sawyer and Keeler-Wolf 1995). Wieslander (1946) produced a first approximation statewide vegetation map based on USDA Forest Service ground observations that only covered about half the state's area. A complementary vegetation classification system was developed later by Jensen (1947), but was not comprehensive for the entire state. In the 1970's, Barbour and Major (1977) developed a statewide compilation of physiognomic types centered largely on vegetation types and based somewhat on work done by Barry (1971). These authors further divided aspen forests into nine distinct "habitats,"which included: sagebrush scrub, Jeffrey pine woodland, northern juniper woodlands, red fir forest, lodgepole pine forest, subalpine forest, mixed conifer forest, ponderosa pine forest, and montane chaparral (Barry 1971; Barbour and Major 1977). Unfortunately, this work did not go beyond mention of these types, and did not describe physical traits separating one type from the next. During this period, other regions were moving ahead with habitat typing and plant association guides such as those developed by Daubenmire and Daubenmire (1968). California later developed a systematic manual for forest classification (Sawyer and Keeler-Wolf 1995) following numerous publications of the previous decade centered on the concept of potential natural vegetation (Driscoll and others 1984; Allen 1987; Hall 1988; Kauffman 1990; USDA Forest Service 1991).

In the past two decades, vegetation mapping and classification have been enhanced by remote sensing technology. California implemented a Gap Analysis Project (GAP) habitat mapping system in the early 1990s. This study found that 89 percent of all aspen in the Sierra Nevada are on National Forest System land, with the next largest landowner being "private" with 6 percent of the aspen stands (Davis and Stoms 1996). However, the GAP likely missed many small aspen stands (and other infrequent vegetation types) because of the coarse resolution (minimum 240 acres [97.1 ha]) of this database (Sawyer and Keeler-Wolf 1995). Using classification and mapping techniques, Sawyer and Keeler-Wolf produced a statewide vegetation manual. At this scale, these authors describe a single aspen "series" for California that is a co-dominant with red fir and/or white fir in the forest canopy. Perhaps, in the end, we are left with too small of a vegetation type to be adequately represented at a statewide-scale.

## *Aspen Vegetation Types*

Greater progress has been made toward classifying aspen as a distinct type, or types, in smaller geographic regions, with a more pointed focus on forest vegetation. In the Sierra Nevada, the most detailed classification of montane forests provides two aspen associations or "potential natural communities"—quaking aspen/mountain pennyroyal (*Monardella odoratissima*) (fig. 3-18) and quaking aspen/California corn lily (*Veratrum Californicum*) (fig. 3-19) (Potter 1998). The most striking commonalities among aspen associations in the montane zone are that they are mostly less than 5 acres (2.02 ha), seem to have the deepest and richest soils of Sierra Nevada forests, and as the stands increase in age they are increasingly invaded by shade-tolerant conifers. Both described types are found in moderate to very moist sites in the red fir belt, with the mountain pennyroyal association representing a slightly dryer and upland group, and the California corn lily association

**Figure 3-18.** The quaking aspen/mountain pennyroyal (*Monardella odoratissima*) association is usually found in drier or more upland locations than the aspen association with corn lily (Fig. 3-19). These stands will have more available subsurface moisture than the surrounding general forested landscape.

**Figure 3-19.** California corn lily (*Veratrum californicum*) is a large understory forb common in wetter aspen stands of the Sierra Nevada.

representing a wetter riparian, near-riparian, and wet meadow fringe group. The distinction between these two associations is slight enough that the California corn lily is found on mountain pennyroyal sites, but pennyroyal is not found on corn lily sites. Other characteristics of these sites are that they are on low slope angles (less than 25 percent), have deep water retaining soils, usually Inceptisols, and are relatively high in plant diversity. Aspen communities in the upper montane zone are second in species richness to the very diverse western juniper/sagebrush (*Juniperus occidentalis*/*Artemisia* spp.) association (Potter 1998). Interestingly, Potter does not use quaking aspen as a plant associate in either the understory or overstory of the remaining 24 forest communities described.

Much of the aspen in the Sierra Nevada is commonly associated with riparian and meadow communities. This seems to be the case for west slope and montane forests, but may be less true on the east slope of the Sierra Nevada and in the Southern Cascades and Modoc Plateau. A recent classification for eastside riparian zones features two distinct aspen types in a total of 16 "ecological types" (Weixelman and others 1999; Kay 2001a). These authors place aspen in riparian communities in the higher elevation "eastside mixed conifer forest," the somewhat drier "yellow [ponderosa/Jeffrey] pine forest," and in narrow strips along with black cottonwood (*Populus trichocarpa*) in the lowest and driest "Reno floristic section" (although they do allude to distinct "hillslope aspen" types that join some of their riparian types). The wetter of the two types, aspen/mesic graminoid, appears to be different from either of Potter's (1998) associations in terms of the plant community described. This type is characterized by coarser soil sediments, moderately deep soil profile, an "at field capacity" water table, and low slope angles (6 to 7 percent). The highest percent constancies on these sites were in graminoids, while California corn lily displayed only a moderate presence (20 percent of plots). The second type, aspen/tall forb, had deeper soils (also with coarse stream bed sediments), a dark/rich surface horizon, and barely higher slope angles (8 to 9 percent). Weixelman and others (1999) noted slightly drier conditions on these types with lower water tables that were adjacent to incised stream channels. Aspen/tall forb ecological types are more vulnerable to conifer invasion, in their estimation, because of their record of past human disturbance and suppression of wildfires. In sum, they describe two types that are similar to Potter's (1998) plant associations (that is, both Potter indicator species are present, but only at moderate levels), but they also key in on some distinctions, such as the high presence of graminoids on wetter plots and alternate forbs and shrubs on tall forb plots.

Both the Modoc Plateau and the Southern Cascades aspen forests are less dependent on wetland habitat and thus may be considered more similar to aspen community types found in the Interior West (Mueggler 1988). One effort to address ecological communities on the Modoc National Forest features an "aspen moisture regime" within a Land Type Associations (LTA) system that classifies all lands on the National Forest (Smith and Davidson 2003). This Forest considers aspen an "emphasized forest type," meaning its managers should be cognizant of, and manage for, aspen communities within any LTA where it occurs. Though this is not technically an aspen classification system, they do distinguish aspen types as being both riparian and upland types, with the qualification that "aspen most often occurs in azonally moist areas." As in many dry Interior West forests, where aspen is common on non-riparian sites, aspen on the Modoc Plateau can be found in relatively moist climatic and topographic pockets on lower slope angles.

### *Models for Community Typing in the Sierra Nevada*

A model for aspen forest classification in the Sierra Nevada region may be found in Mueggler's (1988) work in the Interior West. Certainly the plateaus and ranges of the Modoc Plateau have similarities to Rocky Mountain, or Great Basin and Range highlands, where aspen is a vital component of forested landscapes. Mueggler's *Aspen Community Types of the Intermountain Region* includes eight "cover types" and 56 "community types" for Nevada, Utah, southern Idaho, and western Wyoming. Fourteen of Mueggler's community types describe two-thirds of all stands sampled—these he later calls "major community types." For those familiar with "habitat types" (vegetation communities with an assumed successional course toward specific climax forest cover), Mueggler is cautious to distinguish aspen community types as being more temporary and transitory. As a mostly seral species, aspen community types are viewed as distinct at any point in time, but usually on a path toward some other climax tree cover. In his words, "Community types are what the manager actually sees in the field."

At least one of Mueggler's habitat types, *P. tremuloides/Veratrum californicum*, resembles a prominent type described by Potter (1998) and perhaps Weixelman and others (1999), in that the understory species is common, along with deep saturated soils in this type. Though this habitat type is relatively uncommon for the Interior West, it may provide a point of departure, where such stands appear common in the Sierra Nevada, for an aspen based community typing system in this region.

It is likely that further development, with a focus on aspen communities rather than all montane forests or all riparian ecological types, would yield a more refined aspen classification system for this region. The earlier work of Barry (1971) may provide a model for a detailed aspen classification in the Sierra Nevada. He reviewed aspen communities with a cursory listing of plant associates for each major cover type along an east-west transect of the range. Though the emphasis of this work was not a classification system, it does provide a framework, with aspen as the focal point, for better species and community management.

Vegetation classification systems that look at the total forested landscape may be overly focused on contemporary aspen coverage. It may be that contemporary aspen forests have retrenched to moister physiographic zones as a result of a century of grazing, fire suppression, and advancing conifer succession (see Chapter 2: Historical Disturbance Ecology). We believe that an alternative approach would view any occurrence of aspen on the landscape today as being a potentially viable aspen community with the addition of sucker inducing disturbance (Bartos and Campbell 1998), provision for a proper growth environment, and protection of resulting suckers from browsing animals (Shepperd 2001; Rogers 2002; Shepperd 2004). This approach, in combination with a "community types" or "plant association" classification, would strive to delineate both current and potential aspen (those with advanced conifer succession) plant communities.

## Terrestrial Biota

### *Evaluating Diversity in Aspen Systems*

In the early to mid-20th century, forest managers were not overtly concerned with vegetation diversity and considered wildlife management, a field in its infancy at the time, to be primarily the regulation and maintenance of game species. A key element in this period of forest management history was the principle of "scientific management." That is, having the ability to calculate outcomes of management actions in natural systems with a high degree of certainty (Zimmerer 1994; Hirt 1994). An exemplar of scientific management during this era was the same Stuart Bevier Show, discussed earlier, who promoted formalization of fire suppression in the U.S. Forest Service in the early 20th century. Show and colleagues (Show and others 1947) addressed aspen as wildlife habitat in their 1940s handbook in this way:

> Aspen—Though limited in area this type is highly productive of food, furnishes good cover or is associated with good food and cover types. Can easily become a problem with high populations of big game animals. Is assigned to the Canadian Life Zone although it may follow water courses into the Transition [Zone]. Summer water supplies are abundant. Is in the belt of heavy snow. Most species using the type are migrant, however it is the natural home of the beaver.

Aside from placing beaver firmly in aspen terrain, a subject we will return to later, these authors generally regard aspen forests as favorable, though transitory to most wildlife. Though they are unclear on the "problem" with "high populations of big game animals," it is assumed they are suggesting that limited aspen cover can easily be overloaded, thus leading to habitat damage.

The wildlife handbook goes on to promote the "working circle" (a period term referring to actively managing for all successional stages) as the primary tool for increasing productivity of both wildlife and domestic livestock. They summarize their advocacy thus: "The total capacity of a managed working circle of forest land for both wildlife and livestock is far higher than for undisturbed virgin forest." Though the main focus of the handbook is on game and fish species, the authors do associate aspen with three species: beaver, sagehen (also sage-grouse, *Centrocerus urophasianus*), and mink (*Mustela vison*). We will expand this limited treatment of aspen's terrestrial biota to include both plants and animals dependent upon aspen forests (see Aspen-related wildlife and Plant diversity in aspen forests, below).

Before we discuss aspen related species, it is important to understand the overall biological diversity in our area. An example of diversity assessment within the region was recently completed for the Lake Tahoe basin (Manley and others 2000). This large research effort yielded the following category totals for species currently in the basin (as opposed to historic sightings of transitory individuals): 312 vertebrate species consisting of 217 bird, 59 mammal, five amphibian, eight reptile, 23 fish; 1,308 vascular plants; 115 non-vascular plants estimated; 810 invertebrates; and 573 fungi and lichens. Perhaps more telling is the assessment of wildlife species that have become locally extinct since Euro-American settlement (table 3-1). In addition to this short list of extirpated wildlife, we may safely presume that some native vascular plants, non-vascular plants, invertebrates, and fungi and lichens have been eliminated due to both human and natural causes in association with ubiquitous 19th century resource extraction and 20th century land development in the Sierra Nevada. In this same period, numerous species have been introduced to this region as well (see Chapter 4: Invasive Species and Aspen Communities).

There are certain aspen-related focal species that either directly or indirectly enhance regional biodiversity. Alteration of aspen forests may have cascading trophic effects on these and (likely) not yet documented plant and animal species. In addition to the idea of specific species dependence, we will address the concept of greater plant diversity in aspen communities. Both of these themes should be further considered in light of changes in aspen extent at the regional level.

**Table 3-1.** Locally extinct wildlife of the Lake Tahoe basin.

| Group | Common name | Scientific name |
|---|---|---|
| **Birds** | | |
| | Canyon wren | *Catherpes mexicanus* |
| | Peregrine falcon | *Falco peregrinus* |
| | Lewis's woodpecker | *Melanerpes lewis* |
| | Savannah sparrow | *Passerculus sandwichensis* |
| **Mammals** | | |
| | White tailed hare | *Lepus townsedii* |
| | Wolverine | *Gulo gulo* |
| | Heather vole | *Phenacomys intermedius* |
| | Canyon mouse | *Permyscus crinitus* |
| | Mountain sheep | *Ovis canadensis californiana* |
| | Sierra nevada red fox | *Vulpes vulpes necator* |
| | Grizzly bear | *Ursus artos* |
| **Amphibians** | | |
| | Northern leopard frog* | *Rana pipiens* |
| **Fish** | | |
| | Four exotic species have gone locally extinct in the past three decades (Lake whitefish, Arctic grayling, Atlantic salmon, Chinook salmon). | |

* It is unknown at this time whether this is a true native species.

Source: Schlesinger, Matthew D. and Romsos, Shane J. 2000. Appendix G: Vertebrate species of the Lake Tahoe Basin. Murphy, Dennis D. and Knopp, Christopher M., editors. Lake Tahoe Watershed Assessment: Volume II. Appendices. Albany, CA: USDA Forest Service, Pacific Southwest Research Station; pp. G1-15.

**Figure 3-20.** Sapsucker (*Sphyrapicus* spp.) wounds often scar aspen bark in a distinctly horizontal pattern. Excessive sapsucker bark penetration may encircle the stem thereby girdling and killing a tree.

## *Aspen-Related Wildlife*

For the western U.S., Flack (1976) and DeByle (1985c) provide good overviews of bird species that specialize in aspen habitats (fig. 3-20). Flack conducted a systematic survey of aspen/bird habitat in both western Canada and the U.S. Across this vast region he looked at pure and near-pure aspen stands for patterns associated with forest structure and bird species diversity. Fortunately, Flack's dataset includes one plot at Monitor Pass just south of Lake Tahoe. The most common birds found at this aspen site were warbling vireo (*Vireo gilvus*), Empidonax flycatcher (*Empidonax* spp.), house wren (*Troglodytes troglodytes*), and Oregon junco (*Junco hyemalis thuberi*). In fact, the Warbling vireo is a common denominator in aspen forests throughout western North American as evidenced by Flack (1976) and others (McGraw 1986; Turchi and others 1995; Matson 2000; Borgmann and Morrison 2004). Heath and Ballard (2003), working in the eastern Sierra Nevada, found that warbling vireos are highly associated with aspen, which indirectly suggests that recent declines in warbling vireo may be associated with concurrent reductions in aspen extent reported by Bartos and Campbell (1998) and Di Orio and others (2005). Matson's (2000) work in Wyoming suggests that warbling vireo, along with Orange-crowned warbler (*Vermivora celata*), which is also found in the Sierra Nevada, be used as "indicator species" for aspen habitats.

In terms of aspen stand structure and bird diversity, Flack's (1976) broad regional study found bird species abundance decreased with increasing tree density or decreasing tree diameter. Put another way, bird diversity was greatest in older (larger diameter), more open aspen stands. The implication is that stand age enhances bird diversity as stands naturally tend to thin over time. However, this may not be the case where invading conifers begin to change the species composition of aspen stands.

In Rocky Mountain National Park in Colorado, Turchi and others (1995) established a clear positive relationship between number of bird species and aspen cover; fewer species were consistently found in surrounding conifer stands. They attribute bird species richness in aspen to high understory cover and, in particular, increased shrub cover.

Similar results have been found in eastern Sierra Nevada aspen forests. Bird species richness and abundance increased with lower percent conifer cover, increased herbaceous cover, and lower shrub-class aspen cover (Richardson and Heath 2004). Shrub-class aspen are those trees that are either stunted or young, in either case often being located on recently disturbed sites. While researchers have found decreased bird diversity in shrub-class, greater diversity has been noted in mature aspen stands (McGraw 1986), especially where conifer invasion was minimal (Richardson and Heath 2004). These authors and Verner (1988) describe the following specific benefits to bird diversity that are provided by aspen in eastern Sierra Nevada forest communities: 1) thick herbaceous layer for forage and cover; 2) aspen's susceptibility to heart rot as a benefit to both primary and secondary cavity nesters; 3) increased abundance and diversity of insects; and 4) the ability of aspen sites to remain moist provides a ready water source, for birds as well as ensuring more insects as a food source. An Arizona study of bird populations, also found greater diversity in aspen compared to conifer/aspen and pure conifer stands (Griffis-Kyle and Beier 2003). Heath and Ballard (2003) reported that habitats dominated by aspen and black willow trees support "some of the most diverse riparian breeding songbird populations in the eastern Sierra Nevada."

**Figure 3-21.** Woodpeckers often use aspen for nesting because of its thin bark and propensity for decay, thus making cavity excavation easier. This red-breasted sapsucker (*Sphyrapicus ruber*) is shown just below the nest. Fledglings still occupy the nest, despite a recent attempted predation by an unidentified mammal that peeled bark away from the entry hole.

A subgroup of birds that nest in both live and dead tree cavities seem to favor aspen over other tree species in the West (Flack 1976; DeByle 1985c; McGraw 1986; Dobkin and others 1995). Common cavity nesters in our region include flickers (*Colaptes* spp.), woodpeckers (*Picoides* spp. and *Melanerpes* spp.), chickadees (*Parus* spp.), and nuthatches (*Sitta* spp.) (fig. 3-21). Their affinity for aspen may be due to a generally limited hardwood resource in many western forests. Additionally, this particular "hardwood" actually has fairly soft wood, a thin bark, and a propensity toward various heartwood decays in older stems (Baker 1925; Hinds 1985; Rogers 2002) that allow easier cavity excavation.

Decades of western regional research have documented the symbiotic relationship between cavity nesters and stem pathogens in aspen (Shigo and Kilham 1968; Flack 1976; DeByle 1985c; McGraw 1986; Dobkin and others 1995). In southeastern Oregon, Dobkin and others (1995) found that 73 percent of trees with cavities had some sort of fungus present on the stem. In addition to initial cavity builders and nesters, secondary colonizers like owls and sparrows also inhabit aspen cavities. They found that cavity nesters prefer dead trees over live trees and large trees (> 9.4 inches [23.9 cm] dbh) over small trees. A similar study comparing Great Basin with Sierra nesting habitat concluded that cavity nesters preferred mature stands over younger stands (McGraw 1986). Concern has been expressed that lack of large live and dead trees can lead to declining habitat for cavity nesters, especially where grazing is compounding the problem by severely limiting regeneration (Dobkin and others 1995). In sum, invasion by conifers, a limited supply of mature trees, and lack of regeneration may lead to declining habitat for several bird species dependent on aspen forests.

In addition to breeding birds, a few mammals are notable for their aspen affinity. In the Sierra, like most of the West, beaver were intensively trapped for their fur in the early- to mid-19th century. Trappers, and later managers, during the late 19th and early 20th century began reintroduction programs to improve population viability for the fur trade and ecological restoration. It was estimated in 1940 that there were about 680 beaver across California, most of these near the Sacramento River delta (Tappe 1942). Show and others (1947) distinguish between two native and one introduced subspecies in the Sierra Nevada:

> The native Shasta beaver [*Castor canadensis shastensis*] is found in the Pit and Klamath drainages and has recently been transplanted to the Walker River. The Canadian beaver [Castor canadensis canadensis], introduced from Oregon and Idaho, is located in the drainages from the Feather River to the Tuolumne. Golden beaver [*Castor canadensis subauratus*], a native of the Great Valley, has been planted on the Mendocino, Los Padres, Stanislaus and Sierra forests.

According to Tappe (1942) the Shasta beaver occurred naturally in the Southern Cascades and Modoc Plateau areas. This race was nearly wiped out, but subsequent reintroductions appear to have revived populations. Native beaver populations in the Sierra Nevada proper have not been documented, except for a single footnote where Tappe interviewed a range rider who attests to beaver sign in the upper Carson River drainage during the late 19th century. At this point, most beaver populations in the Sierra Nevada have been introduced or reintroduced following extensive historic trapping.

Opinions vary widely on how introduced beaver have affected and will continue to affect the natural aspen community. Periodic introductions and culling of exotic beaver populations have had unknown long-term effects on forest ecosystems, including aspen. It is known, however, that beaver have a strong preference for aspen as a food source and for dam and lodging

**Figure 3-22.** Beaver (*Castor* spp.) damage to a mixed aspen/conifer forest in the Sierra Nevada. Trees are killed by girdling and toppled for den material and as a beaver food source. There is also incidental aspen mortality from dam water inundation.

material (fig. 3-22). Hall (1960) estimates that beaver need about 3 pounds of aspen bark per day to sustain themselves and they seem to favor eating smaller sapling-sized trees—likely because they are also a good size for building material—though they do often take large diameter stems. Beaver may completely remove a stand's overstory, similar to a logging clear cut or fire, except that most downed stems remain on site. Those branches and stems that are hauled away by beaver may be used for lodging or dams. Aspen felling and dam building may temporarily alter forests drastically; a raised water table behind the dam will impede further aspen regeneration. However, following eventual dam breaching, a longer term outlook may see the area recolonized first by aspen, then by beaver. Weixelman and others (1999) feel that beaver may be equally as important to riparian aspen stand regulation as fire: "Beaver periodically renew aspen stands. As long as beaver populations are not too dense, aspen sites recover between periods of beaver colonization." Though cyclic interactions of the introduced beaver and natural processes—fire, flooding, aspen regeneration and growth—are not well understood at this time, local studies on these questions have resulted in a pessimistic outlook for beaver and aspen interactions (Hall 1960; Beier and Barrett 1987). Both of these studies concluded that beaver may lead to local aspen extinction if population numbers are not closely controlled.

The mountain beaver (not a true beaver [*Aplodontia rufa*]) is a candidate for federal endangered status and uses aspen forests for habitat and forage. Beier (1989) considers mountain beaver habitat to be marginal in the relatively dry Sierra Nevada as compared to the Pacific Northwest. In the Sierra Nevada, this species is somewhat limited to cool and moist regimes with deep soils provided by riparian habitat containing aspen and non-aspen woody species (Beier 1989; Todd 1992; Carraway and Verts 1993). Apparently, mountain beaver feed on conifers in the winter when other species are not available. In Oregon, researchers found that a high percentage of conifer seedlings were eaten by mountain beaver (Carraway and Verts 1993). In the Sierra Nevada, Steele (1989) documented use of aspen bark for food and found clippings in "haystacks," a mix of vegetation used in nest building.

Mule deer (*Odocoileus hemionus*) are the largest native ungulate currently on the Sierra Nevada landscape. Domestic cattle (*Bos taurus* spp.) and sheep (see Chapter 2: Historical Disturbance Ecology), though they prefer non-woody forage, have been known to trample suckers, denude their foliage, and promote exotic grasses and forbs in overgrazing situations (Kay and Bartos 2000). The combined effects of deer and cattle on aspen communities have been examined by researchers in the McCormick Creek basin of the Stanislaus National Forest (Loft and others 1987, 1991, 1993). One conclusion of this series of studies is that deer and cattle are attracted to the same dense forb communities that aspen provide, but deer often avoid these sites when cattle are present (Loft and others 1993). The aspen/corn lily vegetation type (see Plant Associations, this chapter) was more highly used by cattle than adjacent willow types because of high quality forage (Loft and others 1987). They found deer must spend more of their day feeding and less time resting, and that there was significantly less hiding cover for fawns, when cattle are competing for the same forage in aspen stands (Loft and others 1993). As summers progress, deer must expand their range further to make up for denuded preferred aspen habitat that cattle have been grazing (Loft 1989). In sum, these authors felt that the limited aspen cover in their study area (4 percent of total area) should be devoted to mule deer (and other wildlife) habitat rather than cattle grazing since the negative effects of competition with livestock were so pronounced on deer and livestock could use other forage types (Loft and others 1993).

Where native ungulate herbivory is unchecked by predation, animal disease, extreme weather, recent disturbance, or wildlife management measures, aspen regeneration can be severely limited. Though elk exist in small numbers in the Southern Cascades and Modoc Plateau, they have not become the dominant consumers of aspen sprouts as they are in the Rocky Mountains (Baker and others 1997; Kay and Bartos 2000; Romme and Turner 2004). Further growth of these herds may begin to show increased effects on aspen communities in this area, particularly in reducing regeneration. In the Greater Yellowstone region, research has demonstrated that large herbivores relax their natural predator avoidance behavior when top carnivores are absent, linger in open aspen stands, and decimate aspen regeneration (Ripple and others 2001). Aside from minor predation from mountain lions (*Felis concolor*) in the Sierra Nevada, unimpeded deer, or small elk populations farther north, may consume prodigious amounts of aspen suckers.

Aspen seedlings or sprouts may be partially protected from herbivory where recent disturbance, such as fire or aspen felling by beaver or windthrow, has resulted in large amounts of downed trees. Downed trees can impede localized ungulate travel by presenting natural barriers. Where downed trees are not dense enough to block travel, large logs can physically hide regenerating aspen from herbivores (Barry 1971; Ripple and others 2001). After the 1988 fires in the Greater Yellowstone region, a large pulse of aspen seedlings were discovered on burned sites (Romme and others 1997). Many of the burned trees, predominantly lodgepole pine, subsequently fell to the forest floor providing protection for new growth of various species, including the rare crop of aspen seedlings (Ripple and others 2001). However, a trade-off exists between the protection offered by downed logs and the effect that their shade has on soil temperature and sprouting. Shepperd (1996) found that in Colorado, heavy slash loadings greatly reduced aspen sucker establishment. A final factor, the reintroduction of gray wolves (*Canus lupus*) to the Yellowstone ecosystem, has provided an additional element of protection for aspen seedlings and sprouts in that the threat of predation keeps elk on guard and moving so that they do not browse excessively in any given area (Ripple and others 2001).

The trophic links in Yellowstone may provide a model for a healthy aspen terrestrial biota in the Sierra Nevada and elsewhere. Burgeoning populations of introduced or native herbivores have the potential to severely affect aspen stands, which in turn, will have cascading impacts on other species, such as rare breeding birds or diverse plant communities. Maintenance of ecosystem function and structure will likely enhance the broadest species composition (Noss 1990), provided that the ecosystem is within its "natural range of variability" (Landres and others 1999). Our limited discussion of terrestrial biota has thus far explored aspen-fauna interactions. Let's now balance our review by discussing the floral diversity of aspen communities.

## *Plant Diversity in Aspen Forests*

Just as aspen is associated with many different types of animals, aspen is also associated with certain plant species. As previously discussed (see Plant Associations, this chapter), aspen is usually a minor forest type surrounded by, or included within, drier conifer forests in the Sierra Nevada and surrounding areas covered in this work. Therefore, we may view aspen communities as oases of plant and animal diversity. Several authors cite high levels of plant diversity in aspen when compared to surrounding vegetation types (Mueggler 1985; Potter 1998; Manley and Schlesinger 2001; Chong and others 2001). Specifically, Manley and Schlesinger (2001) observed greater than 60 plant species in riparian zones of the Sierra Nevada where at least 10 percent of a stream reach was occupied by aspen-cottonwood. Additionally, they found increases in rare plant species and even mammal observations when cover of aspen-cottonwood increased in riparian corridors. In the Interior West, however, Mueggler (1985) found plant species richness was high in aspen types, but did not find a corresponding association of aspen endemics. He observed that most plants in aspen forests also occurred in surrounding communities, but adjacent types did not bear all of those plants in close proximity, hence aspen's commonly higher diversity level. Potter's (1998) work reflects a more detailed study of plant communities, including aspen, in the upper montane zone of the Sierra Nevada. As a byproduct of his plant association classification work he found that aspen/mountain pennyroyal association had higher vegetative diversity than all of its forest associates except those in the western juniper/sagebrush (*Juniperus occidentalis*/*Artemisia* spp.) series. The higher density of plants, many with larger cover values, make aspen appear more diverse, though they are merely more lush than the western juniper type. Potter's aspen/California corn lily association had a slightly lower species richness than the two associations just mentioned.

Little work has been done specifically on aspen and lichen communities, though preliminary evidence suggests that aspen, often occurring as a sole hardwood among conifers, possesses a unique lichen flora. In their brief discussion of aspen and macrolichen interactions as part of a larger forest monitoring effort in Colorado, McCune and others (1998) refer to the "distinctive lichen community" found in "mature to old aspen." They go on to suggest that, "Loss of aspen would affect all of the species dependent on it, including the characteristic lichen communities." In Colorado forests, as well as in European aspen (*Populus tremula*), the greatest lichen diversity was documented where older aspen were mixed with conifers; younger and pure aspen stands do not appear to provide a diversity of substrates and local moisture (humidity) needed to support an increased lichen flora (Hedenås and Ericson 2004).

# Chapter 4.

# Current Forest Issues Related to Aspen Communities

Thus far we have examined Sierra Nevada natural history, human impacts on the forest component, and basic ecology of the aspen community. The intent of this review was to lay a foundation for discussing current aspen-related issues, monitoring activities, and potential management actions. We now turn to an evaluation of important issues affecting aspen health in the Sierra Nevada, often turning to the Lake Tahoe basin for specific examples. Although these issues may be interrelated and complex, we will attempt to advance an informed discussion and recommend appropriate alternatives. A clear understanding of ecological benefits, as well as potential cautions, of aspen related issues is necessary to make informed decisions about managing aspen in specific landscapes or to improve aspen community vigor at the regional scale.

## Threats to Aspen Sustainability

### *Advancing Conifer Succession*

An overarching theme in this chapter, and one alluded to throughout this publication, is succession of vegetation in Sierra Nevada forests over the past century. Aspen ramets are relatively short-lived when compared to their coniferous counterparts. Numerous authors have documented the disturbance dependent nature of aspen forests (Sampson 1916; Baker 1925; Mueggler 1985; Jones and DeByle 1985b; Bartos and others 1991; Rogers 2002). Following forest disturbance, such as a wildfire or avalanche, aspen suckers sprout from existing root stock to take advantage of open sunlight created by clearing of the previous forest. As stands age, the new aspen cohort will self-thin over time due to competition for limited resources. Eventually, in most aspen forests, more shade tolerant tree species will colonize stands. As these trees begin to overtop the aspen, a decline in growth and concordant onslaught of pathogens typically causes a rapid reduction in stand vigor (Baker 1925; Hinds 1985; Rogers 2002) (fig. 4-1). Remaining aspen may persist if they can maintain some open light in the canopy of conifers (Ko 2001) (fig. 4-2). These trees may act as root-stock refugia that will eventually sucker anew

**Figure 4-1.** Stem cankers may have profound effects on entire aspen stands. As stands age, they become more susceptible to serious decay.

**Figure 4-2.** Although aspen is often overtopped by conifers, it may persist with low levels of regeneration where ample gaps allow sunlight to reach the understory. The photo shows young aspen reaching for sunlight around this small forest opening.

with a stand replacing disturbance. In the absence of stand replacing (or at least stand opening) disturbance, all ramets of the previous generation will eventually die out. Viable root stock cannot be maintained without at least some living ramets to procure photosynthetic energy, so complete loss of aspen from a site may be the final outcome of vegetation succession from aspen to conifers.

As discussed previously, aspen may also regenerate from seed, although this appears to be a rarity in the West, perhaps occurring on a scale of centuries at any given locale (Kay 1993; Romme and others 1997). Although we assume that seedling establishment is possible in the Sierra Nevada, since both male and female clones exist (Burton 2004b), as yet we are unaware of specific documentation of true seedlings. Thus, as a short term strategy, re-establishment via natural seeding events does not appear to be a reliable option for regional maintenance of the species.

Aspen is generally associated with canyon bottoms and meadow communities in the Lake Tahoe basin. Figure 4-3 presents a preliminary census of aspen stands in this basin. At this scale, the association between aspen and primary streams is evident. Overall, aspen cover


**Figure 4-3.** Aspen stands in the Lake Tahoe basin. Stands indicated in this map are located on land administered by the Lake Tahoe Basin Management Unit, California Conservancy, and California and Nevada State Park Systems. As of the printing of this map, the Forest Service has not inventoried its lands in the northern part of the Basin. Verified aspen locations shown at this scale are generally aligned with canyon bottoms. No data are available for aspen stands located on private lands. Each indication on this map represents an individual geo-referenced point. The size of stands is not reflected on this map.

a b

**Figure 4-4a,b.** Dramatic change over a 130-year period at Spooner Summit: **(a)** an historic photo from 1876 at height of logging/mining boom during the Comstock era. The voracious need for wood for railroads, mining materials, flumes, housing, and fuel resulted in denuded slopes and transformed landscapes; **(b)** this 1992 photograph of the same landscape shows ample aspen growth in the riparian zone with conifers upslope. Some invasion of aspen by conifers is already underway. ©Reproduced by permission (Goin and Blesse 1992).

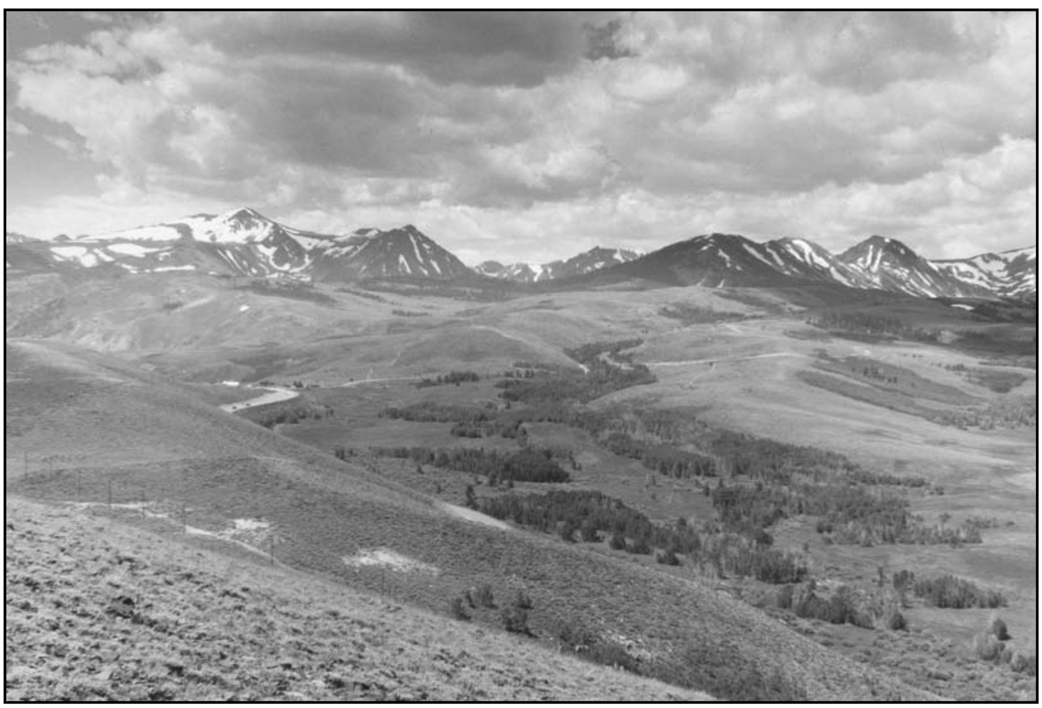
only a small portion of the basin's landscape—about 0.5 percent by recent estimations (Manley and others 2000). Was this always the case, or are there particular human-induced circumstances that have led to the current vegetative configuration? One way to examine this question is through the historical record of disturbance, which we discussed previously (see Chapter 2: Historical Disturbance Ecology).

Comparison of historic and recent photographs is another method of documenting landscape change over time. A few researchers have used historic photos in the Interior West to document change in aspen communities (Gruell 1983; Manier and Laven 2002; Kay 2003). The photographic record in the Sierra Nevada seems to bear out historic and climatic evidence, as reflected in vegetative cover, of intense disturbance in the 19th century being followed by advancing succession of shade-tolerant trees in the 20th century. Figure 4-4 consists of a photo pair dated 1876 (a) and 1992 (b). In the historic photo you can see the immense impact that the mining era had on the Carson Range, and specifically at Spooner Summit where forested hillsides were denuded to supply logging trains traveling east to Virginia City area mines (Strong 1984). Drainage bottoms, where aspen exist today (fig. 4-4b) were impacted most by the construction of rail lines, wagon and horse trails, small houses, and loading platforms. All of this activity virtually wiped out the native tree cover on the summit. The modern photo shows aspen clones occupying moister and deeper soils, with a century of conifer growth dominating the higher slopes. Some conifers can be seen penetrating through the aspen, signifying a gradual succession to conifers. Signs of past development (rail tracks, homes, logging flumes) are absent from this more recent landscape view. The assertion by Potter (1998) that contemporary aspen began their development following land clearing by post-settlement industrialists is evident in these photos. Human activities in the area today, including fence and power lines, a picnic area, and adjoining trails, continue to shape contemporary forest development, although in more subtle ways.

Aspen stands shown near Conway Summit (fig. 4-5a and b) present a very different view of advancing succession. In this instance, near-pure aspen stands in a non-forest matrix have proliferated and expanded during this 80-year period. Since natural fire is very limited at this high elevation, we presume that previous decades of intense livestock grazing kept aspen regeneration at bay in the 1906 photo. Aspen is not readily visible in the 1906 photo that was apparently taken in late spring prior to leaf-out, but aspen cover seems to be limited in stature and located primarily within drainage bottoms. The modern photo of the same area shows a more vibrant aspen community, apparently thriving in upland conditions (foreground).

Contemporary photos around the Lake Tahoe basin depict primarily riparian aspen with conifers invading the edges of aspen stands. Figure 4-6 shows 20- to 30-year old white fir beginning to shade out a much older

a



b

**Figure 4-5a,b.** Photo pair taken at Conway Summit depicts a different type of change from our previous example (figure 4-4a,b), although advancing succession in this instance resulted in greater aspen cover where historic overgrazing and related fires kept regeneration in check. The historic photo **(a)**, taken in 1906, shows limited aspen cover confined predominantly to the drainage bottoms, while the modern photo **(b)**, from 1998, illustrates substantial growth of woody plants, mostly aspen, with the removal of livestock over recent decades. Source: (1906) W.D. Johnson, Conway Summit-Virginia Creek, Mono County, California. Photo #666, Geological Survey Photography Library, Denver, Colorado. ©(1998) George E. Gruell, Carson City, Nevada.

**Figure 4-6.** This small aspen stand at the edge of a meadow in Blackwood Canyon is being actively invaded by white fir (*Abies concolor*). Ample light under mature aspen is encouraging some regeneration of aspen, but little regeneration is occurring under the heavily shaded fir portion of this stand.

aspen stand. When taking this photo, we noted that regeneration was plentiful under mature aspen, but no aspen sprouts were evident where fir was dominant.

## *Limited Aspen Regeneration*

Advancing succession presents only one part of the aspen story in the Sierra Nevada. Not only do conifers shade out mature aspen trees, but they severely limit the possibility of aspen suckering. Overstory clearing, whether in small gaps or in large openings, provides the needed light for suckers to proliferate. A recent study of aspen regeneration in the Lake Tahoe Basin suggests that aspen is not declining overall because of a high rate of small-scale gap filling by seedlings and saplings (Ko 2001). However, this study apparently focused on stands where aspen comprised the dominant overstory and not on locations where remnant aspen trees are now outnumbered by a conifer canopy. Though gap replacement may engender small-scale population stability, it will not curtail the larger trend of conifer succession in stands currently dominated by aspen and in stands where conifers have long since overtopped the previous aspen forests. Where aspen abut larger forest openings, either natural or human-caused, new suckers may arise in an "apron" of regeneration where aspen roots penetrate into the opening (fig. 4-7). In the past century, reduced wildfire, related to relatively moist climate patterns (Millar and others 2004) and fire suppression, appears to have led to reduced aspen regeneration (fig. 4-8). Compounding this situation (mostly outside the Tahoe basin) is the possibility of losing aspen sprouts because of domestic and wild ungulate use (see Chapter 3: Terrestrial Biota Earlier and Range Management and Aspen Communities, below).

Other factors can also affect aspen regeneration success. Figure 4-9 shows a conifer removal cut with very limited aspen regeneration in the Lake Tahoe basin. Since neither livestock nor elk are present, this may be due to a limited aspen root system resulting from previous conifer dominance and/or persistent shading from surrounding uncut trees. This clone may require additional disturbance to initiate suckering, so additional management actions, such as "root ripping" (see Chapter 6: Treatment Alternatives to Regenerate Aspen—Root Separation) may be warranted. An example of normal regeneration following disturbance is shown in figure 4-10.

In essence, the true threat to aspen sustainability is maintaining the status quo: suppressing natural fires and/or avoiding active management options, such as targeted cutting, prescribed burning, and regeneration protection. Alternatives that can promote aspen rejuvenation, which is dependent on moderate-to-intense disturbance, are limited in the highly developed Lake Tahoe basin. The basic choices are: 1) allowing natural disturbances to take their course, 2) actively managing for aspen

**Figure 4-7.** Aspen may continue to grow out in "waves" from an established stand where there is a lack of competition from other trees, and adequate growing conditions (full sunlight, moisture, soils, etc.).

**Figure 4-8.** Lack of regeneration under mature aspen cover. The stand appears to be changing cover types from aspen to tall grass meadow, or possibly pine (*Pinus* spp.), and is showing signs of encroachment near the granite outcrop.

**Figure 4-9.** Three years post-harvest there is very little regeneration in this North Canyon aspen stand.

**Figure 4-10.** Typical flush of aspen regeneration one year after a fire on the Modoc National Forest. Each alternating color stripe on the pole equals six inches (13 cm).

rejuvenation, or 3) intelligently crafting geographically specific syntheses of both options. For instance, at sites farther from human development it may be more appropriate to allow natural fire or conduct occasional prescribed burns. Management near residential areas may require a more precise, less random, course of action, such as small patch clearings with precisely controlled burning. A more detailed discussion of management options for particular situations, including highly developed areas, can be found in Chapter 6.

# Aspen Habitat and Species of Concern

## *Aspen as Prime Habitat*

A recent comprehensive watershed assessment of the Lake Tahoe basin declares aspen forest types as one of nine "Ecologically Significant Areas" (ESAs) (Manley and others 2000). The criteria used for this designation are minimum human alteration, rarity on the landscape, and potential for high biological diversity. Aspen is one of two ESAs that is both geographically rare and shows high diversity—the other being marshes. Most of the nine ESAs were closely related to water proximity. This places a premium value on existing aspen stands and evaluating options for stands where other forest types may be encroaching on the very limited aspen cover in the Lake Tahoe basin. Numerous authors have broadly discussed the high biotic diversity of aspen stands (DeByle 1985c; Chong and others 2001) and we have devoted considerable discussion to the topic as it applies to the Sierra Nevada (see Chapter 3: Terrestrial Biota). But how dependent are identified wildlife species on aspen in the Lake Tahoe basin and how will management (or lack thereof) affect those species? If, as Manley and others (2000) asserted, aspen is truly "ecologically significant," then important steps should be taken to preserve aspen not only for its own sake, but for the species that are dependent upon aspen for critical habitat.

## *Species of Concern, Lake Tahoe Basin*

Several species within the Lake Tahoe basin are formally designated on state threatened or endangered lists. In this section we highlight those species of concern that are either somewhat or highly dependent on aspen ecosystems. Table 4-1 shows threatened vertebrates known to use aspen in the Sierra Nevada and Lake Tahoe areas. Federally endangered species carry the greatest restrictions. California "threatened" and Nevada "rare" species include legislative prohibitions on intentional destruction (for example, hunting or trapping). The Nevada "watch list" is the least restrictive category, designating species of some demographic concern. At this time there are no confirmed southwestern willow flycatchers (*Empidonax traillii extimus*), a federal endangered species, in the Lake Tahoe basin, although this subspecies is known to inhabit the southern Sierra Nevada. Survey data from around the basin shows mountain willow flycatcher (*Empidonax traillii adastus*), a threatened species in California, either directly or indirectly using aspen habitat (Morrison 2005). Preliminary results showed an estimated 43 mountain willow flycatcher territories in the Lake Tahoe basin (Morrison and others 2002). In many cases, willow (*Salix* spp.) used by willow flycatcher is co-located with aspen stands around wet meadows or along streams. Where conifers are invading, meadows will become drier, decreasing willow/aspen

**Table 4-1.** Listed vertebrates for the Lake Tahoe basin known to use aspen habitat.

| | Common name | Latin name | Status notes |
|---|---|---|---|
| **Amphibians** | Mountain yellow-legged frog | *Rana muscosa* | Nevada rare species list; federally endangered in southern California |
| **Birds** | Northern goshawk | *Accipiter gentillis* | Nevada rare species list |
| | Mountain willow flycatcher | *Empidonax traillii adastus* | Califronia threatened species; Nevada rare species list |
| | MacGillivary's warbler | *Oporornis tolmiei* | Nevada watch list |
| | Flammulated owl* | *Otus flammelous* | Nevada rare species list |
| | Red-naped Sapsucker | *Sphyrapicus nuchalis* | Nevada watch list |
| **Mammals** | Sierra (Mono Basin) mountain beaver | *Aplodontia rufa californica* | Nevada rare species list; see Terrestrial Biota discussion |
| | Northern flying squirrel | *Glaucomys sabrinus* | Nevada watch list |
| | North American wolverine | *Gulo gulo* | Califronia threatened species; Nevada watch list |
| | Western red bat | *Lasiurus blossevillii* | Nevada rare species list |
| | Sierra Nevada snowshoe hare | *Lepus americanus tahoensis* | Nevada watch list |
| | American marten | *Martes americana* | Nevada rare species list |
| | American pika | *Ochotona princeps* | Nevada watch list |
| | Sierra Nevada red fox | *Vulpes vulpes necator* | Califronia threatened species; Nevada watch list |
| | Western jumping mouse | *Zapus princeps oregonus* | Nevada watch list |

**Sources:** Manley, Patricia N.; Fites-Kaufman, Jo Ann A.; Barbour, Michael G.; Schlesinger, Matthew D., and Rizzo, David M. Biological integrity.
Murphy, Dennis D. and Knopp, Christopher M., editors. Lake Tahoe watershed assessment: Volume I. Albany, CA: USDA, Forest Service, Pacific Southwest Research Station; 2000; p.554-557.
* Powers, Leon R.; Dale, Allen; Gaede, Peter A.; Rodes, Chris; Nelson, Lance; Dean, John J., and May, Jared D. Nesting and Food Habits of the Flammulated Owl (Otus Flammeolus) in Southcentral Idaho. Journal-of-Raptor-Research. 1996; 30(1):15-20.
Nevada Natural Heritage Program: http://heritage.nv.gov/lists/animls04.htm
California Department of Fish & Game: http://www.dfg.ca.gov/whdab/pdfs/TEAnimals.pdf

habitat and increasing predation of mountain willow flycatchers (Morrison 2005).

The USDA Forest Service Lake Tahoe Basin Management Unit (LTBMU) has recently conducted center point bird counts in aspen stands surrounding Lake Tahoe. One state listed species, MacGillivray's warbler (*Oporornis tolmiei*), has been tallied six times in these counts along with numerous other birds that are not listed as using aspen habitat (data on file, Lake Tahoe Basin Management Unit). LTBMU wildlife biologists have recently documented northern goshawk (*Accipiter gentillis*) nesting sites associated with aspen within the Lake Tahoe watershed (fig. 4-11). A 2004 Lake Tahoe basin survey of goshawks detected 23 nest sites and 45 individuals (29 adult and 16 juveniles). Approximately 9.5 percent of goshawk nests were located in aspen trees in a variety of forest types and over half (61 percent) were within 300 ft of a water source (USDA Forest Service 2004b). Researchers in the Great Basin have documented the close relationship of goshawks to aspen communities (Younk and Bechard 1994). This study found that goshawks preferred larger and older aspen, with relatively open understories, in close proximity to water similar to the Lake Tahoe findings described here.

Surveys of intermediate size native carnivores in the Sierra Nevada have not confirmed sightings of either the North American wolverine (*Gulo gulo*) or the Sierra Nevada red fox (*Vulpes vulpes necator*) in over 60 years. The lack of sightings of these two species may be attributed to their notorious aversion to people (Zielinski 2004). Zielinski also notes a decline in American marten (*Martes Americana*) throughout the Sierra Nevada, especially outside of reserved areas (lands reserved from logging and alteration, such as designated wilderness, National Parks, and wildlife preserves). It is thought that reductions in marten numbers are due to forest fragmentation, but this assertion has not been specifically tested in the Sierra Nevada. The LTBMU, in cooperation with agency and private enterprise partners, is involved in several surveys of mammals with some focus on marten. Their interests in marten vary from Off Highway Vehicle (OHV) impacts, to general baseline biodiversity surveys and urban/development impacts. Thus far, they have been monitoring up to 17 marten detection sites around the basin. Although Manley and others (2000) describe marten as using aspen habitats, it is unclear how critical this type is to their survival. In the Rocky Mountains, researchers have depicted

**Figure 4-11.** A goshawk (*Accipiter gentilis*) (inset) and its nest located along Taylor Creek in Sugar Pine Point State Park on the West Shore of Lake Tahoe. Source: R. Young. Sierra District, California State Parks.

marten as an old growth conifer species (Hargis and others 1999). Further research is clearly needed on habitat types used by American marten and potentially specific needs derived from aspen.

In summary, specific surveys are not being conducted for most threatened species found in table 4-1 and therefore definitive data sets are scarce on these species. However, we concur with Manley and others (2000) that aspen stands that are apparently succumbing to succession in parts of the Lake Tahoe basin are a potentially critical resource for maintaining diverse faunal, as well as floral, populations. It would seem reasonable that targeting aspen as a keystone species may be beneficial to several species of concern. It is clear, however, that land managers will be under continued scrutiny to monitor threatened aspen communities, as well as to document the status of individual species.

## Invasive Species and Aspen Communities

We use the term "invasive" here in the most general sense: denoting active spread of non-native plants into native landscapes. Aspen communities possess at least three characteristics that present fertile ground for invasive plants: 1) they have deep, rich, soils; 2) their proximity to moist meadows and riparian zones offer a ready source of water; and 3) their dependency on disturbance and open light is shared by many invasive species. Monitoring for invasives at aspen management sites is crucial. Some of the management suggestions advocated in this publication may in fact lead to spreading of weedy plants if precautions are not taken, such as washing and sterilizing machinery to avoid bringing invasive seed into aspen stands. The immediacy of human development and recreation to forest lands also influences the spread of invasives in the Lake Tahoe basin. People are the prime transporters of non-native plants. In the Sierra Nevada, construction and road building, escaped domestic plants from private residences and commercial nurseries, importation of fill soil containing foreign seed, and the movement of people and domestic animals may also carry seed into wildlands (Schwartz and others 1996). In addition to these direct modes of introduction, other human activities indirectly encourage invasive species, which are often generalists that are able to tolerate a wide range of conditions. For example, it is well known that humans are contributing excessive nitrogen and carbon dioxide into the soils and atmosphere from various waste products. Excess amounts of these compounds often discourage native species growth while favoring fast-spreading invasives. "Quite simply, increased human presence means increased risk of plant invasion"

(Schwartz and others 1996). This certainly does not bode well for the Lake Tahoe basin.

Aspen communities are known for high plant diversity (see Chapter 3: Plant Associations), and serve as oases of animal habitat even when covering only a small proportion of total land area (see Chapter 3: Terrestrial Biota). But high diversity does not necessarily equate with low plant invasion. Recent research suggests that diverse plant communities, such as aspen forests, are not necessarily more resistant to invasive plants as is commonly believed (Lonsdale 1999; Stohlgren and others 2003; Gilbert and Lechowicz 2005). A study of several forest types in Rocky Mountain National Park found more invasive species present in aspen stands than other forest cover. Of 42 total invasive species in the study, 90 percent were found in aspen and 39 percent of those were exclusive to the aspen type (Chong and others 2001). Interestingly, they did not find a large cover of invasives, only a large diversity of their presence in aspen stands. Thus, Chong and others caution that given appropriate disturbance, these aspen stands located in a relatively pristine setting, but with invasive seed present, are poised for higher levels of invasion that could crowd out native species.

## *Invasive Species of the Sierra Nevada*

Many of the highly disruptive activities of the settlement era (1850 to 1900, see Chapter 2: Historical Disturbance Ecology), in addition to modern road building and related development, have provided an ecological opening for invasive plants. We might imagine that invasive or exotic species colonize wildlands in a rapid or dramatic fashion, but most plant invasions have been underway for decades or centuries. Often an introduced species will persist at low levels for decades before spreading rapidly when favorable climatic or disturbance conditions present themselves. Many of the exotic species found in California forests today were introduced either intentionally or unintentionally by European settlers, beginning in the 18th century (Bossard and others 2000). Nearly all of these species are of Eurasian origin and are noted for their ecological amplitude. For example, common mullein (*Verbascum thapsus*) was likely intentionally introduced to the eastern United States as a medicinal plant in the 1700s from Europe. It was subsequently transported by settlers, either intentionally or not, and established in California by the 1880s. Jepson (1925) acknowledged 292 non-native species in the state. By the end of the 20th century the estimate was at 1,045 invasive plants (Randall and others 1998). Of these 1,045 non-native species in California, about 10 percent are considered serious threats (Bossard and others 2000). In table 4-2 we list species that constitute the most serious threats to Sierra Nevada forests according to the California Exotic Pest Plant Council (Bossard and others 2000; D'Antonio and others 2004; Calflora database [www.calflora.org/index0.html]). Thus far, many of these plants have only been documented in low quantities above 5,000 ft (1,524 m) in elevation where aspen habitat exists. Changing conditions may promote further expansion of any one of these plants, so it is essential for managers to detect, monitor, and eradicate (if appropriate) non-native species at an early stage (D'Antonio and others 2004). This strategy is recommended for economic efficiency and protection of native diversity. Exponential spread of invasive species can result in dominance of resources used by native plant communities within a short time.

## *Invasive Plant Survey of Lake Tahoe Basin*

Though the Lake Tahoe basin has most of the basic ingredients for rapid dissemination of invasive weeds, one thing working in its favor is its relatively high elevation. Generally, the impact of invasive species is less at higher elevations. "While there are species (for example, Kentucky bluegrass [*Poa pratensis*]) that invade high-elevation Sierra Nevada meadows, the number of these is few relative to lower elevations in the Sierras" (Schwartz and others 1996). Most invasive species found in our list (table 4-2) thrive at elevations lower than the basin's 6,200 foot (1,890 m) base. A preliminary survey of invasive species conducted by the LTBMU is depicted in figure 4-12. This map shows a spotty pattern of non-native intrusions, mostly correlated with heavy development and recreation sites, but also with riparian zones where aspen is prevalent. Basin-wide geographic patterns of invasive species are evident. Those invasive species that are evenly distributed throughout the basin and are away from major roads, such as bull thistle (*Cirsium vulgare*), have likely been here longer and have efficient dispersal and germination mechanisms for this location. Others, such as nodding bluegrass (*Poa reflexa*), display the opposite pattern (locally distributed, near roads) suggesting a recent introduction or limited dispersal ability in this

**Table 4-2.** Major invasive exotic plants of forested communities above 5,000 feet (1,524 m) elevation in the Siera Nevada.

| Common name | Latin name | Elevation (ft.) | Notes |
|---|---|---|---|
| Cheatgrass | *Bromus tectorum* | up to 7,200 | eastern Sierra Nevada; Modoc Plateau |
| Hairy whitetop | *Cardaria pubescens* | up to 6,600 | proliferate in moist riparian uplands |
| Nodding plumeless thistle | *Carduus nutans* | up to 6,500* | fields and roadsides |
| White knapweed | *Centaurea diffusa* | up to 7,500 | northern Sierra; uncommon in Lake Tahoe basin |
| Spotted knapweed | *Centaurea maculosa* | up to 6,600 | widespread; aggressive colonizer |
| Tocalote | *Centaurea melitensis* | up to 7,200 | woodlands and field, of lesser invasiveness |
| Yellow starthistle | *Centaurea solstitialis* | up to 7,500 | dry sites; spreading in Cascades, Sierra, and Modoc |
| Canada thistle | *Cirsium arvense* | up to 6,000 | spreading by roots; a robust plant up to 6 ft. in height |
| Yellowspine thistle | *Cirsium ochrocentrum* | up to 10,000 | pine, pinyon-juniper, sagebrush communities |
| Bull thistle | *Cirsium vulgare* | up to 7,500 | widespread; colonizes recently disturbed sites |
| Scotchbroom | *Cytisus scoparius* | up to 6,200* | found on river banks, road cuts, and forest clearcuts |
| St. Johnswort | *Hypericum perforatum* | up to 7,100* | woodlands and field, of lesser invasiveness |
| Broadleaved pepperweed | *Lepidium latifolium* | up to 7,200 | riparian, roadsides, wet meadows |
| Ox-eye daisy | *Leucanthemum vulgare* | up to 7,000 | northern Sierra, mountain meadows, riparian forests |
| Butter and eggs | *Linaria vulgaris* | up to 6,300* | recently introduced in Lake Tahoe area |
| Dalmation toad-flax | *Linaria dalmatica* | up to 7,000* | forest openings and grasslands |
| Purple loosestrife | *Lythrum salicaria* | up to 6,000 | found in wetlands, riparian, and meadow habitat |
| Scotch thistle | *Onopordum acanthium* | up to 5,200 | widespread throughout region |
| Kentucky bluegrass | *Poa pratensis* | up to 8,000 | widespread in moist and dry sites |
| Sulphur cinquefoil | *Potentilla recta* | up to 6,400* | roadside; recently introduced in Lake Tahoe area |
| Black locust | *Robinia pseudoacacia* | up to 6,200 | mature groves may shade out native vegetation |
| Himalayan blackberry | *Rubus discolor* | up to 5,200 | Bossard et al. (2000), occurs in the Sierra Nevada |
| Russian thistle | *Salsola tragus* | up to 8,900 | Shrublands, Calflora is requesting more information |
| Common dandelion | *Taraxacum officinale* | up to 10,800 | widespread; usually in non-wetland areas |
| Common mullein | *Verbascum thapsus* | up to 7,200 | broad range in forest cuts, riparian, and meadows |

Sources: Bossard, Carla C.; Randall, John M., and Hoshovsky, Marc C. 2000. Invasive plants of California's wildlands. Berkeley, CA: University of California Press; 360 p.
D'Antonio, Carla M.; Berlow, Eric L., and Haubensak, Karen L. Invasive exotic plant species in Sierra Nevada ecosystems. In: Murphy, Dennis D. and Stine, Peter A., editors. Proceedings of the Sierra Nevada science symposium. Albany, CA: USDA Forest Service, Pacific Southwest Research Station; 2004; PSW-GTR-193. 175-184.
Hickman, James C. The Jepson manual: higher plants of California. Berkeley, CA: University of California Press; 1993. 1400 p.
Calflora taxon report: www.calflora.org

* Documented at higher elevations than acknowedged elsewhere in Sierra Nevada in Lake Tahoe area by USDA Forest Service, Lake Tahoe Basin Management Unit.

area. Not surprisingly, the most invaded areas within the Lake Tahoe basin are those with the highest human use. A quick glance at figure 4-12 shows moderate invasions at several populated points along major highways around the lake, and heavier invasion at high use areas on the south shore and in Blackwood Canyon midway up the west side of the lake.

A closer look at Blackwood Canyon, a moderately infested watershed, reveals patterns and potential risks when we compare an invasive species survey with the location of delineated aspen stands (fig. 4-13). Of a total of 6.05 acres (2.45 ha) of surveyed invasive weeds in Blackwood Canyon, 75 percent are St. Johnswort (*Hypericum perforatum*) and 25 percent are bull thistle. All introduced plants surveyed here are near roads and many are adjacent to aspen stand polygons. Not coincidently, roads play an important role in weed introduction. Loosely affixed invasive seeds are often transported by cars and deposited at stopping points or while vehicles are moving. The road follows the drainage bottom in the lower reaches of Blackwood Canyon, which is a riparian corridor with deeper soils, common prerequisites for aspen stands in the Tahoe basin. Musk thistle (*Carduus nutans*) has been found in aspen treatment areas elsewhere in the Sierra Nevada (figure 4-14). It is classified as an "A" rated noxious weed by the California department of Food and Agriculture, and should be targeted for eradication or containment when found.

Human disturbance associated with recreation (see Recreation Impacts, this chapter) along this corridor are also present. Activities such as horseback riding or all terrain vehicle use, reduce plant cover, expose mineral soil, and help disperse invasive plant seeds. Considering that aspen regeneration may require additional disturbance and that at least two invasive plants are already established adjacent to aspen

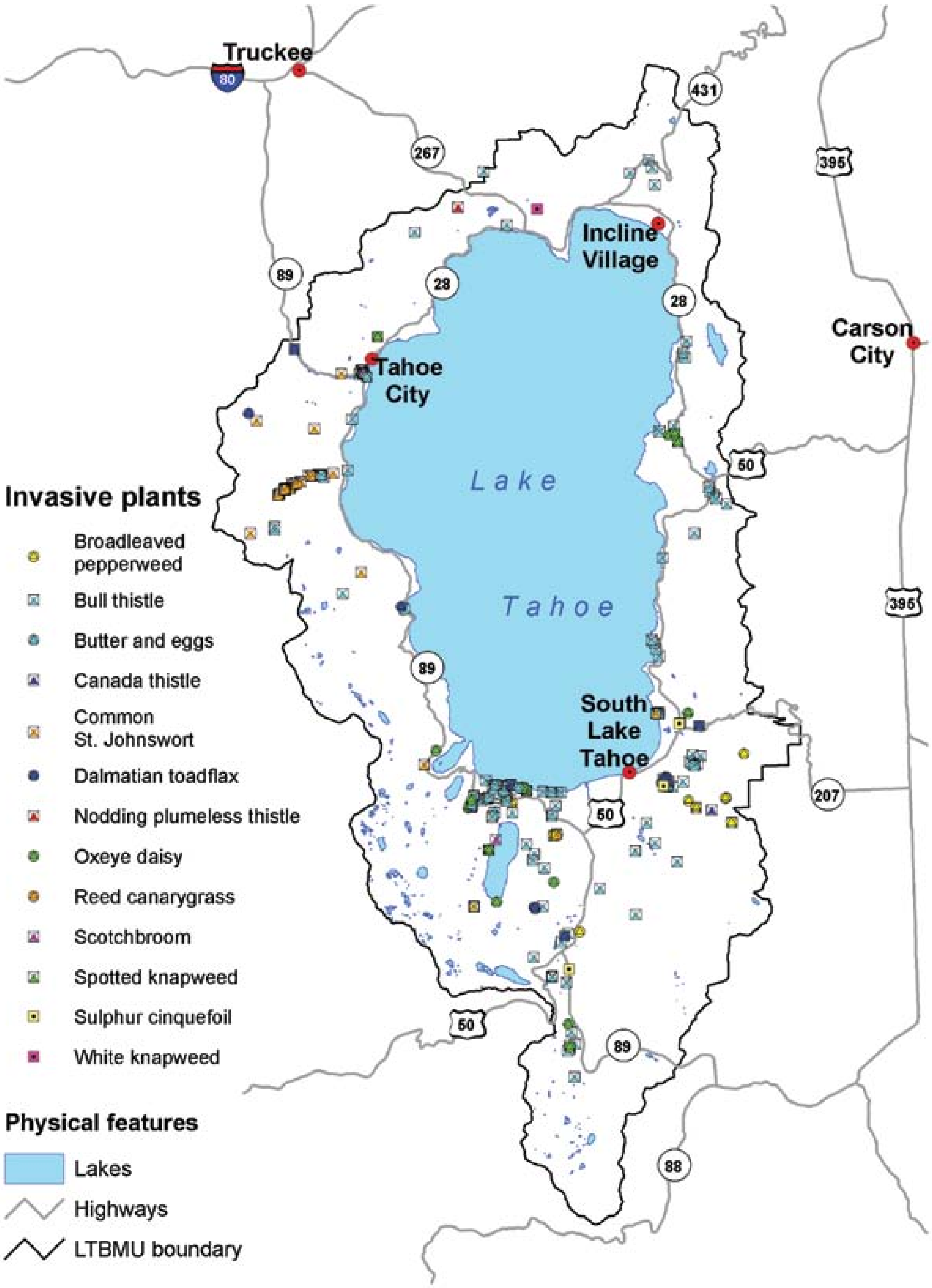



**Figure 4-12.** A basin-wide survey of invasive species by the USDA Forest Service Lake Tahoe Basin Management Unit depicts the location and diversity of species present. Lake Tahoe basin has a modest level of invasive species compared to lower elevation sites.

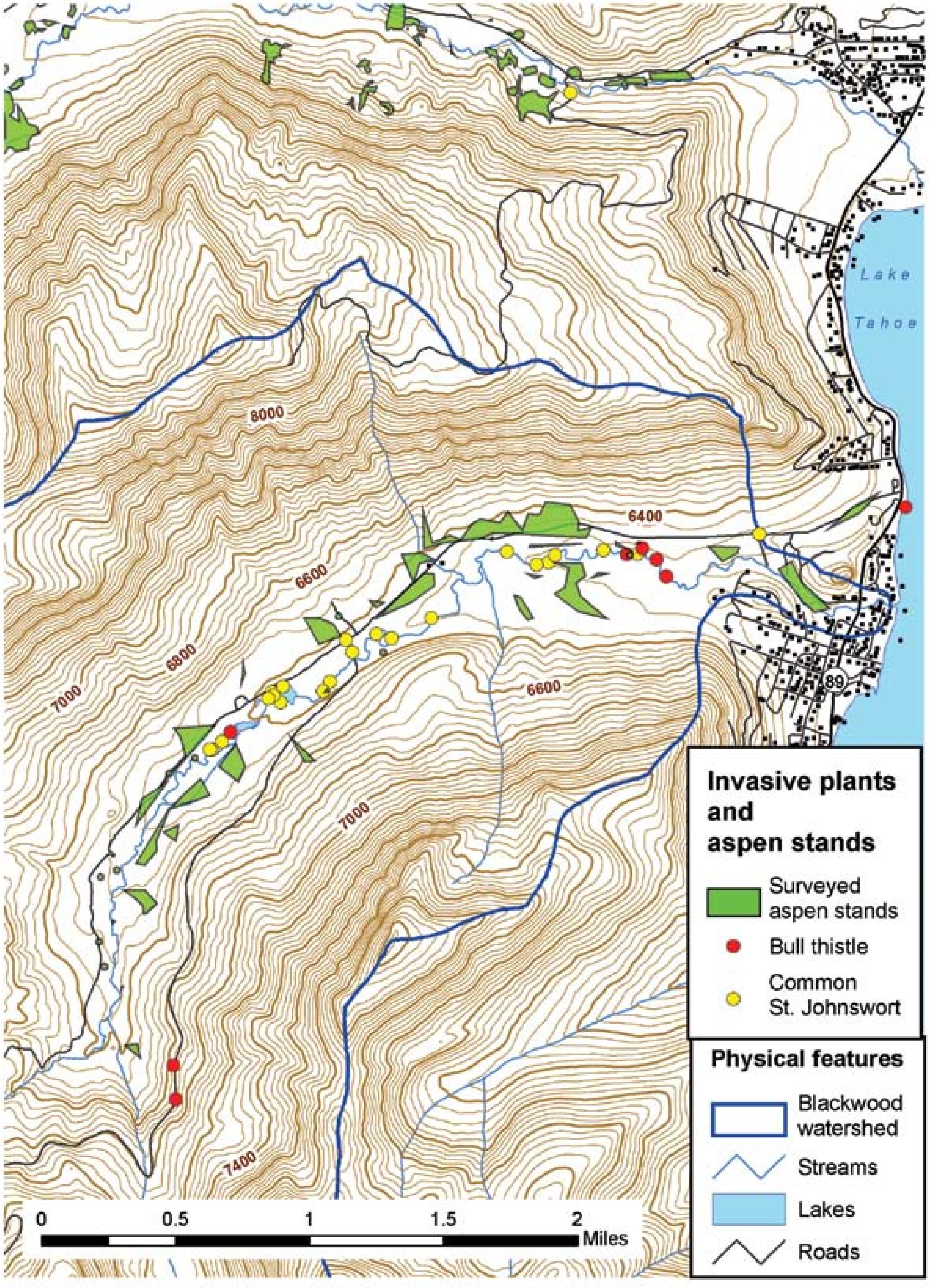



**Figure 4-13.** Association of field verified aspen stands, and St. Johnswort (*Hypericum perforatum*) and bull thistle (*Cirsium vulgare*) survey data in Blackwood Canyon, on Lake Tahoe's west side. This large-scale view shows a clear relationship between plant invasions and road and riparian corridors, as well as plant invasion in close proximity to aspen stands.

**Figure 4-14.** Musk thistle (*Carduus nutans*) colonizing a recently burned site where the soil was particularly disturbed. Young aspen are regenerating in the background.

communities in Blackwood Canyon, preventative measures to eliminate or reduce plant invasions following aspen regeneration would be recommended. In addition to out-competing native understory species, aggressive non-native plants may limit the regeneration success of aspen in this area. Careful treatment and long-term monitoring will be needed to insure successful aspen reestablishment.

# Aspen in the Wildland Urban Interface (WUI)

## *Development and Natural Process Conflict*

An aspect of aspen community health that is somewhat unique to the Lake Tahoe basin is its proximity to large tracts of human development. Natural disturbance processes, as well as forest management actions, often conflict with homeowner expectations or values. Many residents and visitors to Lake Tahoe view forests as beautiful settings for human enjoyment that remain unchanged over time. Disturbance ecology tells us that there is a certain inevitability, such as "building on a flood plain," that all forests eventually succumb to significant change agents (wildfire, landslide, beetle infestation, natural pathogens, weather events, etc.), whether or not they are populated by people (Rogers 1996). Aspen are particularly dependent on dynamic environments where disturbance spawns stand rejuvenation. Although aspen thrive on disturbance, either natural or human engineered, it may be difficult to allow stand-replacing disturbance events to occur near developed or urban landscapes. Commonly, land managers will manage disturbance processes more intensively in developed situations near the urban interface, while forests farther from settlements are allowed greater leeway in the magnitude of disturbances that are acceptable.

We must realize that a potential conflict exists between encouraging aspen to regenerate and protecting human developments. Patches of forest thinning with subsequent prescribed burning may be enough to stimulate aspen regeneration in heavily managed zones. Although such actions may not be popular, they may be necessary to arrest vegetation succession and regenerate aspen. Managers and residents alike should realize that forests will eventually renew themselves via natural disturbance events if preventative actions are not periodically taken to reduce forest density. Interference in fire regimes, for example by suppression, eventually will favor larger fires. To seek acceptable methods for managing aspen, understanding basic aspen ecology is an essential first step in the dialogue between land managers and residents of the area.

## *Lake Tahoe Defense Zones*

The map shown in (fig. 4-15) depicts the designation of wildland urban interface zones in the Lake Tahoe basin. Defense zones are defined as "the buffer in closest proximity to communities, areas with higher densities of residences, commercial buildings, and/or administrative sites with facilities" (USDA Forest Service 2004c). Threat zones, in most instances, are used to buffer defense zones from potentially catastrophic fire situations. Threat or defense zones may be adjusted for local conditions where fire suppression is projected to be difficult.

Aspen not only thrives on periodic disturbance, but pure aspen forests in the Rocky Mountains are considered a deterrent to crown fire spread because of the moisture

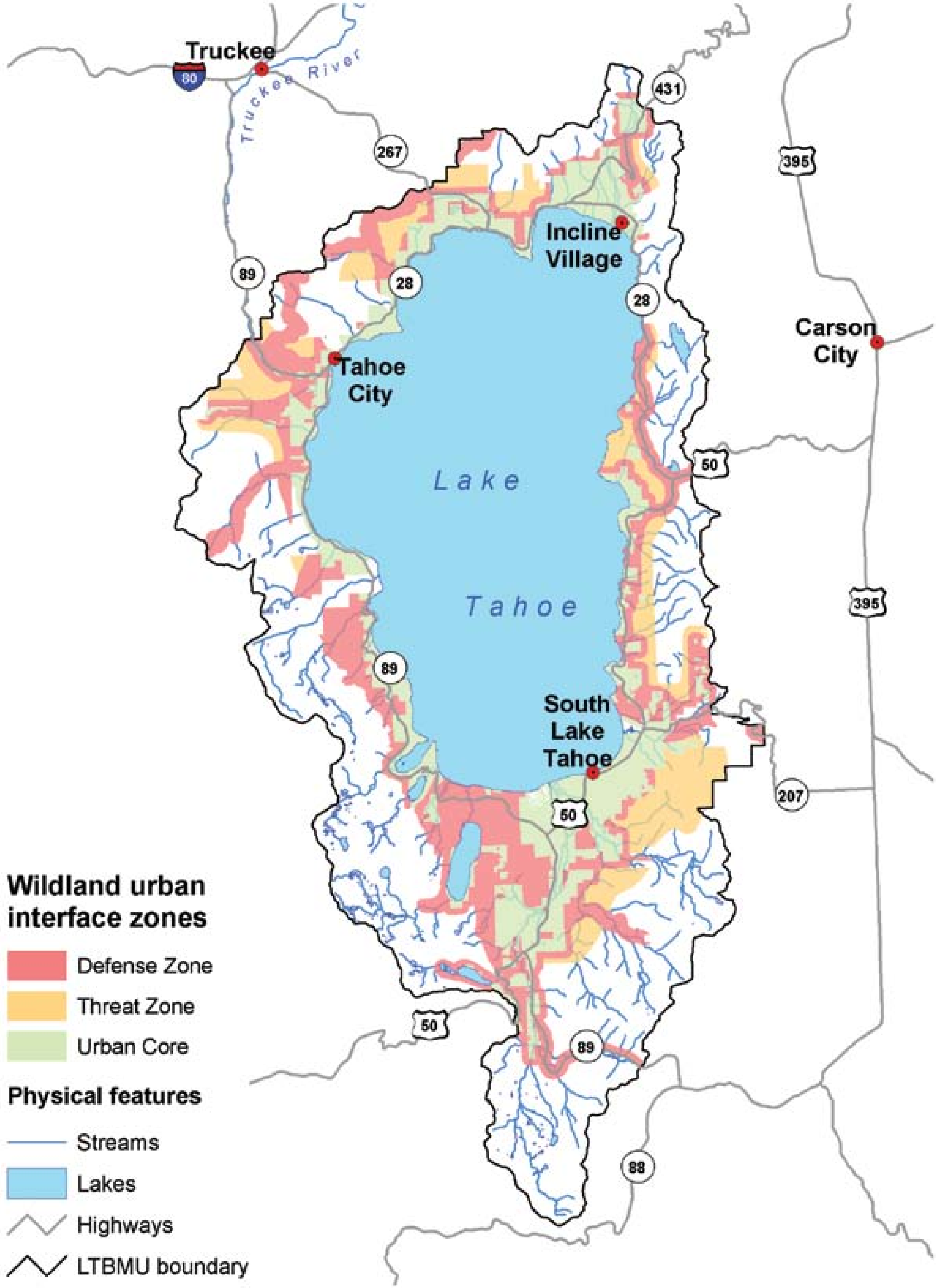



**Figure 4-15.** A basin-wide view of wildland urban interface defense zones. Defense zones are usually found closest to developed property, while threat zones are meant to buffer defense zones from potential disturbances, most commonly fire.

often held in the dense understory and the lack of aspen bark flammability (Fechner and Barrows 1976; Jones and DeByle 1985b). Thus, silvicultural techniques, prescribed burning, or wildfire that serve to restore aspen communities may, in turn, provide effective fuel breaks in the Lake Tahoe basin and other developed interface areas. Of the 388 aspen survey plots in the basin (fig. 4-3), 63 percent fall within either designated defense zones on Forest lands or developed urban private and municipal lands. Recall from figure 4-3 that much of the north and east portions of the basin had not been formally inventoried to date. Nonetheless, 35 percent of aspen stands inventoried fall in the wildland urban defense zones, providing excellent opportunities for fire prevention through bioremediation; in this case, promoting aspen health while reducing crown fire potential near developed areas.

Nearly all of the inventoried aspen polygons in the Blackwood Canyon example fall within the defense zone. Including aspen in the defense zone allows maximum flexibility to take preventative actions in an area of high use, but only moderate development. Because Blackwood Canyon is not a typical highly developed defense zone, managers feel no need to designate a surrounding threat zone. Therefore, managers may be able to stimulate additional aspen growth using prescribed fire or other management techniques in this canyon and other places where declining aspen stands occur within wildland urban interface (WUI) designated defense zones. If aspen regenerate beyond browse height, then expanded aspen forests may serve a complementary goal of providing a natural fire break near recreation and development locations.

## Recreation Impacts

Recreation is just one of many forest values in our area of concern, but recreational use has the potential to severely compromise other values (Cole and others 1987). This section presents an overview of the impacts of recreation on aspen habitats and factors that influence the severity of these impacts. In the management section (Chapter 6) we will explore ways of reducing the conflict between recreational use and conserving aspen communities.

From a recreation standpoint, aspen stands are aesthetically pleasing locations, and are often used for dispersed hiking, hunting, camping, and OHV travel. Occasionally, agencies have developed roads or trails, or constructed picnic or camping areas in aspen stands (fig. 4-16). However, recreational activities at concentrated levels are often detrimental to sensitive aspen communities. For example, the thin bark of aspen is easily damaged by human activity and subsequently penetrated by a variety of diseases (Walters and others 1982; Hinds 1985). Likewise, human activity may impede aspen regeneration through trampling and soil compaction.

**Figure 4-16.** A developed picnic ground in an aspen stand at Spooner Pass.

Many variables determine the impact of recreational uses of ecological habitats. The most significant are the: 1) amount of use, 2) type of recreational activity, 3) behavior of recreationists, and 4) the spatial and temporal distribution of use. Combinations of these factors can have a range of impacts on four ecological components of habitats-soil, vegetation, wildlife, and water (Cole 1993). In their review of literature on human impacts in wilderness areas across America, Leung and Marion (2000) summarize a broad range of impacts to sensitive areas like aspen stands caused by recreation activities (table 4-3).

In a Rocky Mountain study, Hinds (1976) found the principal causes of damage to aspen through recreational use are: 1) cutting and carving aspen trees, 2)

**Table 4-3.** Direct and indirect effects of heavy recreation impact on soils, vegetation, wildlife, and water on aspen habitats (Leung and Marion 2002).

| | Ecological Component | | | |
|---|---|---|---|---|
| | **Soil** | **Vegetation** | **Wildlife** | **Water** |
| **Direct effects** | Soil compaction | Reduced height and vigor | Habitat alteration | Introduction of exotic species |
| | Loss of organic litter | Loss of ground vegetation cover | Loss of habitats | Increased turbidity |
| | Loss of mineral soil | Loss of fragile species | Introduction of exotic species | Increased nutrient inputs |
| | | Loss of trees and shrubs | Wildlife harassment | Increased levels of pathogenic bacteria |
| | | Tree trunk damage | Modification of wildlife behavior | Altered water quality |
| | | Introduction of exotic species | Displacement from food, water, and shelter | |
| **Indirect/derivative effects** | Reduced soil moisture | Composition change | Reduced health and fitness | Reduced health of aquatic ecosystems |
| | Reduced soil pore space | Altered microclimate | Reduced reproduction rates | Composition change |
| | Accelerated soil erosion | Accelerated soil erosion | Increased mortality | Excessive algae growth |
| | Altered soil microbial activities | | | Composition change |

trampling community understory, and 3) soil compaction. Human induced wounds to aspen not only damage the physical function of the trees, but provide a pathway for pathogens to enter individual trees and sometimes even entire clones (see Chapter 3: Damaging Agents Affecting Aspen). For example, in a Colorado study of camp grounds, Hinds (1976) found 83 percent of aspen trunks contained mechanical damage from human cutting, carving, and axing of aspen trees (fig. 4-17), whereas only two percent of the aspen in an adjacent natural setting contained trunk wounds. In these campgrounds, 47 percent of the living trees had trunk cankers versus only 11 percent in the natural setting.

Soil compaction can occur from concentrated human foot travel, horse travel, or use of OHVs (Weaver and Dale 1978). Additionally, concentrated camping can cause extensive damage to aspen because of soil compaction, trampling, and sucker removal (fig. 4-18) (DeByle 1985b). Human foot traffic, pack stock, and OHV use can significantly alter soil properties. The forces exerted upon the soil reduce pore space, particularly macro pore spaces, that provide for air and water movement through soils (Cole and others 1987). In a

**Figure 4-17.** Damaged trees are common in aspen stands in developed and dispersed camping areas within aspen stands.

**Figure 4-18.** Soil compaction can result from repeated use of dispersed camping sites.

study on aspen soils similar to those described for aspen in the Serra Nevada (Potter 1998), Shepperd (1993) found that near-surface aspen roots were damaged by soil compactive forces. This occurred most commonly when numerous vehicle passes caused the stripping of small moisture-absorbing roots from large lateral roots. Soil compaction within stands may increase runoff from storm events and lead to erosion and sedimentation of waterways. Impacts can differ greatly with the type of recreational activity. Weaver and Dale (1978) reported that although there are exceptions, the general rule of thumb is that motorized uses will usually cause more impact than non-motorized uses, and horses will cause more impact than hikers. All of these impacts are amplified when soils are saturated. They found that 200 passes by a motorcycle removed twice as much vegetation as the same number of passes by a horse, and nine times as much vegetation as 200 hikers in a controlled experiment on a grassland in Montana. Shepperd (1993) found in Colorado that compaction and damage of aspen roots were affected by the number of vehicle passes and soil organic matter content with maximum damage occurring after 16 vehicle passes. Compaction effects in this study did not diminish for up to 14 years. Cole and Schreiner (1981) cite numerous studies in the Sierra Nevada that have documented compaction and damage to ground vegetation from recreation activities on wetter, more developed soils, such as those favored by aspen in this region (Potter 1998).

DeByle (1985b) speculated that winter use of aspen areas is generally not damaging because of the uniform snow cover that normally protects aspen regeneration and limits soil compaction. However, there has been a great boom in snowmobile use on public lands in the winter, and as is the case with concentrated summer recreation, attention should be given to concentrated uses of these over-snow vehicles for possible habitat alteration and increased wildlife harassment. Although we found no research data to indicate that snow machines harm aspen, their presence in young sprout stands could contribute to sucker damage caused by snow compaction and settling (See Chapter 3: Damaging Agents Affecting Aspen and fig. 3-11).

Extensive concentration of people in aspen stands may also have a negative effect on bird and mammal behavior patterns in aspen. Cole and Landres (1995) found that vegetation in newly established campsites can change within a year as sites are trampled and soil becomes compacted. Cover begins to decline, especially in ground and shrub layers. Hinds (1976) reported that dead and downed wood was quickly scavenged for fires or removed for safety in Colorado campgrounds in aspen stands. Plant species diversity, as well as horizontal and vertical structural diversity may decline. Moreover, bird communities change in response to habitat alteration. Habitat changes will generally cause the greatest reduction in bird species that rely on shrub and ground cover (juncos, thrushes, warblers, sparrows, vireos, and wrens) and those that depend on standing dead and downed woody debris (woodpeckers and secondary cavity nesters). Additionally, Marzluff (1997), reviewing studies on the effect of recreation in a range of habitat types, found that disturbance during certain times of the year may have an impact on bird behavior. For example, repeated intrusions during the nesting season may cause birds to minimize or stop singing, decrease defensive behavior at nests, and possibly cause birds to abandon nest sites leading to an overall decline in nesting productivity. Most significantly, Marzluff (1997) reported that the potential influence of human disturbance increases with the frequency and intensity of disturbance.

From a recreation standpoint, pronounced aspen mortality and site degradation lower the quality of the recreation experience. In his study of Rocky Mountains campgrounds in aspen stands, Hinds (1976) found that many of the aspen camping sites were no longer able to provide significant shade to campers due to mortality of the mature canopy. He reported average campsite tree loss of 44 percent in 8 years in one campground, 68 percent in 12 years in another, and 23 per cent in 8 years in yet another one. The heaviest loss he found was a 90 percent tree loss after 14 years.

In our area of interest, aspen make up a small percentage of the landscape and are disproportionately important in affecting ecological diversity. Therefore, it would be prudent to avoid developing recreation sites in aspen stands, but it might be helpful from the recreational quality perspective to place sites within view of aspen landscapes or provide trails that pass near aspen forests.

# Water Quality and Quantity_

Since riparian ecosystems are often found in or adjacent to aspen communities, there is an increasing interest in relationships between these unique habitats. Understanding those relationships is critical to their management as will be detailed in the management section of this synthesis. Four important variables within these aspen habitats contribute to water quality and quantity in riparian systems: 1) the nature of the soils found under the aspen, 2) the structure and composition of the vegetative community found within the habitat, 3) the interaction of rain and snow with specific soils and vegetation cover, and 4) the evapotranspiration that takes place in the ecosystem.

## *Soils*

Soils formed in aspen communities play an important role in the water quality and quantity of adjacent riparian ecosystems because of the aspen soil's water-holding capacity. The most significant factor in the formation of aspen soils is the presence of a nutrient-rich litter created from the annual leaf fall of aspen. Results from a study in the Intermountain west (Bartos and DeByle 1981) indicate this litter decays rapidly, forming a thin surface organic horizon that is typically underlain by a thick mollic horizon, high in organic matter content and available nutrients. Breakdown of organic matter from the understory contributes additional litter to the formation and maintenance of the mollic horizon.

In another Intermountain study, Tew (1968) reported that the surface 6 inches (15.2 cm) of soil under aspen had 4 percent more organic matter, a higher water holding capacity, a slightly higher pH, and more available phosphorus than adjacent stands of shrubs and herbaceous vegetation. This is consistent with Potter (1998), who reported that the *Populus Tremuloides/Veratrum Californicum* association in the upper montane area of the central Sierra Nevada had the highest Available Water Holding Capacity (AWC) of any forested associations. He defined AWC as the capacity of soils to hold water available for use by most plants. He believed that this was a reflection of the deep soils, finer soil textures, and low levels of coarse fragments throughout the soil profile. This association was often found in or adjacent to riparian corridors in the upper montane.

Cryer and Murray (1992) suggested that soil types in thriving aspen stands in western Colorado are significantly different than those of adjacent aspen forests that have recently converted to conifer types, although other evidence challenges this assertion (Bartos and Amacher 1998). The logic behind Cryer and Murray's (1992) assertion is that decomposition occurs much faster in aspen than in conifer forests, thus making nutrients more readily available for soil organisms and plant roots in aspen communities. Soil therefore becomes reflective of what type of vegetation has occupied the site for the longest time. They feel that in as short as one generation, conifer encroachment in western Colorado aspen can increase water percolation through the soil profile and lead to the formation of an albic (leached) horizon. Although Bartos and Amacher (1998) found similar morphological changes occurring in soil profiles as conifers invaded aspen in a Utah study, they did not find any evidence of corresponding changes in chemical properties. Nevertheless, it seems reasonable that the cyclic relationship between soil nutrient availability with aspen and its accompanying understory and the breakdown of organic matter from those species (thus returning the nutrients to the soil), is the foundation for development of a stable water holding capacity of typical aspen soils, wherever they occur.

## *Overstory and Understory Protection*

Overland flow leading to erosion is a major factor in lowering water quality in riparian ecosystems. However, DeByle (1985b) hypothesized that a well stocked aspen stand provides excellent watershed protection. The trees, shrubs, and herbaceous layer can provide virtually 100 percent soil cover. This is particularly true in Potter's (1998) aspen/California corn lily association in the Sierra Nevada. He reported that the mean percent cover of all species was 94 percent with a range of 82 to 99 percent cover in that association. The aspen/mountain pennyroyal association, found in relatively drier conditions, contained a mean total vegetative cover of 94 percent, but had a slightly wider range from 70 to 100 percent. This mixture of high cover of herbaceous and woody stemmed root systems, which penetrates and anchors the soil (fig. 3-3), is likely to reduce the probability of overland flow in these stands (DeByle 1985b). In an earlier Utah study, Marston (1952) reported that adequate infiltration occurred when the combination of aspen, shrub, herbaceous, litter, and rock cover was over 65 percent with only small amounts of bare cover. However, Marston did find that erosion can occur if cover is lower than 65 percent due to intense or heavy ungulate use. This study further demonstrated that even storms with 5-minute intensities approaching 6 inches per hour were able to infiltrate the porous, humus-rich soil in Utah. Snow melt, which accounts for the greater percentage of precipitation in California aspen stands, is rarely this intense.

## *Shading Quality*

A study in Oregon of aspen habitats adjacent to riparian corridors found some interesting results relating to the quantity and extent of shading in streams (McNamara 2003). The vegetation communities surveyed for shading were sedge/grass, willow/shrub, alder, lodgepole pine, ponderosa pine, white fir, and cottonwood/aspen. The categories included numerous species and were derived from the dominant species types present. Using randomly selected shade survey sites, McNamara (2003) found that the average percent of shade, as well as the maximum and minimum percent of shade in aspen/cottonwood, was greater than that provided by many conifer species. For example, the study found that in streams with a wetted width of less than 5 feet, aspen/cottonwood shading averaged greater than lodgepole pine, ponderosa pine, or white fir. In streams with a wetted width between 5 and 15 feet, aspen/cottonwood still provided more shading on average than lodgepole pine or ponderosa pine. This study calls attention to the value of aspen in providing shade in a riparian ecosystem. In the monitoring chapter (Chapter 7), we review a current study being conducted in the Sierra Nevada that should help evaluate the role of shade in aspen habitats along the short reaches where they occur.

## *Evapotranspiration*

Water quantity is greatly influenced by evapotranspiration rates of the vegetation occupying the landscape. There is greater evapotranspiration in conifer dominated forests due to the conifer demands in spring and fall before aspen leaf bud and after aspen leaf fall. One Utah study reported a 5 percent decrease in water yield when conifers replace aspen (Harper and others 1981), while a second Utah study modeled water yield decreases of 3 to 7 inches (7.6 to 17.8 cm) under similar circumstances (Gifford and others 1983b). This loss of water means that it is not available to produce understory vegetation, recharge soil profiles, or contribute to streamflow (Bartos 2001) (see Chapter 2: Physical Environment—Water and hydrology). An early study that completely cut a mixed aspen/conifer watershed at Wagon Wheel Gap, Colorado increased measurable streamflow for 7 years until aspen reclaimed the site (Bates and Henry 1928). DeByle (1985b) reported an additional increased yield after fire because of removal of understory vegetation. However, increases in stream flow are proportional, not only to the amount of conifer or aspen removal, but also to other factors including the shape of watershed, drainage patterns and soil characteristics, and proximity of cuts to stream sides. For example, Tew (1967) found that aspect, elevation, and the age of vegetation affected the amount of soil moisture during the growing season in Utah. Significantly, Johnston (1984) found that suspended and bedload sediments during post treatment indicated good quality water and generally low erosion rates in treated aspen stands in Utah. While he did find significant difference in pH, Ca, Mg, and $NO_3$, he also found significant difference in the control, indicating that treatment was not a factor. Apparently, this was a result of other environmental fluctuations not associated with low levels of canopy removal. In Utah, where aspen distribution is more extensive than California, Johnston reported that removal of less than 20 percent of the forested canopy from an aspen dominated watershed did not cause a detectable change in stream flow.

# Range Management and Aspen Communities

## Livestock and Aspen Stands

Like wild ungulates and many other terrestrial species, domestic livestock, whether cattle, sheep, or horses, are drawn to aspen communities because of their association with water and the quality of forage that is consistently found under aspen (Potter 1998; Mueggler 1988). In California, for example, we know that plant diversity in two recognized aspen types was among the highest of all the plant communities of the upper Montane zone of the Central and Southern Sierra Nevada (Potter 1998). This included not only total species, but also the number of species providing hiding cover (see Chapter 2: Plant Associations).

Not only are aspen stands more diverse in understory plants, but they appear to have greater quantities of herbage as well. Woods and others (1982) found that Rocky Mountain aspen stands have significantly more herbage in their understory than other forest types. Reynolds (1969) showed in an Arizona study that aspen may have 10 times more herbaceous vegetation than that found in conifer understories. Mueggler (1988) reported that productive aspen communities in Wyoming can produce as much as 2,900 lb/acre (3,200 kg/ha) of air-dry undergrowth material. However, he notes that forage production in aspen habitats is site specific and that aspen communities are generally less productive in their northern and southern ranges. Richardson and Heath (2004) working in the Sierra Nevada, and Dobkin and others (1995) working in the Great Basin, found that vegetative diversity plays an important role in distribution of wildlife species found in aspen communities.

While we would expect regional variation in the biota associated with ungrazed aspen, domestic livestock have altered natural patterns over time. For example, Loft and others (1987) noted that the removal of hiding cover by intense cattle grazing and browsing adversely affected wildlife in Sierra Nevada aspen communities. Kie and others (1991) showed that the natural range of deer in the Sierra Nevada was affected by cattle grazing. Mueggler (1988) noted extensive alteration of plant communities related to a history of excessive grazing and browsing in the Intermountain West. In addition, DeByle (1985a) reminds us that "any ground-nesting bird can be adversely affected by heavy grazing during the nesting season."

## Range Management History and Aspen

In their study of 20th Century management of rangelands in the Sierra Nevada prepared for the Sierra Nevada Ecosystem Project, Menke and others (1996) found that throughout most of the central part of the last century (1930 to 1970), use and changes of range intensity and range management improvements in the Sierra Nevada were most often driven by socioeconomic and forage production reasons rather than decisions based on ecological condition. There was little focus on the potential for natural vegetation to develop on site. Most ranges were stocked above carrying capacity until very recently (1979 to the present) (Menke and others 1996). Alterations in plant communities have resulted from changes in intensity, frequency, and seasonality of livestock use. These factors, in combination with fire suppression, have likely had significant impacts on the remaining forage for both livestock and wildlife.

In the second half of the century, Menke and others reported that general range conditions in the Sierra Nevada may have slightly improved or at least remained static. However, they found this was not the case for drainages, meadows, watering places, and other natural concentration areas that generally continued to decline. It was not until the 1970s and 1980s that resource protection became a greater emphasis relative to forage resource production.

## Grazing Effects on Aspen Stand Structure

While there is not extensive historical evidence on the effects of grazing in the Sierra Nevada on aspen

**Figure 4-19.** Excessive ungulate grazing can lead to the introduction and multiplication of invasive weeds.

communities, Potter (1998), in his study of upper montane vegetative communities in the Central and Southern Sierra Nevada, noted that the age of the current aspen component in many stands corresponds well with the end of the intensive grazing pressures of the late 1800s and the institution of fire suppression policies in the early 1900s. This interpretation is consistent with other views in the West. Mueggler (1988) speculated that over a century of frequently intense grazing in the Intermountain West (sometimes by multiple classes of livestock in a season in addition to wildlife) left both pronounced and subtle alterations of species composition. From a contemporary standpoint, Potter (1998) found that many of the stands he sampled in the Sierra Nevada were found adjacent to meadows and other moist areas where livestock congregate in the summer season for shade, forage, and water. He observed that livestock would often graze the understory heavily and use aspen as a primary browse species. Kie and Boroski (1996) and Loft and others (1991) quantified this observation in Sierra Nevada studies, finding that cattle had a strong summer-long preference for riparian habitats. This is consistent with Menke and others (1996), who reviewed range management records of Sierra Nevada national forests. They reported that potentially productive habitats located in drainages, meadows, watering places, and other areas where livestock concentrate were in the poorest shape.

## *Range Quality*

In the Interior West, research has focused on the effects of intensive grazing and browsing in aspen communities. We believe these findings are applicable to California aspen communities as well, since the intensity of livestock use appears to be similar. As a rule of thumb, livestock grazing tends to shift plant species composition in the understory to those of lower palatability (Houston 1954). Intense grazing can also lead to increases of annuals, the introduction of invasive weeds (fig. 4-19), and a lowering of ground cover (DeByle 1985a). For example, Mueggler (1988) found in the Intermountain West that in many of the stands that were severely overgrazed for extended periods of time, the amount of perennial forbs was generally reduced and the proportion of annuals or graminoids increased. As palatable species were eliminated by repeated use, a change in dominance to lower growing, more drought resistant, and less palatable species occurred. Mueggler (1988) found severely depleted ranges to be dominated by annuals, ruderals, and unpalatable perennials. Dominance by a single species or very few species can be a sign of overgrazing (Houston 1954). Another potential effect that may be critical to shallow-rooted aspen is that litter cover is lessened as it is pulverized and trampled, and soil may be compacted with a potential increase in soil erosion (DeByle 1985a).

## Aspen Regeneration

It seems logical to assume that light grazing while the herbaceous understory is lush and succulent is less likely to damage aspen regeneration than grazing late in the season after the herbaceous plants cure and become less palatable (DeByle 1985a). We acknowledge, however, that early season grazing may cause more intense soil compaction, thereby limiting growth in many species. It has been shown that domestic livestock consume aspen with increasing pressure through summer and early fall as preferred forage decreases in volume and nutritional quality (DeByle 1985a; Fitzgerald and others 1986). This browsing can be very severe, especially on young succulent sprouts, and can be site specific by all ungulates. This increased utilization of aspen by domestic livestock as the season progressed is parallel to a similar pattern found with deer browse in Utah (Julander 1952) and observed in California (Personal Comm., Chuck Lofland, Wildlife Biologist, USDA Forest Service). Julander also noted that deer also utilize aspen leaves that have fallen on the ground after leaf fall, which does not harm the aspen. However, repeated heavy browsing will lead to bushy, multi-stemmed aspen shrubs, leaving them susceptible to browsing year after year until use ceases, or the aspen eventually disappear (Keigley and Frisina 1998).

## Conifer Encroachment on Rangelands

Much of the aspen rangeland in our area of interest is found in the fire-adapted ecosystems of the Sierra Nevada, Southern Cascades, and Modoc Plateau (Taylor 1998, 2000). Fire regimes began to change radically with the advent of intense grazing during the late 1800s and early 1900s. Grazing reduces "fine fuels" that would carry frequent low intensity fires through the understory of forests and shrubland ecosystems. The advent of fire suppression resulted in an initial increase in shrub components followed by conifer invasion that eventually led to the development of dense conifer canopy covers, which burn as high-intensity crown fires. While we are not aware of specific studies of the effect of conifer encroachment into aspen in the Sierra Nevada, Bartos (2001) documented loss of vegetative diversity in aspen forests in Utah and attributed it to fire suppression and subsequent conversion to conifer dominated systems. Conifer encroachment shades out understory plants, lowering plant cover, forage productivity, and species diversity. Mueggler (1988), in his study of aspen communities of the Intermountain West, found that production of understory herbaceous and shrubby cover decreased as conifer overstory increased. This effect becomes apparent when as little as 15 percent of the basal area is made up of conifers. Furthermore, Reynolds (1969) reported that an Arizona study found aspen habitats contained 10 times more forage than adjacent ponderosa pine forests. Succession of aspen to conifers therefore results in a considerable lowering of the grazing capacity and a preference by both wild and domestic ungulates for aspen communities over conifer communities. This issue is significant because with no changes in stocking intensity, livestock and wildlife are forced to compete for diminishing resources.

## Livestock/Wildlife Interactions

Removal of forage, as well as disruption of nesting site cover, can have negative effects on both large and small mammals (Kie and others 1991; Loft and others 1987 ; Dobkin and others 1995). Kie and others (1991) reported that deer in the Sierra Nevada of California increased their home range as cattle grazing increased. Loft and others (1987) found that deer and fawn hiding cover decreased with increases in browsing intensity by domestic livestock in the Sierra Nevada.

Livestock grazing is limited to stringer meadows, riparian areas, brush fields, and transitional areas in mixed-conifer forest at mid-elevations on the western slope of the Sierra Nevada (for example, areas created after wildfires, or plantations installed after clear cutting or small group selection harvests). Many of the aspen on the Western slope of the Sierra Nevada are found in stringer meadows and riparian areas. Loft and others (1993) found that as the grazing season progressed, cattle were attracted to the patchy meadow-riparian and aspen habitats where herbaceous forage was most available. Therefore, we feel confident in stating that grazing management is a critical issue in aspen type in the Sierra Nevada and that timing and intensity of livestock use is critical as it relates to aspen regeneration and wildlife values.

A final consideration is that elk herds have recently become established in the Southern Cascades and Warner Mountains (Personal Comm., Mary Flores and Tom Rickman, Wildlife Biologists, USDA Forest Service, Modoc NF and Lassen NF). Elk can put added pressure on aspen habitats, especially when aspen are found on winter ranges (DeByle 1985c; Baker and others 1997; Suzuki and others 1999; Barnett and Stohlgren 2001). We conclude it is essential that management of both domestic and wild animals be closely linked to forage carrying capacity to avoid adverse effects on the aspen resource.

# CHAPTER 5.

# Assessment of Current Aspen Conditions

## Ecological Status

To understand the significance of the management discussion in Chapter 6, we feel it is best to first examine the current ecological condition of aspen communities in our area of interest. Individual aspen inventories and assessments have been conducted throughout the three ecoregions in this area (fig. 2-3) by the U.S. Forest Service, Bureau of Land Management, California Department of Fish and Game, California Tahoe Conservancy, California and Nevada state park systems, and National Park Service. While these inventories and assessments have yet to be unified for statewide analysis, in the areas where they have occurred they individually increase the body of knowledge about: 1) aspen spatial distribution, 2) current ecological condition of the stands assessed and, 3) further management implications at a variety of scales. They illustrate, among other things, the importance of focusing on site-specific evaluation of information when looking at such issues as range of natural variability and how current ecological conditions may have been affected by anthropogenic factors such as fire suppression and browsing intensity. We examined three large data sets, one from each region, to gain understanding of the ecological condition of the aspen habitats over the broad range of our area. We believe that these data sets are representative of the other assessment efforts that we have examined.

### *Sierra Nevada Section*

The first data set is from the Forest Service's Lake Tahoe Basin Management Unit (LTBMU). There are four state or federal agencies in the Lake Tahoe basin that have been conducting aspen assessments since 2002. While this data set does not represent the entire potential inventory of the LTBMU, it is large enough to help understand the distribution and condition of aspen across the Lake Tahoe basin landscape. The LTBMU conducted assessments between 2002 and 2005 (fig. 4-3) using a protocol developed by the Aspen Delineation Project (Aspen Delineation Project 2002, Data on Record at the LTBMU). Detailed information about this protocol can be found in Assessment and Monitoring Methodology (Chapter 7). The protocol examines three subjects: 1) spatial descriptors—where the stand is located and its extent; 2) stand condition data—ecological measures to assess risk of decline and/or imminent loss of an aspen stand; and 3) management information—what unique conditions exist that may affect management options.

We focus here on 542 stand assessments from the 2002 to 2005 survey of the Lake Tahoe basin. Aspen stands are located from lake level at 6,226 ft (1,897 m) to over 8,800 ft (2,682 m) with 40 percent of the stands within a 1 to 300 ft (0.3 to 91 m) height gradient above lake level (fig. 5-1). This propensity for low elevations is not necessarily related to their close proximity to Lake Tahoe, but rather to the broad canyon bottoms of the Lake Tahoe basin (fig. 5-2). Stand sizes range from less than a quarter acre (0.1 ha) to 97 acres (39.2 ha) (fig. 5-3), with 51 percent of the stands being half an acre (0.2 ha) or smaller. The LTBMU assessments also note stand associations with specific geographic or habitat relationships (fig. 5-4). For example, 57 percent of the stands are associated with riparian corridors or springs. Probably the most significant result of this effort was the assessment of the ecological condition of each aspen stand. Each stand was assigned a "stand

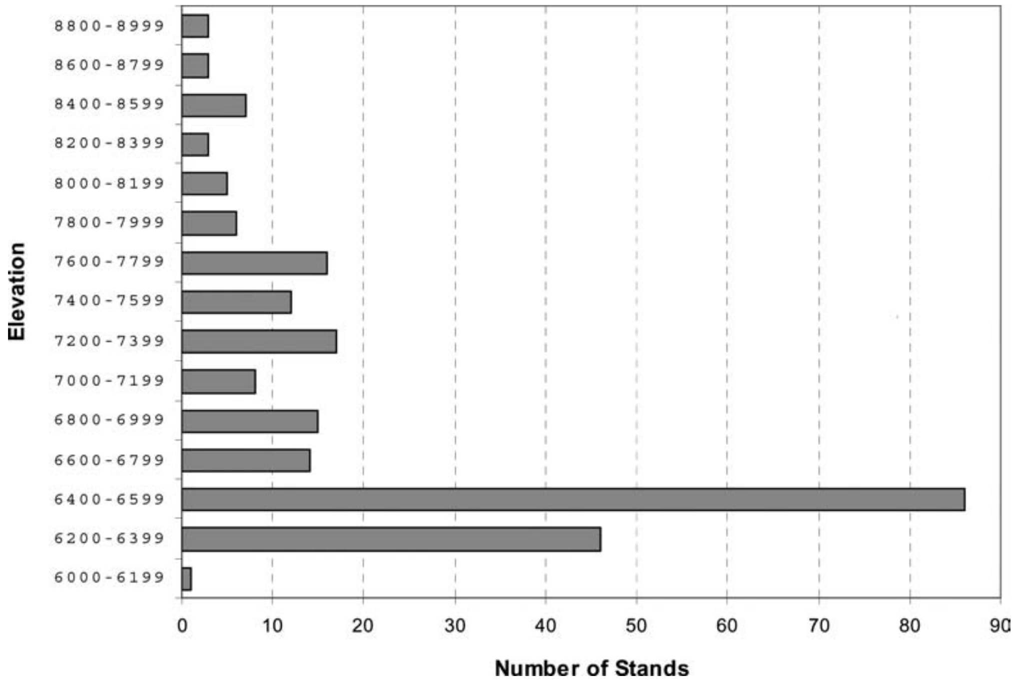



**Figure 5-1.** Elevation range of the 542 aspen assessments conducted between 2002 and 2005 by the Lake Tahoe Basin Management Unit.

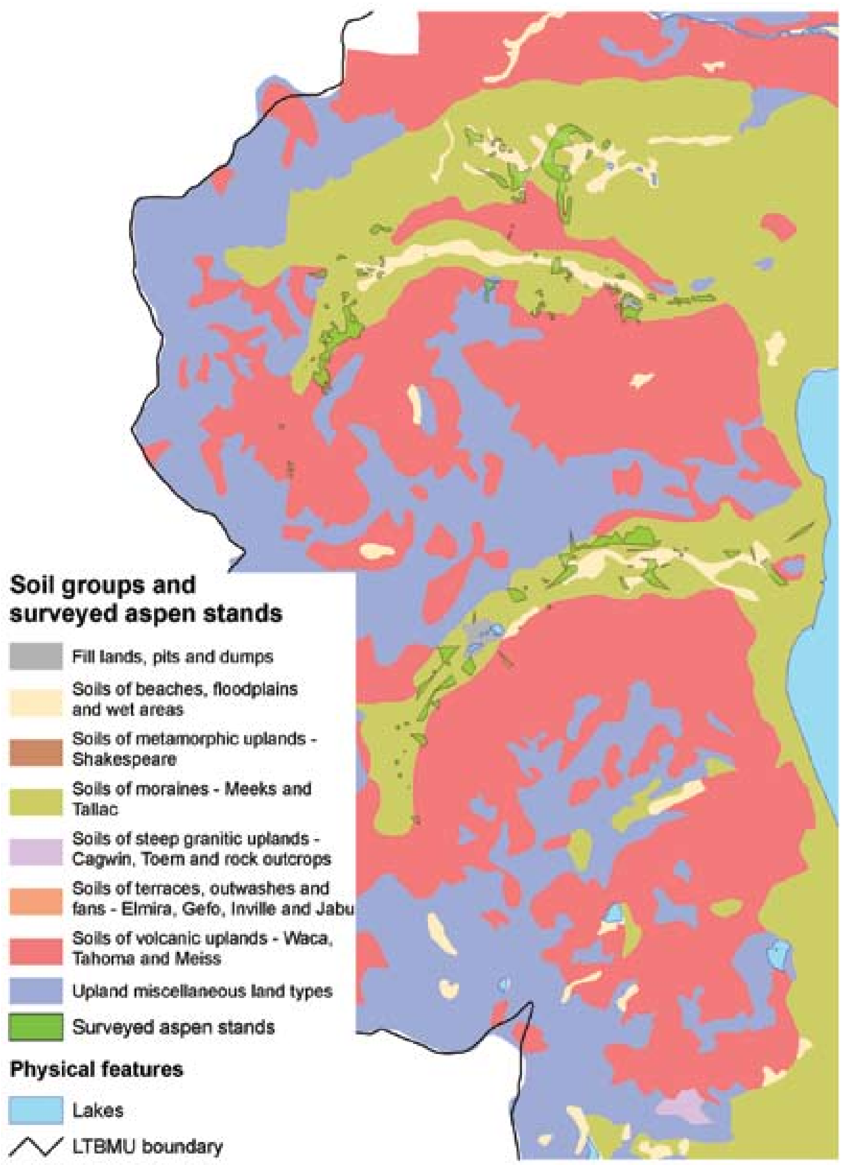



**Figure 5-2.** Aspen stands in Blackwood and Ward Creek Canyons. The location of aspen appears to be associated with certain soils and landforms in the Lake Tahoe basin.

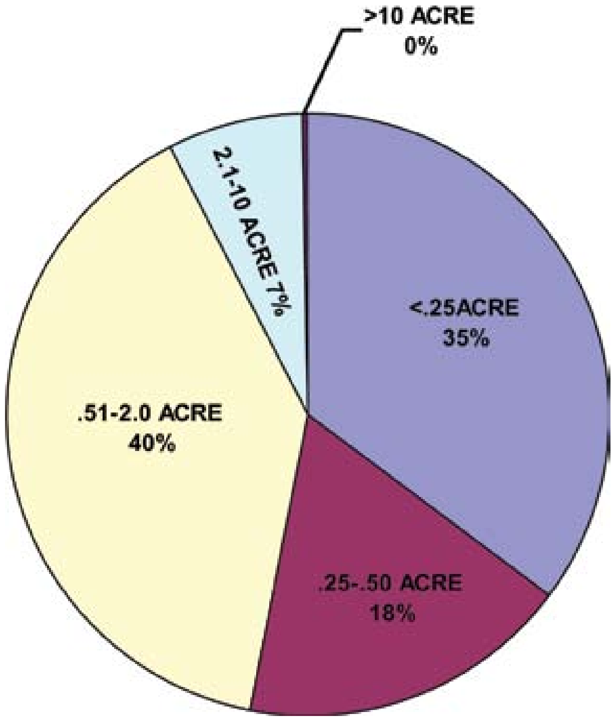



**Figure 5-3.** Distribution of stand sizes for 542 aspen assessments conducted between 2002 and 2005 by the Lake Tahoe Basin Management Unit.

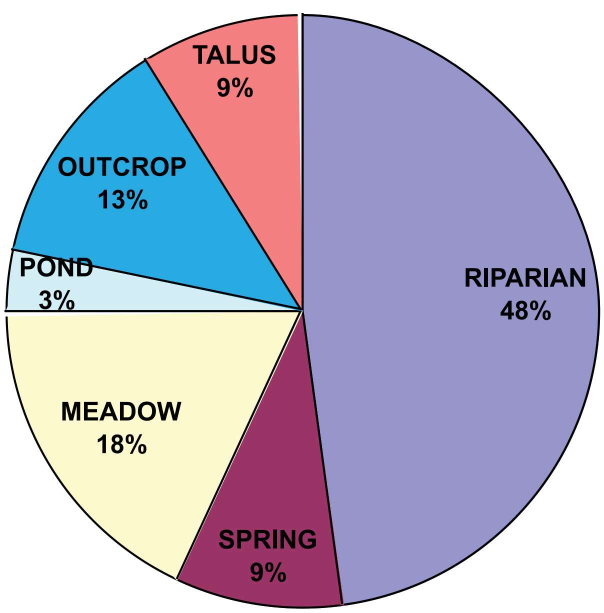



**Figure 5-4.** Distribution of 542 aspen stands by landform. From an assessment conducted between 2002 and 2005 by the Lake Tahoe Basin Management Unit.

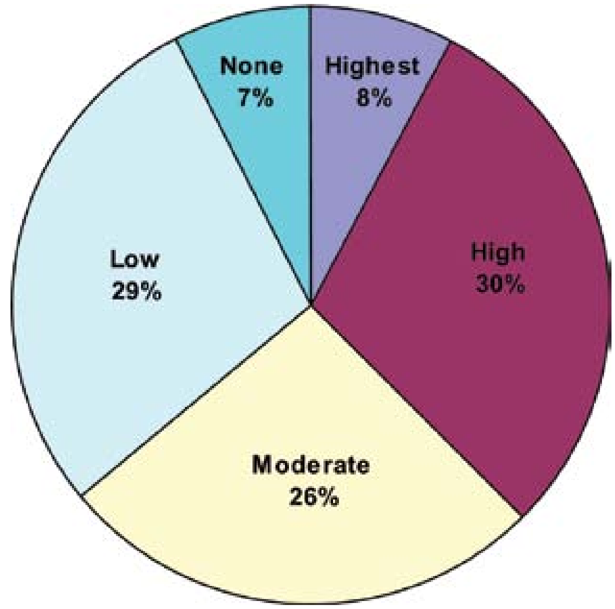



**Figure 5-5.** Distribution of 542 aspen stands assessed between 2002 and 2005 by the Lake Tahoe Basin Management Unit, grouped as to relative risk of loss.

risk" rating based on a classification developed by Bartos and Campbell (1998). The classification includes five risk categories: highest, high, moderate, low, and none. The highest and high categories apply to aspen stands with extensive risk factors that may either cause them to disappear from the landscape entirely in the near future, or at the very least, diminish in extent and ecological significance. Moderate risk stands have risk factors associated with growing threats to the stand's vitality. Low and no risk stands are basically healthy and viable stands that require no management intervention at the present time. The LTBMU assessments found that 70 percent of the stands sampled in the basin were at moderate to highest risk related to their ecological viability (fig. 5-5). The map in figure 5-6 illustrates how the assessment of ecological risk is distributed across aspen stands in two canyons in the Lake Tahoe basin, Blackwood Canyon, and Ward Creek.

## *Southern Cascade Section*

To examine the condition of aspen in a representative location in the Southern Cascades, we reviewed an assessment from the Eagle Lake Ranger District, Lassen National Forest. This area is located in eastside ponderosa pine forests bordering Lassen National Park on the west and Eagle Lake, which is part of the Modoc Plateau Region, on the east. District personnel mapped and assessed aspen stands from 2000 to 2004 using

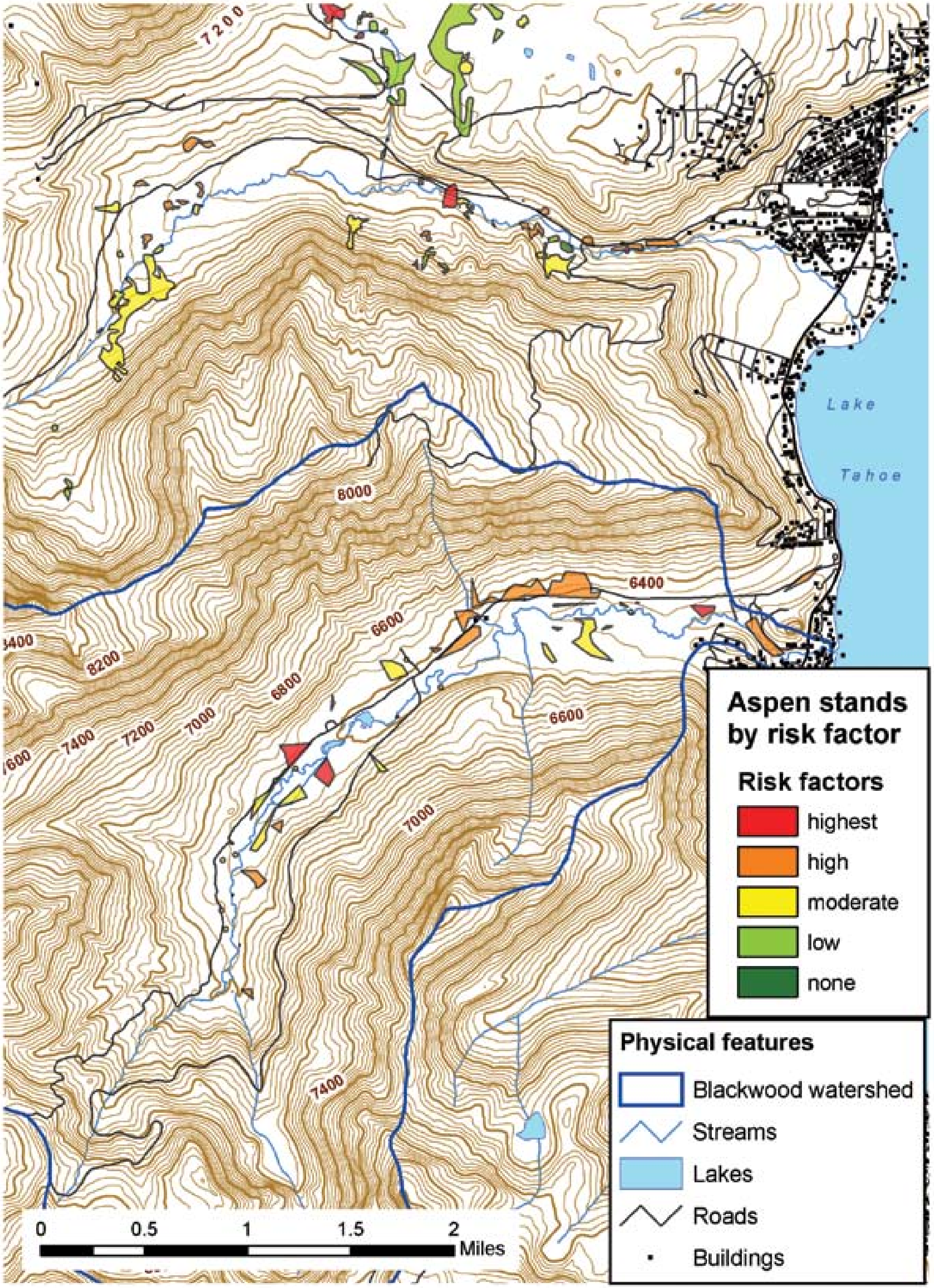



**Figure 5-6.** Aspen in Blackwood Canyon and Ward Creek (map developed by Lake Tahoe Basin Management Unit from 2002 and 2003 data). Assessment data are grouped by ecological factors indicating stands at risk of diminishing in ecological significance or being completely lost from the landscape.

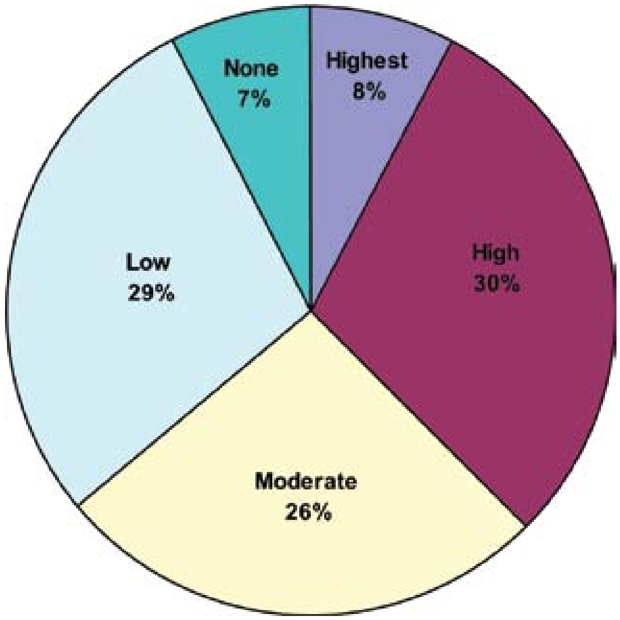
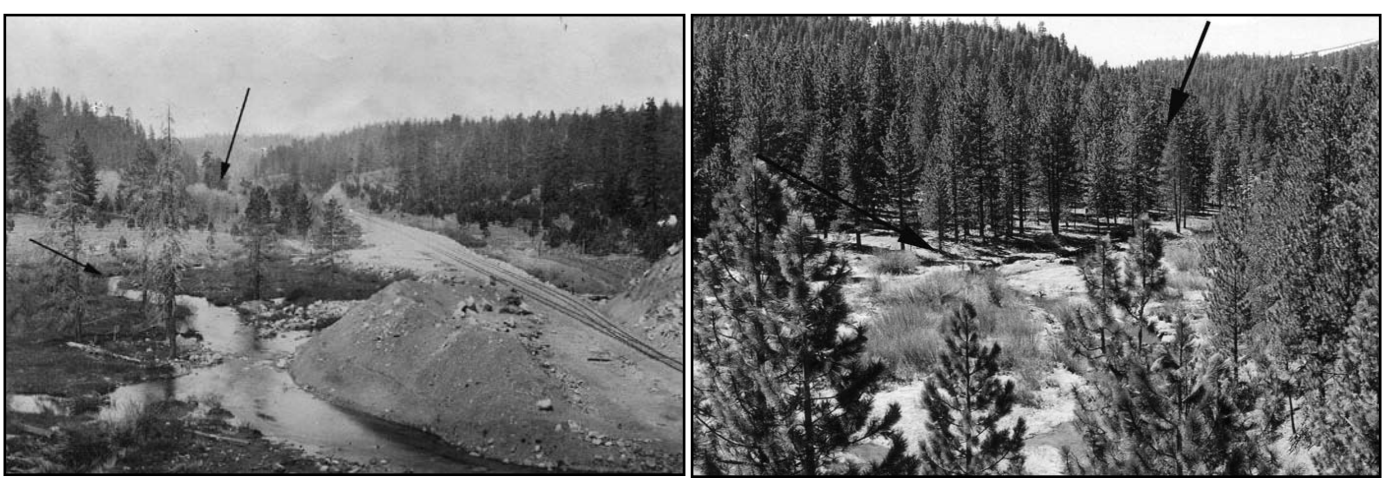



**Figure 5-7.** Distribution of factors indicating risk of stands diminishing in ecological significance or being lost completely from the landscape. Data are from 522 aspen stands assessed in the Southern Cascades in 2002 and 2003 by the Eagle Lake Ranger District, Lassen National Forest, using the Bartos and Campbell (1998) protocol.

the Bartos and Campbell (1998) risk factor protocol described above (Personal Comm., Bobette Jones and Tom Rickman, Wildlife Biologists, USDA Forest Service, Lassen NF, and data on file at the Eagle Lake RD). The assessment, which covered 522 stands on 3,157 acres (1,277 ha), found that 430 (82 percent) of the stands were at high to highest risk of loss (fig. 5-7). Seventy-three percent of the inventoried acreage fell into these risk categories, meaning that most of the aspen stands on the Eagle Lake District may disappear in the near future without intervention.

A significant element of the Eagle Lake Ranger District protocol was the identification of 37 stands where there are no longer any living aspen stems present. The Eagle Lake assessment revealed that 491 aspen stands (94 percent) were in need of conifer removal, and 321 aspen stands (61 percent) needed control of browsing to allow aspen regeneration to establish. All told, conifer removal was recommended for 3,122 acres (1,263 ha) of aspen, or 99 percent of the District's aspen area. Control of browsing was an added management action recommended for 1,534 acres (621 ha) or 48 percent of the District's aspen.

It is interesting to note that the Eagle Lake Ranger District also conducted an extensive search of historic records that have helped establish a better interpretation of the spatial and ecological condition of aspen in their area. For example, only 24 percent of the stands in the entire inventory has been affected by wildfire since 1910. This is in a locality where historic mean and median fire interval rates of 5.0 and 7.2 years respectively have been reported for sites adjacent to meadows, along with mean fire intervals in upland pines sites of 14.4 years and 25.6 years in mixed conifer sites (Taylor 1998, 2000). Additionally, the Ranger District has been able to historically document the loss of at least one specific aspen stand. Fig. 5-8a is a 1915 photograph of the Susan River showing an extensive aspen stand. The stand is no longer visible in figure 5-8b, taken from the same photo



a b

**Figure 5-8a, b.** Repeat photos taken in **(a)** 1915 along the Susan River in the Lassen Nation Forest reveals an extensive aspen stand. A repeat photograph **(b)** taken in 2003 reveals increased conifer densities with no aspen present. Arrows have been added for orientation, noting a bend in the river that can be seen in both photos. Ground surveys confirmed that there are no longer aspen on this site.

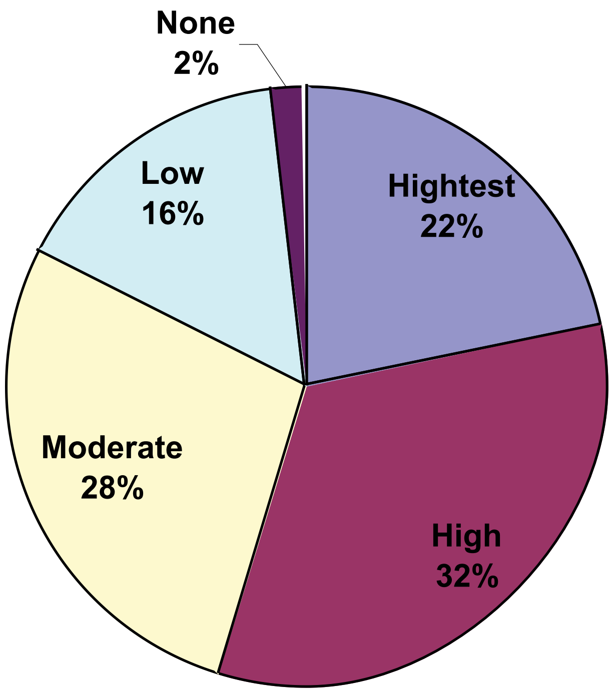



**Figure 5-9.** Percentages of 199 aspen stands assessed in the Modoc Plateau in 2003 and 2004 by the Alturas Field Office, Bureau of Land Management, that identified risk to stands diminishing in ecological significance or being lost completely from the landscape. The Aspen Delineation protocol (2003) described in Chapter 7 was used in this assessment.

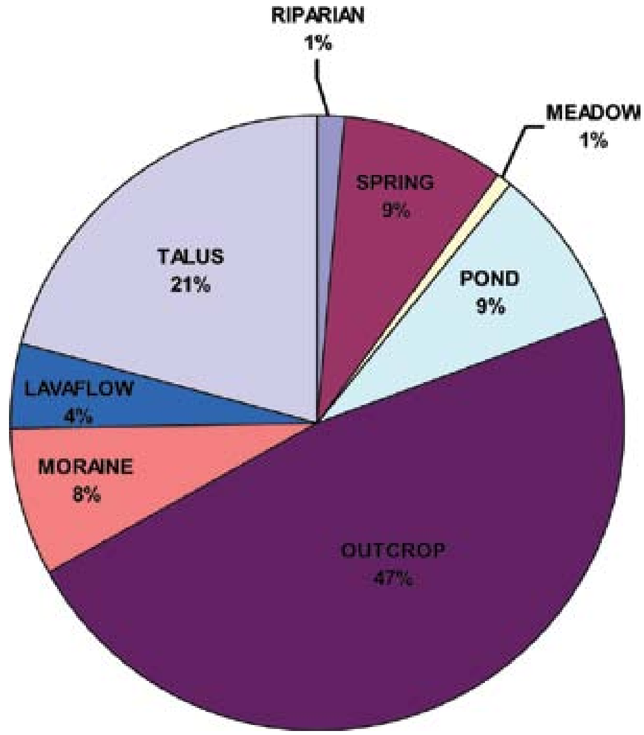



**Figure 5-10.** Distribution of Modoc Plateau aspen stands in figure 5-9 by land form.

point in 2003. An intensive on-the-ground assessment of the area conducted by District staff found no aspen.

## *Modoc Plateau Section*

Two assessments of aspen habitat have occurred in the Warner Mountains in the Modoc Plateau. One effort was a 2-year (2002 to 2003) assessment conducted in the BLM's Alturas Resource Area (data on file at the Alturas Field Office). The other was an assessment conducted by the California Department of Fish and Game in the Modoc National Forest (Di Orio and others 2005).

The BLM effort included 199 aspen stands. Sixty-four percent of the stands were found to be half an acre in size or smaller. Overall, the ecological condition of these aspen stands was at-risk. The assessment found 54 percent of the stands were in the high or highest risk category, with 28 percent at moderate risk of loss (fig. 5-9). Of interest geographically, 62 percent of the stands in the Modoc assessment were found to be associated with talus, lava flows, or rocky outcrops, whereas only 38 percent of the stands were associated with areas more closely linked to surface moisture sources such as riparian zones, meadows, springs, and ponds (fig. 5-10). This is consistent with Smith and Davidson's (2003) Modoc National Forest's Terrestrial Ecological Unit Inventory (TEUI). The User's Manual for the TEUI states that sources of azonal moisture (above average moisture compared to the adjacent area) can be riparian springs and seeps, moist meadow, or stream sides, but can just as likely be related to topographic orientations, positions, and site protections such as found in toe slopes, north slopes, talus slopes, and areas that accumulate and retain snow because of topography and/or weather patterns.

The second assessment in the Warner Mountains was undertaken by the California Department of Fish and Game (Di Orio and others 2005). The authors compared, scanned, and orthorectified photographs from 1946 that were repeated in 1994. From this, they calculated that there was a 24 percent decline in aspen coverage during the 48-year period between the photos. Total aspen acreage in the study area went from 9,689 acres (3,921 ha) in 1946 to 7,495 acres (3,033 ha) in 1994, a loss of 23 percent. However, there were actually 8 percent more aspen polygons identified in 1996, due to increased fragmentation of the stands over time.

# Current Aspen Stand Types in the Sierra Nevada

The above assessments illustrate that aspen can be found in communities located in a range of elevations, geographic settings, and biotic relationships with other species. These communities can be adjacent to moist meadow complexes or on steep talus slopes. They can exist in an ever-changing seral relationship with conifer species or exist in pure "stable" communities (Mueggler 1988). The dynamics of these aspen communities have been shaped by climate, soil development, topographic settings, moisture regimes, natural disturbance, and human impacts over an extensive spatial and temporal scale.

After examining many of the existing inventory and assessments data sets, reviewing the ecological classification of Potter (1998) and Smith and Davidson (2003), as well as calling upon our own knowledge of aspen in California, we have noted that a number of characteristics are common to aspen within the defined area of interest. We feel it would be valuable to describe these aspen types and use them as a basis for our discussion of management alternatives in Chapter 6. We offer the following descriptions of seven common aspen community types that can be found in the Sierra Nevada. This approach is not meant to replace the value of a more detailed ecological classification, but will provide a framework for discussing possible aspen management alternatives. Aspen management is best approached on a site-specific basis since that is the level at which management activities will occur. Site-specific characteristics will determine which management options are necessary and, in some cases, even possible. Actions that work well on one site may not be suitable on another. We hope discussing ecological variability found within the following seven classifications will help the reader in developing site-specific management alternatives for aspen.

### *Meadow Fringe (Seral Aspen Community)*

This classification includes aspen communities located on the fringe of meadows or within meadow complexes (fig. 5-11). In these cases, the meadows themselves are often found in sites of very high soil moisture. For proper root function, aspen require that soils are unsaturated at least seasonally, hence their

**Figure 5-11.** Meadow Fringe aspen. Note absence of aspen in the meadow.

restriction to the drier meadow fringe. These stands generally have a rich diverse herbaceous component within the stand except where moderate to heavy conifer encroachment has occurred. Soils are deep and seasonally very damp. These communities, which may be composed only of pure aspen in the overstory, are still considered seral because of the close proximity of conifer seed sources. With conifer seed sources nearby the aspen can provide a "nursery" location (that is, an ideal location for seeding establishment) for shade tolerant species such as white fir (Abies concolor). Many of the stands in this category fall into the Quaking Aspen/California Corn Lily association described in Potter (1998).

### *Riparian Aspen (Seral Aspen Community)*

Riparian aspen communities are located along permanent or seasonal watercourses or adjacent to fens, springs, or seeps (fig. 5-12). The stands may be: 1) alongside the watercourse's high water mark, 2) on alluvial material near water courses, or 3) along watercourses where soil buildup has occurred from water flow slowing or flooding. Stands may contain thick herbaceous material or may contain little herbaceous material depending on moisture presence and conifer encroachment. If a riparian corridor is wide, aspen communities can be large. If narrow or steep, the communities can take on the form of narrow stringers located between the stream and the

**Figure 5-12.** Riparian aspen. These stands are restricted to areas along watercourses where sufficient moisture is available for aspen to grow. They may occur as either pure aspen, or mixed with conifers.

**Figure 5-13.** Upland aspen/conifer. These stands occur outside of riparian zones and can be conifer forest with a minor aspen component, or aspen stands containing a minor conifer component. All can be expected to become pure conifer forests in the absence of disturbance.

upland forest landscape. This category also includes aspen communities that are located along alder groves or with other deciduous species like willows. In many cases, the aspen community exists in a narrow line between the alders or willows and the forest canopy. Depending on soil moisture content, alders or willows may or may not be intermixed with the aspen.

## *Upland Aspen/Conifer (Seral Aspen Community)*

In California, aspen is a facultative wetland species that is equally as likely to occur in wetland or non-wetland locations (USDI FWS 1997). These aspen communities are located away from obvious surface moisture regimes (fig. 5-13) on flats and hillsides in upland locations and generally have drier soil regimes than those located around meadows, seeps, springs, and fens. These stands have an early successional relationship with the particular conifer communities they are associated with, meaning that we can expect conifers to replace the aspen in the absence of disturbance. Associated conifer species can be Jeffrey pine (*Pinus jeffreyi*), white fir (*Abies concolor*), red fir (*Abies magnifica*), western juniper (*Juniperus occidentalis*), and lodgepole pine (*Pinus contorta*). Because of fire suppression, climate change, and browsing over the past 100 years, these successional relationships may have changed significantly. Openings in these aspen communities may contain very thick herbaceous material or little or no herb or forb component depending on subsurface moisture presence and conifer encroachment. Smith and Davidson (2003) described these sites as subhygric or slightly moist in relation to zonal sites. They often found these associations: 1) at the base of steep forest hillsides or moraines, 2) at the base of talus slopes, or 3) in forest zones where no riparian watercourses are present. In the Sierra Nevada, many of these sites fit into the quaking aspen/mountain pennyroyal association described by Potter (1998). We have personally observed that these communities are often upslope, but still adjacent to the damper soil of the meadow fringe aspen communities. Potter also found these stands on

**Figure 5-14.** Lithic aspen. These stands are associated with glacial moraines, talus-colluvium, rock falls, or lava flows.

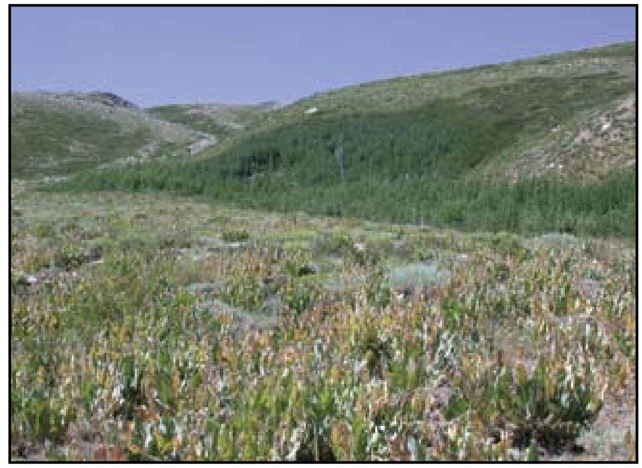


**Figure 5-15.** Snowpocket aspen. These stands are associated with snow accumulation areas in the Great Basin and eastern Sierra Nevada.

benches and high on slopes where subsurface water appears to be plentiful.

## *Lithic Aspen (Lava, Bolder, Talus)*

Lithic aspen communities are located on lateral or terminal moraine boulder material, talus-colluvium, rock falls, or lava flows (fig. 5-14). It has been said that such sites act as refugia for aspen (Jones and others 2005b). There are four significant relationships that support the concept that lithic sites act as refugia for aspen: 1) the damp bare mineral soils found in these rocky sites may provide an ideal site for one or more aspen seeding events that could account for the clone or clones currently on-site; 2) the rocky locations may be subhydric—that is, extremely moist in relationship to the zonal site that surrounds the community (Smith and Davidson 2003), again making them suitable for establishment of aspen clones; 3) over time, these sites may have provided a safe haven for aspen regeneration from herbivory by both native and domestic animals; or 4) the sites may limit conifer establishment. Additionally, lithic stands of aspen are naturally resistant to wildfire due to limited surface fuels. This is somewhat perplexing given the fact that we believe aspen to be a generally fire-dependent forest type.

## *Snowpocket Aspen (Stable Aspen Community)*

Snowpocket aspen communities occur in topographic positions where snow accumulates (fig. 5-15), mostly at higher north facing elevations. While these aspen communities are much more common in the Great Basin, they occur in our area of interest, mostly east of the Sierra Nevada proper. Smith and Davidson (2003) describe these sites as subhygric—that is, slightly moist in relation to the surrounding vegetation types. We have observed such communities in the Sweetwater Mountains north of Bridgeport and on Glass Mountain southeast of Mono Lake. The aspen trees in these communities are often short and stunted and rarely reach true tree stature because of a short growing season and harsh winter conditions. Snowpocket aspen stands tend to be pure and "stable" aspen stands. Even though conifers may be within seeding distances, they are unable to become established within the "snow pocket" because of the short growing season available to the species.

## *Upland Pure Aspen (Stable Aspen Community)*

Upland pure aspen stands are rare, except in locations in the Southern Warner Mountains of the Modoc Plateau ecosystem, to the south of Lake Tahoe on the eastern side of the Sierra Crest, or on ranges that branch off

**Figure 5-16.** Upland pure aspen. These stands occur outside of riparian zones, do not contain conifers, and can be expected to persist on the landscape as aspen.

the main Sierra fault block such as the Monitor Range and the Sweetwater Mountains and Glass Mountain south and east of Mono Lake. Probably the largest established pure aspen communities are located west of Highway 395 in the Conway Summit area north of Mono Lake (fig. 5-16). Mueggler (1985) recognized two conditions that help clarify what is meant by the term stable or pure aspen. First, he conceded that over extended time periods—sometimes as much as 1,000 years—stable aspen could become successional to conifers. He also felt that the presence of some conifers in a pure aspen stand doesn't necessarily drop the community from the stable classification. Seral classification in Mueggler's (1985) view implies "incipient or actual prominence of conifers, which suggests active replacement of the aspen overstory by more shade tolerant trees. Conifers, however, must be prominent, not merely present. Occasional conifers can be found in a basically stable aspen community because of highly unusual and temporary conditions that favor their establishment."

## *Krümmholz Aspen (Stable Aspen Community)*

Krümmholz aspen communities are pure aspen stands located in a range of habitats including some lithic situations. Their distinguishing characteristic is that the aspen component of the community is always found growing in a distinct shrub or krümmholz stature (fig. 5-17) with little stem height development and a highly deformed appearance. They can be found on ridgelines or other windswept locations, but are most often found on the upper elevation limits of other aspen communities described in our classifications.

**Figure 5-17.** Krümmholz aspen. These pure, stable aspen communities are limited to ridgelines, avalanche tracks, and wind-swept locations that restrict stem development.

# Chapter 6.

# Management Alternatives for Aspen in the Sierra Nevada and Tahoe Basin

## Characteristics of Aspen in the Sierra Nevada Ecosystem

As discussed earlier, aspen in the Sierra Nevada is the same tree species (*Populus tremuloides*) that grows throughout North America. However, it does not occur as extensively, or grow in large stands as elsewhere, but rather is restricted to sites where it has been able to establish in the past and successfully compete with other vegetation within the Sierra Nevada ecosystem. Although aspen is a minor component of Sierra Nevada landscapes, particularly on the west side of the Sierra (Potter 1998), we nonetheless can expect it to have the same ecologic and adaptive characteristics as aspen found elsewhere. First of all, it is intolerant of shade, needing full sunlight to establish, grow, and prosper. It grows best on deep heavy soils as elsewhere, but can exist on a variety of soil types, including rocky soils, glacial till, volcanic ash, and alluvial deposits. Aspen's growth rate is directly dependent upon available soil moisture and the microclimate of the site. The size and growth rates of individual aspen trees in some Sierra Nevada locations rival those of aspen anywhere (fig. 6-1).

**Figure 6-1.** Large aspen tree in Blackwood Canyon, Lake Tahoe basin.

Limited information exists on the ages of aspen in the Sierra Nevada. Aspen is notoriously difficult to age properly and requires special techniques to prepare wood samples to obtain accurate ages (Asherin and Mata 2001). However, given the recovery of forests since settlement-era logging and fires in the Sierra Nevada, we can assume that much of the aspen growing in association with post-settlement conifers is of similar age.

Earlier, we discussed how aspen can occur either in pure, stable stands that do not succeed to other vegetation types, or in mixed species stands associated with conifers (Mueggler 1988). Although mixed aspen/conifer stands predominate in the Sierra Nevada, there are instances where pure, stable aspen stands can be found. These include isolated "snowpocket aspen" described in the previous chapter that occur in the eastern Sierras, in the Modoc Range, and near Mono Lake. Since no conifers exist within these stands or within seeding range, they can be considered to be stable. That does not mean, however, that individual stems in stable stands live to long ages in the absence of disturbance. Disturbances that are active in these stands are more subtle than the fires that periodically reset succession in mixed aspen/conifer stands. Such factors as drought, insect defoliation, frost, disease, etc. can kill enough trees to allow suckering to periodically introduce new age classes of aspen into the forest.

Although crown fire is often thought to be the disturbance of renewal in aspen/conifer forests, it does not necessarily have to occur at a landscape scale to be effective. Mixed severity fire regimes, where surface and crown fire are both active at sub-landscape scales, can create a mosaic of age-class patches across a given landscape. It is likely that the active fire regimes of the past resulted in a healthier and more diverse distribution of aspen age, stem sizes, and successional stages than exist in much of the Sierra Nevada today. The key to successful aspen management in the Sierra Nevada is to seek ways to sustain and increase the diversity of aspen by emulating natural disturbance regimes (Rogers 1996; Franklin and others 2002).

## Identifying the Need to Regenerate Aspen

From an ecological standpoint, before we can "fix" aspen we must be able to identify what is "broken." This requires identifying the chronologic, pathologic, or successional stage of development for particular aspen clones or stands. By that we mean determining whether or not aspen trees that currently make up a clone are all of one age or contain multiple age classes; whether they are young, mature, in decline from competition and disease, or being actively replaced by conifers or other vegetation. A dichotomous key showing how managers might use some of these features to identify aspen stands in need of management intervention will be presented later in Chapter 7: Assessment and Monitoring. Our intent here is to discuss the physiologic and ecologic factors behind those classifications, from the perspective of the aspen, so readers might understand the reasons for their development.

First, aspen has evolved to be a disturbance dependent species. Given the proper growth environment, it can establish from seed on bare mineral soil left after fire, flood, or other major disturbance. However, if a clonal root system exists on a site, disturbances that remove competition from other vegetation and kill existing aspen trees can stimulate the root system to initiate a suckering response. Suckers arise from pre-existing roots and will appear only where roots from the previous aspen exist, normally no more than a tree-height from the edge of the previous aspen stand (although lateral roots have been documented to spread farther [see Chapter 3: Aspen Genetics).

Because new roots establish with each ramet generation (Shepperd and Smith 1993), periodic disturbances with replacement of some or all of the stems in a clone will result in the expansion of the clonal footprint through time. Although very large and old clones have been documented in Colorado (Grant 1993) and Utah (Mitton and Grant 1996), and hypothesized in the Sierra Nevada (Potter 1998), the spatial extent of an aspen clone's lateral root system depends as much upon the existence of suitable resources for the aspen to grow and survive as the length of time a clone has occupied a site. Aspen may be limited to where sufficient water exists for growth, such as riparian areas, or along the lee side of ridges where snow accumulates, or aspen may be limited by competition from other trees. Aspen has been documented to persist in mixed aspen/conifer stands in Colorado for multiple generations (McKenzie 2001), where periodic small-scale disturbances provided for the establishment of new cohorts and maintained a viable root system. Conversely, aspen/conifer forests may become pure aspen given the right disturbance (for example, a high intensity crown fire that kills all conifers in a landscape). Some landscapes in Colorado are currently occupied by aspen that sprouted after large extensive fires in the 19th century and may cover more area than before the fires (Kulakowski and others 2004). But again, those aspen forests would not exist today if root systems from a previous generation of aspen had not been present to initiate new suckers.

Similarly, the number of suckers that arise following a disturbance is dependent upon the number and density of roots that exist from the previous generation

(Shepperd and others 2001). A vigorous, dense clone will produce more suckers if burned or cut than a poorly stocked clone because of the proportionality of above- to below-ground biomass in an aspen clone (Shepperd and Smith 1993; Shepperd and others 2001). Therefore, it may be easier to regenerate a healthy, dense young clone than an old, sparsely-stocked one.

The presence of suckers or younger established stems in a clone indicates that the clone is healthy, has a vigorous root system, and is genetically predisposed to regenerate with minimal disturbance. Conversely, a poorly stocked clone with few remaining live stems is not likely to have a vigorous and extensive root system (Shepperd and others 2001). Aspen roots are living tissue and have respiration demands that require replacement of stored carbohydrate reserves through photosynthesis to remain alive. Most roots in a mature clone are physically connected to only a few stems (DeByle 1964; DesRochers and Lieffers 2001) and will therefore die if separated from the parent tree when conditions do not allow the successful establishment of new suckers.

The belief that an extensive aspen root system exists underground where an aspen grove once stood is a fallacy, as is the notion that thousands of suckers will spring up if a clone containing only a few live trees is cut or disturbed (Ohms 2003). A better rule of thumb would be "as goes the above-ground portion of an aspen clone, so goes the below-ground portion." Consideration of this rule is essential when estimating the need for protecting aspen sprouts from browsing after a regeneration treatment.

Large, dense, vigorous aspen clones are likely to produce many more sprouts than small, poorly-stocked clones. However, reintroduction of repeated disturbance in poorly-stocked clones may eventually allow significant regeneration and clone spread over a number of disturbance cycles as the clonal root system develops over time. Although all of the above examples are drawn from studies conducted outside of the Sierra Nevada, it seems reasonable to assume that similar dynamics are occurring in Sierra Nevada ecosystems.

## Treatment Alternatives to Regenerate Aspen

As discussed earlier, laboratory studies of the general physiology of the species indicate that vegetative regeneration of aspen requires the interruption of auxin flowing from shoots to roots to stimulate root buds to begin growing (Schier and others 1985). This can result from disturbances that kill the parent trees outright, such as a fire, disease, or timber harvest, or from disturbances that only temporarily defoliate the parent tree, such as a late frost, defoliating insect attack, or light herbicide application. Severing lateral roots from parent trees can also cut off auxin flow and initiate suckering. This might occur when fire, burrowing animals, or human factors (for example, road building) kill portions of a lateral root or when roots are mechanically separated from parent trees (Shepperd 2004). This sucker-initiating process has been referred to as interruption of apical dominance (Schier and others 1985).

In any case, the initiation of shoot bud growth must also be accompanied by sufficient sunlight and warmer soil temperatures to allow the new suckers to thrive (Doucet 1989; Navratil 1991). Optimal aspen sucker growth occurs when soil temperatures are 59º F (15° C) or above. Full sunlight to the forest floor best meets these requirements. However, young aspen suckers are susceptible to competition from other understory plants and herbivory from browsing ungulates, even if abundant suckers are present.

The interaction and co-dependency of factors that affect aspen sucker initiation, growth, and survival can be expressed as a triangle model similar to the fire behavior triangle used by firefighters (Shepperd 2001) (fig. 6-2). Successful aspen suckering depends upon three key interacting components: hormonal stimulation, growth environment, and protection of the resulting suckers. One or more of the silvical characteristics of aspen discussed above is involved in each of these factors. Any manipulation of aspen must satisfy all

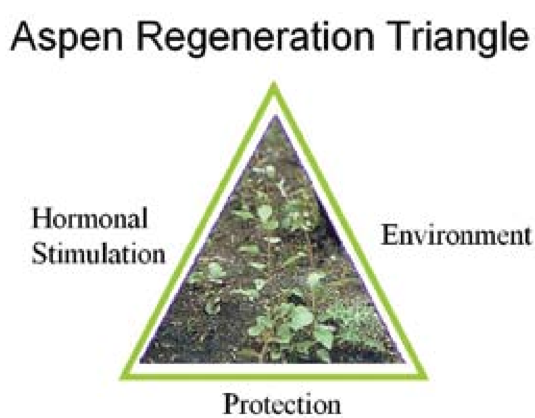



**Figure 6-2.** The aspen regeneration triangle management decision model (Shepperd 2001, 2004).

three of these requirements to successfully regenerate the species.

The three elements of the aspen regeneration triangle may not always need to be actively provided by managers when trying to regenerate aspen. One or more of the elements could already exist in any particular aspen stand, so identifying which factors are lacking is crucial.

Techniques that can be used to initiate aspen suckering and provide a favorable growth environment include removal of existing trees through harvest, separation of roots from parent trees, removal of competing vegetation, and prescribed burning. Protection of suckers from browsing can be provided by satiating the demand, constructing physical barriers to browsing animals, or controlling animal movement.

## Clearfell-Coppice Harvest

Complete removal of all aspen trees has been the traditional method of regeneration where commercial markets exist for aspen. The correct silviculture term for this activity is clearfell-coppice (Ford-Robertson 1971) rather than clearcutting, since the forest will be regenerated by root suckering and not by seeding or planting. Clearfell-coppice regeneration fully stimulates the roots to produce new suckers by completely removing all parent trees. It also provides an optimal growth environment by allowing full sunlight to reach the forest floor. Because commercial quality aspen stands are generally quite large, harvest blocks can be large enough to add an element of protection from browsing animals and diseases through the sheer numbers of suckers that are produced.

Clearfell-coppice harvest probably has limited application in the Sierra Nevada. In addition to requiring large aspen stands, commercial markets for the aspen trees that are removed are needed in order for projects to be economically viable. Clearfelling does not work well in areas where aspen stands are small, unless cut units are fenced from browsing animals (where they are a problem) following treatment. Although clearfell-coppice harvest can introduce new age classes of aspen into landscapes, old trees, which provide many ecologic characteristics that are desirable for aspen forests, are eliminated within cutting units. Soil compaction and death of lateral roots from which suckers arise has occurred during harvest operations in Colorado (Shepperd 1993) and may also occur on similar clay soils (described by Potter [1998]) in the Sierra Nevada.

## Root Separation

Mechanically severing lateral roots at some distance from parent trees is one means of regenerating aspen while retaining an older tree component in the aspen forest. This technique relies on the wide-spreading root habit of aspen to establish suckers in locations where they have a more favorable growth environment than that found under dense large aspen. Severing lateral roots blocks the flow of auxin from parent trees and provides the hormonal stimulation to allow pre-existing buds to produce suckers, provided a good growth environment exists and suckers are protected from excessive animal browsing.

This particular treatment technique was developed after a study in Central Colorado (Shepperd 1996) found that bulldozed areas produced more suckers than cut areas and that more suckers established in fenced areas than in those left unfenced. However, leaving all cut or bulldozed aspen trees on site clearly inhibited aspen sucker establishment. The stimulation effect of the bulldozed treatments was attributed to the complete severing of the stems from the roots. Apparently the stumps from cut trees retained some auxin, which had an inhibitory effect on subsequent suckering when the stumps were left attached to the roots.

Results from this initial study prompted the establishment of two additional studies in Arizona to investigate alternative mechanical treatments that might be used to stimulate aspen suckering (Shepperd 2004). In the first, a crawler tractor with a ripper attachment was used to sever lateral roots in an open mature aspen stand that had been partially harvested 15 years earlier (fig. 6-3). This treatment stimulated about 486 suckers per acre (1,200 suckers / ha) while an unripped, but fenced portion produced only half that amount. Although fencing the stand clearly influenced increased sucker survival, the extra hormonal stimulation provided by tractor ripping doubled the number of suckers without any mortality to overstory trees.

A second study on the Coconino National Forest in Arizona (Shepperd 2001) ripped along the edge of a small isolated aspen clone that was growing beside a meadow. Using a single tractor pass cutting to a depth of 7.9 inches (20 cm) roots extending into the meadow away from the existing trees were severed. This simple treatment resulted in the establishment of the equivalent of over 10,500 stems per acre (26,000 stems/ha) up to 45.9 ft (14 m) away from existing trees into the meadow. In this case, lateral roots produced suckers about 1 to 1½ tree heights away from existing mature trees. No suckers were noted between the ripped zone and existing

**Figure 6-3.** Severing lateral aspen roots to stimulate suckering using a tractor-mounted ripper. Coconino NF, Arizona (Shepperd 2001, 2004).

trees (fig. 6-4), indicating that auxin from the parent trees inhibited suckering in the portion of roots in that zone. As in the previous study, no existing trees were killed by the ripping treatment.

These results are consistent with natural suckering events that we have observed in isolated Sierra Nevada aspen clones surrounded by meadows or shrublands. Therefore, we feel that ripping offers the potential for expanding the size of some existing Sierra Nevada aspen clones, or introducing new aspen age classes into others without sacrificing existing aspen trees. However, if clones are small and browsing animals are present, protection of sprouts may be necessary. A single pass of the ripper along the edge of existing trees should be sufficient to isolate roots and stimulate suckering. Multiple passes may excessively injure roots and result in diminished suckering. Care should be taken if root diseases are present as ripping will provide entry ways for disease.

## *Removal of Competing Vegetation*

Changing the growth environment may be all that is needed to successfully regenerate aspen, if hormonal stimulation already exists and protection for the

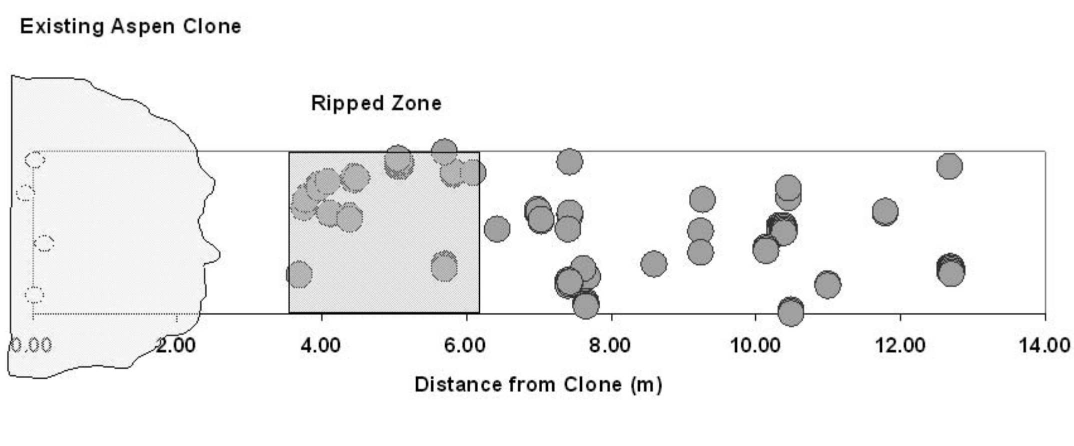



**Figure 6-4.** Map of aspen suckers in a 6 x 45 foot (2 x 14 m) transect extending into a meadow adjoining an edge-ripped aspen clone, one year after treatment. Coconino NF, Arizona. Each circle represents one aspen sprout (Shepperd 2001, 2004).

suckers will be provided. If older aspen trees are stressed, they may already be trying to sucker, so the hormonal stimulation to regenerate already exists. This is often the case in late successional aspen/conifer stands where aspen is a minor component of the stocking. Removing the conifers will allow sunlight to reach the forest floor, raising soil temperatures, and providing the proper growth environment for aspen suckers to thrive. Managers can "punch holes" in the conifer forest surrounding isolated pockets of residual aspen and this will often cause the area to be restocked with aspen. As with other treatments, care should be exercised when browsing animals are a problem.

Removal of competing conifers will enhance any natural sucker production already occurring in declining clones and can retain any remaining old aspen trees for aesthetic and wildlife purposes. This technique has been successfully used in the Sierra Nevada (Jones and others 2005b). However, new aspen suckers in the clones in advanced stages of decline may require protection in order for them to successfully establish.

The effects of removing competing vegetation can be quite dramatic. Shepperd (2004) described a case in Arizona where removing conifers and fencing the area surrounding a clone consisting of two mature aspen trees resulted in over a hundred established aspen trees after 5 years (fig. 6-5). Removing competing vegetation produced similar results in (Jones and others 2005b) Sierra Nevada study (fig. 6-6).

## *Protection From Browsing*

If an aspen clone is attempting to sucker, and if suckers are heavily browsed and shrubby in appearance with no central growth axis, protection from browsing may be all that is needed to successfully re-establish

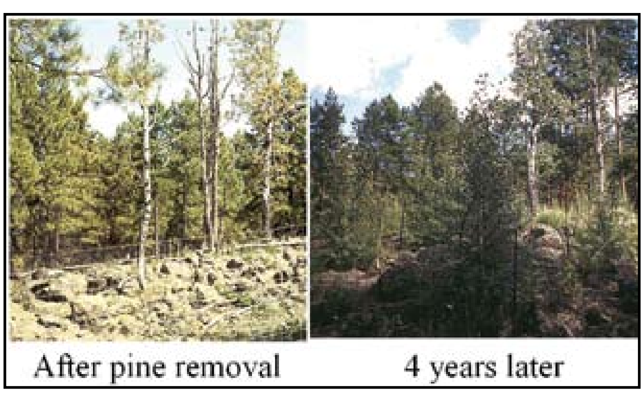



**Figure 6-5.** Removing competing conifers and fencing this two-stem aspen clone allowed new suckers to establish. Kaibab NF, Arizona (Shepperd 2001, 2004).

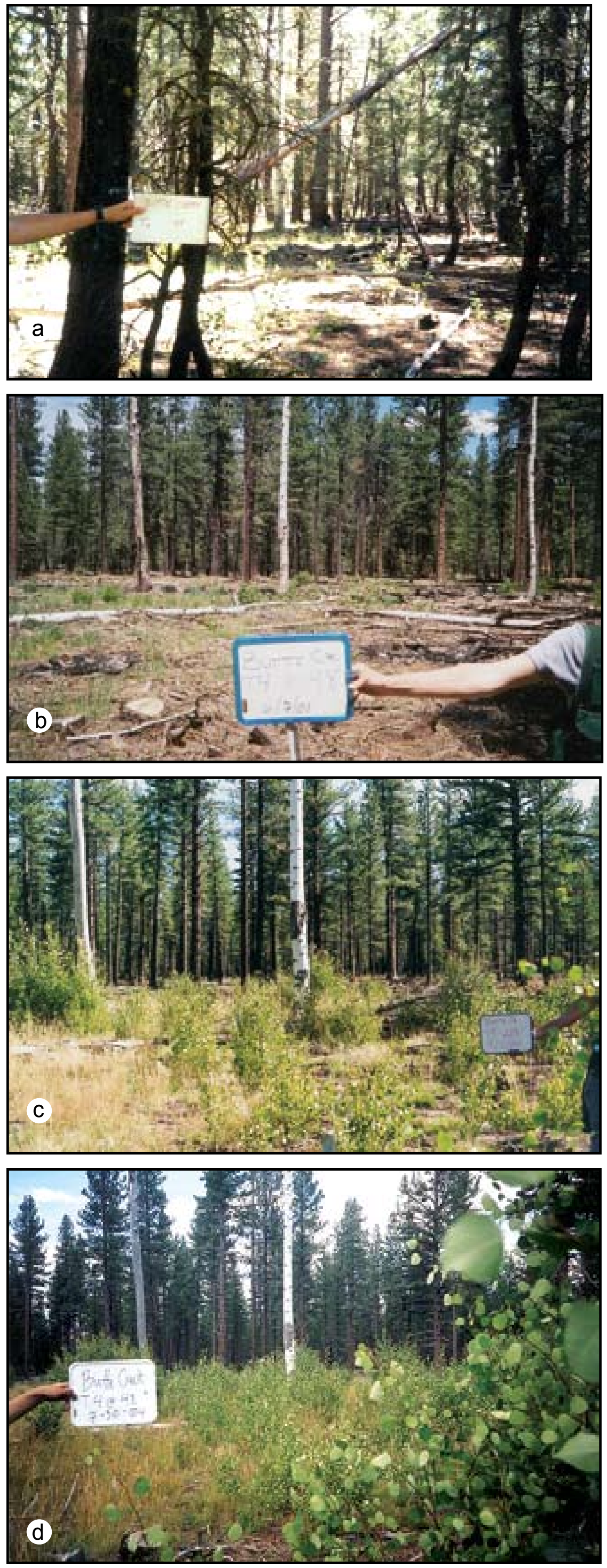



**Figure 6-6a-d.** Photo series showing aspen regeneration response to removal of competing overstory conifers. Photo (**a**) was taken in 2000, prior to treatment. Photo (**b**) was taken in 2001, photo (**c**) in 2003, and photo (**d**) in 2004. Eagle Lake Ranger District, Lassen NF.

the stand. Obviously, the hormonal stimulation to sucker exists if few overstory conifers are present and if a favorable growth environment also exists. The heavily browsed suckers would indicate that they need to be protected in order to grow above the reach of animals.

Direct protection of aspen reproduction will likely be expensive because of the cost of constructing fences (Rolf 2001; Kees 2004). However, it may be the only way to successfully reestablish aspen in the many areas in the Sierra Nevada where aspen is a minor component of forested landscapes and browsing animals are present. Manipulating logging slash (Rumble and others 1996) and "hinging," or partially felling aspen or conifer trees around the perimeter of clones (Kota 2005), have been used in South Dakota to keep browsing animals at bay and may also be an option in some Sierra Nevada situations.

Whatever the method used, the goal is to prevent browsing of the terminal leader of the young aspen suckers, which can lead to "hedging," or a shrubby growth form that will never develop into a tree. Efficient fence designs have been developed (Rolf 2001; Kees 2004), but require regular maintenance to be effective. A perimeter clearance of one tree length of forest on both sides of the fence is suggested to minimize damage from trees falling on the fencing. Leaving too much slash on the ground can inhibit suckering (Rumble and others 1996; Shepperd 1996). Hinging requires skilled sawyers and a sufficiently dense aspen stand to create a perimeter barrier around the clone (Kota 2005). Chemical browse repellents were found to be effective at high dosages in a Colorado study using penned elk (Baker and others 1999), but are likely too expensive for most wildland applications.

The length of time that suckers need protection depends upon whether the browsers are domestic livestock or elk. Domestic livestock will usually not bother suckers over 6 ft (2 m) in height, but elk can break off and consume aspen saplings up to 1.5 inches (4 cm) in diameter at breast height (4.5 ft or 1.4 m). In most cases 8 to 10 years of normal growth are necessary for suckers to attain these sizes (Shepperd 2004).

## Prescribed Fire

Because aspen is a fire-adapted species, prescribed fire can be used very effectively to regenerate aspen. Fire provides two of the three essential elements of the aspen regeneration triangle. Killing overstory stems and injuring lateral roots provides hormonal stimulation to initiate sucker production. Removal of competing vegetation and blackening the soil surface (allowing it to be warmed by the sun) creates ideal growing conditions for suckers. Burning also releases nutrients that contribute to the growth of suckers. However, fire may not provide protection for the new sprouts, unless large enough areas of aspen have been burned to satiate browsing animals' appetites for aspen sprouts.

Pure aspen forests are somewhat difficult to burn because fuel loadings are generally light and the lush understory vegetation usually has high moisture content and does not contain sufficient biomass to burn effectively (Fechner and Barrows 1976). Effective burning to regenerate aspen in these stands requires timing the fire when fuels are dry, or using alternative fuels to carry the fire into the aspen (for example, burning adjacent shrublands) (Shepperd 2004). Fire will usually burn into the aspen far enough to stimulate new aspen suckering along the edges of clones, even if the overstory aspen trees are not killed outright. This can create a diverse landscape in which some clones are completely replaced by new suckers, while others have some surviving overstory stems, but with new suckers beneath them and extending out from the periphery of the surviving trees. In both cases, the footprint or the area occupied by aspen in these landscapes will be increased to the area occupied by lateral roots surrounding the existing clone. This has been reported to be about 1½ to 2 times tree height away from existing aspen stems from studies in South Dakota (Keyser and others 2005), Arizona (Shepperd 2004), and Idaho (data on file, Rocky Mountain Research Station, Ft. Collins, CO). Similar results could be expected in the Sierra Nevada.

Prescribed crown fire has been used successfully in southern Utah in mid- to late successional aspen/conifer forests where conifer crown bulk density is sufficient to carry a crown fire (Shepperd 2004). It should also work in similarly structured mixed aspen/conifer forests in the Sierra Nevada. This technique requires natural fuel breaks to keep the fire from spreading outside desired treatment areas. Such burns should be planned when soil moisture is high to avoid excessive damage to the shallow aspen roots. Although risky, prescribed crown fire provides all elements of the aspen regeneration triangle and can reintroduce large areas of pure aspen into mixed species landscapes. Although it also carries the social stigma of resembling a wildfire (killing all existing aspen as well as conifers), there are many positive benefits to this approach. Prescribed crown fire will not only rejuvenate aspen and reset vegetation succession, but it can also increase understory vegetation diversity, forage production, and water yields, as well as improve habitat for many wildlife species (Bartos and Campbell 1998).

A major disadvantage to using prescribed crown fire is safety. It can be used in isolated aspen/conifer stands surrounded by non-forest vegetation or where mixed crown and surface fire can be tolerated across large landscapes. Although there is a certain degree of risk that an unintended wildfire might result, this type of fire is probably what maintained many Sierra Nevada aspen/conifer forests in pre-settlement times.

## *Combined Treatment Techniques*

Many times a combination of mechanical treatment and prescribed fire is the best course of action to regenerate aspen in mixed aspen-conifer stands. A combined treatment can provide a means of emulating natural fire regimes by providing maximum hormonal stimulation and optimal growth environments for aspen suckers as well as eliminating or reducing competing conifers. Shepperd (2001, 2004) combined commercial harvest, prescribed burning, and fencing to successfully regenerate aspen in a study in northern Arizona. All ponderosa pine were removed within and surrounding isolated aspen clones using a commercial timber sale, and the entire area was fenced with an elk-proof wire fence. Logging slash was then scattered throughout the area and a prescribed burn applied to half of the area the next spring following snowmelt when soils were wet. The prescribed burn had a striking effect on both the numbers of suckers that were produced and survived over a 5-year period (fig. 6-7) and on the sucker height growth (fig. 6-8). Part of this effect was undoubtedly due to nutrients introduced into the soil by the fire, but the solar warming of the soil during the first few growing seasons following the fire (figure 6-9) likely contributed as well.

Burning heavy logging slash in harvested areas can be detrimental to aspen suckering, especially when conditions are dry (Shepperd 2004). Intense heat penetration into the soil from the burn can kill aspen roots beneath heavy fuel concentrations (fig. 6-10), but studies in Colorado have demonstrated that adequate suckering can be maintained if soil conditions are wet when burning heavy slash (Shepperd 2004).

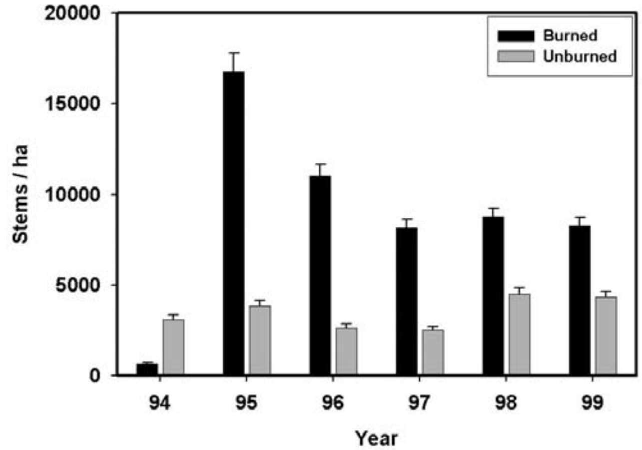



**Figure 6-7.** Sucker densities (with standard deviation bars) before (1994) and 5 years after a spring prescribed burn in light logging slash. Coconino NF, Arizona (Shepperd 2004).

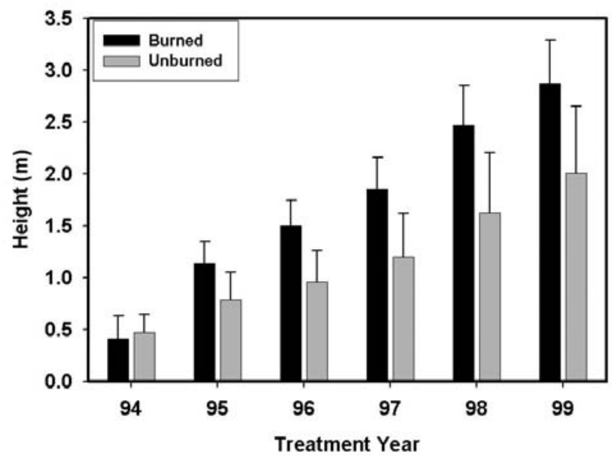



**Figure 6-8.** Average dominant sucker height (with standard deviation bars) before (1994) and 5 years after a spring prescribed burn in light logging slash, Coconino NF, Arizona (Shepperd 2004).

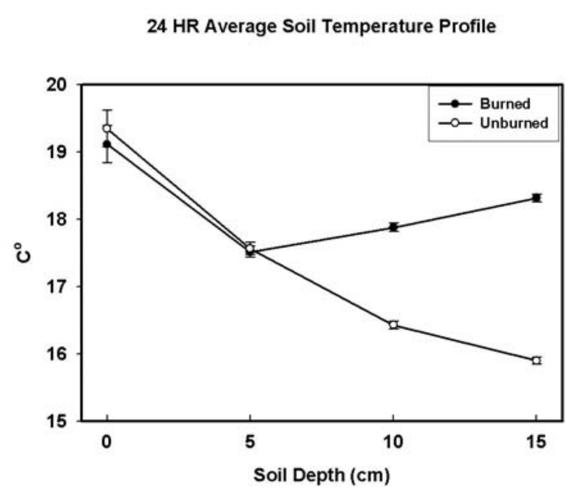



**Figure 6-9.** Average soil temperatures during the first growing season after treatments for burned and unburned aspen sites, with standard error bars. Coconino NF, Arizona (Shepperd 2004).

**Figure 6-10.** An excavated aspen root segment ends at the edge of soil scorched by burning a small pile of slash. Roots under the pile were consumed by the fire.

# Treatment Opportunities Specific to the Sierra Nevada and Lake Tahoe Basin

Aspen in the Sierra Nevada and Lake Tahoe basin are typically characterized by small stands that are intermixed with conifers, or isolated pure stands that occur in riparian areas, snow accumulation zones, or other topographic zones where moisture conditions are favorable for aspen. Although aspen in the Sierra Nevada is the same species and occurs in association with the same vegetation as elsewhere in the west, it does not grow in extensive landscape-wide forests. Therefore, management opportunities and techniques are more limited in the Sierra Nevada than those available to managers elsewhere.

A major difference between aspen in the Sierra Nevada and other places in the West is that commercial markets do not exist for aspen here. Consequently, the need to optimize growth of defect-free trees is not a primary goal of management. Instead, the principal objective of aspen management in the Sierra Nevada is to retain aspen on the landscape and restore declining or disappearing clones to a more healthy condition.

The seven Sierra Nevada aspen types described in Chapter 5 can serve as a framework on which to base our discussion of factors to consider in developing management alternatives. These classifications are not defined by associated vegetation, or limited to individual genotypes or clones, but are based solely on our observations of aspen's occurrence in the Sierra Nevada across physiographic positions, soil conditions, and associations with conifers.

## *Upland Pure Aspen*

These stands are typically found along the east side of the Sierra Nevada or Modoc Plateau in association with grass or shrublands, where conifers are not present (fig. 5-16). Although site productivity is not high, some of these stands are several hundred acres in size. They may appear single-aged, but such stands usually contain cohorts of different ages and likely are made up of multiple aspen genotypes, or clones. Since these stands are similar to those found on the eastern edge of the Great Basin and in the Rocky Mountains, we recommend using the key by Campbell and Bartos (2001) (see Chapter 7) to identify the need for management intervention. Basically, intervention is needed if clones are in decline and no successful aspen suckering has occurred.

Management alternatives could include any of those discussed earlier, including clearfelling to introduce new aspen age classes into a landscape. These large stands are likely the only type of aspen occurring in the Sierra Nevada where clearfelling might be a viable option to stimulate sufficient suckering to satiate browsing animals.

## *Upland Aspen/Conifer*

Aspen is most commonly associated with conifers on upland (nonriparian) physiographic locations in the Sierra Nevada (fig. 5-13). These associations can occur with most, if not all, conifer forest types in the Sierra Nevada and can range from aspen forests containing a conifer understory to a few isolated individual aspen stems surviving in an otherwise pure conifer forest. The common feature of aspen in these situations is that the current ramet generation will most likely be replaced by conifers without a stand replacing fire or other disturbance to open the canopy and allow aspen to regenerate.

Clearly the stands most in need of immediate management intervention are those that contain the smallest component of aspen—the isolated mature stems described above. Identification of stands in need of treatment can be done by using the assessment techniques described in Chapter 7 developed by Campbell and Bartos (2001). To have successful regeneration, aspen in this situation will require the most intensive management actions. A large number of mature conifers may have to be removed to allow enough light to reach the forest floor for successful suckering. Even so, sucker densities are likely to be low because aspen lateral root systems are likely to be sparse in these situations. Fencing will likely be required if browsing animals are present. Prescribed burning is not likely useful if overstory conifers are large fire-resistant species. Prescribed surface fire may be useful in stimulating suckering, provided activity fuels are not too heavy. Burning in spring when soils are wet will avoid excessive damage to aspen roots.

Mixed aspen-conifer forests that contain a sizable component of aspen are most likely to benefit from conifer removal. They still have sufficient stocking and root density to sucker well, and at high densities. Complete conifer removal should be implemented to maximize the longevity of the treatment and introduce the attributes of a pure aspen forest into the landscape. However, an alternative treatment would be to "punch holes" in the conifers around the aspen (see discussion above in this section) to allow suckering to occur from roots extending into the conifers. Removal of some aspen may be necessary to break apical dominance if clones are vigorous and healthy, but complete removal of all aspen is unnecessary.

Care should be taken in the logging process to avoid damaging aspen trees that are intended to be left. Track-mounted mechanical feller-bunchers are the most efficient means of accomplishing conifer removal without damaging aspen stems or roots, but careful directional hand felling can work, too. Conifer logging slash should be removed to allow sunlight to reach the forest floor, unless a prescribed fire is planned to stimulate additional suckering. In the latter case, only scattered branches and tops should be left. Broadcast burning of heavy loadings of 1000-hour fuels will likely kill too many shallow aspen roots and result in poor suckering. In any case, a prescribed fire burning through logging slash will likely kill any remaining overstory aspen stems. Similarly, any piling and burning of slash should be done outside of the aspen lateral root system footprint that extends at least one tree height away from existing stems. Burning even small hand-piles can kill aspen roots (fig. 6-10).

Two additional issues should be discussed with regard to upland aspen/conifer forests. We remind the reader that goshawk nesting sites are off limits to any cutting under the record of decision for the FSEIS SNFPA guidelines (Appendix I). Therefore, any aspen occurring in these areas cannot be actively managed. Second, conifer trees larger than 30 inches can be cut outside goshawk PACs, if the action is properly justified (Appendix I). We believe that the removal of large conifer trees is justified (and in fact ecologically necessary) to restore aspen, if the aspen is overtopped by large trees. Leaving large conifers may not allow enough light to the forest floor to stimulate adequate aspen suckering and will certainly provide a ready source of conifer seed to quickly re-establish a dense conifer understory.

## *Riparian Aspen*

These aspen stands occur along perennial and intermittent watercourses throughout the Sierra Nevada and are especially common within the Lake Tahoe basin (fig. 5-12). Although individual clones may extend upland beyond the riparian zone, our concern here is for those aspen stands where growth and development is influenced by the deeper soils and moist growing conditions associated with the streamside riparian plane. Because these aspen stands are located in riparian zones defined in the Sierra Nevada Forest Plan Amendment (USDA Forest Service 2004c), management activities and options are more restricted here than elsewhere. Some riparian clones appear to be in good shape and contain multiple age classes of healthy trees, while others are rapidly being replaced by conifers. Still others have aspen regeneration that is being over-utilized by browsing animals.

Providing the proper aspen growth environment and protecting aspen regeneration from browsing will probably be essential to rehabilitating these clones. Prescribed burning and hand-felling of small conifer trees may help alleviate conifer competition in some cases, but removal of large mature conifers will often be required to provide the proper growth environment for aspen. Such activities are not specifically prohibited in the Record of Decision for the FSEIS SNFPA (USDA Forest Service 2004c) (Appendix I), but will require additional planning, coordination, and innovative techniques to avoid adverse effects to the riparian zone.

Soil disturbance and compaction is a major concern with mechanical treatment activities in the riparian zone. Compaction in aspen soils increased with the number of times equipment passed over the site in a Colorado study (Shepperd 1993), so innovative harvest techniques may be needed to remove large trees. Mechanical harvesting by a tracked feller-buncher, which can drive into the riparian area, harvest a tree, and carry it directly back out over the same track without turning, will create very little soil disturbance and minimize compaction. Similarly, harvesting in winter when soils are frozen, dry, or snow covered minimizes soil disturbance and compaction. Regardless of the harvest technique used, whole-tree harvesting will remove all slash and allow maximum light to reach the forest floor and stimulate new aspen sprouting.

It is extremely important that all overstory conifers be removed to allow light to reach aspen roots. This should include cutting conifers that likely shade aspen roots that extend away from existing aspen stems. A good rule of thumb would be to remove conifers from a large enough area to allow sunlight to reach an area 1½ tree heights away from existing aspen stems as described earlier (see Chapter 6: Treatment Alternatives to Regenerate Aspen).

Although prescribed burning will remove competing conifer seedlings and maximize aspen sprouting, it may not always be feasible to use fire in riparian zones where soot and ash might reach streams and potentially affect water quality.

## *Meadow Fringe Aspen*

This type of aspen is similar to riparian aspen, but instead of occurring along stream corridors, the aspen is situated along the edges of meadows, juxtaposed between the mesic grassland vegetation and the drier upland forest in a narrow band where conditions are ideal for aspen (fig. 5-11). Often, the presence of residual aspen stems and downed logs in the conifer forest behind the aspen indicates that these stands may have been larger under the frequent fire regimes of the past. In some instances, the presence of younger aspen stems near the meadow indicates that aspen is continuing to invade the meadow. However, in some marshy meadows, further aspen invasion appears to be limited by saturated soils.

Opportunities exist to expand many meadow fringe aspen by removing conifers behind the aspen, away from the meadow, and allowing the aspen to re-colonize the area where aspen lateral roots still exist. Careful inspection of the conifer forest behind the aspen can locate ephemeral aspen sprouts in the understory that will reveal the extent of the aspen root system. Conifers should be removed for a sufficient distance (at least 1 to 1 ½ tree heights) beyond the aspen roots to allow full sunlight to reach the forest floor and stimulate sprouting. If logging slash remains, it should either be removed and piled outside the area occupied by aspen roots, or burned when soil conditions are wet to minimize damage to aspen roots. Fencing may also be necessary if browsing animals are present since aspen sprouting may be sparse due to low root density under the conifer forest.

## *Snowpocket Aspen*

These types of aspen stands are common along the eastern fringe of the Sierra Nevada and into the Great Basin where snow accumulates along the lee side of ridges and isolated mountains. The extra moisture that accumulates in these topographic locations is sufficient to support aspen within and just beneath the zone of maximum snow accumulation (fig. 5-15). These aspen stands are often pure, or contain few conifers, and are characterized by small misshapen stems that have been damaged and contorted by the drifting snow. The spatial extent of these stands is often limited by the topographic conditions that allow extra snowpack to accumulate. Heavy snow years damage aspen trees and provide sufficient mortality to stimulate the periodic production of new aspen suckers.

Snowpocket aspen is more resilient than other types of aspen in the Sierra Nevada because these stands are often pure aspen (not being invaded by conifers) and contain multiple age cohorts as a result of periodic snowpack disturbance. Active management intervention may not be needed if all of these features are present, even though the stand may not fit our ideal vision of what an aspen stand should look like. However, if a snowpocket aspen stand is in obvious decline without any new recruitment, or the aspen have been largely replaced by conifers, then active management may be needed. Alternatives may include fencing to exclude browsing animals or removal of conifers by mechanical means or by prescribed crown fire. The latter option may be viable because snowpocket aspen is often topographically isolated and surrounded by grasslands or shrublands that provide natural fire breaks. If snowpocket aspen occur on active sheep allotments, simply requiring herders to avoid them may be sufficient to allow the aspen to successfully regenerate.

## *Lithic Aspen*

We use this term to describe aspen that is growing on talus slopes, basalt flows, and other rocky situations that would seem to be the antithesis of what thriving aspen require (fig. 5-14). In spite of the apparent contradiction, such rocky conditions serve as refugia for aspen and allow it to persist in some landscapes. Wide-ranging aspen roots can penetrate into the spaces between rocks to access pockets of soil. The rocks essentially act as mulch, limiting water evaporation and preventing buildup of fuels that would allow fire to kill aspen. Aspen suckers can rely on root reserves to grow quickly above the rocks, where they enjoy full sunlight and may be protected somewhat from browsing animals.

Some lithic aspen may require removal of competing conifers and fencing to protect sprouts from browsing animals, but other management options may be limited. Before embarking on further actions, we recommend monitoring to ensure that the aspen is persisting and not in danger of disappearing.

### *Krümmholz Aspen*

These are rare, but ecologically unique aspen stands that occur near upper treelines in the Sierra Nevada (fig. 5-17). Aspen often do not achieve tree form in these stands, but persist as misshapen shrubs that barely cling to life near the upper reaches of forest vegetation. Any attempt at stimulating additional sprouting by use of mechanical treatment or prescribed fire in Krümmholz aspen stands is likely to upset the delicate balance under which they exist and may do more harm than good. Management intervention for these aspen stands should probably consist of careful monitoring to ensure that browsing animals are not adversely affecting the aspen, and fencing clones that are being over-browsed.

## Managing Aspen in the Wildland Urban Interface___

We've included this section to discuss alternatives that might be used to enhance aspen growing in areas that would not normally be managed for aspen or where other management objectives overshadow management for aspen. With some additional thought, actions can be undertaken in many of these circumstances that will fulfill the primary management objective and also benefit aspen that happens to occur in these areas.

Currently, many fuels treatment activities are underway within the Wildland Urban Interface (WUI). These treatments include thinning, mechanical mastication, and prescribed burning to remove understory conifers and accumulated ground fuels. Such activities will inherently benefit any aspen in these forests by allowing light to reach the forest floor to stimulate new suckering. However, aspen could benefit further by the removal of all conifers over an aspen clone's root system footprint. Such removals would add spatial diversity to the forest and create pockets of pure aspen that may also act to alter the behavior of fire burning through the area. Including aspen-benefiting activities in WUI fuel treatments is certainly justified and beneficial to the forest ecosystem in the long run. We should note that diameter limits apply to the removal of conifers in fuel treatment projects (Appendix I). If large conifers need to be removed to benefit aspen, the activity needs to be planned and funded as an aspen restoration project so that diameter limits would not apply (Appendix I).

Similarly, private landowners whose property adjoins and is interspersed within the WUI (fig. 6-11) can also benefit from activities that retain and regenerate aspen. Because aspen will not burn with the intensity of conifers it can be planted or retained closer to structures than conifer trees. Creating aspen glades on even a small property will alter fire behavior (Fechner and Barrows 1976) while retaining a forested appearance. We encourage counseling private property owners about the benefits of retaining aspen wherever possible.

## Managing Aspen on Rangelands________________

Adaptive management of aspen communities on range allotments may be one of the most valuable tools in preserving regional aspen communities. As was described in Chapter 4: Range Management and Aspen Communities, Potter (1998) found that many of the stands he sampled in the Sierra Nevada were located adjacent to meadows and other moist areas where livestock congregate in the summer season for shade, forage, and access to water. During his study, he found that livestock would often graze heavily in these areas and use aspen as a primary browse species. This is consistent with Menke and others (1996) who found the most degraded range habitat to be located in drainages, meadows, watering places, and other natural livestock concentration areas. Loomis and others (1991), Kie and Boroski (1996), and Loft and others (1991) also noted similar intensive use of these types of habitats in the Sierra Nevada, as did Julander (1955) in Utah. Therefore, active management (restricting livestock) on rangeland will likely be necessary to successfully establish aspen suckers and retain biodiversity when aspen stands occur in these locations.

**Figure 6-11.** Aspen regenerating after fuels treatment activities on a private lot.

While we focus this part of our discussion on browsing of aspen by domestic livestock, we want to accentuate that long term management of aspen communities in rangelands needs to address the cumulative impacts of both wild and domestic ungulates. For example, by using three way enclosures in Utah, Kay and Bartos (2000) were not only able to document when domestic livestock were preventing aspen from regenerating, but they also found that fluctuations in deer herd size affected aspen's ability to regenerate. The effects that livestock have on aspen ecosystems depends upon the type and class of livestock, animal density, and the seasonal timing, intensity, and frequency of use (Roath and Krueger 1982) (See Chapter 7 for techniques to monitor these variables).

## *Management Objective: Establish New Stems Above Browse Height*

A principle objective of regenerating aspen on rangelands is to establish new suckers above the height that browsing animals can seriously damage them. The size at which aspen sprouts are vulnerable to browsing depends upon the size of the animal eating them. Smith and others (1972) and Sampson (1919) found that sheep will browse up to 45 inches (1.14m) and cattle and deer up to 5 ft (1.5m). These heights have been generally accepted as being adequate to establish new aspen. However, in areas of recent elk introduction in the Southern Cascades and Modoc Plateau, aspen may need to reach at least 12 to 15 ft (4 to 5 m) and at least 1.5 inches (4 cm) dbh to avoid damage similar to that reported in other areas (Shepperd 2004). There are several site specific management techniques that are appropriate for modifying livestock distribution, alleviating concentration problems, and minimizing real or potential conflicts with aspen resource values.

### *Fencing*

Fencing is an obvious tool for ungulate management. It is important to identify whether intense browsing by wild ungulate, domestic livestock, or a combination of both is keeping a stand or group of stands from successfully regenerating. Fence designs differ depending on which animals are browsing the aspen. Steel, plastic, and pole fencing have been used successfully for aspen protection (Rolf 2001; Kees 2004). Additionally, using brush piling or conifer trees that have been hinged when felled to create livestock barriers has been successful (Kota 2005). All of these techniques require close monitoring during those times that regeneration is vulnerable to browsing to ensure that barriers remain intact.

### *Salt Blocks and Water Source*

Location of water and salt blocks are magnets for cattle grazing, browsing, trampling, and bedding (Roath and Krueger 1982). Keeping salt and water sources away from regenerating aspen communities will help disperse cattle and relieve grazing pressures.

### *Seasonal Utilization*

Seasonal herbivory on aspen regeneration generally increases when the herbaceous vegetation in and around an aspen community has cured and lost much of its value (for example, after the first killing frost). Aspen utilization will also occur when the amount of herbaceous vegetation available within or near aspen communities can no longer provide the carrying capacity of the range. Proper timing of allotment use can greatly benefit aspen. For example, successful regeneration of aspen has been demonstrated on the Sierraville Ranger District, Tahoe National Forest by moving cattle away from aspen as forage preferences change from herbaceous vegetation to aspen (Personal Comm., Fred Kent, Range Management Specialist, USDA Forest Service, Tahoe National Forest).

Wild ungulates may exhibit similar seasonal preferences. For example, it was observed on the Amador Ranger District, Eldorado National Forest that deer with fawns began bedding down in an aspen/meadow community and browsing intensely on aspen regeneration every year in mid-July (Personal Comm., Chuck Lofland, Wildlife Biologist, USDA Forest Service, Eldorado National Forest). Evidence of multi-stemmed and bush shaped aspen suckers were evidence that this process had occurred regularly over many years. Constructing a temporary woven fence around the area prior to July 15 each year allowed those suckers to release and grow in subsequent years.

### *Class of Animal*

While we were unable to find research to document this type of event, we feel that changing livestock from cow-calf to dry cow may increase the movement of the cattle enough to successfully allow aspen suckers to get above browse height. Successful aspen regeneration occurred in a number of aspen stands on the Sierraville Ranger District of the Tahoe National Forest within three seasons of moving from cow-calf to dry cows (Personal Comm., Fred Kent, Range Management Specialist, USDA Forest Service, Tahoe National Forest). It has also been noted that yearlings do less damage to aspen than cow-calf pairs.

### *Type of Livestock*

Sheep have been reported to brows aspen more than cattle, which tend to prefer grazing over browsing. Sheep are often moved into steeper topography that cattle seem to avoid. This may place increased pressure on upland aspen communities. Good range management objectives should include herding sheep away from regenerating aspen, especially if the aspen is intended to be used as bedding grounds.

### *Cycling of Grazing to Benefit Aspen*

To promote regeneration, DeByle (1985a) recommended moderate grazing until an aspen overstory begins to decline, then heavy grazing for a couple of years to eliminate or weaken much understory competition, and then removing all grazing pressures for 3 to 5 years. This process could be repeated every 20 to 30 years to establish uneven aged stands. We believe that this approach needs to be modified to remove grazing pressures when aspen is “ready to regenerate” (show signs of unsuccessful sprouting). Waiting for the end of the life cycle of a mature age cohort to allow the production of a new age cohort may be ill-advised. A stand that is becoming decadent may not have enough root structure left to provide proper stocking (Shepperd and others 2001; Ohms 2003). Thus, we recommend close monitoring of aspen stands and providing protection to aspen clones when they naturally begin to regenerate a new age cohort.

### *Post Fire Recovery*

Some National Forests in the Pacific Southwest Region (for example, the Modoc NF) currently practice a minimum of 2 years of allotment rest after wildfires to meet vegetation recovery objectives. This would benefit aspen clones when they are most likely to produce a new age cohort. Aspen clones are more susceptible to elimination by repeated browsing if all older aspen trees were killed during the fire. Aspen regeneration should be closely monitored during initial years following the rest period to ensure successful establishment of a new aspen stand. Because aspen suckers can be suppressed by chronic post-fire herbivory (Bartos and others 1994), poor range management or excessive wild ungulate use could hasten the death of a clone.

## Management Strategies Relating to Recreation Impacts

As we discussed in Chapter 4, establishing developed recreation areas in aspen stands is not a good idea.

Although aspen stands are highly desirable for their aesthetic appeal, their susceptibility to damage from concentrated human activities make them poor candidates for picnic areas and camp grounds. Root compaction from vehicles and intense foot traffic can kill aspen roots and stress trees. Any injury to the living bark of aspen is a potential entryway for canker infections that can kill the tree (Walters and others 1982) and aspen trees in developed recreation areas are commonly damaged by irresponsible users.

Research has looked extensively at recreation impacts on wildlands. Cole (1993) and Cole and others (1987) identified the importance of recognizing problems and carefully evaluating all potential solutions. As we discussed in our section on impacts of recreational use of aspen habitats (Chapter 4), the principal problem is from concentrated recreational uses in aspen. Any single recreational activity done in excess can set in motion events that can cause impacts to the ecology of the landscape. Most recreation activity conflicts that we have observed elsewhere in aspen were associated with developed and dispersed camping locations, along developed road and trail systems, in areas of high OHV use, and in or adjacent to pack stock corral or holding areas.

There are a number of options available to the manager to alleviate or prevent damage to the ecological values of aspen in these situations. First, the location of use within problem areas can be modified. Although it may not be possible to move existing developed campgrounds, planning of new facilities should keep the protection of aspen in mind. Steps can be taken in existing recreation facilities that have been established in aspen stands to prevent further injury and loss of aspen. Raised trails covered with wood chips or mulch can protect roots, and aesthetically pleasing fencing can be constructed to keep people away from aspen stems. Interpretive signs explaining that aspen bark is living, just like a person's skin, can be used to discourage carving.

If shading is an important campground element, more resilient tree species can be established in existing campgrounds. Access to dispersed camping sites in highly impacted aspen areas can be discouraged or prohibited. Special use facilities such as corrals and horse stables can be located away from aspen. Pack stock use concentrations in aspen can be discouraged through education or prohibited through action.

If camping sites cannot be closed, educational programs can be developed to inform potential visitors of the disadvantages of damaging the critical aspen component of campgrounds. One element of the educational program could be the development of interpretive signs explaining the ecological value of aspen habitats.

Generally speaking, we are not overly concerned about the impacts of dispersed recreation use of aspen communities. Activities like walking, picnicking, nature study, photography, and other permitted consumptive uses such as fishing and hunting each have slightly different impacts on aspen, but in moderation their effects are usually light. Where concentrated uses of aspen habitat occurs, cumulative recreational impacts can cause ecological damages equal to those in developed or dispersed camping areas. This is especially true along trails, roads, or in OHV use areas, where more intense recreation management practices would be needed.

## Management: Water Quality and Quantity

Several of the aspen types discussed earlier are associated with moist physiographic positions where possible effects of management actions on water quality and quantity could be an issue. Management of aspen within the Forest Service's Riparian Conservation Areas (RCAs) classification is within the parameters of the Sierra Nevada Forest Plan Amendment (SNFPA) (USDA Forest Service 2004c). In fact, the SNFPA singles out aspen as a species that can be managed in RCAs. This interpretation of the SNFPA has been confirmed by the Regional Office (Appendix I). Likewise, the Lahonton Regional Water Quality Control Board, which has regulatory control of the Stream Environment Zones (SEZ) on lands on the Eastern Slope of the Sierra Nevada (including the Lake Tahoe basin), has allowed activities to occur near streams, but under very close scrutiny. Agencies must work closely to develop management methods that will pass regulatory review.

Implementation of management objectives for restoring aspen communities adjacent to, and within riparian ecosystems, should have the principal goals of minimizing soil erosion, preserving water quality, and improving stream flow. This may occur by implementing treatments that minimize soil disturbance and allow aspen communities the opportunity to return quickly to a state where it is contributing to the quality of the riparian ecosystem. Conifer removal and prescribed fire treatments should be designed to reach these goals, and range management practices should be adjusted to limit habitat degradation and improve water quality within riparian zones.

In concluding this chapter, we remind readers that successful aspen management simply involves understanding aspen's unique growth habits and applying treatments that favor the species. Regardless of the type of aspen they encounter, the descriptions discussed earlier can help managers identify the need for intervention. The three critical elements of the Aspen Regeneration Triangle (fig. 6-2) describe what must be provided in order for any attempt at regenerating aspen to succeed.

# Chapter 7.

# Assessment and Monitoring Methodology

As described in the introduction to this synthesis, directives and supporting standards and guidelines from multiple governmental agencies call for the ecological assessment of vegetative communities such as aspen, and for management actions that will move plant communities toward their range of natural variability. This chapter will focus on the actual methodologies that have been developed for: 1) deriving ecological assessments of aspen communities, 2) monitoring herbivory of aspen regeneration, and 3) examining whether management objectives to change the ecological status of aspen are being met. Our discussions will be framed with the realization that time and monetary constraints are always factors in the development and implementation of ecological assessments and monitoring protocols. To accommodate these constraints, we will tier our discussion—moving from qualitative to quantitative methods in all three cases. We recognize that no single method or protocol fits all management situations and that whatever methodology is used should be designed to measure whether management objectives are being met (Elzinga and others 1998).

The Record of Decision of the Sierra Nevada Forest Plan Amendment's Final Environmental Impact Statement (USDA Forest Service 2004c) calls for identifying whether a vegetative community is outside the range of natural variability or moving in that direction. Therefore, resource managers need to identify indicators that can reflect the ecological status of the ecosystem. Many biotic relationships can act as indicators for the natural variability of the ecosystem (Richardson and Heath 2004; Martin and others 2004). Bartos and Campbell (1998) presented a case for using aspen itself as an indicator. They believe: 1) loss of aspen will cause a parallel loss of biotic diversity within the ecosystem; 2) aspen regeneration is closely linked to the natural disturbance factors in the ecosystem; and 3) aspen clones provide a guide as to the spatial extent of aspen communities through time (see Chapter 3 for additional discussion of these topics).

The loss of aspen itself may be the best variable to indicate whether a stand has moved outside its range of natural variability. The complete loss of a clone marks, for all practical purposes, an ecologically irreversible event (Campbell and Bartos 2001). Planting aspen does not appear to be a viable method of replacing lost aspen clones (Shepperd and Mata 2005).

Because the loss of aspen is irreversible if the root system dies, development of assessment protocols capable of determining whether aspen is at risk of being lost is crucial to establishing the ecological condition of the ecosystem. Also essential are monitoring protocols that measure whether aspen will remain in a properly functioning condition (PFC) as part of these unique ecological systems.

To understand how aspen can be lost from the landscape, we must first look at: 1) the relationship of aspen to the rest of the habitat's biota; 2) how site variables and natural disturbances affect aspen in space and over time; and 3) how historic and current human use of the landscape may be affecting the ecological viability of aspen. Some researchers and resource managers (Romme and others 2001) believe that human induced factors can increase intensity of environmental stressors on aspen communities and result in aspen loss from the habitat. For example, aspen's apparent dependence on vegetative reproduction makes excessive browsing by wild or domestic ungulates a significant stressor to the viability of aspen regeneration and a potential factor in the loss of aspen. The remainder of this chapter will illustrate how the relationship of aspen to stressors like these can be used to: 1) assess the risk of aspen being lost from the habitat; 2) measure the amount of herbivory; and 3) monitor changes to the ecological condition of an aspen habitat under a given management practice.

# Stand Assessment Methodology

## *Developing Qualitative Assessment Protocols*

Assessment protocols examining the ecological relationships between aspen and stressors on the habitat have become common techniques for identifying the ecological condition of an aspen habitat and for identifying the intensity of risk factors to aspen's survival in that habitat. Elzinga and others (1998) illustrate the value of using ecological models in assessing a plant community, designing management objectives, and developing sampling designs for monitoring.

Many assessments have as their framework the materials presented in this synthesis. They capture the asexual reproductive characteristics of aspen, the interaction of aspen with a range of disturbance factors creating its range of natural variability, and aspen's relationship to human induced variables such as fire suppression and livestock browsing. For example, Mueggler (1989) introduced an assessment model for identifying the risk of aspen loss from the ecosystem (fig. 7-1). Mueggler's model used variables such as the ecological relationship between aspen and conifers, stand age, and browsing intensity to assess aspen condition. Bartos and Campbell (1998) further developed Mueggler's basic model by quantifying risk factors for aspen stands. They surmised that aspen stands were at risk when: 1) conifer cover in the understory and overstory was > 25 percent; 2) aspen canopy cover was < 40 percent; 3) dominant aspen trees were > 100 years old; 4) aspen regeneration < 500 stems per acre; or 5) sagebrush cover was > 10 percent.

Later, Campbell and Bartos (2001) developed a key for prioritizing risk factors for landscapes with aspen (fig. 7-2). The resulting model has been used extensively by resource managers for rapid assessment of the ecological condition of aspen stands (Brown 2001; Burton 2004a; Jones and others 2005b). An example of the use of the Campbell and Bartos model was illustrated in Chapter 5.

A cooperative effort of the Forest Service and the Bureau of Land Management (Aspen Delineation Project 2002) used a qualitative approach to assessing the ecological condition of aspen habitats that was also based on the Campbell and Bartos model. This effort incorporated an additional level of assessment to assist resource managers in evaluating the management implications of existing aspen stand conditions. Burton (2004a) explains that stand structure is the key variable used in this protocol to analyze a stand's ecological condition. The definition of "stand," adopted from the CNPS (California Native Plant Society 2004), calls for separating aspen ecosystems into units that have both compositional and structural similarity. By using this definition of stand, the resource manager can establish not only the presence and condition of aspen age cohorts, but the relationship of those age cohorts to any conifer encroachment, as well as the effects of browsing by wild and domestic ungulates. This delineation presents the resource manager with a clear picture of the ecological condition of the stand and provides an indication of possible restoration efforts.

Other assessment protocols developed in the West have used similar approaches. Jones and others (2005a) used the Bartos and Campbell (1998) risk factors in the Eagle Lake Ranger District, Lassen National Forest (we reviewed these Eagle Lake findings in Chapter 5). A protocol developed for the Bureau of Land Management in Oregon by Otting and Lytjen (2003) used aspen age/size classes similar to those in the Aspen Delineation Project protocol—overstory, recruitment (mid-aged cohorts free from browsing) and understory (vulnerable to browsing). Additionally, the Oregon assessment quantified a protocol for establishing overstory senescence as the percent of overstory trees that are dead or showing signs of decline—that is, trees including many dead limbs, conks, or weeping cankers. In Utah, a protocol developed for the Fishlake National Forest (Brown 2001) assessed stand structure, conifer and aspen dominance or co-dominance, and the presence or absence of regeneration. This protocol looked at the presence of "successful aspen regeneration" rather than the presence or absence of aspen regeneration still within the browse zone. The Fishlake National Forest protocol also used the Campbell and Bartos (2001) prioritized key discussed earlier in this chapter. The common denominator in all these protocols is that they are qualitative assessments.

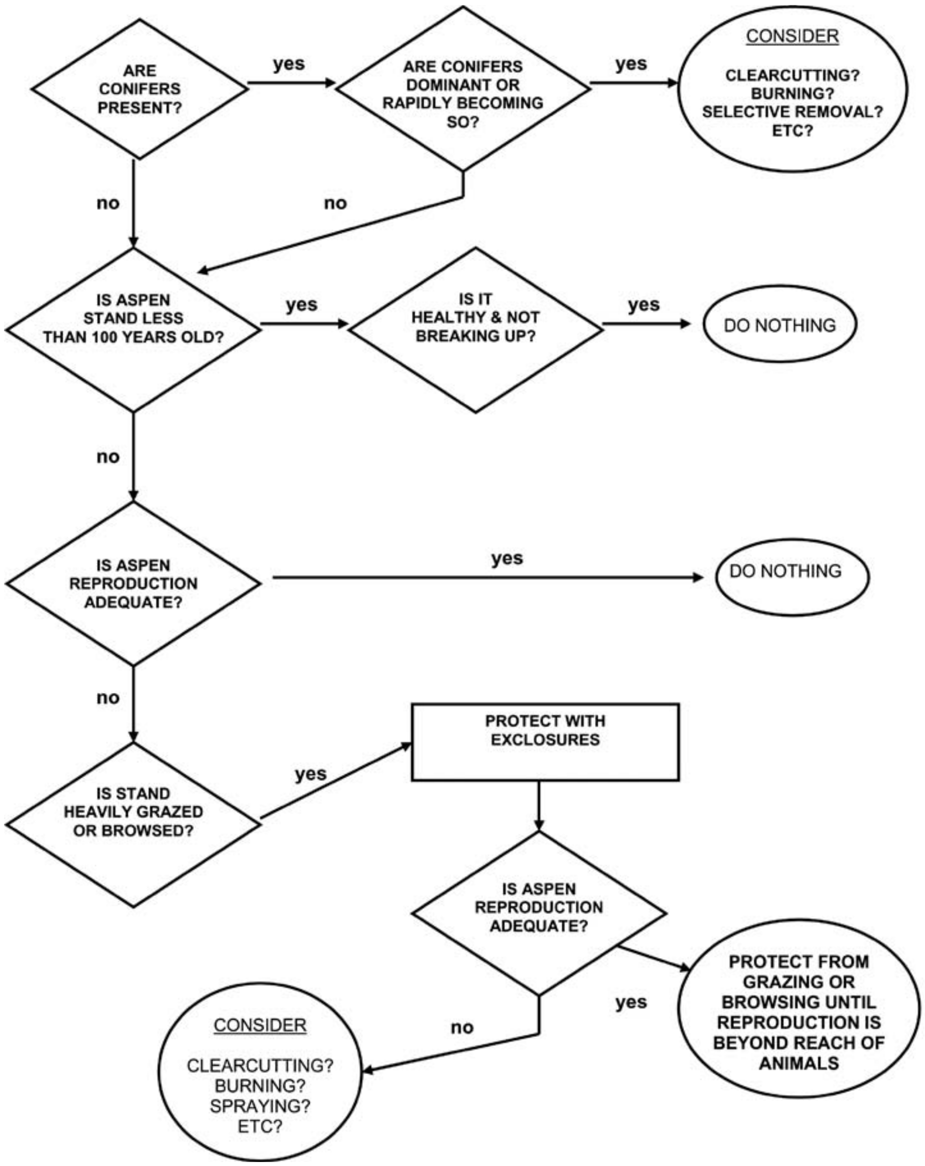



**Figure 7-1.** Assessment model for maintaining aspen stands in the Intermountain Region developed by Walt Mueggler (1989).

## *Photo Points*

Any discussion of qualitative assessments of aspen should include the value of photo points. Whether used with a field conducted assessment or as a stand-alone process, photo points can be particularly effective in documenting seral stage relationships between aspen and conifers in an aspen ecological assessment (Kay 2001b, 2003). In addition to documenting the ecological condition of the stand, photo points can assess the need for implementing treatments to move stands back to an earlier seral stage. For example, figure 6-6a-d illustrates how conifer harvest and biomass removal re-established an aspen-dominated forest. Mechanical harvest was chosen over prescribed fire as a treatment option because only an intense crown fire, difficult to apply, could accomplish the same ecologic effect.

Photo points have an additional value. Repeat photographs taken from specific photo points can be a valuable tool in capturing the changes of aspen condition from the perspective of history or for illustrating whether management objectives are being met (Gruell and Loope 1974; Kay 2001b, 2003). Photo points are also valuable in monitoring aspen conditions into the future (see Implementation monitoring, later in this chapter). However, it is important to geo-reference all photo points when using repeat photographs. Agency publications (Hall 2002) have demonstrated the significance of the repeated photos in general, and published studies using repeated photo points emphasize their

**Figure 7-2.** A key developed by Campbell and Bartos (2001) used to prioritize aspen areas for restoration and conservation. The authors assume in this key that aspen are present with a density of at least 20 mature trees per acre. Note: Option 1 refers to relative cover; options 2 through 5 refer to absolute cover.

| Option number | Decision | Action |
|---|---|---|
| 1 | a. Conifer species comprise at least half of the canopy cover. | Highest Priority |
| | b. Aspen comprises more than half of the total canopy cover. | option 2 |
| 2 | a. Aspen canopy cover is less than 49%; and sagebrush, usually a dominant understory species, exceeds 15% cover. | High Priority |
| | b. Not as above. | option 3 |
| 3 | a. Conifer cover (including overstory and understory) exceeds 25%. | Moderate to High Priority |
| | b. Conifer Cover is less than 25%. | option 4 |
| 4 | a. Aspen regeneration (5 to 15 feet tall) is less than 500 stems/acre. | Moderate Priority |
| | b. Aspen regeneration exceeds 500 stems/acre. | option 5 |
| 5 | a. Any two of the following three risk factors are represented:<br>- Aspen canopy cover is less than 40%.<br>- Dominant aspen trees are greater than 100 years old.<br>- Sagebrush cover exceeds 10%. | Low to Moderate Priority |
| | b. Two of the three risk factors in 5a are not represented. | option 6 |
| 6 | a. One of the three risk factors in 5a is represented. | Low Priority |
| | b. None of the risk factors above are represented. | Candidate for properly functioning condition |

value as it relates to aspen (Gruell and Loope 1974; Kay 2001b).

### *Quantitative Assessment Protocols*

While resource managers may not find the collection of quantitative data necessary or even economically feasible, such data are particularly valuable in providing baseline data for monitoring trends or effectiveness treatments. For example, if the management objective is to establish a new aspen age cohort above browse height, a quantitative assessment of the current condition of aspen suckers within the browse zone could act as the baseline data for management planning (Jones and others 2005b). However, if a manager wants to determine if a new practice is successful in establishing a new aspen age cohort, then a quantitative assessment of the current condition of aspen suckers within the browse zone would act as the baseline data in the effectiveness monitoring process (Kilpatrick and Abendroth 2001). Similar data taken in plots where management practices have been changed, and in plots where the practice has not been changed, can provide the additional element of a control treatment. Since quantitative assessments are so closely linked to effectiveness monitoring, they will be discussed in detail later in this chapter.

## Implementation Monitoring

Federal agencies managing lands in the Sierra Nevada have standards and guidelines limiting browsing to specific percentages of the annual leader growth of mature riparian woody vegetation (USDI BLM 1999a; USDI BLM 1999b; USDA Forest Service 2004c). Resource managers may find it necessary to develop monitoring protocols for determining whether agency standards and guidelines are being achieved. Likewise, directives such as the Forest Service's SNFPA (USDA Forest Service 2004c), which calls for removal of livestock when browsing of woody stemmed vegetation is evident, are helpful when managers or permitees need ways to impartially and repeatedly evaluate this impact.

## *Measuring and Monitoring Plant Populations*

Elzinga and others (1998) state that implementation monitoring, or assessing whether management practices are carried out as designed, is the appropriate technique for monitoring browse intensity. Previously existing protocols were developed to measure woody stemmed shrub vegetation (Keigley and Frisina 1998; USDA Forest Service 2004c). However, it is important to use a protocol that recognizes that aspen is a tree and not a shrub, as terminal leaders of young aspen must be protected so they can grow into trees.

The USDA Forest Service Pacific Southwest Region protocol (USDA Forest Service 2004a) focuses on assessing browse damage to the terminal leaders of young aspen stems. Terminal leader damage is used as the key indicator of browse because the terminal leader needs to remain intact while within the browse zone in order for an aspen tree to have uninterrupted growth (Keigley and Frisina 1998). This protocol also considers that the browse zone height may vary, depending on the species of the animal involved. If the terminal bud is damaged or removed, it takes up to two years for a new primary stem to establish. Jones and others (2005b) use 5 ft (1.5 m) as the level at which the terminal leaders of aspen sprouts are above the reach of sheep, cattle, and deer, while (Shepperd 2004) recommends 7.5 ft (2.3 m) with a dbh of 1.5 inches (4 cm) as an appropriate height and size to avoid elk damage.

Monitoring locations for the Pacific Southwest Region protocol are chosen based on key or "critical areas" used in the interagency technical report titled *Sampling Vegetation Attributes* (USDI BLM 1996). A critical area is defined as an area that must be treated with special consideration because of inherent site factors, size, location, condition, values, or significant potential conflicts among users (Society of Range Management 1998). Because aspen habitats have a unique biodiversity (Dobkin and others 1995; Bartos and Campbell 1998), the protocol adopted by the Pacific Southwest Region recognizes that individual aspen stands shall be referenced as critical areas, or identified as key areas if they reference what is happening in a larger area as a result of on-the-ground management actions. A key area is therefore a representative sample of a larger stratum, which can be defined as a collection of aspen stands, a livestock pasture, a watershed, or an entire grazing allotment. Therefore, management decisions based on implementation monitoring can be applied to the entire stratum that the key area represents.

The Pacific Southwest Region protocol recommends making monitoring sites permanent. This practice is valuable because the power to detect change is often much greater with permanent sampling units, and spatial variability associated with repeated sampling using different plots is removed from analysis (Elzinga and others 1998). The reliability of permanent sampling units depends on the degree of correlation between sampling years. Elzinga and others suggested that the increase in power afforded by using permanent sampling points outweighs the initial increased costs of establishing them on the monitoring site.

The objective of the Pacific Southwest Region protocol is to determine whether a current management practice exceeds the Regional utilization standard of 20 percent for aspen regeneration. The same basic process may be applied to any level of utilization (Personal comm., John Willoughby, California State Botanist, USDI Bureau of Land Management). For this protocol, the objective is to obtain a 95 percent confidence level around a mean value of 20 percent use. It was reported (Burton 2004a) that a sample size of 90 met these objectives. To obtain this number, Burton assumed that the 20 percent use was achieved by sampling aspen suckers up to 5 ft (1.5 m) tall and recording whether or not the terminal leader was browsed. These binomial data (yes/no) allow for calculation of confidence intervals based only on the initial estimate (in this case, 20 percent) and the sample size (Zar 1999). Table 7-1 shows upper and lower 95 percent confidence limits for 20 percent use with different sample sizes. Using a sample size of 90, the lower confidence limit is 0.123 and the upper confidence is 0.298. Thus, lower and upper confidence limits are within 10 percent of the utilization standard (20 percent).

It is important to remember that this protocol will quantify browsing intensity of a particular management practice at a specific time. While this protocol will not indicate to a resource manager whether the current management practice is moving the aspen habitat toward a desired condition (management objective), the utilization measurement, together with range management information (the type and number of animals, length of grazing season, when animals were brought on and removed), may help in the analysis of effectiveness monitoring data.

Keigley and Frisina (1998) developed another method to monitor browse utilization of aspen for the Montana Fish Wildlife and Parks. Similar to Pacific Southwest Region protocol, this method stresses the importance of focusing on utilization on the terminal leader of the primary stem. In addition to measuring the presence or

**Table 7-1.** Upper and lower 95 percent confidence limits for different sample sizes to estimate 20 percent browse utilization of aspen sprouts (Burton 2005).

| Number of sampling units (aspens < 1.5 m) | Lower confidence limit | Upper confidence limit |
|---|---|---|
| 30 | 0.077 | 0.386 |
| 40 | 0.09 | 0.357 |
| 50 | 0.1 | 0.338 |
| 60 | 0.107 | 0.324 |
| 70 | 0.113 | 0.313 |
| 80 | 0.118 | 0.305 |
| *90* | *0.123* | *0.298* |
| 100 | 0.126 | 0.292 |
| 150 | 0.139 | 0.274 |
| 200 | 0.146 | 0.263 |
| 500 | 0.165 | 0.238 |
| 1000 | 0.175 | 0.227 |

absence of browse, the intensity of browse and historic browsing trend of a stem are noted. The Keigley and Frisina technique can be implemented either as a qualitative rapid assessment or as a quantitative assessment. In either case, it is based on the identification of four architectural structures for young aspen stems and their relationship to browsing history. The first growth form, described as "uninterrupted-growth-type," is the tree-like structure produced under light or moderate levels of browsing when the terminal leader is vulnerable to being killed. The second "arrested-type" form is a bush-like structure produced when a plant experiences an intense level of browsing throughout its life. The third, "retrogressed-type," is a bush-like structure and the base of a dead tree structure, produced by a change from a light-to-moderate to an intense level of browsing. The fourth, "released-type" growth form, identifies a tree-like structure growing out of a bush structure and is produced by a change from intense browsing that caused arrested or retrogressed structures, to a light-to-moderate level of browsing.

The quantitative version of the protocol developed by Keigley and Frisina (1998) is also based on these same four growth forms. It is a comprehensive-level survey that assesses browsing history by actually identifying when browsing occurred. Since this protocol can be used to establish current browsing intensity, it is still a utilization protocol, but since it examines stems over time, it can be used for evaluating the history of the stand.

## Effectiveness Monitoring

As reported earlier, multiple agencies have identified the importance of identifying whether current management practices are keeping vegetative communities like aspen within a range of natural variability. Directives such as the SNFPA FSEIS (USDA Forest Service 2004c) call for "an active and focused adaptive management and monitoring strategy" to establish if vegetative community goals are being met. Elzinga and others (1998) diagram an adaptive management cycle. They explain that the effectiveness of any corresponding monitoring lies in the development of management objectives that "set a specific goal for attaining some ecological condition or change value," and the development of sampling objectives to measure the condition or change in value. In other words, know what your objective is before designing a scheme and selecting indicators to monitor it.

Successful regeneration of aspen suckers has often been the management objective of resource managers (Kilpatrick and Abendroth 2001; Jones and others 2005b). Reliable and repeatable methods for measuring regeneration success are needed. For example, a four-year study on the Eagle Lake Ranger District on the Lassen National Forest by Jones and others (2005a) examined the effect of removing conifers from a mixed aspen/conifer stand that was not subject to heavy browsing pressures. They tallied aspen sucker counts into four size classes to measure changes in aspen height in the plots. The size classes used were adapted from those used in research studies reported by Shepperd (2004):

- Size Class I = less than or equal to 1.5 ft (0.46 m)—meant to capture new recruitment of suckers;
- Size Class II = greater than 1.5 ft (0.46 m) to 5 ft (1.5 m)—meant to capture older suckers that are vulnerable to browsing of the terminal leader;
- Size Class III = greater than 5 ft (1.5 m) and up to 1.0 inch (2.5 cm) dbh—meant to capture young

aspen that have grown past the browsing threat to the terminal leader; and

- Size Class IV = greater than 1.0 inch (2.5 cm) dbh—meant to capture information of the size classes of the remaining cohort in the plot.

Using these size classes on permanent plots makes it possible to monitor the growth and establishment of aspen suckers through time as they shift to larger classes, or to identify the need for remedial protection of suckers if they do not grow into larger size classes.

Using these protocols, Jones and others (Aspen Delineation Project 2002) developed a protocol titled Effectiveness Monitoring of Aspen Regeneration on Managed Rangelands for application on Forest Service rangelands in the Pacific Southwest Region. The authors stress the significance of monitoring site selection for aspen. Relative abundance and distribution must be carefully considered during establishment of monitoring plots. This protocol calls for plot sites that are randomly chosen based on the spatial distribution of suckers. It calls for establishing stratified random sampling using existing protocols (USDI BLM 1999a; USDI BLM 1999b) for small or large aspen stands, that have suckers sparsely distributed and/or in small clumps, and for establishing restricted random sampling transects for small or large aspen stands with uniformly distributed suckers.

Another protocol was developed for the Wyoming Game and Fish Department to monitor the effects of prescribed fire and mechanical treatment in aspen stands near elk winter feeding grounds (Kilpatrick and Abendroth 2001). This protocol specified tallying suckers by 1-foot (0.3 m) to 10-foot (3 m) height classes in randomly-placed circular plots. It recommends choosing a plot size based on pretreatment tree density estimates (for example, 1/50th to 1/100th acre (200 to 40 $m^2$) plots for stands with 150 to 250 trees per acre (370 to 617 trees per ha), and 1/100th to 1/500th acre (40 to 8 $m^2$) plots for 4,000 to 15,000 trees per acre (9,880 to 37,050 trees per ha). The study also recommends increasing plot size with increased stand/clone heterogeneity. Larger sample plots will likely be needed to assess regeneration from sparsely-stocked stands because root density and subsequent suckering will be lower in these situations (Shepperd and others 2001).

## Monitoring: Water Quality and Quantity

While there have been monitoring and research studies examining the positive effect of aspen communities on riparian ecosystems (Johnston 1984; Bartos and Campbell 1998), the intense scrutiny by regional regulatory agencies of water quality relating to management activities in riparian ecosystems warrants continued monitoring. Such monitoring can provide managers with the information necessary to adjust management practices in order to obtain desired conditions and address regulatory concerns. Monitoring key stream indicators such as stream flow, stream canopy, stream and air temperature, aquatic macroinvertebrates, pH, dissolved oxygen, electrical conductivity, turbidity, total suspended solids, total N, total P, nitrate, ammonium, phosphate, and potassium will help evaluate the effect of treatments on water resources. Monitoring stations established above, within, and below treatment and control stands can clarify how these variables are affected by management actions. With reliable monitoring data, interested parties will become increasingly more confident in presenting and reviewing future management actions. Currently, an ongoing research study is examining how these variables are affected by conifer removal treatments in aspen stands along short reaches of streams (Tate 2003). Results from this study should provide a foundation for decisions related to aspen management along riparian corridors as well as develop efficient monitoring protocols for successful adaptive management.

Our goal in this chapter was to present an overview of aspen stand assessment and monitoring methodologies that have enabled resource managers to effectively develop, implement, and evaluate aspen management activities. The consistent threads through all of the protocols we have reviewed are attention to measuring the ecological condition of aspen communities, capture of factors changing that ecological condition, and assessment of the degree of change. We believe that these three focuses will be helpful to managers as they design and adjust management activities to benefit aspen in the Sierra Nevada and surrounding areas covered in this report.

# Chapter 8.

# Summary

Our discussion of aspen in this document has centered on its place in the landscapes it occupies. Aspen is considered to be the most widely distributed deciduous tree in North America (Preston 1976). In western landscapes, this tree grows over wide ecological amplitude and is an important component of many ecosystems. Appreciation and concern for aspen in the western U.S. is held by managers and lay people alike. Many believe that aspen is a true keystone species in forested landscapes of the West. This means that the condition and health of aspen is a reflection of ecosystem composition and processes at large.

This effort is the first time since the publication of General Technical Report RM 119 (DeByle and Winokur, 1985) that a comprehensive synthesis of the existing knowledge and literature pertaining to western aspen has been compiled in one document. Because aspen-specific research from the Sierra Nevada is limited, we often used studies produced elsewhere to address this shortcoming. We view this approach as being informative to the Sierra Nevada region, as well as to the greater aspen literature. Although we have emphasized the ecology and management of aspen in the Lake Tahoe Basin, much of what is discussed here can be applied throughout the Sierra Nevada and potentially to other parts of the West.

Our discussion began with a presentation of the physical and natural environment in which aspen is found. We then discussed the setting for the existence of aspen in the Sierra Nevada as well as the climatic influences associated with aspen in this region. The impacts of humans (recent as well as historical) on the aspen system were reviewed in detail, as was the ecology of aspen. We not only included the physiology and genetics of aspen, but discussed its role as a component of the greater terrestrial biota of the Sierra Nevada.

A number of threats and issues related to the health and continued existence of aspen in the Sierra Nevada are discussed. Advancing conifer succession is a major threat to aspen's sustainability in the Sierra Nevada, as is the restricted ability of aspen to vegetatively reproduce via root suckering. Both of these factors are related to the limited presence of aspen in the Sierra Nevada under the modified natural disturbance regimes that exist today. The threat of introducing invasive species into Sierra Nevada ecosystems also must be considered when managing a disturbance-dependent species like aspen. Social values associated with development in the Wildland Urban Interface influence management options available for aspen in these areas, as do the incompatibilities between heavy recreation use and aspen. Consumption of young aspen sprouts by domestic livestock and wild ungulates must also be dealt with to ensure successful establishment of new aspen age classes in the Sierra Nevada and surrounding environs. Water quality and disturbance in riparian zones is another issue that must be considered when planning aspen management activities in these areas.

We describe seven distinctive aspen stand types that occur in the Sierra Nevada and discuss their current ecological status. These types include aspen types that we can expect to succeed to conifer forests within one generation in the absence of disturbance. These would include *meadow fringe aspen, riparian aspen,* and *upland aspen/conifer types*. Other aspen types that lack a conifer component are likely to remain as pure aspen, as existing trees die and are replaced by new suckers. These types include lithic aspen, snowpocket aspen, upland pure aspen, and Krümmholz aspen.

Many management techniques exist that can be used to treat or restore aspen. These include, but are not limited to, cutting, burning, protection from ungulates, severing lateral roots, removal of competing conifers, or various combinations of these techniques. Selection of a treatment alternative depends upon the health and vigor of an aspen stand, its successional status, its susceptibility to browsing, and management objectives for the stand in its particular location. Treatment alternatives that are appropriate for the seven aspen stand types found in the Sierra Nevada are reviewed and discussed. A decision tree was presented that can be used to identify aspen stands in need of management intervention, along with the aspen triangle model identifying key factors affecting aspen establishment. Because aspen is a critical component of rangelands in the Sierra Nevada, a section of the document is devoted to managing aspen on rangelands. Special management considerations related to urban interface areas, recreation activities, and water quality issues are also discussed.

Accurate assessment of the current ecologic condition of aspen in the Sierra Nevada is essential to making sound management decisions. Several protocols that have been used to delineate and assess aspen in the Sierra Nevada and surrounding areas are reviewed. Likewise, future changes in aspen condition and the effectiveness of any aspen management activities need to be monitored. Any treatment (including the no-treatment alternative) should be documented and tracked to determine its relative success and to guide the adaptive management process. Monitoring techniques that range from the most simplistic (photo points), to the more complicated, are given. In the recent past, considerable effort has been made to monitor aspen in the Sierra Nevada and elsewhere in the West. The knowledge we have gained from these efforts is shared with the reader.

A wealth of knowledge and experience about aspen has been presented in this document. This information should be beneficial to those individuals anywhere who are concerned about aspen, or are responsible for planning, implementing, and monitoring aspen management activities. While we focused this document on the Sierra Nevada and surrounding areas, the information synthesized here should be applicable to other areas of the western United States as well.

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# Appendix I.

## Questions and Responses Related to Region 5 Management Team Concerning Interpretation of Sierra Nevada Forest Plan Amendment Decision Notice (2004a)

Wayne D

Shepperd/RMRS/USD

To

Michael Landram/R5/USDAFS@FSNOTES

03/22/2005 04:37 PM

Subject

Aspen Questions

Mike:

It was good to visit with you this afternoon. The memo with our SNFP aspen questions is attached.

Wayne D. Shepperd, Ph.D.
Research Silviculturist
Rocky Mountain Research Station
970-498-1259
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(See attached file: AspenQuestions-Ltr.doc)
(Attached file: AspenQuestions-Ltr.doc)

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| **United States Department of Agriculture** | **Forest Service** | **Rocky Mountain Research Station** | **240 West Prospect Fort Collins, CO 80526-2098** |

**File Code:** 4000 **Date:** March 22, 2005

**Route To:**

**Subject:** Aspen Questions Pertaining to Sierra Nevada Forest Plan Amendment Record of Decision

**To:** Mike Landram, R5

As you know, The Rocky Mountain Research Station has been funded by the Tahoe Basin Management Unit to produce a synthesis publication entitled "Ecology and Management of Aspen in Sierra Nevada with Emphasis on the Lake Tahoe Basin." We have identified several topic areas where we would like to request clarification on management policy. Specifically, we would like interpretations of some guidelines covered in the January, 2004 Sierra Nevada Forest Plan Amendment Record of Decision. so we might formulate aspen management alternatives that are consistent with the Record of Decision. If possible, we would like to receive written responses to the following five questions in the form of a signed memo or other document that we might cite in our publication.

1. The Sierra Nevada Forest Plan Amendment, Final Supplemental Environmental Impact Statement, Appendix A, p. 361 (A. Management of Uses Other Than Fire Hazard Reduction) states: "Standards and guidelines for crown closure and tree diameter apply only to thinning and regeneration harvest. Exceptions to the vegetation management standards and guidelines include responding to past infestation outbreaks and restoration activities, such as aspen regeneration, hardwood regeneration, sugar pine management, sequoia regeneration." Does this statement still apply, and if so, under what conditions outlined in the Record of Decision? Are we correct in interpreting this to mean that the standard of retaining all live conifers 30" dbh or larger in mechanical thinning treatments (Record of Decision, Appendix A. p. 50, #6) does not apply when restoration of aspen is ecologically justified?

2. Guideline #105 for RCO#2 (ROD, Appendix A, p. 64) specifies: "If conditions are outside the range of natural variability, consider implementing mitigation and/or restoration actions that will result in an upward trend. Actions could include restoration of aspen or other riparian vegetation where other conifer encroachment is identified as a problem." Does the exception to the general forest requirements (SNFPA, FSEIS Appendix A, p. 361) apply in aspen restoration in riparian corridors? Or, do diameter limits on conifer removals still apply? Similarly, may prescribed burning techniques other than backing fires be used to restore aspen in riparian corridors (SNFPA, FSEIS Appendix A, p. 344)? Our concern is that a backing fire might have a longer residency time than a head fire and may damage aspen lateral roots under heavier fuel loadings.

3. Can mechanical activities to restore aspen occur within the 500 ft. radius buffer surrounding Spotted Owl and Goshawk PAC's specified in Guideline #73 (ROD Appendix A, p. 60) provided such activities maintain desired conditions (p. 38) within the overall buffer? Aspen stands are generally small and rare in many Sierra Nevada landscapes and would normally comprise only a small portion of a PAC or buffer area. Retaining viable aspen within these zones may provide a valuable component of the habitat. However, doing so may require removal of competing conifers that could not be killed by prescribed burning.

4. SNFPA, FSEIS Appendix A, p. 345 states: “Strategies should recognize the role of fire in ecosystem function and identify those instances where fire suppression or fuel management actions could be damaging to habitat or long-term function of the riparian community.” Is it therefore proper to advise that (1) wildfires be allowed to burn through aspen stands located in riparian corridors and (2) prescribed burning can be used to ecologically restore aspen communities in riparian corridors?

5. Since the goals of aspen (a hardwood) restoration are synonymous with the desired goals for Lower Westside Hardwood Ecosystems (ROD Appendix A, p. 35-36), could the Standards and Guidelines for Hardwood Management (ROD, Appendix A, p. 53, #18, 19, 22, 24, 25, and 26) apply also to aspen?

Please let me know if you would like additional clarification, or would like to discuss these questions further. I look forward to your response.

/s/

WAYNE D. SHEPPERD, Ph.D.
Research Silviculturist
Rocky Mountain Research Station

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Michael Landram/R5/USDAFS

To

Tom Efird/R5/USDAFS@FSNOTES

03/22/2005 05:27 PM

cc

Stephen Bishop/R5/USDAFS@FSNOTES

Subject

Fw: Aspen Questions

Tom—This is formal request for interpretation of SNFP from The Rocky Mountain Research Station, funded by the Tahoe Basin Management Unit to produce a synthesis publication entitled “Ecology and Management of Aspen in Sierra Nevada with Emphasis on the Lake Tahoe Basin.”

They need a written response which will affect the kinds of alternative treatments considered and described in their work.

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----- Forwarded by Michael Landram/R5/USDAFS on 03/22/2005 05:01 PM -----

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04/13/2005 01:52 PMTo

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cc

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bcc

Subject

Re: Fw: Aspen Questions

Wayne, here are the responses to your questions. Please call if my response is not clear or you need further explanation.

(See attached file: Response to Wayne Shepperd.doc)

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(file: Response to Wayne Shepperd.doc)

**Questions related to Sierra Nevada Framework and Aspen Management**

1. The Sierra Nevada Forest Plan Amendment (SNFPA), Final Supplemental Environmental Impact Statement (FSEIS), Appendix A, p. 361 (A. Management of uses other than fire hazard reduction) states: "Standards and guidelines for crown closure and tree diameter apply only to thinning and regeneration harvest. Exceptions to the vegetation management standards and guidelines include responding to pest infestation outbreaks and restoration activities, such as aspen regeneration, hardwood regeneration, sugar pine management, Sequoia regeneration." Does this statement still apply, and if so, under what conditions outlined in the Record of Decision (ROD)? Are we correct in interpreting this to mean that the standard of retaining all live conifers 30" or larger in mechanical thinning treatments (Record of Decision, Appendix A. p. 50, #6) does not apply when restoration of aspen is ecologically justified?

**Response:**

Yes, the statement still applies. The Record of Decision, Appendix A. page 51, #9 states "Standards and guidelines #6, 7, and 9 above apply only to mechanical thinning harvests specifically designed to meet objectives for treating fuels and/or controlling stand densities." This statement was intended to provide clear direction that activities, such as aspen management, are not subject to harvested tree size, basal area retention and/or residual canopy closure limitations that apply to fuel and/or density reduction treatments.

2. Guideline #105 for RCO #2 (ROD, Appendix A, p. 64) specifies: "If conditions are outside the range of natural variability, consider implementing mitigation and/or restoration actions that will result in an upward trend. Actions could include restoration of aspen or other riparian vegetation where other conifer encroachment is identified as a problem." Does the exception to the general forest requirements (SNFPA, FSEIS Appendix A, p. 361) apply in aspen restoration in riparian corridors? Or, do diameter limits on conifer removals still apply? Similarly, may prescribed burning techniques other than backing fires be used to restore aspen in riparian corridors (SNFPA, FSEIS Appendix A, p. 344)? Our concern is that a backing fire may damage aspen lateral roots under heavier fuel loadings.

**Response:**

In the ROD, page 3, it states, "All of the management direction for this decision is included in this document (Appendix A). The SEIS represents an analysis and planning document and does not provide management direction." So yes, as described above, Appendix A. page 51, #9, provides the direction to exclude non-fuel and/or density reduction management actions, such as aspen restoration, from harvested tree size, basal area retention and/or residual canopy closure limitations. Standards and Guidelines for Riparian Conservation Areas (RCAs) and Critical Aquatic Refuges (CARs) # 91 thru #124 apply to all projects within these designated areas. With regard to prescribed fire techniques, Appendix A does not restrict choices. A site-specific analysis and biological evaluation would be required to assess the consequences of proposed restoration treatments within RCAs and CARs.

3. Can mechanical activities to restore aspen occur within the 500 ft. radius buffer surrounding Spotted Owl and Goshawk PACs specified in Guideline #73 (ROD Appendix A, p. 60) provided such activities maintain desired conditions (p. 38) within the overall buffer? Aspen stands are generally small and rare in many Sierra Nevada landscapes and would normally comprise only a small portion of a PAC or buffer area. Retaining viable aspen within these zones may provide a valuable component of the habitat. However, doing so may require removal of competing conifers that could not be killed by prescribed burning.

**Response:**

No. Mechanical treatments (Including: pre-commercial thinning, biomass thinning, commercial thinning, salvage harvesting, group selection, piling, crushing, and mastication) are prohibited in California spotted owl and Northern Goshawk activity centers (500 foot buffer around the nest site) within the approximately 300 acre Protected Activity Center (PAC). ROD Standard and Guideline # 73. California spotted owl and Northern Goshawk PAC land allocations have the objective to "avoid vegetation and fuels management activities within PACs to the greatest extent possible." Table 1 ROD page 45. Mechanical treatments for project objectives other than hazardous fuels reduction within the PAC are not addressed in the ROD. A site-specific analysis and biological evaluation would be required to assess the consequences of proposed restoration treatments within PACs. Based on the site-specific analysis and biological evaluation a non-significant forest plan amendment may be prepared.

4. SNFPA, FSEIS Appendix A, p. 345 states: "Strategies should recognize the role of fire in ecosystem function and identify those instances where fire suppression or fuel management actions could be damaging to habitat or long-term function of the riparian community." Is it therefore proper to advise that (1) wildfires be allowed to burn through aspen stands located in riparian corridors and (2) prescribed burning can be used to ecologically restore aspen communities in riparian corridors?

    **Response:**

    Referring to the associated objective statement, which calls for enhancing or maintaining the physical and biological characteristics with riparian-dependant species, both advice statements would be appropriate considerations during wildland fire decision-making.

5. Since the goals of aspen (a hardwood) restoration are synonymous with the desired goals for Lower Westside Hardwood Ecosystems (ROD Appendix A, p. 35-36), could the Standards and Guidelines for Hardwood Management (ROD, Appendix A, p. 53, #18, 19, 22, 24, 25, and 26) apply also to aspen?

    **Response:**

    The ROD does not include aspen communities within the definition of the Lower Westside Hardwood Ecosystem, which is comprised of the montane hardwood forest and blue oak woodland vegetation communities. FEIS Volume 1, Chapter 2—page 17. However, site-specific analysis of aspen restoration projects can consider including these, or other, standards and guidelines.

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