To: Matthew Betenson[mbetenso@blm.gov]
From: Backer, Dana
Sent: 2017-07-24T14:23:35-04:00
Importance: Normal
Subject: Fwd: Western Watersheds Project science permit application
Received: 2017-07-24T14:24:02-04:00
Pinyon and Juniper Field Guide - rmrs_2009_tausch_r001.pdf
Purpose of Research.docx
UT-17-030-05-B_WWP_Ratner_corePJ_permit laf.docx
Grow.pdf

Matt,
The proposal is much improved and could contribute some valuable information. Based on my limited knowledge, I would think some soil characterization would need to be done to to determine the correct ecological site. Since this is information we ultimately want, what do you think of doing it collaboratively. Not sure how that would work but something to give some thought to.

The previous application was looked at by Matt Z and Allan B. Do you think it needs to be looked at again by them or others?

We can discuss today or Friday. Whenever works best for you.

Dana

Dana Backer
Science Program Administrator
Grand Staircase Escalante National Monument
Kanab, UT 84741
435-644-1257

---------- Forwarded message ----------
From: **Laura Welp** <laura@westernwatersheds.org>
Date: Mon, Jul 24, 2017 at 10:21 AM
Subject: Western Watersheds Project science permit application
To: dbacker@blm.gov
Cc: "Betenson, Matthew J" <mbetenso@blm.gov>, Jonathan Ratner <jonathan@westernwatersheds.org>

Dear Dana,
Attached is Western Watersheds Project's Purpose of Project statement for our science permit application. We trust that this will be adequate for you to issue our permit as soon as possible. I've also included some relevant references for background information.

Sincerely,

Laura Welp

Ecosystems Specialist, Northern Arizona/Southern Utah
Western Watersheds Project
1117 W Grand Canyon Drive
Kanab, UT 84741
480-271-0349
laura@westernwatersheds.org

Scientific Research and Collection Permit
Grand Staircase-Escalante National Monument

Applicant Names: Jonathan Ratner and Tristan Meek, WWP **Application Date:** 5/8/17
Address: PO Box 171, Bondurant, WY 82922

State Permit Number (if applicable): **Federal Permit Number (if applicable):**

1. **Is the research covered by an assistance agreement with this office and/or other BLM offices? If yes provide the number.** N/A

2. **Description of research. Include as an attachment**

3. **Contact information**
   Phone: 877-746-3628 **Cell:** **E-mail: Wyoming @WesternWatersheds.org**

4. **If collecting is authorized. Materials to be collected**:

Each tree core is 5mm in diameter and around 8” long. The cores will be mounted and sanded for interpretation.

For GSENM office use only below this line.

GSENM Number: UT-17-030-05-B

Issue Date: **Expiration Date:** December 31, 2017

5. **Specialist review complete?** ☒**Yes** ☐ **No**
   Zweifel, Bates, Betenson
6. **Complies w/ MMP?** ☒ **Yes** ☐ **No**
7. **In WSA status?** ☐ **Yes** ☒ **No**
8. **Special Stipulations? A**ttach additional stipulations ☐ **Yes** ☒ **No**
9. **Curation agreement?** ☐ **Yes** ☒**No**
   Attach
10. **Permit granted?** ☐ **Yes** ☐**No**
11. **Permit extension?** ☐ **Yes** ☒**No**

Authorization. Permission is hereby given to the above named individual to collect material(s) specified in the approved research proposal, within the guidelines of permit stipulations outlined below.

By:
Cynthia Staszak Date
Monument Manager

I have read and agree to the stipulations of this permit.

By:
Science Permittee Name Date

Red polygons are the sample units with randomly generated numbered points for tree coring.
Pink polygons are Pinyon-Juniper Historic Climax Plant Community Ecological Site Description.
Yellow polygons are Sagebrush Historic Climax Plant Community Ecological Site Description.

STANDARD RESEARCH PERMIT STIPULATIONS

We ask that you follow all **Leave No Trace Principles** (https://lnt.org) and the following.

1. This permit may not be assigned to any other institution, group, or individual. Any modifications to the permit must be requested in writing to the Science Program Administrator.

2. This permit is valid only for the period specified. The permit may be suspended or modified at the discretion of the Monument Manager. Field work under this permit may be halted temporarily by either verbal or written notice from the Monument Manager or other Authorized Officer for violations of permit terms and conditions or for administrative purposes of the BLM.

3. All terms and conditions of this permit shall remain in effect, including reporting requirements, until all permit terms and conditions have been met, regardless of permit expiration date.

4. A copy of this permit must be carried by the individual in direct charge of field work during the course of all work conducted under permit.

5. This permit shall not be exclusive in character, and the Bureau of Land Management reserves the right to authorize other uses of the land during the tenure of this permit. Field work shall be carried out in such a manner as to not impede other legitimate uses of the Monument, except when a provision has been made by the Monument Manager or delegated representative.

6. The Department of Interior, including its bureaus and employees, shall be held blameless for any and all events, deeds, or mishaps, regardless of whether or not they arise from operations under this permit.

7. Field schedule must be coordinated with the Science Program Administrator or a designated representative in advance of field work.

8. The Monument Manager, and /or designated representatives shall have access to the study area during or after performance of field work, and shall have the right to inspect all materials removed.

9. Any stakes, flagging, or other temporary materials used to identify localities in the field shall be removed upon completion of field activity. No permanent survey monuments or markers shall be disturbed or removed during the course of field work

10. Unless otherwise agreed, all costs shall be borne by the permittee, including costs of curation.

11. Interpreting and sharing the science conducted on GSENM with staff, volunteers and the public, is critical. There shall be a public outreach component for each research project. Recommendations or opportunities for public presentations, a field trip, or the something similar shall be coordinated with the Science Program Administrator.

12. Collections, if authorized, of materials acquired from public lands under the provisions of this permit remain the property of the United States Government and may be recalled at any time for use by the BLM. A designated repository for this project is not necessary. Any recall or transfer of material will be coordinated by BLM with the designated repository. Public display of material collected under this permit shall cite Grand Staircase-Escalante National Monument, Bureau of Land Management, Utah.

13. Grand Staircase-Escalante National Monument, and the BLM, Utah shall be cited in any report, publication, paper, news article, film, television program or other media, resulting from field work under

this permit. Copies of such documents shall be provided to the Grand Staircase-Escalante National Monument Headquarters. To assist in producing the best possible science, you are encouraged to forward manuscripts for review to the Science Program Administrator prior to submitting them for publication.

14. Access to research site(s) is authorized only across BLM administered lands. Use of private lands or lands administered by another agency must be secured separately.

15. A report of all activities conducted under this permit shall be prepared by December 31 of each year during the tenure of the permit. This report will be submitted to the Monument Headquarters, in care of the Science Program Administrator. The report shall include a catalog of all specimens collected, if authorized, a description of work accomplished, results, copies of datasets (with FGDC compliant metadata for final reports) and any recommendations for future research or management activities.

16. For any collections that will be curated, a list of all specimens collected must be provided in the annual report to the Science Program Administrator. Each specimen must contain the following information: scientific name, description, collection location (latitude / longitude or UTM Zone 12, NAD83), collection number, and facility's accession number. Provide the curation facility, address, and a point of contact at the facility.

17. Pursuant to the Native American Graves Protection and Repatriation Regulations at 43 CFR 10.4, the permittee shall notify the Science Program Administrator or Monument Manager immediately upon the inadvertent discovery of human remains, funerary objects, sacred objects, or objects of cultural patrimony, with written confirmation. All work in the vicinity must and reasonable efforts shall be made to protect the remains pending BLM action. Activities may resume within 30 days of receipt of the written confirmation of notification unless the situation is resolved sooner.

18**.** Commercially provided services such as transportation, cooking and packing must be sought from outfitters authorized by the Monument. For a current list of outfitters, please contact Science Program Administrator at 435-644-1257 or dbacker@blm.gov.

19. Please be aware of current hunting activities and locations by visiting www.wildlfe.ut.gov.

Camping
1. Overnight camping in the Monument requires a permit. Currently, permits are free of charge and may be obtained at Visitor Centers or at designated trailheads Camping restrictions described in the GSENM Management Plan, p. 35, must be followed. The GSENM Management Plan is available on line https://www.blm.gov/nlcs_web/sites/style/medialib/blm/ut/grand_staircase-escalante/planning/monument_management.Par.83655.File.dat/GSENM%20Management%20Plan.pdf

2. No camping within 300 feet of an isolated water source (i.e., seep, spring, pond, rock pool, water pocket).

3. Permittee will maintain all premises to standards of repair, orderliness, neatness, and sanitation acceptable to the Monument. Camp areas will be regularly cleaned and no trash or litter will be allowed to accumulate.

Fire
1. Campfires are not allowed in the Escalante and Paria/Hackberry Canyons, No Mans Mesa, nor in archaeological sites, rock shelters and alcoves throughout the Monument.

2. In the Front country and Passage Zones, campfires are allowed only in designated fire grates,

designated fire pits, or mandatory fire pans. Wood collection for campfires is not allowed. Burn all wood and coals to ash, put out campfires completely; leave cool ashes.

3. In the Outback and Primitive Zones campfires are allowed. Use an existing fire ring instead of building a new one. The use of fire pans is encouraged. Only dead and down wood can be collected. Burn all wood and coals to ash, put out campfires completely, scatter cool ashes, and restore the area to a natural condition before leaving.

Group Size Limits
1. Group size is limited to 25 people in the Passage and Outback Zones including guides.

2. Group size within the Primitive Zone is limited to 12 people and 12 pack animals including guides, however within the Paria River corridor in the Primitive Zone group size is limited to 25 people including guides.

3. Group size limits cannot be achieved by staggering individual groups along a single route by time or distance. Instead, individual groups must comply with group size limits by utilizing separate and unique routes, or by traveling from opposite ends of a single route. If traveling from opposite ends of a single route, groups may pass each other, however they cannot gather at a single location.

Wilderness Study Areas
1. Permittee is responsible for knowing the location of wilderness and wilderness study areas (WSA) comply with the restrictions that apply to such areas. Maps and information concerning restrictions are available at the Monument website

Transportation and Access
1. All machinery (street legal motorized vehicles, non-street legal all-terrain vehicles, dirt bikes etc.) that has been used outside the Monument must be cleaned prior to use in the Monument, to prevent the possible introduction and spread of noxious weeds.

2. Motorized or mechanized vehicles may pull off designated routes no more than 50 feet for direct access to dispersed camping areas in the Outback Zone, except in Wilderness Study Areas, endangered plant areas, relict plant areas and riparian areas.

3. Access onto the Monument will be along defined roads listed on the transportation map in the Grand Staircase- Escalante National Monument Management Plan.

4. Cross-country motorized travel on the Monument is prohibited. All motorized and mechanized (bicycles, deer carts) vehicles must stay on designated roads while traveling in the Monument.

5. Permittee shall not construct new trails, or maintain existing trails without written authorization from the Monument.

6. The permittee shall not use paint or flagging, or construct cairns to mark trails, unless specifically allowed by this permit.

Sanitation and Aesthetics
1. Burning and burying food waste are prohibited.

2. Utilize a portable self-contained toilet system when less than 300 feet from water sources, campsites, and trails. All human waste must be packed out and disposed of at a certified disposal site.

3. If a small portable toilet cannot be used, deposit solid human waste in catholes dug 4 to 6 inches deep at least 300 feet from water sources, camp, and trails. Cover and disguise the cathole when finished. Never dig a cathole under an overhang or shelter.

4. If camping in one location for multiple days, a trench may be dug to dispose of human waste. To dig a trench, start with a cathole dug 4 to 6 inches deep and expand it in one direction as additional people use it; soil dug from the trench should be used to cover the feces.

5. To wash yourself or your dishes, carry water 300 feet away from water sources and use small amounts of biodegradable soap. Scatter strained dishwater and pack out remaining food particles.

Supplemental Stipulations for Permittees using Riding or Pack Animals

1. Horses or other pack animals are not allowed in relict plant communities, archaeological sites, rock shelters, or alcoves. Sheep species will not be allowed for pack use.

2. Weed free hay, straw and non-germinable grains may be used to feed and bed livestock, or be placed in the bottom of stock carrying vehicles.


600 GLENDALE BENCH
601 CUTLER PT
500 SKUTUMPAH RD
SKUTUMPAH TERRACE
550 TIMBER MOUNTAIN
555 NEPHI PASTURE RD
556 NEPHI PASTURE
557 JOHNSON LAKES CANYON
SLIDE CANYON
RED BREAKS
551 RED BREAKS
502 FIRST PT
FIRST PT
501 JOHNSON CANYON
501 JOHNSON CANYON RD
LONE PINE PT
COTTONWOOD CANYON / MONTEZUMAS
MONTEZUMA MINE
TIMBER MOUNTAIN
LONG CANYON NORTH
LOCKE RIDGE SPUR

Attachment 1: Coring of pinyon and juniper trees in the Skutumpah Terrace treatment area

Purpose –One of the justifications for the Skutumpah Terrace vegetation treatment is that the area comprises sagebrush communities that have recently (within 100-135 years) been overtaken by pinyon and juniper trees as a result of recent large-scale human activities (e.g., fire suppression, grazing, and climate change). The BLM would like to remove these trees and restore the original sagebrush communities. Moreover, the project proposes to treat trees in other areas on the terrace to create more "opportunity habitat" for Greater Sage-grouse. To best accomplish this, however, more detailed information on ecological site descriptions within the project area is necessary to determine which sites are at their ecological potential and which are not. We propose to collect data on pinyon and juniper tree ages and plant communities in the proposed Skutumpah Terrace treatment area. This information can be used to ground-truth ecological site descriptions and provide a more fine-grained picture of the vegetation communities within the project area.

The success of the Skutumpah treatment will be enhanced if tree removal is only conducted on sites with a sagebrush community potential. Past treatments indicate that trying to convert ecosites from one vegetation community to another has a high rate of failure. Therefore, pinpointing those places that are at pinyon- juniper potential versus those places that are sagebrush ecosites that have been recently colonized by trees would lead to a better treatment plan. In addition, the Monument's draft science plan highlights the need for information on "…understanding the historic and current disturbance regimes, the driving mechanisms, and the variability in types of PJ communities: persistent woodland, wooded shrubland and savanna." The data WWP gathers will add to that body of knowledge on the Monument.

Project Hypothesis – The hypothesis rests on the idea that some, if not most, of the pinyon and juniper communities in the area may actually be at ecological site potential as defined by soil series descriptions. Preliminary tree ring cores show ages over 150-200 years old, and some may be as much as 800 years old (Grow 2002). This suggests that not all the trees in the treatment area constitute recent invasions of shrub communities. The Monument's 2004 soil survey is not intensive enough to use in the project area, which contains a high degree of topograpical and soil variability. This variation contributes to an abundance of interdigitation between soil map units, and the map does not always distinguish between pinyon-juniper and sagebrush ecosites. In addition, ecosite boundaries are complicated by the fact that there are so many transitional zones in the project area. Our project looks more closely at plant communities and tree ages to see if the vegetation on the ground matches the Historic Climatic Plant Community (HCPC) that is expected according to the Monument's soil map.

Methods/scope of work - Methods are adapted from Tausch et al. 2009, " Piñon and Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions." 150 random points will be generated within the proposed treatment area. At each point, a tree core will be taken from the largest tree within 30 meters (100') of the point. This randomizes the tree sizes and ages in the total sample. Then we will run a transect in a north-south orientation from the cored tree. The circumferences of ten trees along the transect will be collected and correlated with the age and circumference of the cored tree to estimate their ages as well. In addition, researchers will conduct ocular assessments of the number of grass and sagebrush plants per square meter. Invasive plant cover will also be documented to provide information on the risk of the spread of exotics from treatment ground disturbance. Information on slope and aspect will be recorded to determine if topography influences vegetation communities.

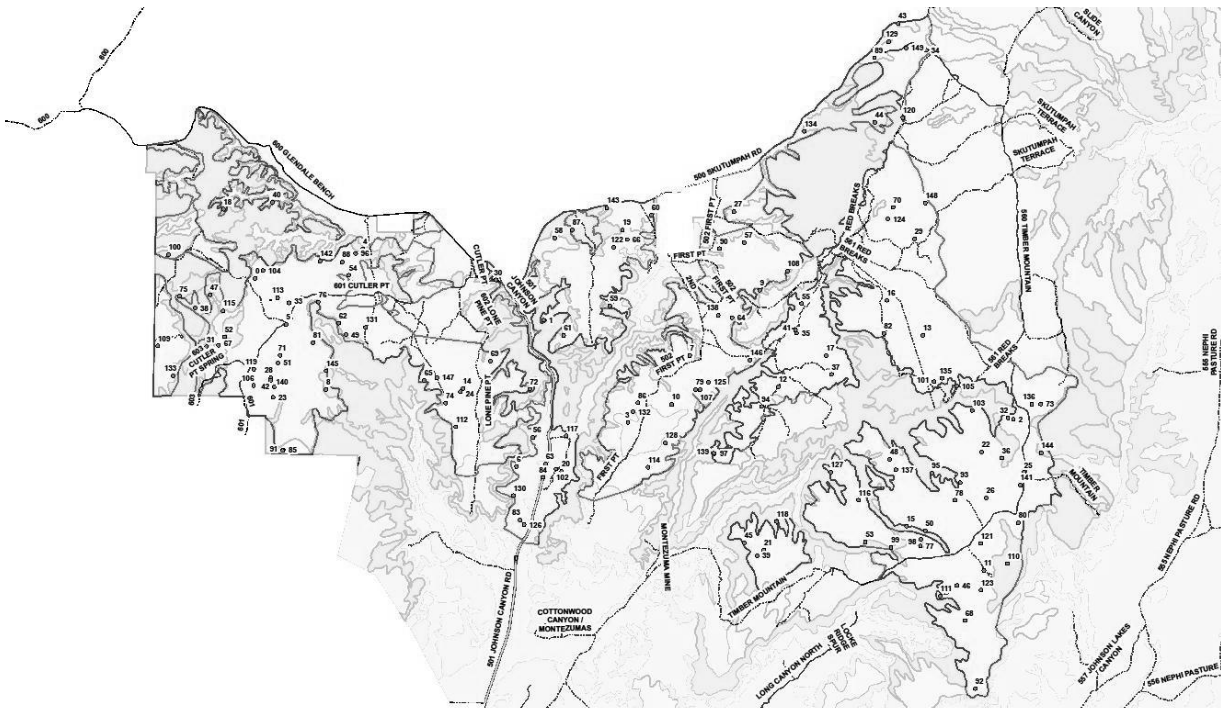
Area of activity: see map below.

Collection dates: July and August 2017

Vehicle identification: WY 23-4599 and UT W224SL

Request for administrative road use: GAGR; 285; 108; 378; 799; 772; 596; 792; 783; 214; 597; 968

Deliverables:

- Raw data tables of ten tree ages at 150 points within the Skutumpah treatment area, with estimates of the number of grass and shrub plants in the sampled area. A species inventory will be conducted, and the presence of exotic species will be noted.
- Report of results including GIS map showing ages of trees.
- Presentation of results to public in conjunction with GSE Partners group as part of public outreach and information dissemination.
- Preparation of results for publication.
- 

- Red polygons are the sample units with randomly generated numbered points for tree coring.
- Pink polygons are Pinyon-Juniper Historic Climax Plant Community Ecological Site Description.
- Yellow polygons are Sagebrush Historic Climax Plant Community Ecological Site Description

Citations:

Grow, D. 2002. Effects of substrate on dendrochronologic streamflow reconstruction: Paria River, Utah with fractal application to dendrochronology. Ph.D dissertation, University of Arizona, Tucson. http://hdl.handle.net/10150/191258

Tausch, R.J., Miller, R.F., Roundy, B.A., and Chambers, J.C., 2009, Piñon and juniper field guide: Asking the right questions to select appropriate management actions: U.S. Geological Survey Circular 1335, 96 p.


600 GLENDALE BENCH
500 SKUTUMPAH RD
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LONE PINE PT
FIRST PT
RED BREAKS
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SKUTUMPAH TERRACE
SLIDE CANYON
560 TIMBER MOUNTAIN
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TIMBER MOUNTAIN
MONTEZUMA MINE
591 JOHNSON CANYON RD
COTTONWOOD CANYON / MONTEZUMAS
LONG CANYON NORTH
LOCKE RIDGE SPUR
557 JOHNSON LAKES CANYON
556 NEPHI PASTURE

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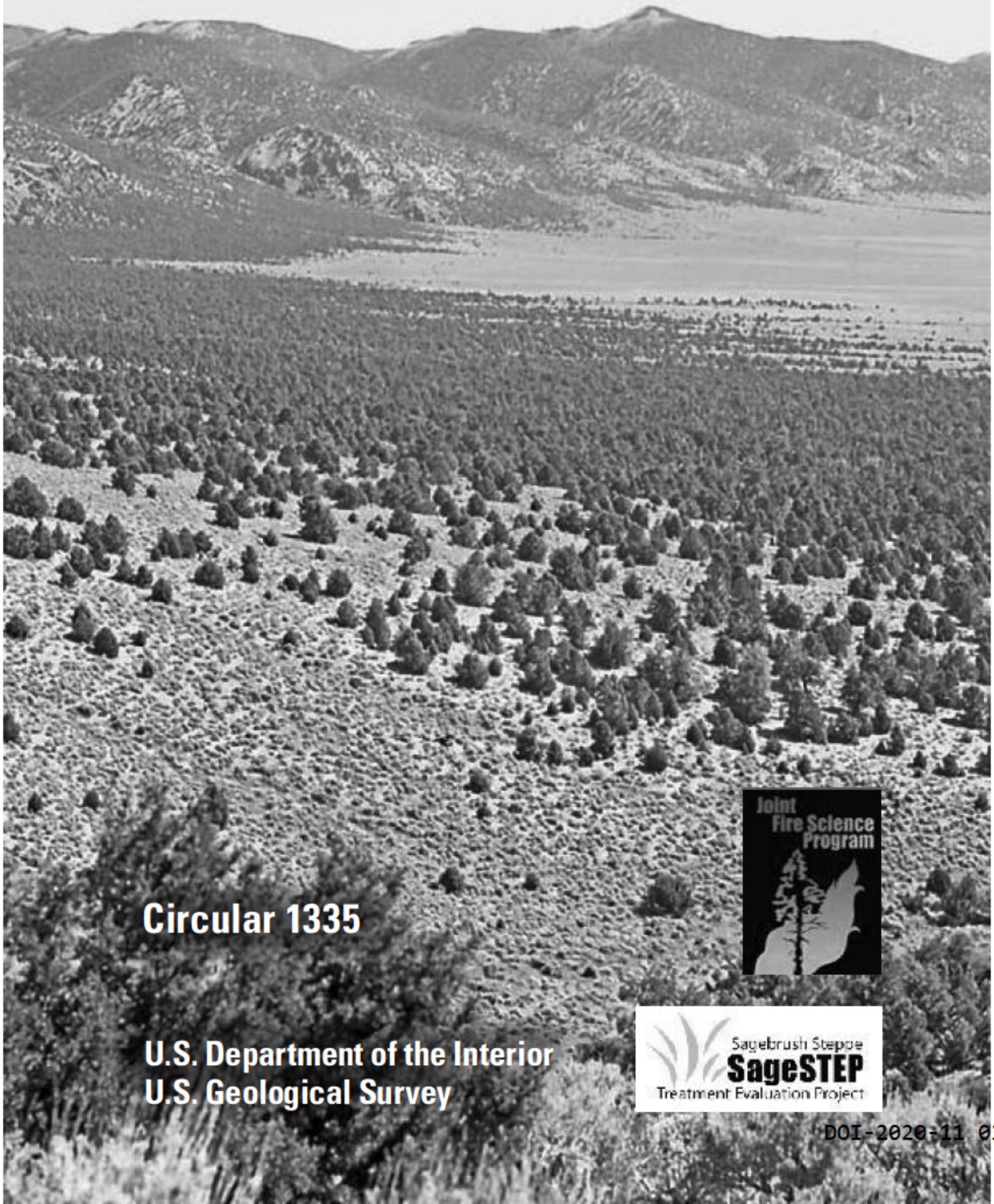
Piñon and Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions



Circular 1335

Joint Fire Science Program

U.S. Department of the Interior
U.S. Geological Survey

Sagebrush Steppe
SageSTEP
Treatment Evaluation Project

Photograph taken by Robin Tausch

Piñon and Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions

By R.J. Tausch, U.S. Forest Service Rocky Mountain Research Station, R.F. Miller, Oregon State University, B.A. Roundy, Brigham Young University, and J.C. Chambers, U.S. Forest Service Rocky Mountain Research Station

This is contribution number 02 of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP), supported by funds from the U.S. Joint Fire Science Program. Partial support for this guide was provided by the U.S. Geological Survey Forest and Rangeland Ecosystem Science Center.

Circular 1335

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

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Suggested citation:
Tausch, R.J., Miller, R.F., Roundy, B.A., and Chambers, J.C., 2009, Piñon and juniper field guide: Asking the right questions to select appropriate management actions: U.S. Geological Survey Circular 1335, 96 p.

Edited and Designed by: Summer C. Olsen and Elizabeth A. Didier, Outreach Program Coordinators, Utah State University, Logan, Utah State University

All photographs in this guide were taken by Richard Miller and Robin Tausch unless otherwise noted.

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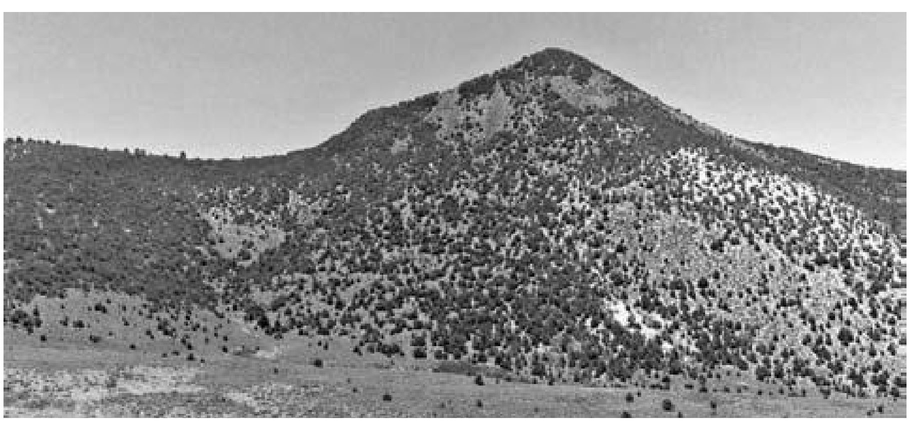
Keys

Introduction

Piñon-juniper woodlands are an important vegetation type in the Great Basin. Old-growth and open shrub savanna woodlands have been present over much of the last several hundred years. Strong evidence indicates these woodlands have experienced significant tree infilling and major expansion in their distribution since the late 1800s by encroaching into surrounding landscapes once dominated by shrubs and herbaceous vegetation (fig. 1). Both infilling and expansion affects soil resources, plant community structure and composition, water and nutrient cycles,

(a)



(b)

Figure 1. Piñon and juniper encroachment at upper Underdown Canyon, Shoshone Mountains, central Nevada, (*a*) 1973 and (*b*) 2007.

forage production, wildlife habitat, biodiversity, and fire patterns across the landscape. Another impact is the shift from historic fire regimes to larger and more intense wildfires that are increasingly determining the future of this landscape.

The major goal of woodland management is to reverse these changing patterns by attempting to restore a functioning and resilient ecosystem through a more balanced plant community, which in areas of woodland expansion include a robust assemblage of grasses, forbs, and shrubs. With a robust assemblage of perennial grasses and forbs, in particular, a properly functioning ecosystem is better able to resist dominance by cheatgrass and other exotic weed species after fire or other disturbances. Even with prevention, maintenance, or restoration efforts to reduce trees by mechanical methods or prescribed fire, significant management will also be directed towards treatment following wildfire. Developing a management approach for implementing either preventive treatments or post wildfire restoration can be a difficult task. This is because of uncertainty about how the vegetation, soils, hydrologic function, and wildlife will respond to treatment.

Woodlands in the Great Basin represent a complex mix of trees, sagebrush, other shrubs, perennial and annual forbs, perennial grasses, and non-native grass and forb invaders. In different parts of the region, the distributions of four tree species overlap. These species include western juniper (fig. 2), Utah juniper (fig. 3), singleleaf piñon (fig. 4), and Colorado piñon (fig. 5). They occur alone or in mixes of two or rarely three species. The distributions of these tree species combined encompass nearly the full range of sagebrush species and subspecies, plus other shrub grass, and forb species. Responses to disturbances, such as insect outbreaks, drought and wildfire, or preventive or restoration treatment usually varies with the mix of tree, sagebrush, and perennial grass and forb dominants present on the site.

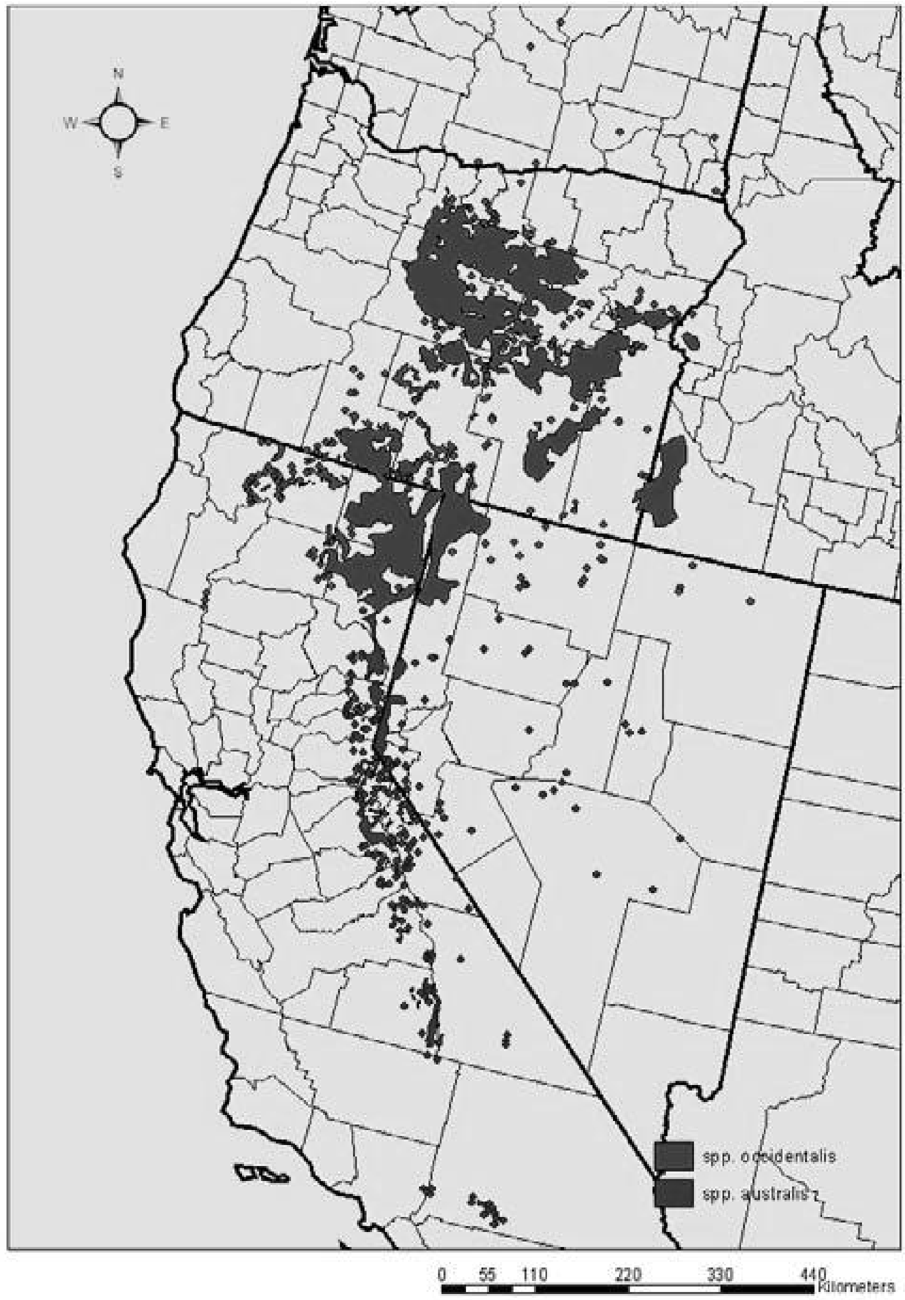


Figure 2. Current distribution of western juniper (*Juniperus occidentalis*) in the western United States (from Miller and others, 2007).

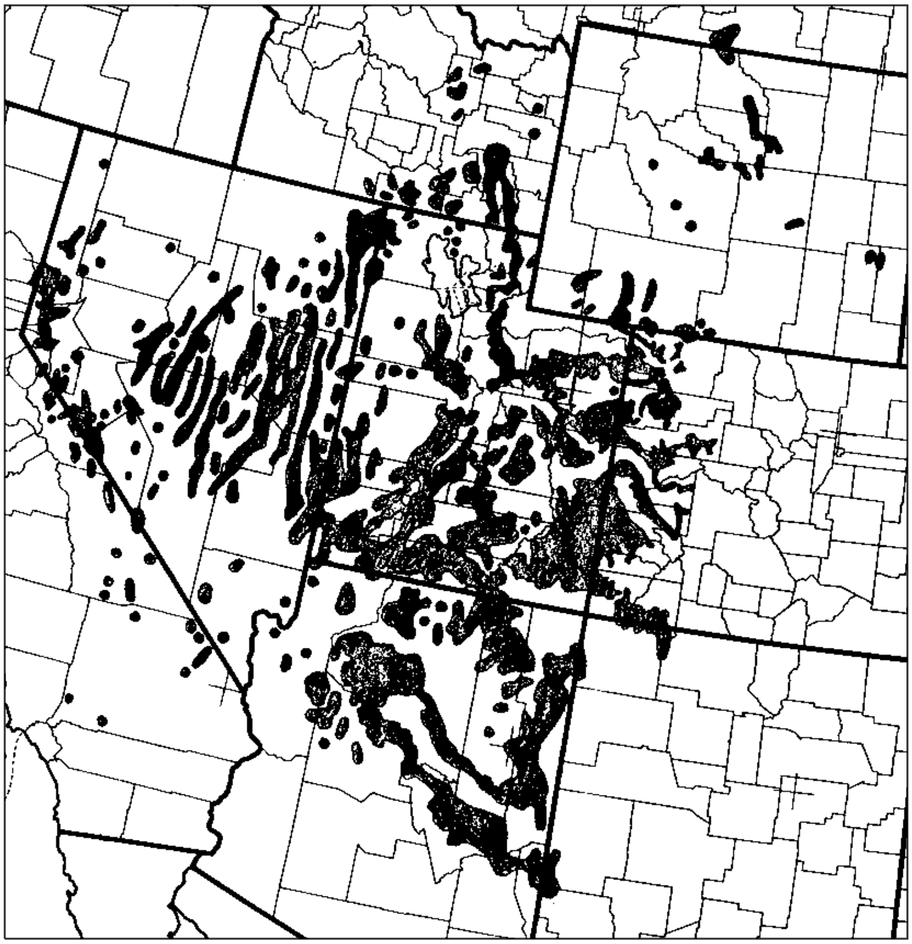


Figure 3. Current distribution of Utah juniper (*Juniperus osteosperma*) in the western United States (from Little, 1971).

When developing a management strategy, the first and possibly most important step towards success is asking the right questions. **Identifying the attributes** of the area to be treated, including the vegetation composition, soils, slope, aspect, elevation, geology, and ecological province, and then **selecting the right treatments** to be applied are of utmost importance. To best match long-term goals and objectives to the site, it can be beneficial to assess potential natural vegetation, soils, and the current successional and hydrologic states of the site. This allows us to best determine what components need to be restored to meet realistic objectives. In addition to the site conditions, it is equally important to determine how the management unit fits in

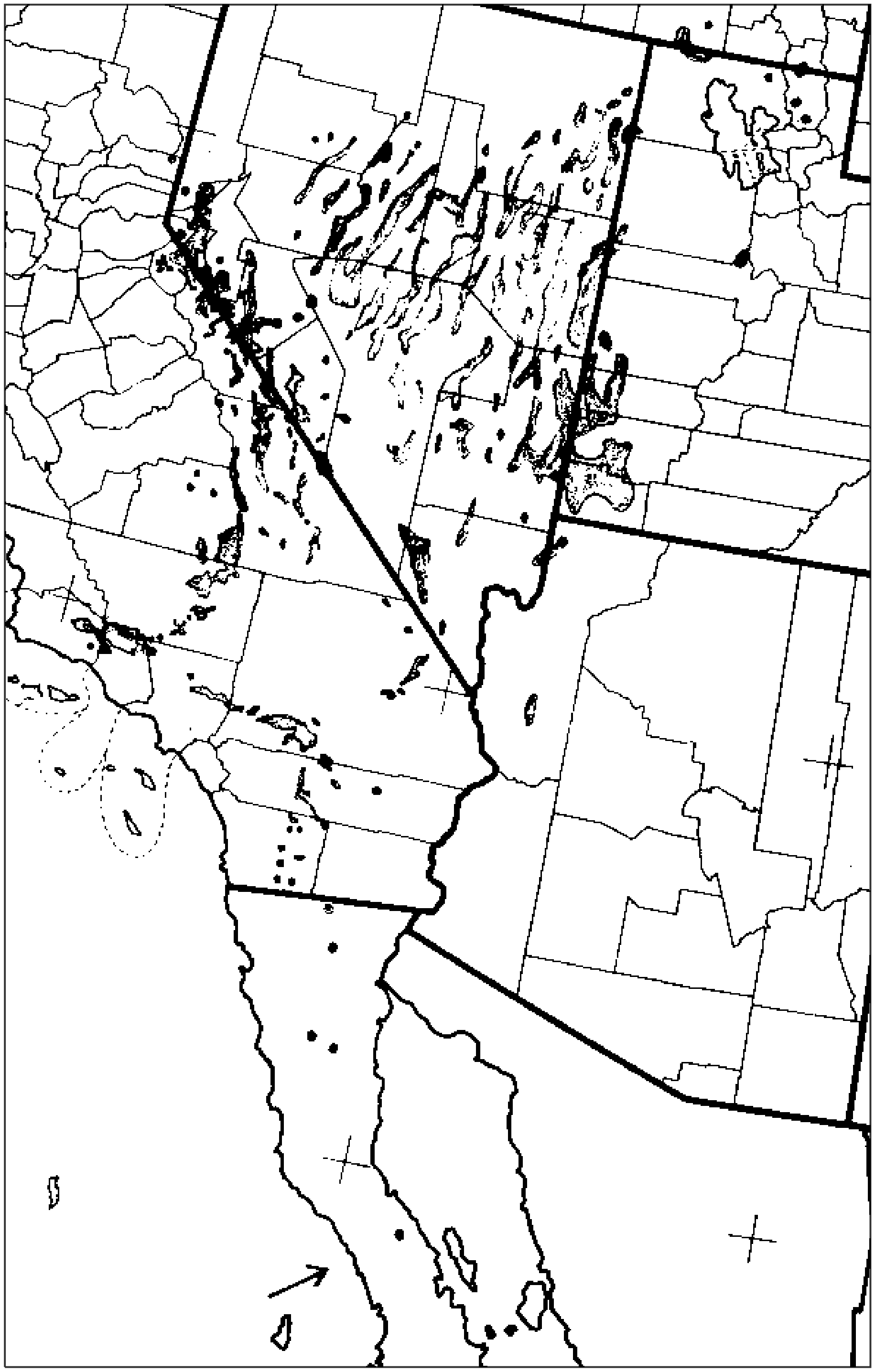


Figure 4. Current distribution of singleleaf piñon (*Pinus monophylla*) in the western United States (from Little, 1971).

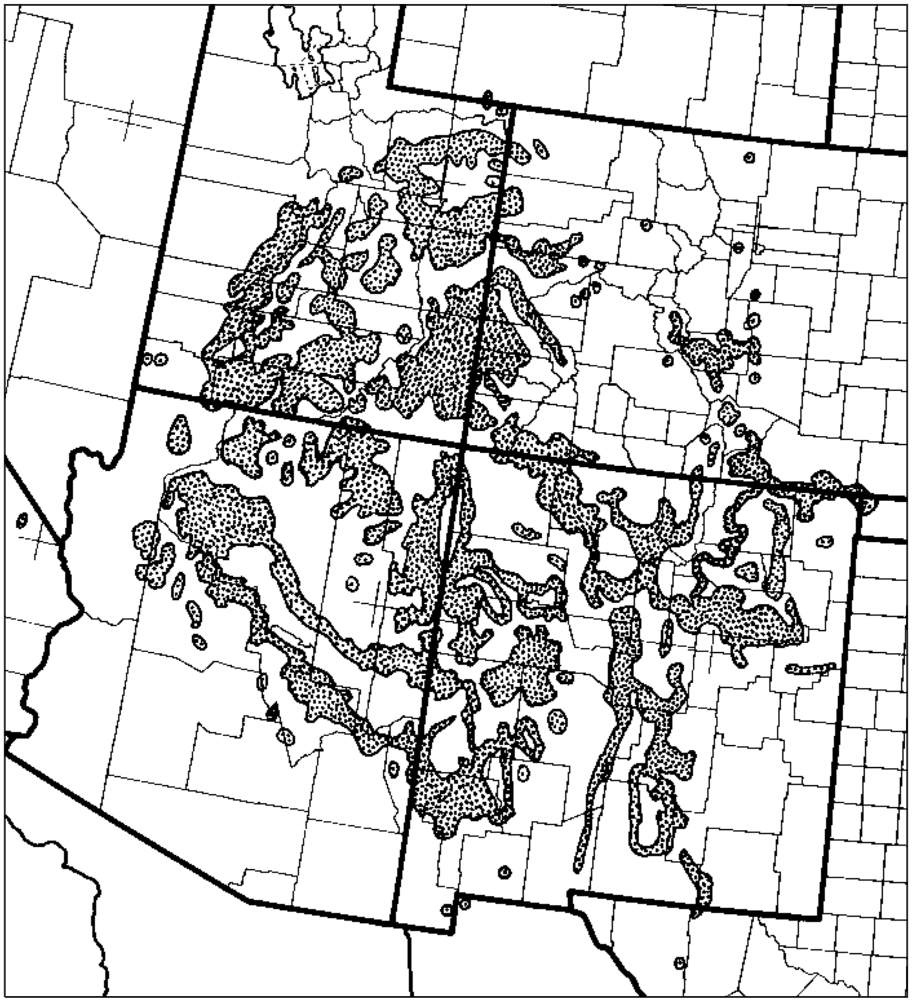


Figure 5. Current distribution of Colorado piñon (*Pinus edulis*) in the western United States (from Little, 1971).

the overall landscape mosaic, including the potential for wildfire. Keep in mind that sagebrush-steppe vegetation is dynamic, and management strategies will be most effective if multi-decade time frames are taken into account, particularly when piñon and juniper trees are present.

This guide provides a set of tools to help field biologists; land managers, including fuels specialists and fire managers; representatives of NGO's; and private landowners conduct rapid, qualitative field assessments that address a site's potential, current state, and relation to the surrounding landscape. These tools include a list of questions to be addressed and a series of photographs, keys, tables, and figures to aid in site evaluation. This assessment is designed to help prioritize sites to be treated, select the best treatment, and help predict outcomes.

Success of a piñon and juniper management program may be greatly enhanced if an interdisciplinary team of experienced local managers and resource specialists use this guide as an aid in decision-making. Knowledge of vegetation, fuels, potential fire patterns, soils, hydrology, grazing, wildlife, and their relationships to the surrounding landscape, as well as economic and sociological aspects of the local area, are essential to successful management and implementation of treatments.

Supporting Literature

This piñon-juniper guide closely corresponds to the publication *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate management Actions* by Richard Miller and others (U.S. Geological Survey Circular 1321, 2007) (fig. 2). It also is closely linked to the synthesis publications

- *Biology, Ecology, and Management of Western Juniper* by Richard Miller and others (Oregon State University Agricultural Experiment Station Technical Bulletin 152, 2005);
- *Age Structure and Expansion of Piñon-Juniper: A Regional Perspective in the Intermountain West* by Richard Miller and others (U.S. Department of Agriculture, Forest Service, Research Paper Report RMRS-RP-069, 2008);
- *Fire related restoration issues in woodlands and rangeland ecosystems* by Jeanne Chambers, (Mixed Fire Regimes: Ecology and Management Symposium Proceedings, *in* L. Taylor, J. Zelnik, S. Ladwaller, and B. Huges (compilers), November 11-19, 2004, Spokane, WA. AFE MIXC03);

- *Piñon-Juniper Woodlands* by Robin Tausch and Sharon Hood, *Chapter 4 in: Fire Ecology and Management of Major Ecosystems of Southern Utah*, (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report, RMRS-GTR-202, 2007); and
- *Atlas of United States Trees* (U.S. Department of Agriculture, Forest Service, Washington, D.C., Miscellaneous Publication No. 1146, 1971) (figs. 3-5).

Please refer to these publications for more information and for literature cited.

Questions to be Addressed

This field guide is meant to help personnel from management agencies, NGO's, environmental groups, and private landowners with a thought process of how to look at the landscape and determine what questions to ask to meet specified goals and objectives. These questions are meant to provide a base or starting point for selecting an appropriate preventive, maintenance, or restoration management action or post-wildfire management response. Because each management unit and its relationship to the surrounding landscape are unique, additional questions may need to be addressed or modified to help evaluate the site. The guide is separated into four parts important for identifying the attributes of an area and selecting the appropriate management action. These components help to clearly define or set goals and objectives through identifying (I) The Ecological Site, (II) The Current State of the Site, (III) Landscape Considerations, and (IV) Selecting the Appropriate Management Action. The right questions also need to address agency procedures and meet the overall goals of the project.

Setting Goals and Objectives

The following questions are written from the perspective of implementing a preventive, maintenance, or restoration treatment, but are easily adaptable for application to post-wildfire management responses. What is to be done to a site should be based on clear and measurable objectives. This field guide also can help managers evaluate the site and incorporate decisions into the Resource Management Plan, Land Use Plan, or Forest Plan of their agency.

1. What are the desired ecological conditions or how should the site look in 5, 10, 20, or 50 years?
2. What vegetation changes need to occur on the site, and possibly over the surrounding landscape, to meet functional goals or habitat needs?

Answers to the questions in Parts I, II, and III are intended to help managers and others determine feasible goals and objectives for a particular site. As a result, goals and objectives should be re-evaluated as these questions are answered.

Part I: The Ecological Site

3. In which Ecological Province is the site located?
4. What is the elevation and topography?
5. What kinds of soils are present on the site?
6. How will the soils and physical features affect erosion and vegetation establishment?
7. What are the dominant plant species currently present, and what is the current and future potential natural vegetation (PNV) or plant association?
8. Are there old-growth trees on the site, and where are they growing?
9. Is the PNV estimated to be woodland or shrub-steppe, and what is the estimated fire return interval?
10. What is the ecological site?

11. Prior to European settlement, what would the potential disturbance regime (frequency, intensity, and kinds of disturbance) have been, and how would different scenarios of this regime influence the historic range of vegetation variability on the site?
12. How have post-settlement changes in vegetation or disturbance affected the vegetation and ecological conditions of the surrounding landscape?
13. What is the potential wildlife habitat value under current compared to potentially restored conditions?

Part II: The Current State of the Site

14. Clearly define the perceived problems: What are the factors affecting proper ecological function?
15. What is the stage of woodland succession (Phase I, II, or III), and how does this vary across the site?
16. What is the current understory herbaceous composition?
17. Is there current recruitment of native understory species?
18. Are there invasive plant species adjacent to the site to be treated?
19. What is the percentage of dead shrubs on the site, and what are the species?
20. What are the fuel characteristics, and what type of fire will the site support?
21. Are there signs of erosion and overland flow? What is the current capacity of the site to capture, store, and safely release water? What is the incidence of high-intensity summer thunderstorms?
22. What is the current wildlife habitat suitability, and what species are involved? How will treatment affect wildlife species?
23. Are there social and/or economic concerns or issues related to the site?

Part III: Landscape Considerations

24. What are the spatial landscape characteristics of the area to be treated with respect to topography, patch size, edge, and connectedness?
25. What is the composition of adjacent patches, what is the landscape distribution of patches, and what are their stages of woodland succession?
26. What is the current variation in understory composition and in the recruitment of native understory species over the surrounding landscape?
27. How do fuel characteristics of tree, shrub, and herbaceous layers vary over the surrounding landscape, what type of fire are they likely to support, and how might this influence the types of fire possible on the site?
28. Are there signs of erosion and overland flow from the surrounding landscape that suggest impacts to the site?
29. Will conditions of the surrounding area influence the wildlife habitat suitability of the site or affect the species involved?
30. What are current uses, management activities, and social and economic concerns for the surrounding landscape that might affect the site?

Part IV: Selecting the Appropriate Management Actions and Treatments

31. What are the factors that will influence selection of preventive, maintenance, or restoration treatments, including personnel availability, grazing schedules, and wildlife risk?
32. What are treatment options, including mechanical, prescribed fire, cut and burn combinations, chemical applications, and seeding?
33. How will post-treatment management, including the need for maintenance on the site, affect site conditions and function on the surrounding landscape?

Setting Goals and Objectives

1. What are the desired[1] ecological conditions or how should the site look in 5, 10, 20, or 50 years?

Desired[1] ecological conditions depend on management objectives, potential uses for the site, and ecological characteristics of the site, such as soil profiles and ecological site type. Managers need to identify conditions that are ecologically, physically, and economically possible on a given landscape and that will satisfy management objectives over the long-term. Knowing these conditions can help determine if a treatment or series of treatments could help to achieve those results.

Setting goals and objectives will often require participation by stakeholders, who may have differing or even conflicting ideas about the values that should be emphasized in woodland-dominated ecosystems such as the appropriate ecological condition of those lands. Natural disturbances and changes in environmental conditions, such as those associated with climate change, also may affect the site and necessitate adjustments in management plans.

Because goals and objectives are influenced by many factors, they should be reevaluated and adjusted as new information becomes available. Answers to the questions that follow will provide information for managers and others that will help them in the ongoing

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[1]Words such a “desired”, or “desirable”, and “best” are sometimes used to describe advantageous or suitable management approaches relative to management goals and objectives and in considerations of ecological responses of vegetation, soils, hydrologic function, and wildlife. These terms are used with recognition that many factors besides the evaluations described or cited in this manual may eventually come to bear in a decision-making process. In this context, these words should be viewed as relative terms only, not explicit directives or judgments.

process of setting appropriate goals and objectives for a particular site.

2. What vegetation changes need to occur on the site, and possibly over the surrounding landscape, to meet functional goals or habitat needs?

After a "desired condition" has been defined (for example, fig. 6), the next step is to identify the specific vegetation changes necessary for the site to meet functional goals, such as improved watershed health or wildlife habitat. For example, an increase in shrubs and herbaceous vegetation may be needed to increase vertical structural diversity for wildlife. Also, a reduction in trees can reduce evapotranspiration, thereby increasing soil moisture and water availability. Maintaining an open tree canopy with a diverse understory may help achieve these habitat goals. An increase in shrubs could change structural diversity to affect fuels and maintain a desired fire regime. Increases in perennial grass and forb cover may reduce erosion and sedimentation and

Figure 6. Phase II woodland. A management objective for this site might be to maintain a diverse understory by reducing tree dominance.

also enhance the ability of the site to capture and store water. In addition, increases in perennial grass and forb cover often can decrease the invasion of potential exotic species. All of these vegetation changes could help in meeting the desired goal of watershed health or wildlife habitat.

Part I: The Ecological Site

Determination of the Ecological Site is based on the premise that specific physical and climatic characteristics are capable of producing certain types of vegetation. Ecological site and soil maps for the area should be obtained and used to help determine the proper ecological site description, soils, and potential vegetation. Maps should be verified during a site visit to ensure that the descriptions match the site.

3. In which Ecological Provinces is the site located?

The Great Basin is a region of complex topography, geology, and climate. The mountain ranges and intervening valleys vary greatly in size, elevation, configuration, and climate, all of which significantly affect vegetation. Environmental conditions on a particular mountain range are dependent not only on the topographic characteristics of the mountain range the site is located on, but also on the topographic characteristics and configuration of the surrounding ranges and valleys. Woodlands within Ecological Provinces are more similar in climate, topography, elevation, geology, soils floristic composition, and soil-plant relations than those across Ecological Provinces. Most of the dominant tree, shrub, and perennial grass species have wide ecological tolerances, and thus are expected to have more uniform responses within an Ecological Province compared to anywhere else they occur. A species response to disturbance or treatment may vary depending on the species location. Differences between the Ecological Provinces in altitude, topography, environment, geology, and vegetation can affect the outcomes of natural disturbances or treatments. The different Ecological Provinces are illustrated in figure 7.

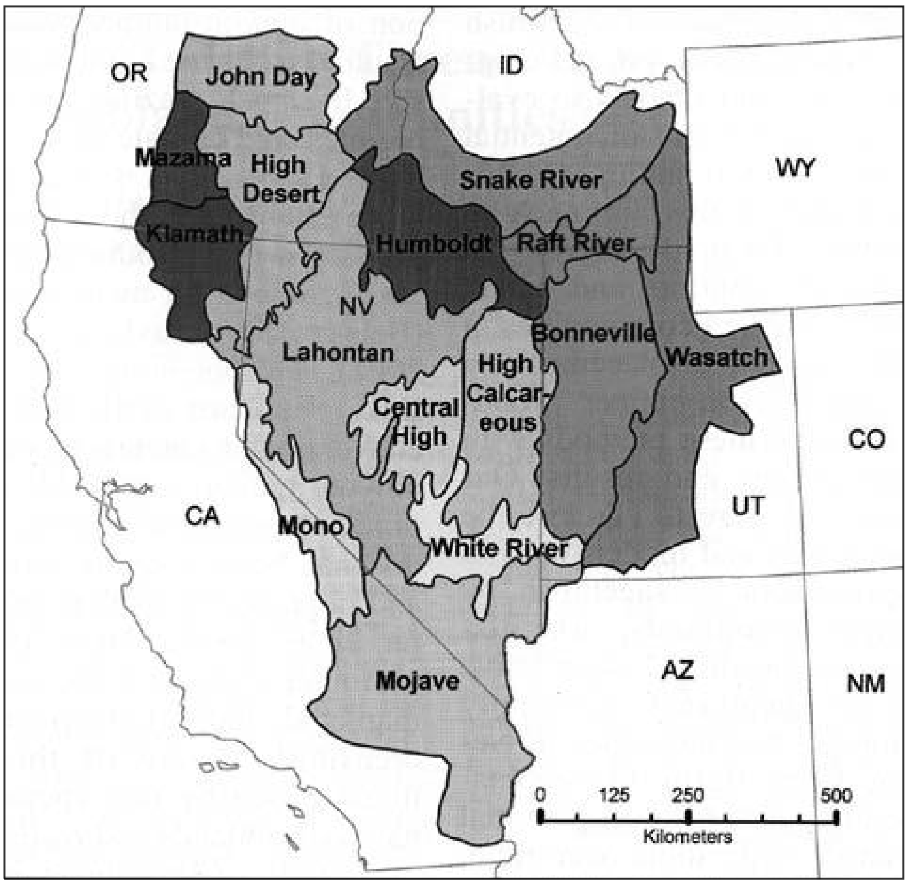


Figure 7. Ecological Provinces of the southwestern United States. Adapted from West, N.E., R.J. Tausch, and P.T. Tueller. 1998, A management-oriented classification of piñon-juniper woodlands of the Great Basin: U.S. Forest Service General Technical Report RMRS-GTR-12.

4. What is the elevation and topography?

Within the complex geology of the Great Basin, topography (primarily slope and aspect) combined with elevation can have a substantial effect on the soil type and the plant community. These factors influence how a site will respond to natural disturbance and applied treatments. For example, resilience and resistance to disturbance and potential for successful restoration often increases with elevation and more northerly aspects. Increasing elevation and shifts in aspect from south to north often result in cooler temperatures, greater moisture availability, and more productive soils. These differences also vary with Ecological Province, site topography, the spatial relatiohship, and topographic differences of surrounding mountain ranges.

5. What kinds of soils are present on the site?

A soils map of the site or area will indicate what type of soils are present. Soil depth, texture, structure, and organic matter content are important soil characteristics that influence water infiltration rates, water holding capacity, soil water availability for plants, and erosion potential. Loamy soils, which have a more balanced mixture of sand, silt, and clay (fig. 8) have better soil-water characteristics for plant growth than excessively drained sandy soils with low water-holding capacity or clay soils with low infiltration rates and very tightly held water.

Soil Texture (fig. 8): To determine soil texture of each horizon, add water to a healthy tablespoon of soil until you can roll it up in a ball without it leaving soil on your palm.

Press the soil between your thumb and forefinger and attempt to form a ribbon.

- Good Ribbon: does not break and has few cracks = high clay content
- Medium Ribbon: ribbon cracks deeply and eventually breaks = moderate clay content
- Poor Ribbon: a ribbon cannot be formed or immediately breaks = low clay content

Add additional water and test for smoothness and grit. Gritty texture indicates sand.

Soil Depth: Soil depth is measured from the surface to the layer that retards root development:

Very shallow: <10 in.
Shallow: 10 to 20 in.
Moderately deep: 20 to 36 in.
Very deep: >60 in.

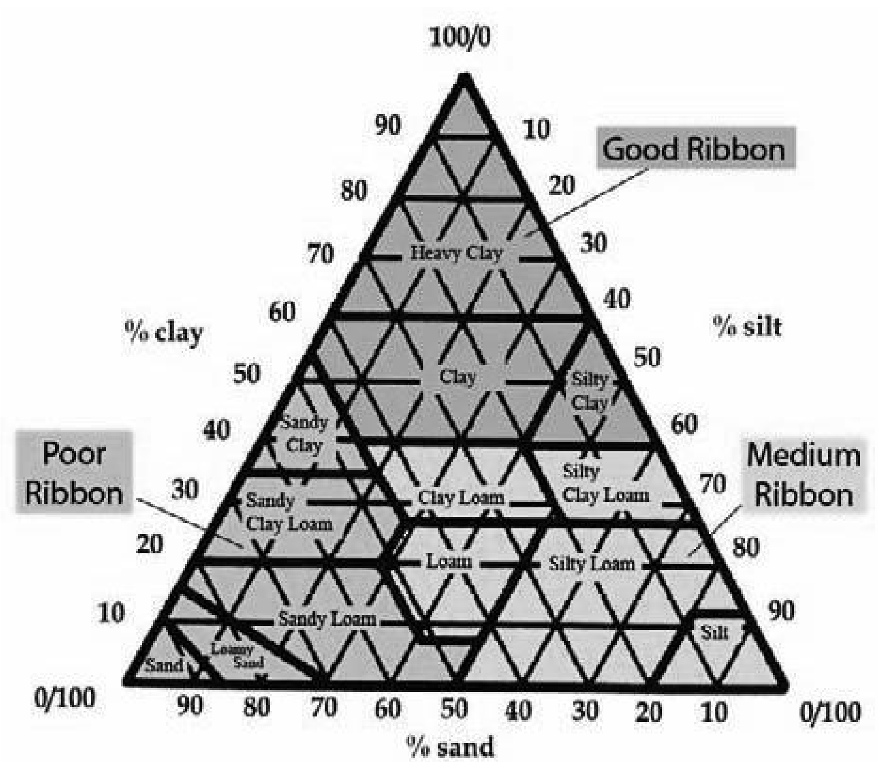


Figure 8. Soil texture triangle (from Miller and others, 2007).

Restrictive soil layers increase below-ground competition. With increasing tree dominance, herbaceous vegetation is likely to decrease on sites where there is a restrictive soil layer 16 to 18 in. beneath the surface. Soil layers (for example, heavy clay argillic layer, petrocalic horizon, duripan, lithic contact, etc.) that restrict water movement also will influence water runoff on the site (fig. 9), and this should be considered before treatment. Where increasing tree dominance is causing the greatest decrease in understory (fig. 10) are often sites that are most susceptible to exotic annuals such as cheatgrass.

Figure 9. Mountain big sagebrush/Idaho fescue plant association with moderately deep (>30 in.), well-drained, clay loam soils. Juniper roots are well distributed throughout the soil profile resulting in a loss of shrubs, but Idaho fescue persists in the understory.

Figure 10a. A shallow restrictive soil layer limits tree rooting depth resulting in a loss of shrubs, grasses, and forbs.

Figure 10b. Former Wyoming big sagebrush community on a site with a restrictive soil layer similar to fig. 10a now fully dominated by Utah juniper.

6. How will the soils and physical features affect erosion and vegetation establishment?

Soil surface characteristics, slope, incidence of intense summer thunderstorms, and wind influence risk of erosion following tree removal treatments. Soil surface stability, soil texture, soil depth, aggregate stability, patterns of bare ground, and evidence of rill and sheet erosion should be examined across the site. These factors in combination with slope interact to determine erosion potential. Treatments like prescribed fire may remove vegetation cover, and the site may be vulnerable to erosion in the short term. Soil can be protected by methods such as cutting or masticating the trees and leaving the slash or chips on the ground. Another factor to consider is whether past erosion due to tree dominance has changed soil characteristics in ways that will affect the success of seeding. For example, has enough topsoil been lost to significantly reduce the seedbed for seed germination or the rooting zone of seeded species?

7. What are the dominant plant species currently present, and what is the current and future potential natural vegetation (PNV) or plant association?

- Which tree species, sagebrush species or subspecies, other shrubs, and perennial grass species are present on the site (key 1 and figs. 11–13; if Phase III, look for shrub skeletons on the site)?
- Is there evidence that pre-settlement trees occupied this site in the past (table 1, key 2)?
- What are some of the diagnostic perennial grass and forb species (fig. 12)?

Figure 11. Dead bitterbrush and big sagebrush remnants can be distinguished by differences in the wood; bitterbrush (top) is clear while sagebrush (bottom) has dark brown bands perpendicular to the annual growth rings (from Miller and others, 2005).

Warm-Dry---Cool-Wet

(generally low elevation) (generally high elevation)

Sagebrush

ARARLO < ARAR < ARNO < ARTRWY
< ARTRTR < ARTRVA

Other Shrubs

TECA < GRSP < PUTR < AMAL < SYMSPP

Perennial Grasses

ACSP12 < ACHY < HECO26 < PSSP5
< ACTH7 < FIED < BRCA

Figure 12. Diagnostic sagebrush community species oriented along a general warm-dry to cool-wet gradient (for definitions of plant codes see appendix 2). Low sagebrush (ARAR) also occurs at high elevations on shallow soils and topographic locations that limit available soil moisture.

Key 1. Common sagebrush species and subspecies associated with piñon-juniper woodlands (figs. 13a-k). Key is based on persistent leaves and flower stalks. This key is for preliminary identification only. Final identification should be based on additional taxonomic information.

1a. Mature shrubs <20 in. tall.

2a. Flowers early summer, leaves broadly cuneate, with deep, well developed lobes, center lobe often buck-toothed (wider than space between two outer leaves) (fig. 13a) ……………… *early sagebrush*

2b. Center lobe usually not buck-toothed, flowers mid-summer to fall

3a. lowering stalks gray pubescent, weakly persistent, leaves grayish green, not sticky or glandular (figs. 13b-c) ……… *low sagebrush*

3b. Flowering stalks brown to straw colored, persisting into the following year, leaves usually darker green and sticky glandular (figs. 13d-e) ……………… *black sagebrush*

1b. Mature shrubs >20 in. tall.

4a. Plant even topped or flat-crowned, flower stalks mostly >1/2 above vegetative shoots, leaves wedge shaped and tapered to base with straight margins, leaves fluoresce bluish white under ultraviolet light (figs. 13f-g) …………… *mountain big sagebrush*

4b. Plant crowns uneven, flower stalks throughout the crown, usually <1/2 above crown, does not fluoresce bluish under ultraviolet light.

5a. Plants usually > 3 ft tall, mature persistent leaves 4 times as long as wide or longer with straight margins (figs. 13h-i) …………… *basin big sagebrush*

5b. Plants usually < 3 ft tall, mature persistent leaves less than 4 times long as wide, margin curves outward giving bell shaped leaves (figs. 13j-k) ………… *Wyoming big sagebrush*

Figure 13. Common sagebrush species and subspecies associated with piñon-juniper woodlands.

(a) Leaves of early sagebrush

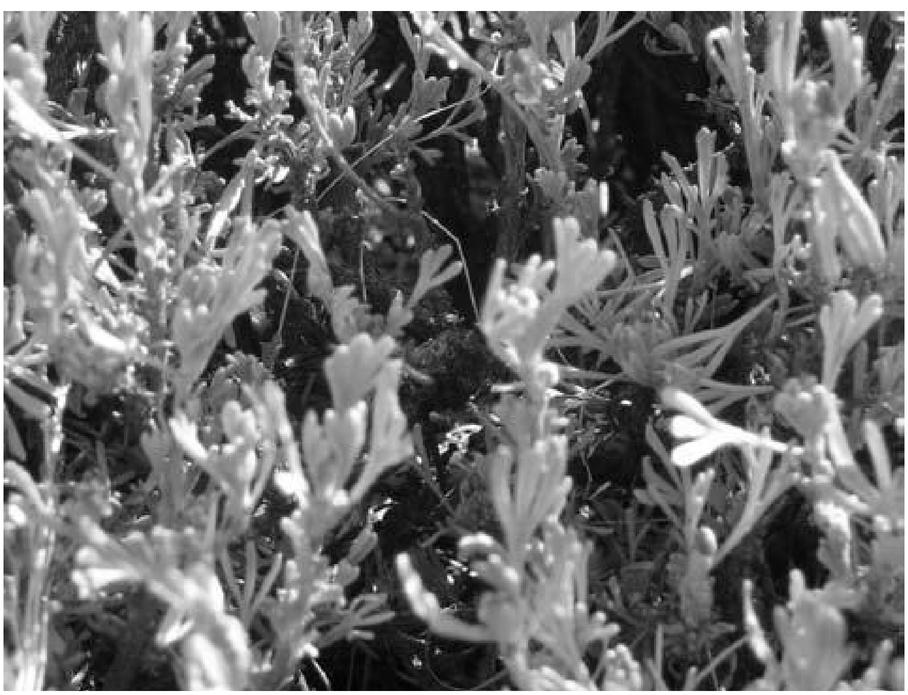
Figure 13. Continued.

(b) Crown of low sagebrush

(c) Leaves of low sagebrush

Figure 13. Continued.

(d) Crown of black sagebrush



(e) Leaves of black sagebrush

Figure 13. Continued.

(f) Crown of mountain big sagebrush

(g) Leaves of mountain big sagebrush

Figure 13. Continued.

(h) Crown of basin big sagebrush

(i) Leaves of basin big sagebrush

Figure 13. Continued.

(j) Crown of Wyoming big sagebrush

Figure 13. Continued.

(k) Leaves of Wyoming big sagebrush

Woodland Tree Growth Form		
Characteristic	**Relatively Young Trees**	**Relatively Old Trees**
Juniper crown shape	Conical with pointed tip	Flattened, rounded, or uneven top (figs. 14a, 16a)
Piñon crown shape	Conical with pointed to slightly rounded tip	Flattened, rounded, or uneven top (figs. 14b, 16b)
Juniper branch structure	Branches become progressively smaller from bottom to top of tree	In open stands, large branches near the base
Piñon branch structure	Branches become smaller from bottom to top of tree, general orientation is vertical	In open stands branches large near base and remain relatively large well into the crown, more randomly oriented.
Dead wood	Little dead wood in bole, few dead branches, little or no foliose lichen on juniper	Dead branches, bark missing, juniper covered by a light green lichen
Juniper bark (figs. 17a-b)	Flaky, relatively thin with limited or shallow vertical furrows	Thick, fibrous with well-developed vertical furrows
Piñon bark (figs. 17c-d)	Relatively thin, flaky, with weak vertical furrows	Thicker, more plate-like structure than furrowed

Table 1. Morphological characteristics of post-settlement (<150 years) and pre-settlement (>150 years) woodland trees (figs. 14–17).

Woodland Tree Growth Form		
Characteristic	**Relatively Young Trees**	**Relatively Old Trees**
Juniper leader growth (figs. 22a-c)	Terminal leader growth in the upper ¼ of the tree, usually >2 in. In open stands, leader growth >2 in. from bottom to top	Leader growth in the upper ¼ of the tree usually <1 in.
Piñon leader growth (figs. 22d-e)	Leader growth in piñon similar to juniper but not directly visible. Must look for bud scale scars to determine length	Leader growth in upper ¼ of the tree usually <2 in.

Table 1. Continued.

Key 2. Identifying ecological site and estimated fire return interval (FRI).

1a. Potentially can grow big sagebrush
  2a. Old live trees on the site (>150 years old)
    3a. Old growth tree canopy >20% .... **woodland** .... FRI > 150 years
    3b. Old growth tree canopy <20% .... **tree shrub savanna**
      4a. Old trees on protected microsites* .... FRI < 50 years
      4b. Old trees scattered but on deeper soils........ FRI 50 100 years
  2b. No live old growth trees on the site
    5a. No large dead wood or stumps on site (>12 in. diameter fluted) .... **shrub steppe** .... FRI < 50 years
    5b. Large dead wood present on the site
      6a. Density >22/acre .... **woodland** .... FRI > 150 years
      6b. Density <22/acre .... **tree shrub savanna**
        7a. Relic wood on protected microsites .... FRI <50 years
        7b. Relic wood scattered but on deeper soils .... FRI 50 100 years
1b. Potentially can grow low sagebrush
  8a. Black sagebrush (ARNO)
    9a. Old live trees on the site (>150 years old)
      10a. Old growth tree canopy >20% .... **woodland** .... FRI > 200 years
      10b. Old growth tree canopy <20% .... **tree shrub savanna**

Key 2. Continued.

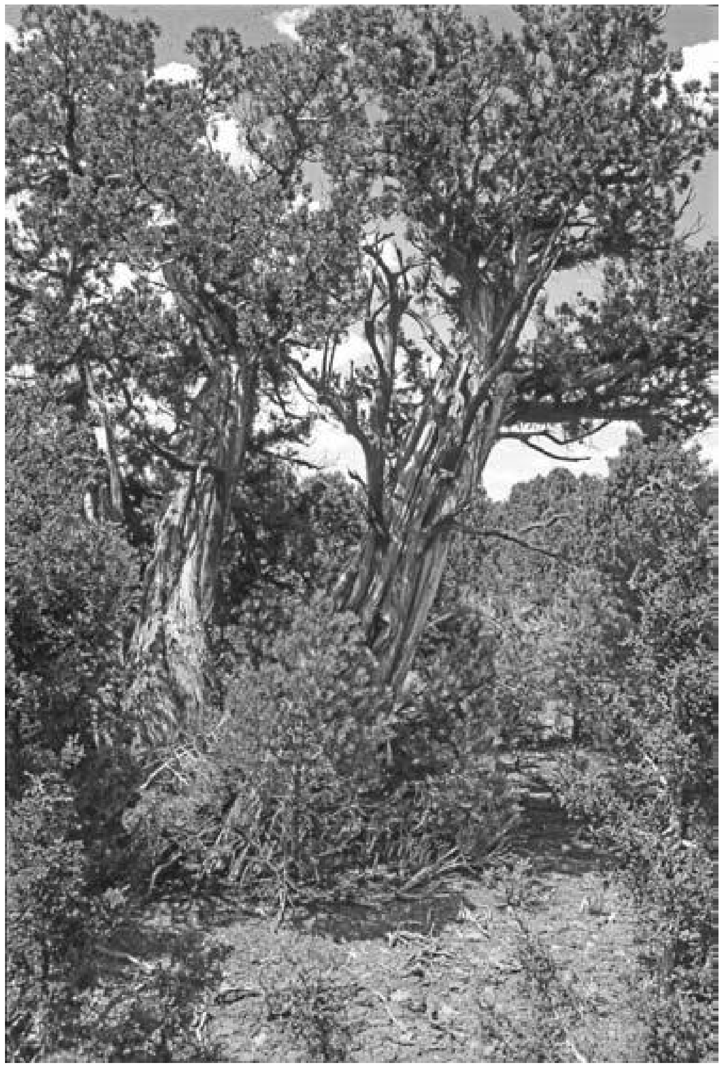
11a. Old trees on protected microsites* ………… FRI < 100 years
11b. Old trees scattered but on deeper soils ………… FRI 50 300 years
9b. No live old growth trees on the site
12a. No large dead wood or stumps on site (>12 in. diameter fluted) …**shrub steppe** ………… FRI < 100 years
12b. Large dead wood present on the site.
13a. Density >22/acre ………… **woodland** ………… FRI > 300 years
13b. Density <22/acre ………… **tree shrub savanna**
14a. Relic wood on protected microsites ………… FRI <100 years
14b. Relic wood scattered but on deeper soils ………… FRI 100 200 years
8b. Low sagebrush (ARAR)
15a. ARAR >12 in. height (go to 2a and 2b)
15b. ARAR <12 in. height
16a. No live old growth or large relic wood ………… **low shrubland** ………… FRI > 150 years
16d. Old live trees or large relic wood (canopy rarely exceeds 20%) …**tree-low shrub savanna**… FRI > 150 years

* 4a and 11a. Are old trees growing uniformly or randomly across the site, or do they grow on microsites (microtopography steep, convex, rocky, unusual soil and parent material, etc.)?

8. Are there old-growth trees on the site, and where are they growing (figs. 14 17)?

Old-growth trees have a long history on many locations in the region and have provided valuable wildlife habitat, added structural and biological diversity, and can be part of the PNV on many of these landscapes. For these reasons, it is important to identify areas where old-growth occurs and to carefully consider the appropriateness and consequences of any tree removal projects that might jeopardize or enhance the integrity of these sites. An appropriate action is the thinning of younger trees, particularly in adjacent areas, where there is a potential for them carrying a stand-replacement fire into the old-growth (fig. 14a). Old-growth trees are associated with various soils, landforms, and plant associations, but typically grow in rock outcrops or on steep slopes (fig. 14b) and have soils that are often shallow and course in texture. Old-growth juniper can occasionally have an understory of deep-rooted perennial grasses (fig. 14c), a situation not observed for piñon. Old-growth stands commonly grow in areas where accumulation of herbaceous fuels is limited, where stand-replacement or mixed-severity fires are infrequent, and where tree removal results in limited increases in understory productivity (fig. 15).

Figure 14. Examples of the range of variation in old-growth woodland sites.



(a) Utah juniper in a former shrub savanna site that has experienced a recent large increase in tree density and fuel loads

Figure 14. Continued.

(b) An old-growth site dominated by piñon on a steep, rocky south-facing slope

(c) An old-growth Utah juniper site in west central Utah

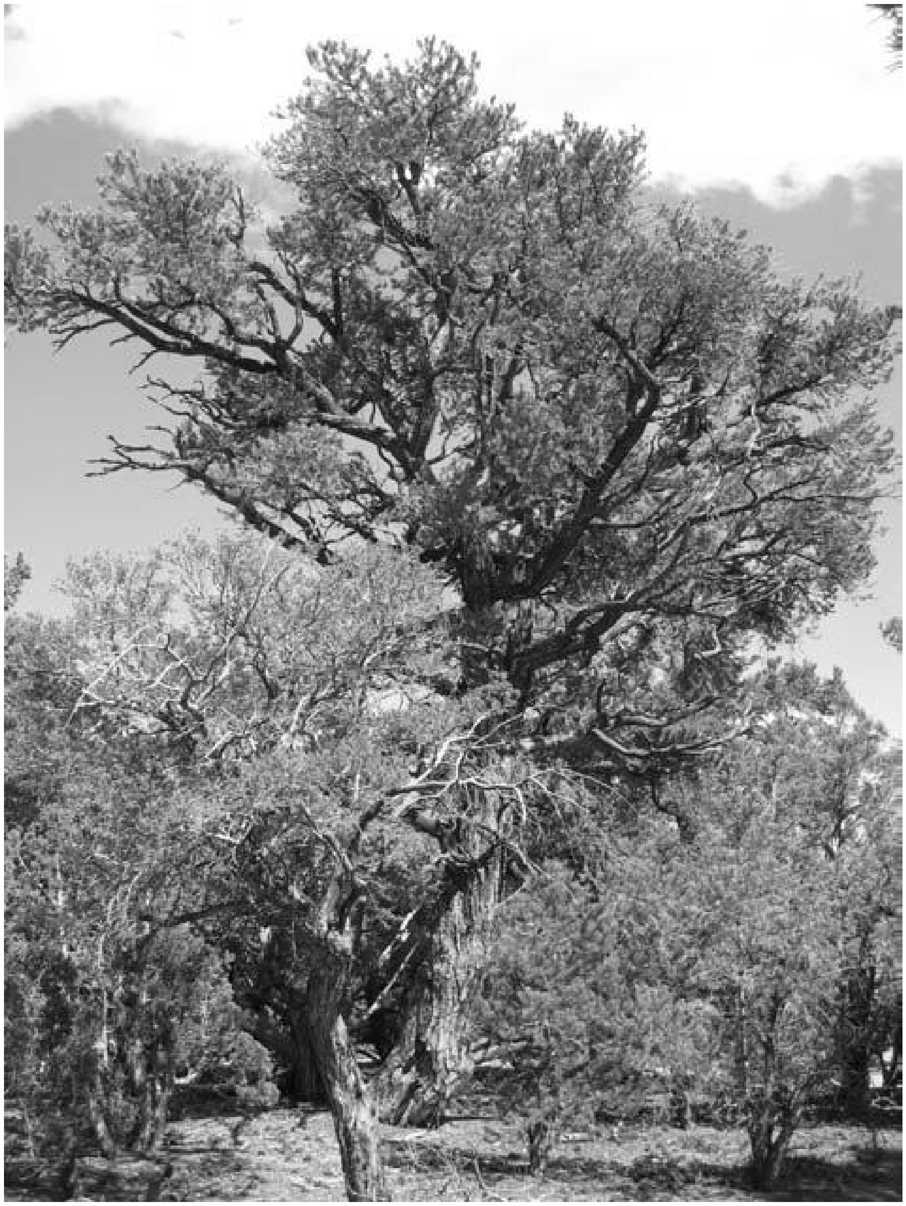
Figure 15. An open old-growth Utah juniper dominated shrub savanna in east-central Nevada.

Questions to ask to determine if the site is or was an old-growth site:

- Are there trees on the site showing old-growth characteristics (fig. 16), or are the trees <150 years old (table 1)?
- Do the soils typically support persistent woodlands, or do they have characteristics such as greater depth and mollic horizons that developed under a grass or grass-shrub dominated vegetation?
- Does tree structure suggest the site is relatively stable (limited recruitment), or are younger trees in-filling?
- Are there large stumps or snags (>18 in. but often > 24 in. in diameter), often covered with char?
- Are there large logs or branches lying on the site?

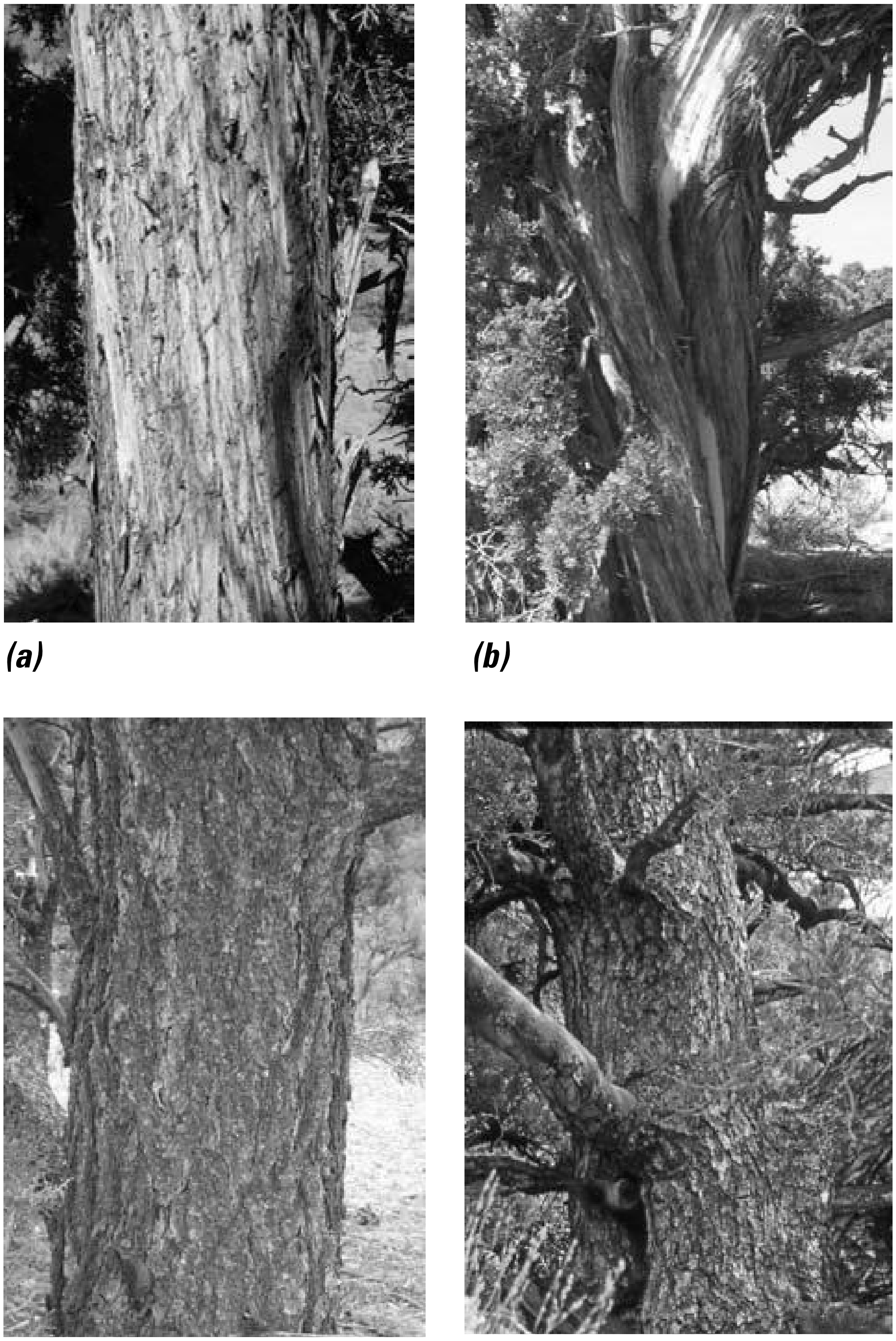
(a)

Figure 16. (*a*) Old-growth Utah juniper and (*b*) singleleaf piñon with dead branches and missing bark.



(b)

Figure 16. Continued.



(a) *(b)* *(c)* *(d)*

Figure 17. Bark characteristics of species of woodland trees of different ages. (*a*) At about 100–150 years, juniper bark is thin and flaky. (*b*) At over 300 years, juniper bark is thick and fibrous, with well-developed vertical furrows. (*c*) At about 100 years, piñon bark is thin, flaky, with weak vertical furrows. (*d*) At over 300 years, piñon bark is thicker, with a more plate-like structure than furrowed.

9. Is the PNV estimated to be woodland or shrub-steppe, and what is the estimated fire return interval?

Key 2 can help identify the potential of the site as tree-shrub savanna (fig. 15), old-growth woodland (existing, fig. 18, or following disturbance, fig. 19), or shrub steppe. The key also gives an estimated fire return interval (FRI) for the site. Return intervals in the key are meant only as a coarse proxy of the number of years between fires prior to Eurasian settlement if other documentation is not available.

Figure 18. Mountain big sagebrush/bluebunch wheatgrass plant association with a stand of pre-settlement Utah juniper trees growing on shallow soils.

Figure 19. Wyoming big sagebrush community with charred stumps on shallow to moderately deep soils that indicate a low density of trees has occupied the site since prior to the mid-1800s.

10. What is the ecological site?

Identification of the ecological site identifies a site's ability to produce a distinctive kind and amount of vegetation and the interrelationships of that vegetation with other ecological sites over the landscape. The characteristics of an ecological site are based on its associated physiographic, climatic, soil, and water features; and on the plant communities comprising its various vegetation states. Information on the specific ecological site descriptions that are available can be accessed at http://esis.sc.egov.usde.gov/ESIS/.

11. Prior to European settlement, what would the potential disturbance regime (frequency, intensity, and kinds of disturbance) have been, and how would different scenarios of this regime influence the historic range of vegetation variability on the site?

The kind and number of years between disturbance events, such as fire (refer to key 2), will help determine what kind of plant community is most persistent on a site (fig. 20). This can provide a baseline to use in gaging how much change has occurred. While conditions prior to settlement may not be replaceable, or be a viable management goal, the future possibilities for a site are not independent of the pre-settlement conditions.

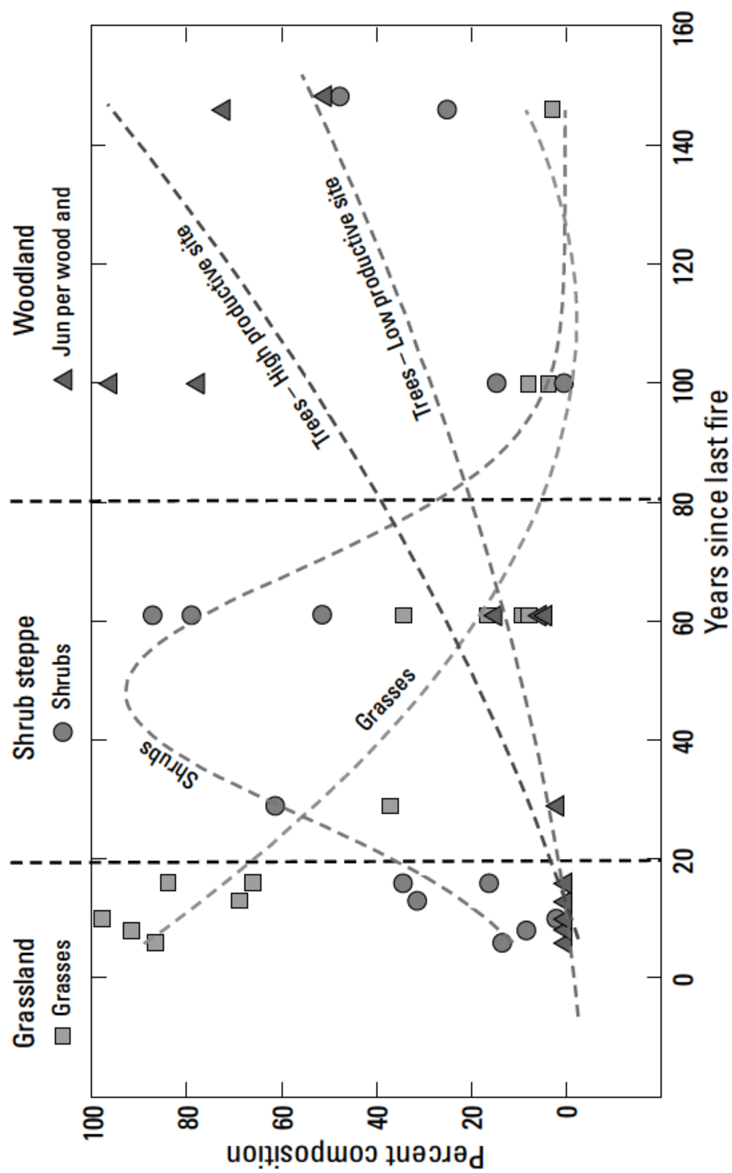


Figure 20. Relation of time since fire and the percent composition (dominance) of grasses, shrubs, and trees (from Miller and others, 2007).

12. How have post-settlement changes in vegetation or disturbance affected the vegetation and ecological conditions of the surrounding landscape?

For example, in some areas scattered old trees that have survived historic fire regimes are currently at risk as a result of post-settlement infill of younger trees or woodland expansion into sagebrush areas adjacent to old-growth patches (fig. 14)

13. What is the potential wildlife habitat value under current compared to potentially restored conditions?

Would vegetation on the site and surrounding area support sensitive wildlife species (that is sagebrush obligates, such as sage grouse, or species seasonally dependent, such as mule deer) (fig. 21)?

- Is it important seasonal habitat (that is, key winter, nesting, brood rearing habitat that is being lost to tree expansion)?
- Would treatment result in improved connectivity between other habitats?
- What vegetation layers (herb, shrub, tree) should be present and in what relative proportion?

Figure 21. Phase II piñon-juniper expansion woodlands in a mountain big sagebrush community with a high level of structural diversity.

Part II: The Current State of the Site

14. Clearly define the perceived problems: What are the factors affecting proper ecological function?

An important attribute that affects proper ecological function is vegetation structure, specifically the amount, type, and distribution of plant ground cover. If the site is not functional with respect to water and nutrient cycles or soil or biotic integrity, physical conditions that are connected to the problem need to be identified. Site condition should be evaluated to determine if an imbalance in plant community composition, a lack of structural diversity in the vegetation community, or a high proportion of bare ground are contributing factors. With the encroachment or increasing density of trees, the best way to maintain or restore hydrologic function and soil or biotic integrity is to implement treatments that reduce tree dominance while ensuring recovery or maintenance of understory vegetation, particularly perennial herbaceous species, on the site. Additional factors that might be weighed in treatment decisions include multiple management objectives (for example, wildlife habitat and fuels management), economic costs/benefits, and social values.

15. What is the stage of woodland succession (Phase I, II, or III), and how does this vary across the site?

The stage of woodland development can influence the type of treatment selected, follow-up treatments and management, understory competition, seed pools, and vegetation response following management action. Patterns of woodland development and understory loss are much the same regardless of which species dominate. There are three transitional phases of woodland development (figs. 22–25 and table 2):

- Phase I – trees are present but shrubs and grasses are the dominant vegetation that influence ecological processes (hydrologic, nutrient, and energy cycles) on the site;
- Phase II – trees are co-dominant with shrubs and herbs, and all three vegetation layers influence ecological processes on the site;
- Phase III – trees are the dominant vegetation and the primary plant layer influencing ecological processes on the site. Shrubs no longer dominate the understory.

Stand characteristics can be used to classify woodland development according to these phases. Early indicators of site dominance include shrub canopy mortality and reduction of leader growth on tree saplings (<10 ft tall). Leader growth patterns are similar for western and Utah juniper, but only directly visible for piñon when the growth for the year is still in the ‘candle’ stage (fig. 22). That is, the stem growth for the year has been completed, but needle elongation has not. Once needle elongation in piñon has been completed, it is necessary to locate the bud-scale scars from the previous fall's terminal bud to determine leader growth. The number of years between initial tree encroachment and stand closure is largely determined by the rate of establishment and climate conditions. On most piñon-juniper sites, stands shift from Phase II to III within 100 years after the first trees establish.

Figure 22. Leader growth, particularly for trees <3m tall, is a good indicator of competition among trees. Although similar patterns exist for juniper and piñon, leader growth is only directly visible in the latter when in the 'candle' state.

(a) Utah juniper leader growth in Phase I woodlands

Figure 22. Continued.

(b) Utah juniper leader growth in Phase II woodlands

(c) Utah juniper leader growth in Phase III woodlands

Figure 22. Continued.

(d) Single leaf Piñon leader growth in Phase I woodlands

(e) Single leaf piñon leader growth in Phase III woodlands

Figure 23. Three phases of woodland succession in piñon-juniper woodlands.

***(a)* Subordinate – Phase I**
A subordinate piñon-juniper site with up-slope woodland expansion into mountain big sagebrush.

***(b)* Co-Dominant – Phase II**
A co-dominate piñon-juniper, Wyoming big sagebrush site with moderately deep soils.

(c) **Dominant - Phase III**
A dominant piñon-juniper site with Wyoming big sagebrush and moderately deep soils.

(d) **Dominant – Phase III**
A dominant piñon-juniper site with Wyoming big sagebrush on a south slope with a restrictive soil layer.

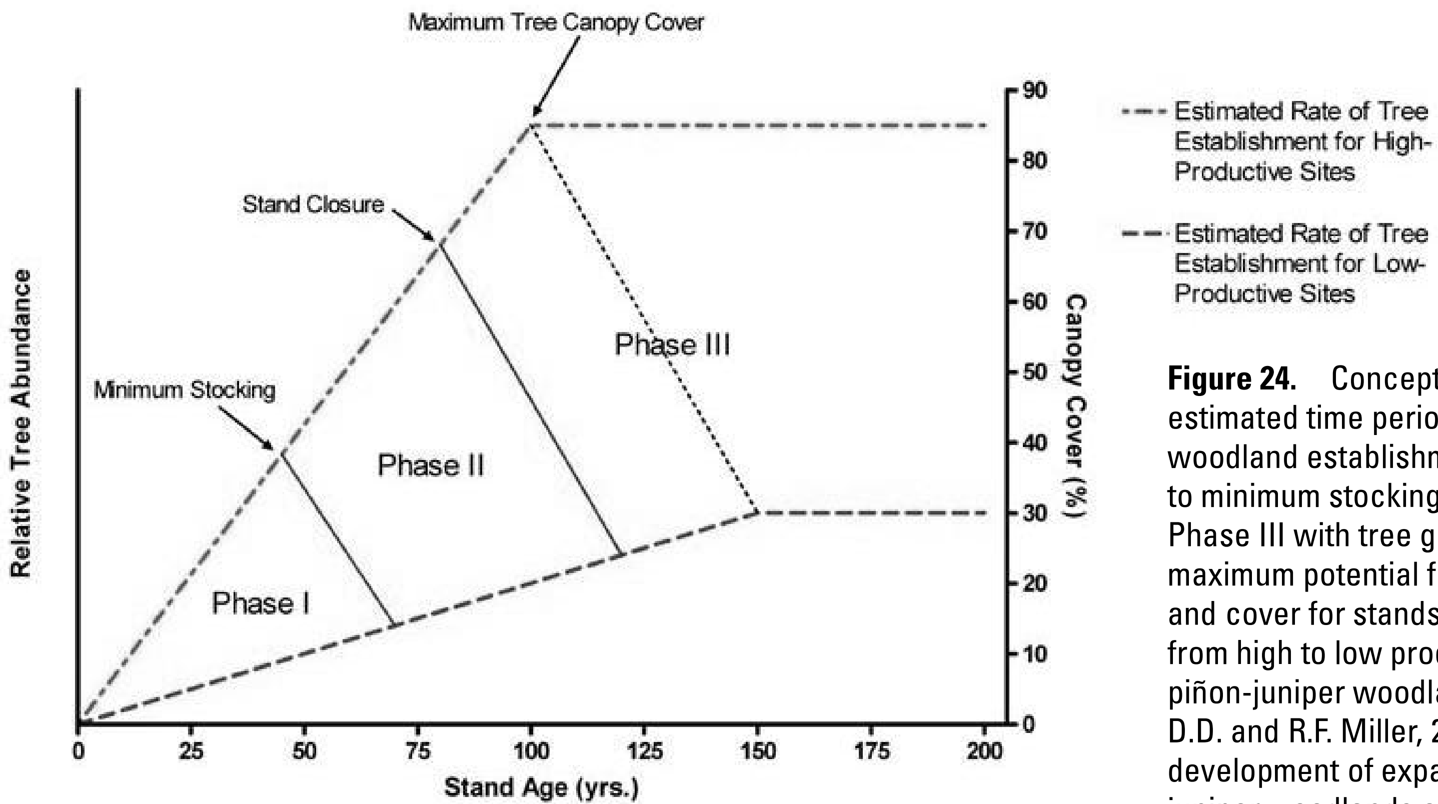


Figure 24. Conceptual model with estimated time periods form initial woodland establishment (early Phase I) to minimum stocking adequate to reach Phase III with tree growth, and estimated maximum potential for relative abundance and cover for stands developing on sites from high to low productivity (modified for piñon-juniper woodlands from Johnson, D.D. and R.F. Miller, 2006, structure and development of expanding western juniper woodlands as influenced by two topographic variables. Forest Ecology and Management 229:7-15).

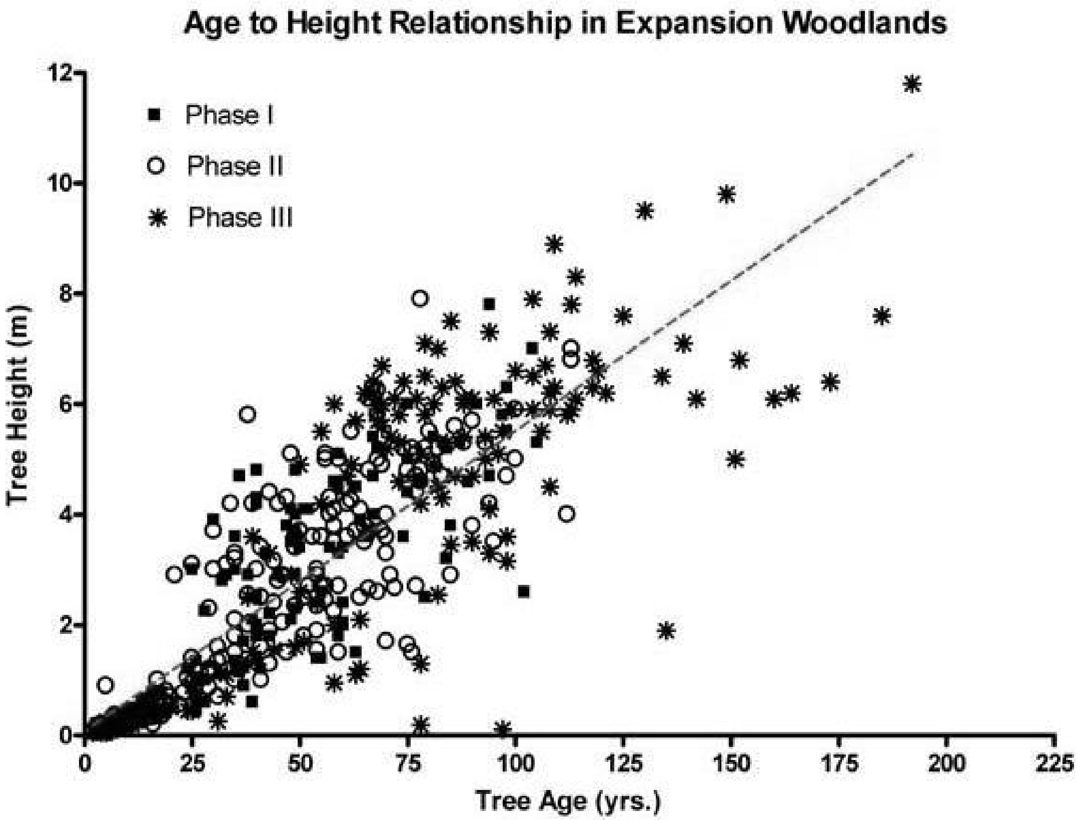


Figure 25. Relation between age and tree height across a range of tree dominance on relatively productive piñon-juniper sites: tree height of dominant and co-dominant individuals more than two meters tall can be used as a coarse proxy to estimate stand age (multiply meters by 3.28 to convert to feet). Drier sites may be older.

Phases of Woodland Succession			
Characteristics (post-settlement stands)	**Phase I (early)**	**Phase II (mid)**	**Phase III (late)**
Tree canopy (% of maximum potential)	Open, actively expanding <20%	Actively expanding 20 to 50%	Expansion nearly stabilized > 50%
Juniper leader growth (dominant trees) (cm/yr)	Terminal >10 Lateral >10	Terminal >10 Lateral 5 to >10	Terminal >10 Lateral <5
Piñon leader growth (dominant trees) (cm/yr)	Terminal >10 Lateral >5	Terminal >8 Lateral 2 <8	Terminal >5 Lateral <2
Crown lift* (dominant trees)	Absent	Absent	Lower limbs dying or dead, usually where tree canopy >40%
Potential juniper berry production	Low	Moderate to high	Low to near absent
Potential piñon seed production	Low	Moderate to high	Low to near absent in expansion woodlands, low to moderate in some old-growth
Tree recruitment	Active	Active	Limited

Table 2. Stand characteristics differentiating three transitional phases of woodland succession for most sagebrush associations.

Table 2. Continued.

	Phases of Woodland Succession		
Characteristics (post-settlement stands)	**Phase I (early)**	**Phase II (mid)**	**Phase III (late)**
Leader growth (understory juniper trees) (cm/yr) (figs. 22a-c)	Terminal >10 Lateral >8	Terminal 5 to 10 Lateral 2 to 8	Terminal <5 Lateral <2
Leader growth (understory piñon trees) (cm/yr) (Figs. 22d-e)	Terminal >10 Lateral >8	Terminal 3 to 8 Lateral 2 to 6	Terminal <4 Lateral <2
Shrub layer	Intact	Nearly intact to significant thinning	>75% dead

*Crown lift is the mortality of lower limbs, usually due to shading by neighboring trees, but also occurs on large, old trees (Figs. 16a-b).

16. What is the current herbaceous understory composition?

- Is the density of tall perennial bunchgrasses adequate for restoration, or should the site be seeded?
- What are the desirable species, and how abundant are they?
- Is there evidence of reproductive effort for the desirable species?
- Are there young, deep-rooted perennial grasses?
- Are there threatened or endangered species on the site?
- Are invasive plant species present, or are seed sources near the site?

Pre-treatment understory composition, especially the relative abundance of native perennial grasses and forbs, is the primary determinant of the success or failure of efforts to restore plant communities by removing or thinning the trees. How does the current understory composition compare to the desired understory composition? Does pre-treatment understory composition, particularly for the herbaceous species, indicate that the species will survive and that the site will recover following a severe natural disturbance or proactive treatment?

Limited research suggests that if at least two deep-rooted perennial grasses (that is, needle grasses, bluebunch wheatgrass, Idaho fescue) per 1 m^2 (10 ft^2) persist on the site, recovery of understory vegetation after treatment is possible, although this is likely to vary with soil type, precipitation regime, and method of treatment. If perennial grasses and forbs are not present, or if existing plants are in such poor condition that they are unlikely to survive the treatment, seeding likely will be necessary. The presence of an invasive species seed source, like cheatgrass, also may increase the need to quickly seed the site (fig. 26).

Figure 26. Third growing season after a high-severity fire in a high-productivity Phase III expansion piñon-juniper site. Crown cover in the pre-burn woodland exceeded 80%. Loss of deep-rooted perennials on an otherwise productive site resulted in cheatgrass and tumble mustard dominance.

17. Is there recruitment of native perennial understory species?

- Are there different size sagebrush or bitterbrush indicating recruitment?
- Are there perennial grass and forb seedlings or small, young-looking bunches?

The presence of established seedlings and young plants indicates ongoing recruitment of species, while presence of healthy, mature, seed-producing plants indicates that the potential for seed production still persists on the site. If old, decadent, or dying plants are common and no signs of active reproduction/recruitment are found, species are likely on the decline and the site may require restoration.

18. Are there invasive plant species on or adjacent to the site to be treated?

If undesirable plants, such as non-native weeds, are present on the site or present on adjacent sites, controlling their establishment and spread is likely to be an important part of the management plan. Weed invasion is more likely on the relatively warmer and drier sites, resulting from lower elevations and southerly aspects. Hot fires where woody vegetation is dense also will increase the potential of weed invasion (fig. 26). Several studies have shown that annual weeds can dramatically increase immediately after a tree-removal project or wildfire, but can decrease over a period of years if an adequate density of native perennials exists on the site prior to disturbance. A careful evaluation of expected desirable plant response based on the perennial grasses and forbs existing on the site prior to treatment, along with clear alternative plans in the event that native understory recovery does not occur as expected, will increase the likelihood of successful restoration.

19. What is the percentage of dead shrubs on the site, and what are the species?

As expansion woodlands increasingly dominate a sagebrush community, the number of suppressed and dead shrubs increases. A large number of dead shrubs indicates a site that was recently and rapidly dominated by trees (fig. 27).

Figure 27. Rapid expansion and growth of piñon-juniper has led to bare ground and dead shrub skeletons. With heavy crown fuels, this Phase III woodland will burn under severe conditions, and introduced annual weeds will dominate the site following fire.

20. What are the fuel characteristics, and what types of fire will the site support?

- What type of prescribed fire will the site support, and will it burn under moderate conditions, or will it require more extreme conditions (fig. 28.)?

Figure 28. This site lacks both woody and herbaceous understory to carry a fire and adequate desirable herbaceous species for restoration. This Phase III woodland often burns under extreme conditions, with the outcome of introduced annual weeds dominating the site following fire (see fig. 26).

An assessment of fuel characteristics and their contribution to fire potential and behavior and an understanding of how natural processes (for example, water, nutrient, fire cycles) may be affected by treatment or no management action are necessary for selecting management treatments. Is herbaceous vegetation in the understory providing fine fuels? Does the amount of shrubs and small trees in the plant community provide sufficient ladder fuels to carry fire into tree canopies? Are the trees dominated by juniper, piñon, or a mix of the two? Does the site have a closed tree canopy? Are there openings in the canopy that may result in a mixed-severity fire with a mosaic fire pattern? Late Phase II, in addition to Phase III sites, often have sufficient crown cover to carry crown fires throughout the entire site with low humidity, high temperatures, and sufficient winds. The more piñon trees in the mix, the more potential for a crown fire. The bark of piñon can provide its own ladder fuels and carry the fire into the canopy if the fuels in the needle mat catch fire and fuel moistures are low. Branching at the base also facilitates fire reaching the crown.

Vegetation composition and fuels of the surrounding landscape landscape can directly affect fire risk and the ability to contain prescribed fire. Very high fuel loads adjacent to a site can greatly increase fire risk, and result in larger fires than planned.

21. Are there signs of erosion and overland flow? What is the current capacity of the site to capture, store, and safely release water (derived from interpreting indicators of rangeland health[2])? What is the incidence of high-intensity summer thunderstorms?

Sites with large areas of bare ground, relatively fine-textured soils, steeper slopes, and potential for high-intensity thundershowers are susceptible to erosion. Runoff can move continuously through connected inter-canopy zones of bare ground, causing accelerated erosion (fig. 29). Soil in bare inter-canopy zones also is more susceptible to raindrop impact, soil crusting, decreased infiltration, and increased erosion due to lack of protection from vegetation. A thick overstory of trees also can reduce soil-water-capture and infiltration by limiting the amount of precipitation that reaches the

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[2]Pellant, M., Shaver, P., Pyke, D., and Herrick. J., 2005, Interpreting indicators of rangeland health version 4: Technical Reference 1734-6. U.S. Bureau of Land Management, National Science and Technology Center Denver, CO, 122 p. Available online at http://fresc.usgs.gov/products/papers/1385_Pellant.pdf.

Swanson, S., Bruce, B., Cleary, R., Dragt, B., Brackley, G., Fults, G., Linebaugh, J., McCuin, G., Metscher, V., Perryman, B., Tueller, P., Weaver, D., and Wilson, D., 2006, Nevada Rangeland Monitoring Handbook, Second Edition: Educational Bulletin 06-03. Available online at http://www.unce.unr.edu/publications/files/ag/2006/eb0603.pdf.

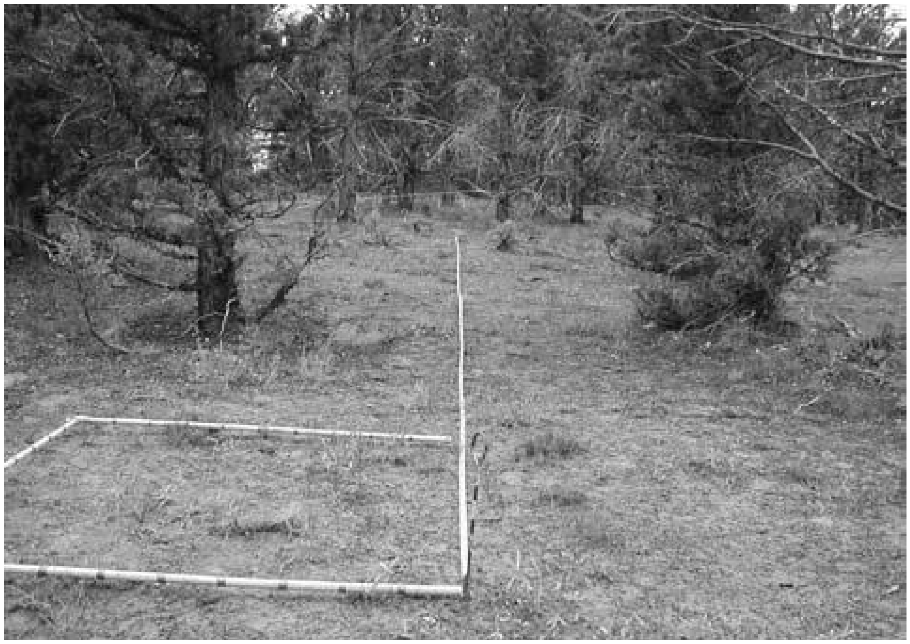

Figure 29. A Phase III Utah juniper site with large areas of bare ground potentially susceptible to accelerated runoff and erosion.

ground. Research indicates that when tree dominance is reduced and herbaceous cover is increased, runoff and soil erosion decrease on sites with relatively fine-textured soils. Leaving tree debris on the ground after mechanical treatments can intercept runoff and increase infiltration, increase soil moisture by reducing evapotranspiration and evaporative loss of soil water, and promote nutrient cycling. Signs of erosion may include rills, gullies, plant pedestals or terracettes, and water movement of large amounts of plant litter. Water flow patterns that show coalescing rills indicate high erosion potential (fig. 30).

Figure 30. A piñon-juniper site with large, connected zones of bare ground and water flow patterns in the inter-canopy.

22. What is the current wildlife habitat suitability, and what species are involved? How will treatment affect wildlife species?

Habitat suitability will largely be determined by the composition and structure of vegetation at the community and landscape level. The spatial arrangement and connectedness of plant community patches are important attributes in determining habitat suitability.

Increasing tree dominance at the community and landscape levels results in a decline in landscape and plant community diversity, which reduces wildlife abundance and diversity. Research has not identified any wildlife species that are obligates to closed (Phase III) woodlands. However, old-growth and open woodlands can provide important habitat especially for cavity nesters. Some habitat suitability conditions to consider when planning treatments are:

- Is the site in a transitional phase that will alter structure and composition, resulting in a change in habitat suitability?
- Juniper berries (female cones) can be an important winter food source for a variety of birds. Piñon nuts also are an important food source for many small mammal and bird species, particularly the Piñon Jay and Clark's Nutcracker. Maintaining a woodland component on sites where these species are present can be beneficial. However, as woodlands transition toward Phase III, juniper berry and pine nut production declines.
- Bird species diversity and richness are greatest in Phase I and early Phase II, when understory vegetation is still intact because these phases provide important structural diversity.
- Greater numbers of tree cavity-nesting birds are usually found in old-growth woodlands (fig. 31).
- Mule deer and elk use tree stands as winter cover. Dense stands with trees more than 5 ft tall provide optimal thermal cover but minimal food resources if dense stands are present across large areas of the landscape.
- Decreased shrub cover due to woodland development and tree dominance results in decreased browse available for deer, elk, and other species.
- Decreases in grasses reduce seed production and seeds eaten by small mammals and birds.

Figure 31. Tree cavity in the trunk of an old-growth singleleaf piñon. Old stands of trees have a relatively high density of cavity nesting birds.

23. Are there social or economic concerns and issues tied to the site?

Treatment of a site may not be feasible or practical due to ecological, economic, or sociological reasons. Treatment can be expensive, especially for Phase III woodlands, because of inputs needed to return the site to a desired condition, and achieving desired results can be difficult. Because Phase III woodlands are increasing in area, the potential for wildfires of increased intensity and severity is greater. Following wildfires, these sites will require expensive treatment to prevent dominance by cheatgrass and other exotic species (fig. 26).

Conducting an economic evaluation of the options may assist a manager in considering the long-term environmental consequences. Not all benefits and costs involved with these treatments are quantifiable or have dollar values attached to them. This also applies to the long-term costs/benefits of not treating a site. In such cases, a social costs/benefit analysis can be used to identify both the quantifiable and non-quantifiable benefits and costs. Where dollar values cannot be determined, other economic principles may need to be determined to assist in allocating resources, such as treatment funds and labor.

Treating a stand in Phase I may make more economic sense than waiting until mid Phase II or beyond even though the apparent immediate benefits may be lower. Regardless of phase, seeding can be more risky on dry sites, where a high amount of erosion has occurred, where safe sites are not plentiful for seedling establishment, or where non-native invasive species are likely to quickly occupy the site. Tree removal on sites where any treatment is not likely to succeed may cause greater ecological damage (for example, increased bare ground, erosion and nutrient loss, increased weed invasion, and loss of wildlife habitat) than no management action. The potential increase in fire intensity and size with a continual increase in tree dominance also may need to be considered.

Social issues to consider include wildland-urban interface values, perceived ecological impacts of different treatments, concerns for sensitive wildlife and plant species, recreation, development, archeological sites, etc.

Part III: Landscape Considerations

24. What are the spatial landscape characteristics of the area to be treated with respect to topography, patch[3] size, edge, and connectedness?

Patch Size: Treatment patch size is especially important to consider in relation to use by wildlife and livestock. Is the treatment size large enough to provide suitable conditions for wildlife species of concern? Is the treatment area so small that post-treatment overuse/overgrazing by domestic or wild herbivores will threaten the survival of newly established understory plants or aspen? Even with adequate forage in the area, the palatability of plants for several seasons after a fire will be higher than before, and burned patches will tend to attract wild and domestic herbivores. Is the patch size large enough to justify post-treatment management changes, such as no grazing for 1 or 2 years before or after the burn? If the treatment site is a relatively small area within a much larger pasture, resting the entire pasture from grazing may not be economically feasible or socially acceptable. Doing so may result in more ecological harm at other sites as grazing pressure is moved to those locations on either public or private land. Fencing a smaller treated area may be a viable option.

[3] A patch is defined here as an assemblage of plant species growing on a contiguous area forming a plant community with a defined boundary and possibly representing different successional stages within an ecological site.

Edge: When needed, will treatment shape and layout create sufficient edge habitat that is valuable to wildlife? What treatment procedures will be used to result in sufficient edge habitat that is valuable to wildlife? How will the spatial distribution of edge influence seed rain from adjacent unburned sites onto the treated site? Feathering the edge can result in a more natural-looking appearance, as well as providing for more edge habitat.

Connectivity: Is the connectivity of various patches across the landscape important for wildlife species of concern? Patch topographic relationships and connectivity can influence wildlife movement, recruitment, predation, etc. Distance to similar patches or patches of concern and the vegetation conditions in between are part of a complex interaction of variables that influence connectivity for different wildlife species. Because they affect wildlife movement, recruitment, predation, etc., they need to be considered.

25. What is the composition of adjacent patches, what is their landscape distribution of vegetation patches, and what are their stages of woodland succession?

After considering how the site is connected to, or isolated from other patches and the distance to similar patches, will the treatment enhance wildlife habitat and watershed health? Do corridors exist between suitable habitat patches for wildlife movement? Does the composition of patches across the landscape provide diverse habitat for a variety of wildlife in all seasons? How will treatment affect biodiversity at the landscape level?

26. What is the current variation in understory composition and in the recruitment of native understory species over the surrounding landscape?

The usefulness of treatment for a particular site can be influenced by the understory composition and recruitment present on the landscape around the site. Treatment of a site surrounded by Phase I and early Phase II woodlands, for example, can do more to enhance wildlife habitat than if it is surrounded by late Phase II or Phase III woodlands that may limit wildlife access and increase the risk of damage from adjacent crown fire.

27. How do fuel characteristics of tree, shrub, and herbaceous layers vary over the surrounding landscape, what type of fires are they likely to support, and how might this influence the types of fire possible on the site?

The fuel load characteristics on the landscape around the site of concern can, and in many circumstances will, override the fuel load characteristics of the site. This can result in types of fires that might not otherwise occur on the site, particularly wildfire.

28. Are there signs of erosion and overland flow from the surrounding landscape that suggest impacts to the site?

Watershed characteristics of the surrounding landscape, particularly up slope of the site, may have more to do with erosion occurring on the site than the conditions on the site.

29. Will the conditions of the surrounding area influence the wildlife habitat suitability of the site, or affect the species involved?

Landscapes are composed of patches of different topographic sites, plant communities, and habitats. Management of landscapes rather than just individual stands includes consideration of patch composition, topographic and spatial arrangement, size, and connectivity. Consideration of which patches and how much to treat are important. Portions of these landscapes may provide key habitat for certain species (that is, sagebrush cover for sagebrush obligates or deer fawning). The initial removal of sagebrush as trees are removed may be necessary to maintain the long-term integrity of these important habitats. An alternative would be to treat a percentage of these key habitats, saving the remaining proportion for treatment at a later date when the treated areas have recovered. Maintaining a mosaic of patches of different successional stages also may be desirable for maximizing habitat diversity, reducing fuel continuity, increasing snow capture, etc.

30. What are current uses, management activities, and social and economic concerns for the surrounding landscape that might affect the site?

It is important to consider how a treatment will affect current use and management activities in the short and long term. If the immediate treatment negatively affects wildlife habitat or livestock grazing, how long will it take to realize benefits of treatment? Are there other areas available for these uses during the short term? If the treatment location is within a larger area that is being managed for other purposes such as fuels reduction, how will the treatment affect, and be affected by this management?

Part IV: Selecting Appropriate Management Actions and Treatments

Woodland structure within and across successional phases, in addition to age, is largely determined by the type, frequency, and intensity of disturbance, especially wildfire. The most ideal management actions will be determined by considering the composition of all vegetation layers of the communities involved, economic feasibility, and social acceptability.

31. What are the factors that will influence selection of preventive, maintenance, or restoration treatments, including personnel available, grazing schedules, and wildfire risk?

1. Pre-treatment fuel composition, loading, and structure
    - Tree sizes
    - Number of trees per acre
    - Dead plant material
    - Herbaceous plant composition, size, and density
    - Shrub composition, size, and density
2. Plant composition
    - Abundance of desirable species
    - Desirable fire-sensitive species (for example, sagebrush, bitterbrush)
    - Invasive species
    - Woodland phase
3. Ecological site, soils, and topography

4. Species of concern (for example, sage grouse)
5. Objectives
6. Size of area to be treated
7. Legal liabilities and risks from proximity to other plant communities (for example, forest)
8. Cost and resources
9. Social acceptability

All nine factors also can be easily modified for use in the determination of post-fire management response.

32. What are treatment options, including mechanical, prescribed fire, cut and burn combinations, chemical applications, and seeding?

Mechanical Treatments

Mechanical treatments are often used to reduce tree dominance in Phases II and III woodlands. However, they make seedbed preparation and sowing difficult when the site requires revegetation. In general, the advantages of mechanical removal of trees include flexibility in timing of treatment application and the ability to precisely control treatment boundaries or targeted trees. For example, old-growth trees can be left as wildlife habitat. With mechanical treatments, the impact to understory vegetation is often minimal. Cut trees, slash, or chips also can be left on site to control erosion and provide safe sites for seedling establishment or to enhance wildlife habitat. Although Utah juniper is non-sprouting, the lower most limbs and green buds at the base must be removed to kill the tree (fig. 32).

Figure 32. Example of juniper resprouting after chainsaw cutting left a lower limb.

Disadvantages are that mechanical methods often require follow-up treatment for small trees not initially removed, fuel loads can be increased by leaving cut trees/slash on the site, and treatment can be difficult to implement and costly when working in areas with rough terrain. Large amounts of slash in late Phase II and Phase III create a fire hazard for a minimum of 2 years and can limit the mobility of large herbivores (domestic and wild). Heavy slash, which may kill desirable plants by shading, will provide open sites for establishment of introduced species. It also may alter site nutrient relations.

Patience may be required in regards to treatment response when using mechanical treatments for restoration. A delayed understory response is common. Understory response in the first year after treatment is unpredictable, and it may take several years for understory plants to fully occupy the treated area.

Heavy machinery: Heavy machinery can be used to reduce tree dominance, but these treatments tend to be expensive and should not be used when soils are excessively wet. Methods include using bulldozers to push trees over, chaining with bulldozers that pull anchor chains or steel cables to uproot trees, or the use of mechanical cutting and grinding devices such as the Bull Hog™ (fig. 33). Chaining can occur in one or two (opposite) directions, usually with seeding occurring between the two directions. When it fits project goals and is economically possible, removal of the downed trees can reduce fuel loads.

Figure 33. An example of tree mastication (bullhogging) on a juniper-dominated site in western Utah.

Soil conditions, such as texture and moisture content, and machinery operation (for example, use of tight turns) should be evaluated, and factored into plans in order to minimize soil compaction and surface disturbance, such as avoiding times when soil-water content is high. Impacts on desirable understory vegetation also may be a concern with use of heavy machinery, but effects are often light to moderate with chaining. While, chaining has not been used in western juniper woodlands since the 1980s, it is still occasionally being used in piñon-juniper woodlands in Nevada, and in Utah after a fire. When not following a fire, chaining often requires a follow-up treatment, such as fire, to eliminate saplings and sustain the life of the treatment. Mastication treatments such as bullhogging are increasingly being used in Nevada and Utah. The short- and long-term ecological effects of these treatments are under study.

Feller bunchers cut and lay groups of 3–8 trees (depending on size) on the ground. Bundles can be left in place, burned, or chipped. However, little is known about the ecological effects of burning piles or leaving chips on site. Soil surface disturbance from feller bunchers is usually minimal on dry soils. Depending on the price being paid for chips and the distance they must be hauled, biomass utilization can significantly offset, if not pay for, the cost of tree removal. For more remote areas in which piñon-juniper woodlands are often found, transportation costs can make hauling the wood chips prohibitive.

Chainsaw cutting: Chainsaw cutting selectively kills trees with minimal soil disturbance (fig. 34). Costs increase when treating areas with steep terrain or areas where use of heavy machinery is not feasible. Cutting may be the only treatment option in areas of cultural resource concern. Expense of cutting treatments increases when limbs or slash are spread across the site, so this should only be done where post-treatment erosion is a risk. Smaller areas can often be more economically treated by opening them to the public for firewood cutting. This treatment will maintain and usually increase stand vigor of non-sprouting understory shrubs like sagebrush. However, cutting that leaves debris in place may increase the risk of fire.

Figure 34. Piñon-juniper chainsaw cutting in woodlands.

(a) On a juniper-dominated site in western Utah.

Figure 34. Continued.

(b) One year after chainsaw cutting on a piñon-juniper, Wyoming sagebrush site in eastern Nevada.

(c) Second growing season after chainsaw cutting on a piñon-juniper, Wyoming sagebrush site with Phase II woodlands.

Figure 34. Continued.

(d) Second growing season after chainsaw cutting on a piñon-juniper, Wyoming sagebrush site with early Phase III woodlands.

Prescribed Fire: Prescribed fire is often the most economical way of treating larger landscape areas, particularly when woodlands are in Phase I or early Phase II. The primary factors that will influence post-burn response to fire are:

- Plant community composition
- The presence or absence of perennial grasses, forbs, and seed pools prior to treatment
- Ecological site (site potential)
- Extent and patchiness of fire
- Climatic conditions before, during, and after the fire, which can increase stand vigor of non-sprouting shrubs like sagebrush. However, cutting that leaves debris in place may increase the risk of fire.

Prescribed fire treatments can produce desirable results on sites with woodlands in Phases I and II particularly when there is an abundance of perennial natives in the understory (>2 desirable grasses/m^2) (figs. 35a-b). On sites that are in late Phase II or Phase III and have a depleted understory, (1) fire may be difficult to carry through the stand as a result of limited ground and ladder fuels, (2) treatment may be more costly due to the need for higher inputs (see cutting and burning), and (3) site response less predictable with potential for success lower (for example, more annuals versus perennials in the response compared to treating sites in earlier states of woodland succession). Where tree dominance is high and woodlands are contiguous, crown fires can rapidly cover large areas. When piñon dominates, their bark can easily carry fire into the crown. When weeds, such as cheatgrass, are present on the site, risk of failure is increased, especially if the site is warm and dry, or where soils are shallow or fine-textured. Additional follow-up treatments to reduce undesirable species and seed herbaceous perennials can be beneficial.

(a)

(b)

Figure 35. Understory responses 2 years after prescribed fire in Phases (*a*) I, (*b*) II, and (*c*) III piñon-juniper dominated Wyoming big sagebrush communities in eastern Nevada.

(c)

Figure 35. Continued.

An initial response to either prescribed fire or wildfire includes decreased litter and woody vegetation and increased bare ground. How will these responses affect wildlife (that is, loss of the shrub layer), water runoff, and erosion in the short term? Mountain big sagebrush usually will recover to pre-burn levels within 25 to 35 years (varies with climate and seed source). Recovery in Wyoming big sagebrush areas is usually slower, but not always (fig. 36). Controlling the temperature and duration of prescribed fire, primarily where 100 and 1,000 hour fuels are heavy, is important for protection of the soil and understory vegetation. This may be achieved by fuel preparation so the fire treatment can be applied under more mild weather conditions. Sites that have a greater incidence of summer thunderstorms, finer textured soils, and steeper slopes have the highest soil erosion potential. Hydrophobicity can be a problem directly beneath the tree canopy resulting in limited seedling establishment and increased soil erosion.

Figure 36. Thirty-five-year-old north-slope wildfire that burned through Phase III expansion piñon-juniper woodlands (still present in the background). It is now dominated by Wyoming big sagebrush with green rabbitbrush and green ephedra sub-dominant.

Burning in Aspen for Juniper and Piñon Removal

Due to high fuel-moisture conditions often found in aspen forests, prescribed fire can be difficult to implement. However, if suitable conditions (for example, fuel preparation – see ‘Prescribed Fire’ on p. 78) exist for fire, burning can produce desirable results. Protection from livestock and wildlife use may be necessary for aspen establishment after treatment. Research indicates this could take about 3 to 5 years to allow the terminal buds to grow above the browse line, but depends on site conditions and climate.

Cut and Burn Combinations: A combination of cutting and then burning is used to (1) increase ground fuels to carry fire or (2) remove tree slash created by cutting. This treatment combination is most often used in late Phase II and Phase III. Late summer or fall burning in Phase III can have severe effects on understory vegetation resulting in >75% mortality. Late fall or winter burning (late Sept.–Mar.) has less-severe effects resulting in 20–50% mortality of the remaining perennial grasses. Cut and burn treatment of Phase III stands is higher risk and more expensive than in Phases I and II. Cutting no more trees than necessary is recommended to keep the treatment as cost-effective as possible and to avoid building a fuel load that will result in a fire that is too hot. Other precautions noted earlier regarding understory vegetation, erosion, wildlife habitat, economic feasibility, and social acceptability on Phase III woodlands need to be considered.

Research on social acceptability of vegetation management in rangelands has found that citizens generally prefer prescribed fire as a treatment because it is perceived as more "natural" than other treatments. However, preference is maintained only insofar as smoke levels and risks of adjacent property damage are low; in locations near human habitation, mechanical treatment may be more acceptable to the public. All other things being equal, citizens are likely to prefer chainsaw cutting over the use of bulldozers. No published research has examined the relatively acceptability of cutting and grinding machines (that is, bullhogging)[4].

Chemical Treatments

Because past chemical application on piñon and juniper, particularly western juniper, has met with poor or mixed results, only limited information is available to guide managers in using this method. The most important consideration for chemical treatment of woodlands is site selection. Chemical treatment should only be used on sites where the herbicide will work as intended (for example where the soil type, especially

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[4]Brunson, M.W., and Shindler, B.A., 2004, Geographic variation in social acceptability of wildland fuels management in the western U.S.: Society and Natural Resources, v. 17, p. 661-678.

high clay content, will not interfere with the chemical's performance) and the understory has potential to respond. Following herbicide treatment, standing trees may interfere with subsequent weed control and seeding of perennials. Social acceptability tends to be lower for chemical treatments than for any other restoration method.

Tebuthiuron and Picloram: Aerial application of pelleted tebuthiuron and picloram has been the most effective way of chemically controlling Utah juniper and piñon. Understory species tend to recover faster from picloram than tebuthiuron applications. Rates of up to 1.1 kb active ingredient/ha have been effective. Applicators should carefully follow label recommendations. High rates are more effective on more clayey or deep soils, while lower rates may be effective on shallow soils near ridge tops.

Other Chemicals: Velpar L. Pronone Power Pellets, Chopper and Arsenal treatments have been shown to be effective in northern California for juniper trees as tall as 6 ft. Chopper and Arsenal also have shown to be effective for treating cut juniper stumps with green limbs remaining below the cut.

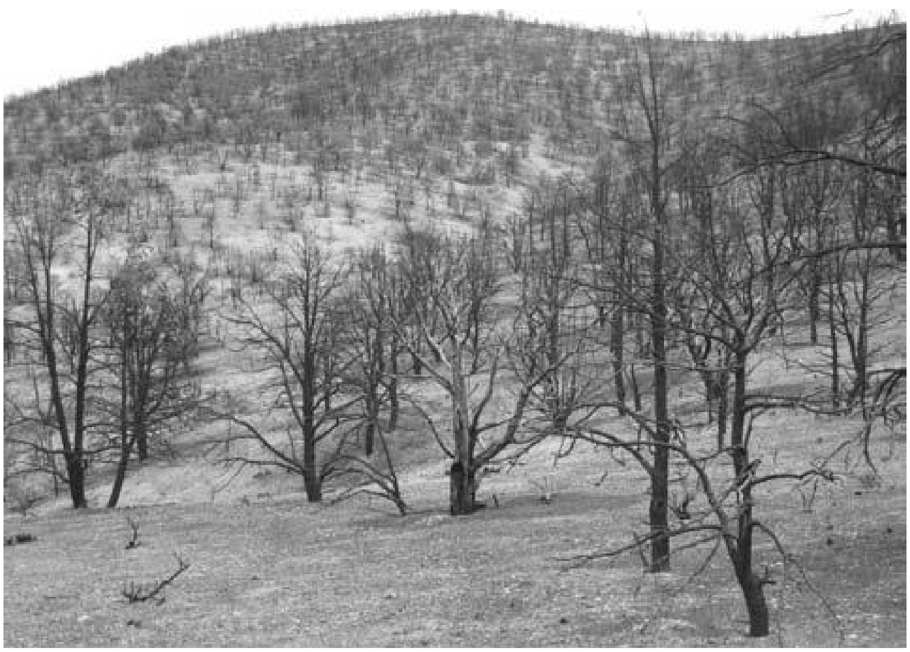
Seeding

Success of seeding on treated sites to reduce tree dominance is greatly influenced by effective precipitation and soil texture. Because tree stumps typically remain following fire and downed trees or slash are present after mechanical treatments, broadcast seeding is often used. Methods that provide for good seed/soil contact should be used if possible. Seeding without some provision for seed coverage has only been successful for years or sites with high precipitation. Drill seeding is preferable in Phase I and low density Phase II stages or broadcast seeding followed by dragging a chain across the surface.

Establishment of introduced and native grasses has been more consistently successful than that of native forbs or shrubs. Establishment of big sagebrush is inconsistent but may be enhanced by dropping seeds and pressing them into the soil surface with a packer wheel on a specialized drill or by aerial seeding on snow. Please see “restoring western ranges and wildlands” for detailed seeding recommendations (http://www.fs.fed.us/rm/pubs/rmrs gtr136.html) (figs. 37 and 38).

Figure 37. Moderate-severity fire (notice needles on trees) where 80% of the native species in the understory survived; no seeding is required.

(a)



(b)

Figure 38. Examples of high-severity fire (notice no needles or bark remain on trees) where mortality of native herbaceous species was >80%. (*a*) One year after a western Utah fire, the site is dominated by introduced annual and biannual weeds; seeding required to reduce the spread of invasives. (*b*) One year after a fire in a dense Phase III expansion piñon-juniper site. Fire severity was such that only a few green plants are visible, most of them exotic annuals. Without seeding, the risk of dominance by exotic annuals is high.

33. How will post-treatment management, including the need for maintenance on the site, and on the surrounding landscape affect site conditions and function?

Maintenance of desirable site conditions is most likely when post-treatment management remains adaptive and flexible, and when plans are continually reassessed. An optimal management approach considers short- and long-term successional responses and evaluates the benefits of maintenance of the site with follow-up treatments. A good post-treatment monitoring plan should be implemented. At a minimum, photographs should be taken at established points on a regular basis and cover of the dominant species should be assessed across the project area. More detailed monitoring may be necessary in areas where negative hydrologic responses or invasive species are potentially a problem. Changes in the condition of the landscape area adjacent to the treated site should also be noted.

How will treatment influence the distribution of livestock and wildlife use of the site? Rest from grazing following treatment will significantly improve the likelihood of success, especially if the understory is depleted. If it is not possible to keep animals out of the treated area, grazing impacts can be reduced by controlling placement of water and mineral supplements or grazing when herbaceous species are dormant in late summer and fall. This may also require the limitation or postponement of grazing in the surrounding area. After fire, 2 years of rest from grazing is a common practice, but plant response is often a better indicator of the actual amount of rest needed. In more arid areas or in areas in poor ecological condition prior to treatment, complete deferment and longer rest periods may be necessary. Grazing during the growing season in the first and second years following treatment has been shown to increase mortality and decrease leaf and seed production of desirable grasses. It also has been shown to increase the establishment and reproduction of invasive species like cheatgrass. Grazing after seed set in the first 2 years following treatment has been shown to have lesser effects on plant health. However, maximizing seed production and seedling establishment after treatment is important, and production of grass and forb seed is not likely to be significant until the second year post-fire. Usually, cutting and chemical applications minimally affect understory vegetation, but heavy equipment or high-severity fire may have greater impact.

Appendix 1: Field Assessment Form

Site Name

Location

Date

I. Ecological Site / Plant Association

A. Diagnostic sagebrush species____________________

B. Bitterbrush present? Y / N

C. Diagnostic perennial grass(es) ___________________

D. Old growth on the site (table 1)? Y / N

E. Large wood found on the site? Y / N

F. Plant association or PNV ________________________

G. Ecological Site _______________________________

a. Soil Type

H. Historic fire return interval (key 2) _______________

I. Soil erosion potential High Moderate Low

J. Species of concern ____________________________

II. Current State

A. Dominant shrub _______________ recruitment. Y / N

B. Desirable shrub _______________ recruitment. Y / N

a. % dead <10% 11-25% 26-50% >50%

C. Dominant grass(es) ____________________________

a. $\geq$2 desirable grasses/m^2? Y / N

D. Post-settlement trees present? Y / N; Phase I II III

E. Invasive species present? Y / N

F. Evidence of surface erosion (rills, sediment dams, pedestals, etc.)? Y / N

G. Current plant community ________________________

H. Perceived problem ______________________________

I. Habitat suitability for target species
Low Moderate High

a. If low or moderate, what is missing?

J. The site will burn With / Without pre-treatment.

K. Social concerns ________________________________

L. Current uses ___________________________________

III. Landscape considerations

A. Size of area to be treated _______________________

B. How will treatment affect adjacent patches? ________

C. Treatment will fragment / link adjacent patches.

IV. Management Action

Phase I and/or II (circle treatment recommendation)

A. Cut

B. Burn

C. Seeding required Y / N

D. Other options _________________________________

Phases II and/or III (circle treatment recommendation)

A. Partial cut and broadcast burn

B. Cut drop and leave

C. Cut drop and burn

D. Cut pile and burn

E. Seeding required Y / N

F. Other options _________________________________

Considerations

A. Small trees may require follow-up

B. Weed potential, shrub layer, liability, structures, containment

C. Post treatment

D. Monitoring

Appendix 2: Species Codes

Species Codes		
Code	**Scientific Name**	**Common Name**
AMAL	*Amelanchier alnifolia*	Serviceberry
ARAR	*Artemisia arbuscula*	Low sagebrush
ARARLO	*Artemisia arbuscula longiloba*	Early sagebrush
ARNO	*Artemisia nova*	Black sagebrush
ARTRWY	*Artemisia tridentata ssp. whyomingensis*	Wyoming big sagebrush
AFTRTR	*Artemisia tridentata ssp. tridentata*	Basin big sagebrush
ARTRVA	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush
BRCA	*Bromus carinatus*	Mountain brome
GRSP	*Grayia spinosa*	Spiny hopsage
PUTR	*Purshia tridentata*	Bitterbrush
SYM	*Symphoricarpos* species	Snowberry
TECA	*Tetradymia canescens*	Spineless or gray horse-brush
ACNE	*Achnatherum nelsonii*	Colombia needlegrass
ACTH7	*Achnatherum thurberiana*	Thurber’s needlegrass
ACHY	*Achnatherum hymenoides*	Indian ricegrass
ACSP12	*Achnatherum speciosa*	Desert needlegrass
FEID	*Festuca idahoensis*	Idaho fescue
HECO26	*Hesperostipa comato*	Needle and thread
PSSP5	*Psuedorogneria spicata*	Bluebunch wheatgrass

Glossary of Terms

Bare ground: exposed mineral soil that is susceptible to raindrop splash erosion. The size, distribution, and connectedness of bare ground are the most important contributors to site stability relative to site potential.

Cover type: see potential natural vegetation.

Ecological site: a type of land with specific physical characteristics that differs from other types of land in its ability to produce distinctive kinds and amounts of vegetation and its response to management. Apparently synonymous with ecological type used by USDA Forest Service, and Rangeland Ecological Site (http://esis.sc.egov.usda.gov/Welcome/pgReportLocation.aspx?type=ESD).

Ecological function: referred to here as the actions or behavior of important processes such as hydrology, nutrient cycling, and energy capture.

Fire Return Interval (FRI) (or fire free interval or return fire interval): the number of years between two successive fires documented in a designated area (that is, the interval between two successive fire occurrences); the size of the area must be clearly specified. Variability in intervals is the meaningful reality of the disturbance regime on the site, not the mean (MFRI).

Fluted: pockets where the cambium layer folds in on itself forming deep grooves or bark pockets.

Fuel: all burnable material live and dead.

Functional goals: examples are watershed health, habitat for a defined set of species, etc., which are met by a desired set of conditions on the site often determined by vegetation composition and structure.

Gullies: channels that have been cut into the soil by moving water.

Ladder fuel: material on or near the ground that will carry fire from the ground to the crown of trees (that is, sagebrush, bitterbrush, dead down wood and branches).

Management unit: an area of land defined by boundaries where a management strategy is to be applied. The land area may be composed of one or more ecological sites, and the entire area may or may not be treated.

Mean Fire Return Interval (MFRI) (or mean fire free interval): arithmetic average of all fire intervals determined in a designated area during a designated time period; the size of the area and the time period must be specified. MFRI only provides the central tendency; variability in intervals is the meaningful reality of the disturbance regime on the site, not the mean (MFRI).

Post-settlement trees: trees establishing after 1860.

Potential natural vegetation (PNV): the vegetation that will persist under the pre-settlement disturbance regimes and climate. PNV is an expression of environmental factors such as topography, soils and climate across an area where cover type is a classification of existing vegetation. The existing cover type at any particular location and time may reflect a vegetation community anywhere along its successional pathway—from seral to climax.

Pre-settlement: trees establishing before 1860 (see old-growth).

Old-growth: a relative term that has been based on morphological characteristics, actual age, or general period of establishment (pre- and post-settlement, before or after 1860).

Rills: small, erosional rivulets that are generally linear and do not necessarily follow the microtopography that flow patterns do.

Savanna or savannah: grassland or shrub-steppe with widely scattered trees (<10% canopy cover).

Soil/site stability: capacity of an area to limit redistribution and loss of soil resources including nutrients and organic matter by wind and water (Pellant, M., Shaver, P., Pyke, D.A., Herrick, J.E. 2005. Interpreting the indicators of rangeland health (version 4). BLM Technical Reference 1734-6. United States Department of the Interior, Bureau of Land Management National Science and Technology Center, Denver CO. 122 p.).

Species of concern: species that require special consideration in restoration. These include species that may increase following treatment (that is, noxious weeds) or species that are declining or appear to be in need of concentrated conservation actions, including State Endangered, State Threatened, State Sensitive, or State Candidate species.

Stocking: fully stocked site is one with enough trees that does or will eventually fully occupy a site (that is, at maturity, interspecific competition limits the expansion or addition of new leaf canopy). Stocking density varies across ecological sites and with tree size.

Water flow pattern: the path that water takes as it moves across the soil surface during overland flow. Evidence of water flow patterns include redistribution of litter, soil or gravel, or pedestalling of vegetation or stones.

Woodland: an area of smaller statured trees usually with canopy cover >10%; open 10-20%, intermediate 20-40%, dense >40%.

Abbreviations

Abbreviation	Definition
in.	inches
ft	feet/foot
m	meter(s)
cm	centimeter(s)
mm	millimeter(s)
ha	hectare
%	percent
yr(s)	year(s)

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USGS Tausch and others—**Piñon and Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions**—Circular 1335

Substrate and Dendrochronologic Streamflow Reconstruction

David E. Grow

Abstract

Two piñon (*Pinus edulis*) tree-ring chronologies developed on each of three substrates (sandstone, shale, and alluvial fan deposits) in southern Utah for the period 1702 to 1997 demonstrate that geologic substrate affects dendrochronologic streamflow reconstructions. Chronologies from alluvial fan deposits explain the most variance of winter streamflow reconstruction (October 1 to May 31) with an adjusted coefficient of determination (R_a^2) equal to 0.59. Chronologies from sandstone deposits account for 52 percent of the variance, while those on shale deposits account for 45 percent. Correlation coefficients among the three substrates are significantly different at the 95% confidence level.

The highest single-site annual discharge reconstruction (October 1 to September 30), $R_a^2 = 0.25$, is provided by chronologies from shale deposits. The highest substrate-pair annual discharge reconstruction, $R_a^2 = 0.27$, is provided by chronologies from alluvial fan deposits. The highest summer reconstruction (July 4 to September 3), $R_a^2 = 0.14$, is provided by chronologies from sandstone. Over 90 percent of the summer reconstructions are below $R_a^2 = 0.10$.

The different substrate response is attributed to varying amounts of clay in each substrate affecting infiltration and available water for tree growth. [5]

Keywords: streamflow reconstruction, substrate, dendrochronology

Introduction

Dendrochronological streamflow reconstructions are a valuable tool to assess the long-term discharge behavior of a river. The long-term behavior can provide insights into the management of discharge, and is useful for planning and restoration projects.

Dendrochronological streamflow reconstructions have been performed since the mid 1930s. Early 1900s streamflow studies (Hardman and Reil 1936, Hawley 1937, Schulman 1945, Schulman 1951) were not strict reconstructions as the term is used today. These early studies generally compared tree-ring records with streamflow, and made estimates for wet and dry periods for pre-gauged streamflow.

Tree-ring growth is directly related to precipitation (Fritts 1976, Loaiciga et al. 1993). Streamflow reconstructions represent precipitation less water lost to evapotranspiration and storage (Jones et al. 1984, Meko and Stockton 1984). Therefore, the climate and vegetation peculiar to a specific basin will directly influence the dendrochronologic streamflow reconstructions for that basin. Fritts (1976) reports that substrate and soil differences affect tree-ring width. The substrate controls infiltration, local drainage, and nutrient supply to the tree. A tree is therefore an integrator of the local environment, and the tree-ring record reflects not only precipitation but also the substrate on which the trees are growing.
The objective of this study is to address the effects of substrate on dendrochronological streamflow reconstructions. Geological substrate controls local hydrological systems. Drainage characteristics peculiar to different substrates are reflected in the tree-ring record, and trees on a particular substrate produce a chronology that provides improved streamflow reconstructions over trees on other substrates.

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The area chosen for this study is the Paria River basin in southern Utah and northern Arizona (Figure 1). The widespread presence of piñon and exposure of geologic strata provide an opportunity to address the effects of substrate on tree-ring chronologies and streamflow reconstructions.

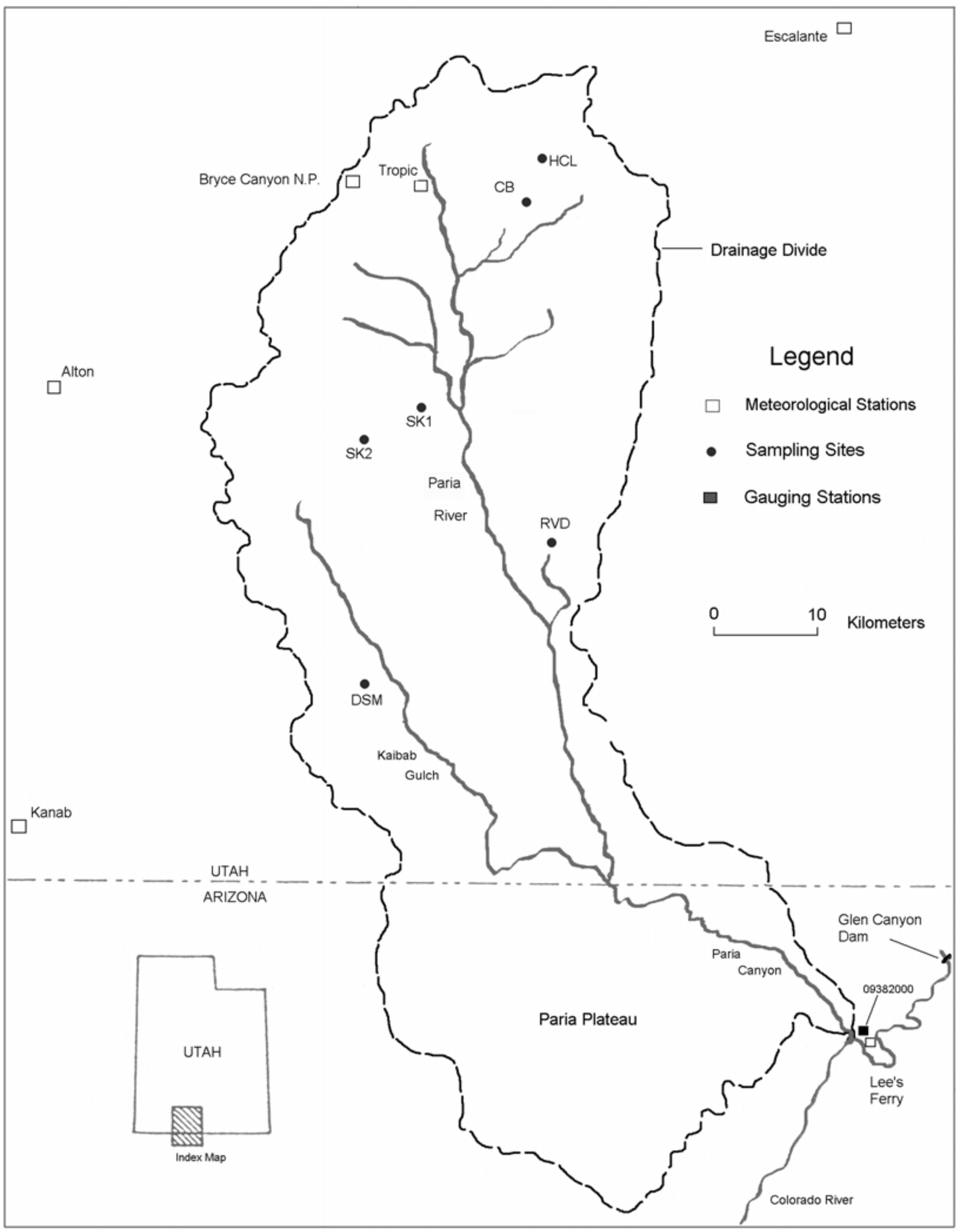


Figure 1. Paria River Basin in southern Utah showing locations of tree-ring sampling sites. Coal Bench (CB) and Henderson Canyon Lower (HCL) are located on alluvial fan deposits. Skutumpah Road site 1(SK1) and Skutumpah Road site 2 (SK2) are located on shale. Round Valley Draw (RVD) and Deer Springs Mesa (DSM) are located on sandstone.

Methods

Six tree-ring standard chronologies (indices) were developed for this analysis. A minimum of 10 trees, 2 cores per tree, was sampled at each site. Samples were prepared and mounted according to procedures described by Stokes and Smiley (1996). Cores were crossdated using skeleton plots, and crossdating was verified by Laboratory of Tree-Ring Research personnel. Ring widths were then measured to within +/- 0.01 mm. A standard chronology was created by removing differential growth trend among trees using a cubic smoothing spline. To obtain tree-ring indices of equal length for comparison, the six different chronologies were truncated so that each chronology spanned the period from 1700 to 1998.

Substrate characteristics

Soils throughout the basin are predominantly fine, sandy loams, very deep, and well drained (Swensen and Bayer 1990). The tree-ring sample sites are located on three different soil series (Table 1). Sites HCL and CB are located on the Hernandez-Clapper Series; DSM and RVD on the Podo Series; and SK1 and SK2 on the Cannonville Series. The Hernandez-Clapper series is formed in alluvium from sandstone and limestone. The Podo series is formed from sandstone residuum and alluvium. The Cannonville series is formed from shale residuum. The clay content of the soil series ranges from 5 to 50%, and permeability ranges from 0.15 to 15.24 centimeters per hour. These features affect the infiltration capacity, hydraulic conductivity, transmissivity, and available water capacity of the different substrates (Birkeland 1984, Ritter et al. 2002, Brooks et al. 2003). All samples were taken on relatively flat aspects of each substrate.

Table 1. Sampling site soil summary (Swenson and Bayer 1990).

Site	Clay Content (%)	Permeability (cm/hr)
CB	18-27	1.52 - 5.08
HCL	18-27	1.52 - 5.08
DSM	5-25	5.08 - 15.24
RVD	5-25	5.08 - 15.24
SK1	40-50	0.15 - 0.51
SK2	40-50	0.15 - 0.51

Streamflow discharge records for the period from 1924 to 1998 were obtained from U.S.G.S. gauging station 09382000 located at Lee's Ferry, Arizona. The total streamflow discharge for a year is based on the water year, October 1 through September 30. The water year was partitioned into three sub-periods: 1) October 1 through March 31 (Winter 1), 2) October 1 through May 31 (Winter 2), and 3) November 10 to April 17 (Winter 3). The annual and the Winter 2 partitions are the subject of this study.

Streamflow reconstructions

Multiple linear regression was used to estimate past streamflow. The chronologies were segregated by substrate: CB and HCL are on alluvial fan deposits, DSM and RVD on sandstone, and SK1 and SK2 on shale. Models of pre-gauged streamflow were developed by comparing the gauged discharge for each year with tree-ring indices for each year, with up to +/- 2 year lags.
The coefficients of determination were adjusted to account for the loss of degrees of freedom due to the addition of predictors (Weisberg 1985). The validity of each model was determined by examining the estimated model coefficients, the residuals from modeling, the root-mean-square-error (RMSE) of calibration and verification, and the reduction of error (RE) statistic of calibration and verification. Each model was verified using the PRESS statistic (Weisberg 1985).

Results and Discussion

The highest adjusted coefficients of determination (R_a^2) show that the Winter 2 partition provides the highest R_a^2 values, with the paired sites CB/HCL providing the highest discharge reconstruction (R_a^2 = 0.59). The differences in correlation coefficients are statistically significant at the 95% confidence level (□ = 0.05) (Table 2).

Table 2. Discharge reconstruction summary (R_a^2) for the annual (October 1 - September 30) and Winter 2 (October 1 - May 31).

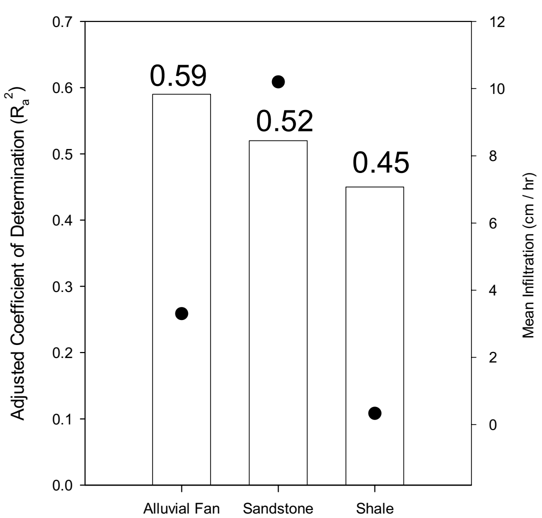
Site	Annual	Oct – May
CB	0.22	0.46
HCL	0.24	0.54
DSM	0.11	0.43
RVD	0.18	0.48
SK1	0.23	0.43
SK2	0.25	0.45
CB-HCL	0.27	0.59
DSM-RCD	0.18	0.52
SK1-SK2	0.25	0.45

Clay content and permeability are highest for sites SK1 and SK2, ranging from 40-50% clay content and 0.15 to 5.0 centimeters per hour permeability. Sites DSM and RVD are located on sandstone residuum.

Compared to alluvial fan and shale substrates, clay content is low, 5 - 25%, and permeability is high, 5.0 to 15.0 centimeters per hour. Sites CB and HCL are intermediate between the other two sites with clay content from 18-27%, and permeability from 1.5 to 5.0 centimeters per hour.

Substrate appears to play a major role in the streamflow reconstructions. The extremes of the infiltration rates of sandstone and shale, 5.08-15.24 cm/hr and 0.15-0.51 cm/hr, respectively, bracket the infiltration rate of 1.52-5.08 cm/hr for the alluvial fan deposits (Figure 2). The extremes represent end-points of water availability for tree growth. The lower infiltration capacity of the shale deposits may result in rapid surface runoff before the precipitation is recorded in the tree-ring record. The higher infiltration rates of the sandstone may result in water passing through the system vertically, again before being recorded in the tree-ring record. The alluvial fan deposits, being intermediate in infiltration, provide the substrate texture more conducive to water availability for tree growth, and is subsequently reflected in the tree-ring record.

Figure 2. Substrate versus the adjusted coefficient of determination (bars) for the Winter 2 discharge reconstruction with mean infiltration (circles).



Conclusions

Several factors influence tree growth and chronology development. This study has successfully compared geologic substrates with respect to tree-ring chronology development and streamflow reconstructions using multiple linear regression. The alluvial fan deposits generally provide the highest coefficient of determination values for streamflow reconstruction. These results suggest that substrate affects the available water for tree growth, and subsequently affects streamflow reconstructions. This information may prove useful to land managers for planning and restoration purposes.

This study provides a foundation to expand the substrate/species component of dendrochronological streamflow reconstructions. Future work on this topic should include more species and substrate comparisons.

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