Management Guidelines for Sagebrush (*Artemisia*) in the Western U. S.

Bureau of Land Management
22May 2000 DRAFT

Attachment 1-1

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PURPOSE

The purpose of these guidelines is to summarize what is known about the ecology of various woody sagebrush (*Artemisia*) taxa (Tribe Anthemideae) and to provide management guidelines for BLM lands and programs. These guidelines have been produced in response to the disturbing long-term loss, degradation and fragmentation of sagebrush vegetation (Connelly *et al. in press*, Wisdom et al, *in press*, West and Young 2000) and the resulting population declines in hundreds of species of plants and animals (see below). There also is considerable concern that as a result of the Federal Wildland Fire Management policy (USDI and USDA 1995) and the direction to restore fire to ecosytems, additional acreage of habitat may be lost or degraded.

The target audience for this guidance is BLM resource specialists involved in activities that affect sagebrush vegetation types. However, this information should be useful to a broader array of land managers, biologists, range specialists and conservationists. This document does not pretend to be a comprehensive review of the extensive literature on the ecology of *Artemisia*, associated species or western shrub communities. The reader is referred to National Research Council (1994), Vavra (1994), Donahue (1999) and West and Young (2000) as current starting points for that literature. Further, additional guidance for other vegetation components, particularly native grasses, forbs and cryptogamic crust, is anticipated.

INTRODUCTION

Sagebrush ecosystems occupy over 62,000,000 ha of the western U. S. (Küchler 1970, West and Young 2000). Sagebrush dominates substantial portions of the entire western landscape, and a large percentage of these ecosystems occur on public lands managed by the Bureau of Land Management.

However, losses from the historical extent of these ecosystems have been substantial. For example, Hann *et al.* (1997) estimate that over 30% of the sagebrush vegetation in the Interior Columbia Basin has been converted to agriculture, dominated by exotic invasive plants or otherwise lost. West-wide, sagebrush ecosystems have been degraded or completely eliminated by agricultural conversion, overgrazing by domestic livestock, invasion of exotic plants, diversion of water, expansion of pinyon and juniper woodlands and uncharacteristic wild fires.

Large portions of remaining sagebrush habitats are at high risk from wildfire as a result of fuel buildup and exotic plant invasion. Within the Great Basin, about 3 million acres of public land is essentially a monoculture of cheatgrass, an exotic annual that creates high wildfire risk and

outcompetes most native plants. Another 14 million acres are infested to the extent that wildfire risk is high and habitat conversion inevitable. Fragmentation is an additional problem, even for higher quality habitats (Hann *et al.* 1997, Wisdom *et al. in press*).

The scope of this habitat loss has led to an increasing number of special status species, several of which may be headed toward threatened or endangered status.

1) Northern Sage Grouse. On May 14, 1999, the U. S. Fish and Wildlife Service (USFWS) received a petition to list the northern sage grouse as threatened or endangered, under the Endangered Species Act, in Washington State. On January 25, 2000, a petition was submitted to list the Gunnison sage grouse in Colorado and Utah. Additional petitions to list northern sage grouse elsewhere are anticipated in April 2000. BLM manages approximately 30 million acres of occupied sage grouse habitat. In 1992 BLM estimated that an additional 10 million BLM acres were suitable habitat but unoccupied. The northern sage grouse is a BLM sensitive species in California, Colorado, Idaho and Oregon/Washington. The Gunnison sage grouse is a sensitive species in Colorado and Utah.

2) Columbian Sharp-tailed Grouse. On October 26, 1999, the USFWS determined that a petition to list Columbian sharp-tailed grouse as threatened contained enough information to warrant a full assessment of that species' status. Comments on the formal status review were due March 27, 2000. Columbian sharp-tailed grouse presently occupy only about 500,000 acres of their historical 5 million acres of habitat on BLM-managed land. The Columbian sharp-tailed grouse is a sensitive species in Colorado, Idaho, Montana and Oregon/Washington.

3) Mountain Quail. On March 15, 2000, the USFWS received a petition to list the mountain quail in the Northern and Western Great Basin and the Interior Columbia Basin and lands westward to the Cascade Crest as threatened or endangered. The mountain quail is a sensitive species in Idaho, Nevada and Oregon/Washington.

4) Loggerhead Shrike. A Conservation Assessment is currently being prepared for the loggerhead shrike, which occurs throughout sagebrush ecosystems.

5) Burrowing Owl. A Conservation Assessment is currently being prepared for the burrowing owl, which also occurs throughout sagebrush ecosystems.

6) Other Special Status Species. Many other priority species that depend on sagebrush ecosystems have been identified by BLM states, Partners In Flight (Rich and Beardmore 1997, Paige and Ritter 1999), the Interior Columbia Basin Ecosystem Management Project (Saab and Rich 1997, Wisdom *et al. in press*), the Nature Conservancy (unpubl.) and Defenders of Wildlife (Defenders of Wildlife 1998). These include 29 species of birds, 49 mammals, 18 reptiles, 3 amphibians, 106 fish (species inhabiting sagebrush-dominated watersheds), 94 invertebrates, 327 vascular plants and 4 species of non-vascular plants (BLM unpubl.).

In the Interior Columbia Basin Ecosystem Management Project, the most comprehensive analysis of sagebrush ecosystems to date (Saab and Rich 1997, Wisdom *et al.* in press), 31 vertebrate species that depend on sagebrush habitat are high priorities for immediate conservation action. These species depend directly on *Artemisia* for food, cover, nest sites or other life requisits.

TAXONOMY OF *ARTEMISIA*

Taxonomy and Variation

A prerequisite for intelligent management of *Artemisia* is to know what species, subspecies, forms and ecotypes of *Artemisia* occur on the landscape in question. Their ecology and response to various impacts and management actions varies. Unfortunately, the *Artemisia* group contains a high level of variation, intergrades and local adaptations which contribute to a complex taxonomy (Hall and Clements 1923, Winward and Tisdale 1977, Daubenmire 1978, 1982, McArthur and Plummer 1978, Winward 1980, Hironaka *et al.* 1983, Miles and Leonard 1984, Schultz 1984, McArthur 1983, McArthur and Goodrich 1986, Mozingo 1986, Walton *et al.* 1986).

Thus, it is critical that land managers use the latest published information and local expertise to determine the taxa that may be affected by some land management activity. This information obviously should include taxonomic keys but also should not overlook ecological site information that may be critically important (Winward 1983, Miles and Leonard 1984, West and Young 2000). Soils and site capability are the foundation for ecological response.

The variation within *Artemisia* occurs not only within species, subspecies, forms and populations, but also among individual plants. The size, productivity, morphology and vigor of individuals depends, in addition, on the composition, depth, texture and other chemical and physical characteristics of the soil. It also is well established that the palatability of individual *Artemisia* plants varies (Stevens and McArthur 1974, Sheehy and Winward 1981, Hironaka *et al.* 1983, Wambolt *et al.* 1987, Welch *et al.* 1991). Thus, land managers also should be alert to all the many variables that affect the health of *Artemisia* plants on a given site.

No keys, range maps, photos or sketches have been included in this document for one reason. There is no single, comprehensive authority on *Artemisia* from which to borrow this information. Each of the references above provides some of this information for some species or geographic areas. It is the responsibility of the user to gather the most complete and current information available. Within the botanical literature, this frequently will be organized by state.

Federal Geographic Data Standards

The Federal Geographic Data Standards (Anderson *et al.* 1998, Grossman *et al.* 1998, http://www.nbs.gov/fgdc.veg/), list the following two formations that pertain to sagebrush - Microphyllus Evergreen Shrubland (generally big sages) and Dwarf Shrubland (generally low sages). As of this date, these standards are simply a classification system. That is, they do not include a map of the U. S. with these standards applied across the landscape. But as mapping and vegetation classification is updated, these standards will become more important. All vegetation mapping in the U. S. will converge on these standards and it is important to begin communicating in these terms.

MANAGEMENT RECOMMENDATIONS

Because of the great ecological, taxonomic and geographic variability in *Artemisia* and the fact that thousands of other species are integrally tied to the health of these ecosystems, it is impossible to specify detailed management recommendations. However, there are some general recommendations that should be considered. These are not necessarily mutually exclusive.

Ecological Site

Recommendation - Ensure that the capabilities of the ecological site are understood prior to any vegetation manipulation on that site.

The characteristics of various ecological sites and their distribution within a given management area must be understood prior to vegetation manipulation or other management actions. Sites vary in their characteristic potential natural community, plant species composition, annual production, soils, effective precipitation and erosion potential, among other factors (National Research Council 1994). When properly classified, managers know what type of ecological community can be expected, following various kinds of disturbance (USDA 1991). This prerequisite knowledge applies to *Artemisia* as well as other taxa.

It is particularly important to identify and understand sites where exotic annuals such as cheatgrass have drastically altered successional trajectories and created new stable states (Hann et al. 1997). Management actions such as prescribed fire can accelerate the transition of a site from one that always has supported *Artemisia* to one that will not support it again without intensive vegetation restoration.

Historical Range of Variation

Recommendation - Manage sagebrush communities within their historical range of

variation.

During preparation of the Interior Columbia Basin Ecosystem Management Project (ICBEMP, http://www.icbemp.gov), the science teams realized that one concept was particularly useful when conducting analyses or making recommendations at the broad-scale (Hann *et al.* 1997, Wisdom *et al.*, *in press*). That is to compare the action in question with our best estimate of the Historical Range of Variation (HRV) of the vegetation community (Tausch *et al.* 1993, Morgan *et al.* 1994).

HRV incorporates the relationships between the energy of a system and the processes of disturbance, e.g., herbivory and fire. HRV can serve as a tool for understanding the causes and consequences of change in ecosystem characteristics over time. Not only can HRV be used to help describe native systems, but it can also serve as a benchmark for understanding the effects of human-induced changes on the landscape. This includes the aiding in the comparison of alternative management scenarios for the future.

The components of HRV are many and establishing HRV for a given geographic region, to the level of detail produced for the ICBEMP (Hann *et al.* 1997), may be prohibitive in the short-term. Yet some of the basic data that concern *Artemisia* dynamics typically are at hand. Key among these are soil type, historical precipitation patterns, temperature patterns, fire return intervals and the nature and degree of herbivory. The idea is to understand the historical ranges within which factors like canopy cover of sagebrush varied, both spatially and temporally. What was the pattern over time on a given site and what was the pattern across the landscape? These patterns are not only an integral part of the ecosystem itself, but they have shaped the evolution and adaptations of many other organisms in that ecosystem. It is a small conceptual leap to believe that mimicking HRV will lead to the healthiest ecosystem for the future.

Although managers can attempt to manage a landscape within HRV, this may be strictly obtainable only within those systems that have not been substantially altered. Livestock grazing, exotic invasives, urban development, roads, fire frequency and other familiar factors complicate management within HRV. Yet this remains as a useful conceptual standard that should help land managers understand tradeoffs between different management strategies.

Density and Extent of *Artemisia* - Limiting Factors and Management Objectives

Recommendation - Define the vegetation objectives for all *Artemisia* sites.

Artemisia communities have existed in a variety of conditions historically, from nearly pure grasslands in *Artemisia-Argropyron* sites following fire, to nearly pure sagebrush on *Artemisia nova* sites or *A. wyomingensis* sites following a century without fire. It is at least theoretically possible, in the absence of major aberrations in the successional process, e. g., cheatgrass (*Bromus tectorum*), to produce a landscape with any configuration and density of *Artemisia* that

we would care to produce. Thus, it comes down to the objectives of our land management. What do we want? Our objectives for patch size, percent canopy cover and connectivity have meaning only in connection with management objectives.

The requirements for some species that use the sagebrush ecosystem differ from the requirements for other species. Burrowing owls like very open vegetation of a low stature while pygmy rabbits greatly prefer dense *Artemisia tridentata tridentata* cover. Even northern sage grouse, the ultimate sagebrush obligate, require different sorts of vegetation at different times of the year (Connelly *et al. in press*). Management guidelines for sage grouse (Connelly *et al. in press*), Columbian sharp-tailed grouse (Ulliman 1995) and other priority sagebrush species (Paige and Ritter 1999, Altman and Holmes 2000, Casey 2000, Wisdom *et al. in press*) will present specific vegetation objectives that will need to be considered for *Artemisia* communities everywhere.

So, it is our task, not only to determine what it is we want in a given area, but also to discover what the limiting factors are, from a vegetation standpoint. Do we have too much sage or too little sage? Are the patches too big or too small? Are the patches connected? What is the problem?

We might decide that everything is perfect the way it is in a given geographic area, and that all we need to do is keep it that way, to manage for complete protection. With the tremendous loss of sagebrush over the past century, this may seem to be a wise approach in the short term. But the reality is that all natural systems are dynamic - we can't manage "snapshots." The historical sagebrush landscape existed as a dynamic mosaic of vegetation wherein individual species are adapted either to the landscape mosaic or to microcosms within that landscape. Thus, pure "protection" might be the correct stop-gap strategy in certain areas but it cannot be the cornerstone of a long-term design for land health.

Spatial and Temporal Considerations - Cumulative Effects Analysis

Recommendation - For any proposed action that will change the canopy cover of any taxa of *Artemisia*, analyze the effects over an area within at least a 45-km (28-mile) radius of the project's center for all land ownerships and project these effects into the future as many years as it will take for the sagebrush to return to its original density, canopy cover and condition.

A basic problem with many NEPA analyses for natural resource impacts on public lands is that cumulative effects are not adequately considered. For *Artemisia* communities as well as many others, this has led to a gradual chipping away of the integrity of ecosystems, one small piece at a time. Thus, while the impacts on a particular local site analyzed for 5 or 10 years may seem negligible (wildlife can go over the hill), the true impacts to the ecosystem are never assessed.

For sagebrush ecosystems, it is possible to somewhat objectively define the true spatial and

temporal bounds within which we should be conducting our analysis of impacts.

1) Spatial Component. Ideally, for any project in the sagebrush, we would consider its impacts on the entire ecosystem, i. e., all 62 million hectares. But from a practical standpoint, this is not (yet) possible.

We propose here that the minimum area to be considered within the cumulative effects analysis should be an area of 1,000,000 ha. This is circumscribed by a circle with a radius of 56.4 km (~35 miles) centered on the project area. The rationale for this unit is based on the home range for sage grouse populations. One can argue that sage grouse are a true umbrella species for sagebrush ecosystems. That is, if we manage for the long-term well being of this species, then we will manage for the long-term health of this ecosystem. A sage grouse population may use an area of up to 6,400 km^2 (2,500 mi^2) (J. Connelly, pers. comm.). The 1,000,000-ha area also is equivalent to the upper limit of subbasins (4^{th} field hydrologic units) in the Interior Columbia River Basin (Hann *et al.* 1997).

Within this circle, all pertinent information pertaining to impacts should be analyzed in typical NEPA fashion. Most critically, the type, canopy cover, vigor and ecological condition of the *Artemisia* vegetation within this area should be described. Past burns, seedings and other vegetation changes should be noted. Roads, urban development, private lands and other obvious factors that cause fragmentation and loss of connectivity within this area should be described for analysis. Any management plans that affect the health of the sagebrush community also are obvious components. This approach will put the project's effects into an appropriate spatial perspective and allow for an improved cumulative effects analysis across the landscape.

2) Temporal Component. The time period considered in a cumulative effects analysis typically covers the life of the project. For vegetation manipulation, that means impacts are analyzed over the entire period of time that is expected to pass until the vegetation returns to the condition it was in before the action. It is particularly important to define the correct time period for assessment of prescribed burns as fire return intervals may be well in excess of 100 years in sagebrush vegetation (Whisenant 1990, Peters and Bunting 1994). But irrespective of the project type, the analysis must consider the entire time period of recovery of the vegetation on the project area as well as all of the vegetation within the 28-mile radius.

As NEPA analysis becomes more sophisticated with improvements in technology (e. g., see http://www.nobility.com/), sophisticated cumulative effects analysis that consider the space and time frames that really apply to an issue, will become easier and more powerful.

Natural Reestablishment of *Artemisia* Populations

Recommendation - Do not reduce sagebrush cover in years of, or years following, poor precipitation.

A single sagebrush plant may produce 500,000 seeds in a typical year (Welch *et al.* 1990). However, seed production is directly related to precipitation. Thus, there is vast annual variation in the amount of seed produced on a given site (Young and Evans 1975, Monsen and Shaw 1986, Walton *et al.* 1986). Because *Artemisia* achenes rarely survive for more than a year in the soil (Young and Evans 1975, McDonough and Harniss 1975, Caldwell 1978), very few *Artemisia* seeds germinate and survive beyond the first year (Walton *et al.* 1986). Thus, one should beware of reducing sagebrush cover during or following years of poor precipitation. This will lead to slower recovery of sagebrush on the site.

Recommendation - Maintain patches of sagebrush plants scattered across the landscape to provide seed sources for the reestablishment of the sagebrush community.

Sagebrush seeds are small and exceedingly light weight. They are dispersed to some degree by the wind despite the fact that they have no particular adaptations for wind dispersal. Nonetheless, maximum dispersal distances are only around 30 m from the parent plant and 85-90% of all seeds fall within 1 m of the edge of the sage canopy (Young and Evans 1989, Wagstaff and Welch 1990). Thus, it is extremely important to maintain live sagebrush plants, at least in small patches, across any landscape to provide seed sources for reestablishment of the community. Long-distance dispersal by wind is ineffective in recolonizing large burns, seedings or other disturbances (Meyer 1994).

This is especially important during fire suppression. In so long as it is compatible with safety and the protection of property, fire fighters should avoid burning out and blacklining along roads, canals and other wide barriers as much as possible. Pockets of unburned *Artemisia* within a fire perimeter should be maintained. Any other activity that is leading to a reduction in sagebrush on the landscape also should maintain natural seed sources as described.

Recommendation - Do not reduce sagebrush cover if conditions are not ideal for a project.

Artemisia plants are long-lived, once they make it past the seedling stage, and may live for 100 years or more (West and Young 2000). This means that there is no urgency in implementing projects. All else being equal, the site will persist for another season or year when conditions may improve.

Fire

Recommendation - Protect all *Artemisia* vegetation from fire unless the vegetation objectives, site potential, limiting factors and capacity for proper post-burn management in the area in question are well defined and understood. This information also should be thoroughly integrated into Fire Management Plans for the geographic area in question. Sagebrush is readily killed by fire (Blaisdell 1953, Hamiss and Murray 1973) and most species, subspecies and ecotypes do not resprout. This is compelling evidence that *Artemisia* is not adapted to fire and has not evolved with fire as a regular and significant factor. While the speed, intensity and temperature of the burn are relatively unimportant to the individual sagebrush plant (Britton and Clark 1985), those factors obviously have a great impact on the burn pattern and its ultimate effect on the landscape. Only *A. tripartita, A. cana* and *Artemisia tridentata vaseyana (form spiciformis*) can resprout from root crowns or lower stem bases after being top-killed by fire (Winward 1985). All other taxa are killed and must reestablish on a site from seed. This general lack of adaptation to burning suggests that most *Artemisia* taxa did not evolve with fire as a regular or significant process in the ecosystem.

Historically, fire return intervals were 12-15 years for *A. vaseyana* (Miller and Rose 1999) and 60-110 years or longer for other taxa, such as *A. t. wyomingensis* on the driest sites (Whisenant 1990, Peters and Bunting 1994, Kaltenecker, pers. commun.). Some low sage sites probably never burned because they never had enough fuel to carry a fire under any conditions. Of course, the invasion of fire-adapted exotic species like cheatgrass has altered the vegetation composition and succession on sites and has made them much more likely to burn, and to burn repeatedly. Return intervals in cheatgrass-dominated landscapes are under 5 years (Whisenant 1990). On these sites, sagebrush can quickly be eliminated, especially if a second fire occurs before new plants can produce seed (4-6 years). After that, seeding will be necessary to restore sagebrush within a timeframe meaningful to human society.

Fire also has the effect of favoring shrubs such as *Chrysothamnus*, *Ephedra*, *Tetradymia* and *Gutierrezia* that do resprout. Thus, even if a site is not invaded by exotic plants which lead to total elimination of *Artemisia*, competition from these other genera may make it difficult to reestablish a healthy sagebrush community.

Thus, no sagebrush sites should be burned under prescribed fire or allowed to burn under a wildfire unless 1) the objectives for the site are very clearly defined, 2) the potential for weed invasion and creation of a new undesirable successional state is well understood, 3) a limiting factor is being addressed, and 4) we have the capability to manage the site properly after the burn to achieve a healthy sagebrush community.

Mechanical Treatment

Recommendation - Use mechanical methods to reduce sagebrush cover where other methods have more undesirable side effects. Minimize root damage and seed burial.

Mechanical treatment has the obvious advantage over fire in that the treatment area can be exactly controlled. However, mechanical treatments vary greatly in their effects on sagebrush. The tops of plants can be reduced or removed with methods such as shredding, roller chopping and hand slashing. In most cases, this produces a temporary reduction in canopy cover and many taxa regrow vigorously (USDI BLM 1991).

Entire plants can be removed with grubbing, bulldozing, chaining, root plowing and disk plowing (Pechanec *et al.* 1965, USDI BLM 1991). The first three methods are capable of killing 90% of the old plants whose rigid stems tend to break while killing less (20-30%) of the younger, more flexible individuals (Pechanec *et al.* 1965). One side effect is that a large amount of litter is deposited on the site and this may contribute to larger and hotter fires.

Both plowing methods completely remove sagebrush and can damage most other species as well (Monsen and Shaw 1986, USDI BLM 1991). Reestablishment of sagebrush seedlings can be poor as seeds can become buried too deeply. This impairment of seedling establishment can then persist for years because the original seeds on the site largely perish after one year (see above). Vigor of mature plants also may decline following this treatment. Basal and root sprouting may not occur and plants can be killed if the main stem was uprooted or cut off.

A major drawback to all soil disturbing mechanical actions is that biological crusts are destroyed. This is a result both of the severe direct disturbance and the accumulation of litter on the soil surface. Desirable microsites for the germination and establishment of *Artemisia* seedlings are all but eliminated. Thus, the damage to the long-term health of the site may make these mechanical options non-viable.

Livestock Browsing

Recommendation - Manage livestock browsing to achieve sagebrush density objectives.

It is well established that excessive cattle grazing increases the cover of *Artemisia* in many systems by reducing the competition from other plants (Whisenant 1990, Daddy *et al.* 1988). Very often, it is these other plants, especially native bunchgrasses and forbs, that are far below healthy levels in the ecosystem and that are the first to go under improper grazing levels (Wambolt and Watts 1996, West and Young 2000). Nonetheless, sagebrush densities can be increased in this way. Further, where invasive exotics, such as cheatgrass, have produced an unnaturally high density of fine fuels that make sites much more susceptible to fire, grazing can reduce these fuels and provide some protection against burning (Peters, pers. comm.). Unfortunately, the timing for this type of management action has detrimental effects on desirable native species.

Late autumn browsing by sheep can reduce sagebrush cover. Animals are essentially forced to

browse sagebrush because herbaceous growth is dried, reduced and less palatable (Laycock 1967). Very heavy browsing by cattle also can reduce cover of *A. t. wyomingensis*, purely through mechanical damage (Wambolt and Watts 1996). But at such extreme stocking levels, the understory grasses and forbs are essentially extirpated from the site.

Native Ungulate Browsing

Recommendation - Manage native ungulate browsing to achieve sagebrush density objectives.

Canopy cover and winter forage production of *Artemisia tridentata* was significantly reduced by elk browsing (Wambolt and Sherwood 1999). Over 19 sites, the average big sagebrush cover inside exclosures was three times that outside exclosures. This relationship held for *A. t. wyomingensis* and *A. t. vaseyana* sites, and for all aspects, topographies and precipitation levels. Both pronghorn and mule deer also often forage heavily on big sagebrush taxa (Welch and McArthur 1979). Thus, big game management, especially on winter ranges, can affect the cover of sagebrush on a given site.

Herbicides

Recommendation - Use herbicides to reduce sagebrush cover where other methods have more undesirable side effects and where potential damage to non-target species is understood and acceptable.

The effects of herbicide applications are very complex because the combination of site conditions, the chemicals themselves, application rates and application conditions can lead to a wide variety of outcomes (USDI BLM 1991). Certainly, herbicides can result in a complete elimination of sagebrush cover and the control over application offers certain advantages (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Monsen and Shaw 1986, Whisenant 1986).

Although herbicide application has been out of favor, it may be preferable to prescribed fire in some situations. Where factors like fuel loading or post-fire plant composition are not within the management objectives for the site, herbicides may be a tool to consider. Damage to non-target species is perhaps that most serious complication (USDI BLM 1991). And as for any treatment, the potential for the site to recover to a healthy condition and the ability to manage the site following treatment is paramount.

ROLES OF OTHER FACTORS

A few other factors have effects on the health of *Artemisia* populations but we do not understand

their ecological roles or significance. Should future research be conducted, certain management strategies may emerge.

Soil Mycorrhizae

Sagebrush are mycorrhizal obligates, particularly big sagebrush taxa. Thus, the recovery of *Artemisia* on a given site likely is dependent on the recovery of the mycorrhizae as well as the other factors discussed above. The effects of fire, invasion by exotic plant species, site occupancy by other non-mycorrhizal species on the recovery of mycorrhizae itself is the subject of current research. But much more about these relationships must be learned if we are to manage and restore *Artemisia* landscapes.

Cryptogamic Crusts

Cryptogamic or biological crusts contribute significantly to soil productivity, soil stability, lower soil temperatures, a higher rate of seedling establishment and higher moisture retention (Belnap and Gardner 1993, Harper and Pendleton 1993, Johansen et al. 1993, St. Clair et al. 1993). Unfortunately, biological crusts have been widely destroyed by trampling during the excessive livestock grazing of the late 1800s and early 1900s (Poulton 1955, Daubenmire 1970, Mack and Thompson 1982, MacCracken et al. 1983, St. Clair et al. 1993). Crusts are particularly important in basin big sagebrush and Wyoming big sagebrush sites (Kaltenecker and Wicklow-Howard 1994, Kaltenecker 1997). The role of biological crusts and the health of *Artemisia* stands is currently being studied in several different locations. Land managers should be alert for further developments in this arena.

Insects

The sagebrush defoliator (*Aroga websteri*) can cause severe defoliation (Gates 1964) primarily of sagebrush taxa in the Tridentatae subgenus: *A. arbuscula, A. bigelovii, A. cana cana, A. nova, A. pygmaea, A. tridentata tridentata, A. t. wyomingensis and A. tripartita* (Hsiao 1986). *A. spinescens,* although not in Tridentatae, also is defoliated. Infestations can kill or reduce the vigor of sage plants. High temperatures and low precipitation cause *Aroga* populations to decline drastically. The most promising strategy for avoiding defoliation where it may be a serious problem is to develop new plant materials that are unacceptable to the defoliator. The moth's high degree of host specificity suggests that this would be a feasible approach (Hsiao 1986). The extent and significance of *Aroga* defoliation in sagebrush ecosystems has not been evaluated.

The leaf-feading beetles *Trirhabda pilosa* and *T. attenuata* may cause significant damage to *A. tridentata* in certain situations (Pringle 1960, Fisser and Lavigne 1961). The extent and

significance of leaf-feeding beetle damage in sagebrush ecosystems has not been evaluated.

Parasites, Fungus and Diseases

A snowmold fungus can reduce the canopy cover and kill *A. t. vaseyana*, *A. t. tridentata* and *A. nova* in areas of deep snow accumulation (Sturges and Nelson 1986). At least 16" of snow are required to maintain the temperature conducive to fungal growth. The extent and significance of this fungus in sagebrush ecosystems has not been evaluated.

Voles

When vole (*Microtus* sp.) population cycles coincide with suitable weather conditions, voles can cause extensive sagebrush kills by girdling plants (Mueggler 1967, Frischknecht and Baker 1972). The extent and significance of vole girdling in sagebrush ecosystems has not been evaluated.

SPECIES-SPECIFIC CHARACTERISTICS AND RESPONSES

The major woody sagebrushes can be grouped in various ways. West and Young (2000) ordinate the taxa by soil moisture, soil temperature and stature (Fig. 1). We will follow that convention.

[inset Fig. 1 here - at end in draft] Ordination of major sagebrush taxa against gradients of soil temperature and soil moisture (reproduced from West and Young 2000 with permission).

A variety of additional characteristics for some taxa can be found in the PLANTS database of the National Resources Conservation Service (http://plants.usda.gov/plants/). Perhaps most useful is a listing of publications on the distribution, ecology and taxonomy of many taxa. Fire effects can be found in the Fire Effects Information System dababase (http://www.fs.fed.us/database/feis/), a database that will be updated in the near future to include more recent scientific literature.

Dwarf Sagebrushes of Warmer Sites

Artemisia bigelovii - Bigelow sagebrush, flat sagebrush, slender gray sagebrush

1) General Characteristics

deciduous above, late deciduous below
habit - low, spreading 8-16 in. tall
vegetative spread - stem layers rarely
flowers Aug-Oct

seeds/lb. - 2,710,000
fire intolerant
range - western Texas, southern Colorado, New Mexico, Arizona, Utah, Nevada and California (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 3200-8000 ft.
moisture regime - dry to very dry
soils - rocky, sandy, shallow, lithic
soil moisture - aridic
soil temperature - mesic

2) Response to Fire

Bigelow sagebrush is severely damaged or killed by fire (McArthur 1981) and burned areas are reoccupied through on-site or wind-borne seed (Wright *et al.*1979). Bigelow sagebrush does not sprout after fire or other disturbance (Wright *et al.* 1979, Walton *et al.*1986). Little is documented concerning the germination requirements or seedling establishment of Bigelow sagebrush. The timing of burn may influence recovery rates of many shrubs in sagebrush-grassland communities (Wright *et al.* 1979).

2) Response to Browsing

No information.

3) Response to Mechanical Treatment

No information.

4) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia arbuscula arbuscula - low sagebrush, gray low sagebrush, scabland sagebrush, dark sagebrush, little sagebrush, dwarf sagebrush

1) General Characteristics

evergreen
habit - dwarf, irregular shape, 15-20 in. tall, 15-30 in. wide
vegetative spread - seldom layers

drought enduring
flowers - Aug-Sep
seeds/lb. - 980,000
fire intolerant
range - southern Colorado to western Montana, west through Utah and Idaho to northern California, Oregon and Washington (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 3000-12,200 ft.
moisture regime - dry
soils - harsh, infertile, alkaline, rocky, shallow, hardpan, gravelly, calcic
soil moisture - aridic
soil temperature - mesic

2) Response to Fire

Gray low sagebrush is a nonsprouter which is readily killed by fire (Britton and Ralphs 1979, Beetle and Johnson 1982). It reestablishes on burned sites through small, light, wind-dispersed seed but this may require 10 years or more (Young 1983). Many gray low sagebrush communities are characterized by a depauperate understory with significant amounts of exposed soil and rock, and stands often lack enough fuels to carry a fire (Beardall and Sylvester1976, Blaisdell *et al.* 1982, Bunting *et al.* 1987). Consequently, fires in gray low sagebrush communities are comparatively rare. In fact, these sites can even be used as fuel breaks (Young and Evans 1971, Young 1983).

The possibility of fire is increased during years of above-average precipitation which can result in increased herbaceous growth. This is especially true on sites that have been invaded by weedy species such as medusahead (*Taeniatherum caput-medusae*) or cheatgrass (*Bromus tectorum*) (Bunting *et al.* 1987, Young and Evans 1971). Recovery time of gray low sagebrush following fire is variable and is described as "slow to rapid." Recovery may occur within 2 to 5 years under favorable conditions but may require more than 10 years on harsh sites.

Even when conditions allow fire spread, prescribed burning in low sagebrush sites often produces few benefits (Blaisdell *et al.* 1982., Young 1983); many experts recommend against widespread burning in low sagebrush types (Bunting *et al.*1987). Sage grouse in particular can be adversely impacted when large, contiguous blocks of low sagebrush are burned (Klebenow 1973). Erosion may also be a problem on many harsh sites where revegetation proceeds very slowly. Reliable prescriptions have not yet been developed for use in low sagebrush habitat types (Blaisdell *et al.*1982).

3) Response to Browsing

A. arbuscula sites are greatly preferred by mule deer and domestic sheep (Sheehy and

Winward 1981). Trampling damage can occur on sites supporting this taxa because soils are often saturated in early spring (Hironaka *et al.* 1983). Livestock should be kept off low sage sites until soils have dried out. These sites also have the potential for well developed biological crusts where the soil surface is covered by rock. Mechanical trampling damage can be particularly detrimental to the establishment of *A. arbuscula* seedlings on these sites.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

This taxa is readily killed by herbicides (Tisdale and Hironaka 1981).

***Artemisia nova* -** black sagebrush, little black sagebrush, small sagebrush

1) General Characteristics

evergreen
habit - erect from spreading base, 6-18 in. tall
vegetative spread - none
drought enduring
flowers Aug-Oct
seeds/lb. - 907,000
fire intolerant
range - Great Basin (see McArthur and Plummer 1978, Schultz 1986, Clary 1986, www.fs.fed.us/database/feis/)
elevation - 4500-9500 ft.
moisture regime - dry
soils - calcareous with rocky pavement, stony, well-drained, thin, gravelly, calcic, pH 6.5-7.5
soil moisture - aridic
soil temperature - mesic

2) Response to Fire

Black sagebrush is highly susceptible to fire. Plants are readily killed by all fire intensities and do not sprout (Wright *et al.* 1979). Its intricate branches, low stature and non-sprouting habit make it very vulnerable (Volland and Dell 1981) where fires can carry through this community. Following burning, reestablishment occurs through off-site seed sources (Tisdale and Hironaka 1981, Wright *et al.*1979, Young 1983).

Information concerning reestablishment after burning is lacking. Effective soil moisture and patterns of burning have an influence upon the rate of site recovery.

Historically fire has had little or no influence in communities dominated by black sagebrush (Winward 1985). Typically the sparse vegetation of most black sagebrush stands precludes the occurrence of fire (Winward 1986). In fact, dwarf sagebrush species are commonly recognized as potential natural fire breaks. Beardall and Sylvester (1976) found that low sagebrush communities in Nevada did not burn on a hot day in mid-August despite wind speeds of up to 25 miles per hour (40.3 km per hour). Use of prescribed burning is not usually feasible where black sagebrush forms dense stands.

Since stands of black sagebrush do not readily burn, existing response data involves information obtained from study sites where this species is not a dominant component of the vegetation. In Utah, West and Hassan (1985) found no evidence of black sagebrush reestablishment up to 2 years following a late July fire. Most black sagebrush seeds are dispersed close to the parent plant. Fire in this type is not recommended.

3) Response to Browsing

Black sagebrush is greatly preferred by pronghorn and sage grouse (Hironaka *et al.* 1983) and was consistently reduced in cover by both cattle and sheep winter grazing (Clary 1986). On some sites, reduction were severe. Low-elevation stands experienced the greatest reductions. Moderate use during mid-winter appears to be compatible with maintaining black sagebrush cover (Clary 1986).

Black sagebrush sites also often have well developed biological crusts due to the calcareous nature of many of the site soils. These crusts also sometimes have a high proportion of nitrogen-fixing species. Mechanical trampling damage can be very detrimental to the health of these sites, particularly through damage to conditions for seedling establishment.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia pygmaea - pygmy sagebrush, pigmy sagebrush

1) General Characteristics

evergreen
habit - cushion-like, 8-10 in tall
vegetative spread - none
drought enduring
flowers Aug-Sep
seeds/lb. - 440,000
fire intolerant
range - Great Basin of Nevada and Utah to northern Arizona, Uinta Basin of Utah and Colorado (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 5200-7500 ft.
moisture regime - very dry
soils - calcareous, clay, gravels, gypseous, shale, calcic
soil moisture - aridic
soil temperature - mesic-frigid

2) Response to Fire

Pygmy sagebrush is killed by fire but readily reoccupies a site through seed (Beetle 1960, McArthur *et al.* 1979). It does not resprout following fire or other disturbance (Beetle 1960, Walton et. al. 1986).

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia rigida - scabland sagebrush, stiff sagebrush

1) General Characteristics

deciduous

habit - low, spreading, with thick, brittle branches, to 16 in. tall
vegetative spread - possible root sprouts
drought evading
flowers Sep-Oct
seeds/lb. - 550,000
fire intolerant
range - Columbia River Basin of eastern Washington and Oregon, western Idaho
elevation - 3000-7000 ft.
moisture regime - dry
soils - rocky, shallow
soil moisture - xeric
soil temperature - mesic

2) Response to Fire

Preliminary tests suggest that stiff sagebrush does not sprout after clipping to a height of 1 to 1.5 inches (3-4 cm) (Tisdale and Hironaka 1981). Establishment following fire depends on off-site seed. Because stiff sagebrush does not sprout, it is likely that it would be killed by most fires. The sparse herbaceous understory of stiff sagebrush stands make them practically immune to fire (Tisdale and Hironaka 1981); consequently they can be used for fire control lines (Clifton 1981).

3) Response to Browsing

This taxa is heavily browsed by big game animals in winter but the effects of this are not known (Hironaka *et al.* 1983). The shallow, rocky soils where stiff sagebrush often grows are good sites for the development of biological crusts. Mechanical trampling damage may occur, thus degrading the site's capability for new seedling establishment.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tripartita tripartita - three-tip sagebrush, tall three-tip sagebrush

1) General Characteristics

early deciduous to evergreen
habit - erect, freely branching, 6 ft. tall
vegetative spread - root sprouts, stem layers, stump sprouts
drought evading
flowers - Aug-Sep
seeds/lb. - 2,500,000 (?)
fire tolerant
range - British Columbia south through Washington to Nevada, east to northern Utah and western Montana (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 3000-9000 ft.
moisture regime - semi-dry
soils - moderate to deep, well drained, loamy, sandy
soil moisture - aridic-xeric
soil temperature - mesic

2) Response to Fire

Tall threetip sagebrush can sprout or layer following fire (Beetle and Johnson 1982, Hironaka *et al.* 1983, Winward 1985). In some areas, fire may cause a large number of plants to sprout. However, Hironaka *et al.* (1983) caution that there may be significant ecotypal variation in this taxa and that populations in different areas may respond differently to the same burn conditions.

Fires can spread in threetip sagebrush stands (Britton 1979) and kill aerial plant parts. The shrub can reestablish through stump-sprouting and layering (Mueggler and Stewart 1980). Beetle (1960) notes that tall threetip sagebrush sprouts vigorously from the stump following fire; layering may also occur. Volland and Dell (1981) list the shrub as a weak sprouter in Oregon and Washington.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Dwarf Sagebrushes of Cooler Sites

Artemisia arbuscula thermopola - cleftleaf sagebrush, hot springs sagebrush, thermopola sagebrush, thermopola low sagebrush

1) General Characteristics

evergreen
habit - spreading, 6-12 in. tall, 12-16 in. wide
vegetative spread - none
drought enduring
flowers - Aug-Sep
seeds/lb. - 980,000
fire intolerant
range - southern Colorado to western Montana, west through Utah and Idaho to northern California, Oregon and Washington (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 5000-9000 ft.
moisture regime - dry
soils - sterile, often volcanic, shallow, claypan, non-calcic
soil moisture - xeric (?)
soil temperature - frigid-cryic

2) Response to Fire

Evidence suggests that hotsprings sagebrush is readily killed by fire. It is not known to sprout, but reestablishes through light, off-site, wind-dispersed seed from surviving plants adjacent to the burn (Hopkins and Kovalchik1983), as is the case for most *Artemisia* taxa. Gray low sagebrush can recover within 2 to 5 years with favorable conditions, but more than 10 years may be required under less favorable circumstances (Hopkins and Kovalchik 1983). However, recovery time is not well documented.

Low sagebrush communities are characterized by much exposed soil and surface rock along with a lower species richness and density of forbs and grasses than that found in many other *Artemisia* types. Many stands lack sufficient fuels to carry a fire even on hot days with winds up to 40 km/hr (25 mph) (Beardall and Sylvester 1976, Bernard and Brown 1977, Blackburn *et al.* 1969). Consequently, fires in hotsprings sagebrush communities are probably rare. The probability of fire increases as herbaceous growth increases as a result of above-average precipitation or increased protection from grazing (Blackburn *et al.* 1969). Weedy species such as medusahead and cheatgrass will increase flammability of low sagebrush stands (Blackburn *et al.* 1969, Hopkins 1979). Gray low sagebrush has been successfully used as a fuelbreak when adjacent big sagebrush

communities have been burned (Hitchcock and Cronquist 1973, Hopkins and Kovalchik 1983).

Prescribed fires may not be possible or desirable in hotsprings sagebrush stands. Fires in most low sagebrush communities produce relatively few benefits (Beardall and Sylvester1976, Blackburn *et al.* 1969, Hopkins and Kovalchik 1983).

3) Response to Browsing

A. arbuscula sites are greatly preferred by mule deer and domestic sheep (Sheehy and Winward 1981). Trampling damage can occur on sites supporting this taxa because soils are often saturated in early spring (Hironaka *et al.* 1983). Livestock should be kept off low sage sites until soils have dried out.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia argilosa - Coaltown sagebrush

1) General Characteristics

deciduous (?)
habit - erect, 20-32 in. tall
vegetative spread -(?)
flowers - Jul-Aug
seeds/lb. -(?)
fire tolerant (?)
range - Jackson County, Colorado (see McArthur and Plummer 1978, Schultz 1986)
elevation - 8000 ft.
moisture regime - moist
soils - strongly alkaline, poor drainage, shaley
soil moisture - udic
soil temperature - cryic

2) Response to Fire

No information.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia longiloba - early sagebrush, alkali sagebrush, early sagebrush, longleaf sagebrush

1) General Characteristics

leaves not persistent
habit - spreading, 6-9 (18) in. tall
vegetative spread - stem layers
flowers June (?)
seeds/lb. - 2,655,000
fire intolerant (?)
range - both sides of Continental Divide, west to southwestern Montana, Utah, Idaho, Nevada and Oregon (see McArthur and Plummer 1978, Schultz 1986, Monsen and Shaw 1986, www.fs.fed.us/database/feis/)
elevation - 5500-8000
moisture regime - semi-dry
soils - alkaline shales, light to tight clays, shallow, claypan
soil moisture - xeric
soil temperature - frigid-cryic

2) Response to Fire

Prescribed burning on early sagebrush sites has rarely been attempted because the understory is normally not sufficient to carry fire (Monsen and Shaw 1986). The two publications on this species are in conflict as to its fire tolerance. A mid-June burn in an early sagebrush/Idaho fescue stand resulted in spotty kills, leaving enough seed to ripen on unburned shrubs to provide a good seed source. A large number of the burned shrubs

recovered via regrowth from remaining branches (Monsen and Shaw 1986). However, Dealy *et al.* (1981) report that early sagebrush does not sprout from the root or stump and reestablishes following fire via seed.

One year after a mid-June burn there was a 26 percent reduction of early sagebrush (Monsen and Shaw 1986). Monsen and Shaw (1986) noted that burning can be used to reduce shrub density and is a good tool if retention of some shrubs is desired. Shrub seedlings could increase rapidly if a sufficient understory is not present to control early sagebrush through competition (Monsen and Shaw 1986).

3) Response to Browsing

Trampling damage can occur on sites supporting this taxa because soils are often saturated in early spring (Hironaka *et al.* 1983).

4) Response to Mechanical Treatment

Discing resulted in a 65% reduction in total shrub population one year later while chaining resulted in a 33% reduction (Monsen and Shaw 1986). Seedling establishment was poor as seeds may have been buried too deeply by these treatments. This impairment of seedling establishment persisted for five years following treatment. Further, the vigor of mature plants declined more rapidly on the treated sites as compare to the controls suggesting that mechanical damage continued to take a toll. Basal and root sprouting did not occur and plants were killed if the main stem was uprooted or cut off. Generally, discing is a more severe treatment than chaining (Monsen and Shaw 1986).

5) Response to Herbicides

Spraying with 2, 4-D resulted in a complete eradication of sage cover (Monsen and Shaw 1986) and the reductions persisted longer than on the disced and chained sites. Spraying must be completed early in the season (by 20 May in southern Idaho) to be effective.

Artemisia cana bolanderi - Bolander silver sagebrush, Bolander sagebrush, white sagebrush, silver sagebrush

1) General Characteristics

evergreen to deciduous
habit - erect, spreading, much branched, 8-24 in. tall
vegetative spread - stem layers, root sprouts
drought evading
flowers Aug-Sep (?)

seeds/lb. - 846,000 to 2,200,000 (?)
fire tolerant
range - central Oregon, western Nevada, eastern California (see McArthur and Plummer 1978, Schultz 1986, Walton *et al.* 1986, www.fs.fed.us/database/feis/)
elevation - up to 5000 ft.
moisture regime - semi-dry
soils - extremely clayey, alkaline, granitic, poor drainage
soil moisture - udic (?)
soil temperature - cryic (?)

2) Response to Fire

Bolander silver sagebrush resprouts vigorously from the root crown (Beetle 1960, Dealy *et al.* 1981) and rhizomes following most fires, suggesting that this taxon is adapted to higher fire return frequencies. Postfire regeneration also involves the germination of wind-dispersed seed (Volland and Dell1981, Wright *et al.* 1979, Hironaka *et al.*1983). In most cases, recovery is relatively rapid. Fire response information on the silver sagebrush complex as a whole indicates that densities are rapidly regained and even enhanced following burning.

The ability of Bolander silver sagebrush stands to carry fire is low because of seasonally high water tables and sparse understories. Plant manipulation via prescribed burning in communities dominated by this subspecies appears questionable because few species are adapted to the moisture regimes and alkaline soils characterized by these sites (Dealy *et al.*1981, Richard and Currie1983).

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

Silver sagebrush can regenerate from root sprouts following disturbance (Harvey 1981, Walton *et al.* 1986) and can recover quickly following mechanical disturbance (Umess 1966).

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia cana cana - Plains sagebrush, silver sagebrush, plains silver sagebrush, hoary sagebrush, hoary silver sagebrush

1) General Characteristics

evergreen to readily deciduous
habit - erect, rounded, freely branched, 3-5 ft. tall
vegetative spread - root sprouts, rhizomes, stem layers
drought evading
flowers Aug-Sep
seeds/lb. - 846,000 to 2,200,000 (?)
fire tolerant
range - souther Alberta, Saskatchewan south through Montana, western and central North Dakota, South Dakota, Wyoming, northwestern Nebraska, northern Colorado (see McArthur and Plummer 1978, Schultz 1986, Walton *et al.* 1986
elevation - 5000-10,000 ft.
moisture regime - moist
soils - coarse, well-drained, deep, loam to sandy pH 6.5-8.5
soil moisture - udic (?)
soil temperature - cryic (?)

2) Response to Fire

Like *A. c. bolanderi*, the ability of this taxon to sprout suggests a history of higher fire return intervals and an adaptation to burning. Plants that are not killed by fire resprout vigorously, both through basal and root sprouts, and may return to pre-burn canopy coverage in three years (Peters pers. comm.). Plants that are burned annually up to three consecutive years, and not killed, will continue to sprout, although vigor declines substantially (Peters pers. comm.).

Burning causes complete top-kill of plains silver sagebrush regardless of the degree to which aerial plant parts are consumed. The extent to which plants survive burning, however, is directly related to fire intensity. Totally consumed plants sustain higher mortalities than those less thoroughly burned. This trend is further accentuated by season of burning as it relates to fire severity and plant phenology. More plants survive spring burns than fall burns (White and Currie 1983, 1984).

This range in plant response suggests that fire can be an effective method of managing plant densities, at least over periods of a few years. On winter ranges where this subspecies is a palatable forage, spring burning can be used to enhance plant coverages and rejuvenate stands. Where plant control is deemed necessary, fall burning can drastically reduce coverages. Apparently silver sagebrush is under greater moisture stress as the season progresses, and this stress is compounded in thick stands (White and Currie

1984).

3) Response to Browsing

Big game browse on silver sagebrush (Peters pers. comm.) but are not known to cause obvious reductions in extent. Livestock do not use this taxa (Peters pers. comm.).

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia cana viscidula - mountain silver sagebrush, silver sagebrush, coaltown sagebrush

1) General Characteristics

not persistent
habit - erect, thickly branched, 3.3 ft. tall
vegetative spread - stem layers, root sprouts
drought evading
flowers Aug-Sep
seeds/lb. - 2,200,000
fire tolerant
range - southwestern Montana to New Mexico, west to Arizona, Nevada, Utah and Idaho (see McArthur and Plummer 1978, Schultz 1986, Walton *et al.* 1986, www.fs.fed.us/database/feis/)
elevation - 5500-10,000 ft.
moisture regime - semi-dry
soils - deep, rich loams
soil moisture - udic (?)
soil temperature - cryic (?)

2) Response to Fire

Fire effects information on mountain silver sagebrush has not been widely documented. Studies on the morphologically similar plains silver sagebrush indicate that the extent to which plants survive burning is directly related to fire intensity and severity. Totally

consumed plants sustain higher mortalities than those less thoroughly burned. This trend is further accentuated by season of burning; more plants survive spring burns than fall burns (White and Currie 1983). Apparently soil moisture and phenological stage at the time of burning have a significant influence on plant survival (White and Currie 1984) as well.

Information from related species indicates that silver sagebrush resprouts vigorously via root sprouts and rhizomes following fire (Beetle 1960, Winward 1985). Apparently, however, resprouting abilities differ between the mountain (ssp. *viscidula*) and high desert (ssp. *bolanderi*) subspecies (Young 1983). Postburn regeneration also involves the germination of off-site, wind-dispersed seed (Wright *et al.* 1979). Preburn coverages are rapidly regained in most cases. Studies on plains silver sagebrush indicate that as burn intensity and severity increase, plant mortality also increases and regrowth decreases (White and Currie 1983).

Herbaceous production is potentially quite high on mesic sites characterized by mountain silver sagebrush (Winward 1980), and dense stands are candidates for control measures. Although burning appears to be an effective means of managing plant densities in the plains subspecies, the degree to which these data apply to mountain silver sagebrush is unknown. The mesic nature of most areas dominated by this subspecies suggests that burns must be well-timed, especially where shrub control is an objective.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tripartita rupicola - Wyoming three-tip sagebrush

1) General Characteristics

evergreen to early deciduous
habit - decumbent, 6 in. tall, 12-20 in. wide

vegetative spread - root sprouts, stem layers, stump sprouts
drought evading
flowers - Aug-Sep
seeds/lb. - 2,500,000 (?)
fire tolerant
range - central and southeastern Wyoming (see McArthur and Plummer 1978, Schultz 1986)
elevation - 7000-9000 ft.
moisture regime - semi-dry
soils - rocky, gravelly, shallow to deep
soil moisture - xeric
soil temperature - frigid-cryic

2) Response to Fire

Wyoming threetip sagebrush can sprout from its root crown following fire (Beetle 1960, 1977; Winward 1985). It may also layer (Beetle 1960). Fire on some sites occupied by its sister taxa, *A. tripartita tripartita,* may cause a large number of plants to sprout. However, Hironaka *et al.* (1983) caution that there may be significant ecotypal variation in this taxa and that populations in different areas may respond differently to the same burn conditions.

Wyoming threetip sagebrush can stump-sprout or sprout from its rootcrown following fire (Beetle 1960, Beetle 1977). However, sprouting ability varies considerably regionally, indicating that several ecotypes may exist (Barrington *et al.*1988, Bunting *et al.* 1987).

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Large Sagebrushes

Artemisia filifolia - sand sagebrush, sandsage, sand sage, oldman sage, threadleaf sagebrush, oldman sagebrush

1) General Characteristics

semi-deciduous
habit - freely branched, rounded, 2-4 ft. tall
vegetative spread - none
flowers Aug-Sep
seeds/lbs. - 3,135,000
fire tolerance (?)
range - South Dakota to Wyoming, Colorado, Nebraska, Kansas, Texas, Utah, Nevada, New Mexico, Oklahoma south to Chihuahua, Mexico (see Rasmussen and Brotherson 1986, www.fs.fed.us/database/feis/)
elevation - 2700-7500 ft.
moisture regime - dry (?)
soils - sandy, deep
soil moisture - xeric
soil temperature - mesic

2) Response to Fire

Specific fire adaptations of sand sagebrush are not well documented. In the northern Texas panhandle, sand sagebrush is considered a "nonsprouter' (Wright 1972) and is often severely damaged or even killed by fire (U. S. Department of the Interior, Bureau of Land Management. [no date], Wright 1972). Conversely, it is described as a fire-tolerant species capable of resprouting after fire in the southern Great Plains (Wright and Bailey1980, 1982).

Ecotypic differences in sprouting capabilities obviously exist. Similarly, differences in season of burn, soil characteristics, fire intensity and severity, and climatic factors may also influence the sprouting ability of sand sagebrush. Many sand sagebrush stands are characterized by an abundance of exposed sand and sparse understory vegetation. Fires are probably infrequent on such sites. Fires, however, have been historically important in many grassland or shrubland communities of the Great Plains and Southwest which support the growth of sand sagebrush (Jackson 1965). Fires presumably carry well in sand sagebrush stands with a dried herbaceous understory of forbs and grasses.

Sand sagebrush quickly reoccupies burned sites with an abundance of seedlings (Jackson 1965). It is not known if sand sagebrush typically resprouts, or if reestablishment is more often through seed. Sand sagebrush produces an abundance of light, wind-dispersed seed, and relatively rapid reestablishment through off-site sources is frequently possible.

Grazing may slow recovery of sand sagebrush following fire

Areas dominated by sand sagebrush, shinnery oak, and skunkbush sumac (*Rhus trilobata*) in Texas and eastern New Mexico have been burned to promote forbs and to encourage new shrub growth (Bryant and Morrison 1985). Such fires can enhance the value of these areas to mule deer and other wildlife species. Recommended procedure is to burn small patches of 5 acres or less in years with greater than normal fall and winter precipitation (Bryant and Morrison 1985). The patches should be left unburned for 10 to 12 years and scattered more than 0.25 miles apart to encourage mule deer utilization of these areas (Bryant and Morrison 1985). Burning small patches or swaths minimizes adverse impacts on many wildlife species including small birds (Davis *et al.* 1974, Holechek 1981). Lesser prairie chickens are more mobile than many other species and can reportedly tolerate brush control on blocks of 370 to 740 acres (150-300 hectares) (Holechek 1981).

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia rothrockii - timberline sagebrush, rothrock sagebrush

1) General Characteristics

evergreen
habit - wide, low, 4-32 in. tall, 1-2 ft. wide
vegetative spread - stem layers, root sprouts
drought enduring
flowers Aug-Sep
seeds/lb. - (?)
fire tolerant
range - southern California (see McArthur and Plummer 1978, Schultz 1986)
elevation - 8500-11,000 ft.

moisture regime - dry
soils - deep, fine to coarse, well-drained
soil moisture - xeric
soil temperature - frigid-cryic

2) Response to Fire

No information.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tridentata tridentata - Basin big sagebrush, big sagebrush

1) General Characteristics

evergreen
habit - erect, spreading, heavily branched, uneven topped, 3-6 (15) ft. tall, 5-8 ft. wide
vegetative spread - none
drought enduring
flowers - Aug-Oct
seeds/lb. - 2,500,000
fire intolerant
range - Montana south to New Mexico and all western states, southwestern North Dakota (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 1500-10,600 ft.
moisture regime - semi-dry
soils - deep, well-drained, fertile, coarse to fine
soil moisture - aridic-xeric
soil temperature - frigid-mesic

2) Response to Fire

Adult big sagebrush plants are killed by most fires. If sagebrush foliage is exposed to temperatures above 195 degrees Fahrenheit (90 deg C) for longer than 30 seconds, the plant dies (Britton and Clark 1985). Prolific seed production from nearby unburned plants coupled with high germination rates enable seedlings to establish rapidly following fire. Wind-, water-, and animal-carried seed contribute to regeneration on a site (Goodwin 1956, Johnson and Payne 1968, Tisdale and Hironaka 1981).

Site productivity affects the ease with which big sagebrush will burn. Highly productive sites have greater plant density and more biomass which, in turn, provides more fuel to carry a fire. Among the three major subspecies of big sagebrush, basin big sagebrush is considered intermediate in flammability. Mountain big sagebrush is most flammable, and Wyoming big sagebrush is least flammable (Britton and Clark 1985).

The rate of stand recovery depends on the season of burn as, season affects the availability of seed, postfire precipitation patterns, and the amount of interference offered by other regenerating plant species, particularly exotic annual grasses (Britton and Clark 1985, Daubenmire 1975, Zschaechner 1985).

Where sagebrush stands are dense, rangeland fire may stimulate the growth of forage plants and increase their accessibility. Grazing must be closely monitored in the postfire stand. If the vigor of understory plants is low or their cover is reduced too greatly, newly bared soil may become a seedbed for sagebrush rather than the desired grasses and forbs. Where big sagebrush has been removed by chemical means, it has regained its pretreatment cover in 17 years on stands where grazing was not controlled (Johnson 1969).

3) Response to Browsing

This taxa has low palatability for both wildlife and domestic livestock so browsing impact generally is not an issue (Hironaka *et al.* 1983). However, mechanical trampling damage to soil crusts does occur when these sites are grazed during the hot, dry season. The result is soil erosion and a much less suitable substrate for the establishment of new *A. t. tridentata* seedlings.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale

and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tridentata xericensis - scabland big sagebrush

1) General Characteristics

evergreen
habit - erect, spreading, heavily branched, uneven topped, 3-6 (15) ft. tall, 5-8 ft. wide (?)
vegetative spread - none
drought enduring (?)
flowers - Aug-Oct (?)
seeds/lb. - 2,500,000 (?)
fire intolerant
range - see Rosentreter and Kelsey 1991
elevation - see Rosentreter and Kelsey 1991
moisture regime - semi-dry
soils - deep to shallow clay loams
soil moisture - mesic
soil temperature - frigid-mesic

2) Response to Fire

Scabland big sagebrush is killed by fire (Kaltenecker, pers. comm.) and, like both basin and Wyoming big sagebrush, does not sprout or show any other adaptation to fire. The clay soils preferred by this taxon are especially susceptible to invasion by medusahead (*Taeniatherum caput-medusae*).

3) Response to Browsing

No information. However, soil types preferred by this taxon are particularly susceptible to erosion, implying that mechanical trampling damage by livestock will degrade site quality (Kaltenecker, pers. comm.).

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw

1986, Whisenant 1986).

Artemisia tridentata parishii - no common name

1) General Characteristics

evergreen
habit - erect, spreading, heavily branched, uneven topped, 3-6 (15) ft. tall, 5-8 ft. wide
vegetative spread - none (?)
drought enduring
flowers - Aug-Oct (?)
seeds/lb. - 2,500,000 (?)
fire intolerant (?)
range - coastal ranges of California (see McArthur and Plummer 1978, Schultz 1986)
elevation - 1000-2500 ft.
moisture regime - semi-dry
soils - (?)
soil moisture - (?)
soil temperature - (?)

2) Response to Fire

No information.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tridentata vaseyana - mountain big sagebrush, vasey sagebrush

1) General Characteristics

evergreen
habit - spreading, even topped, 2-4 (6) ft. tall
vegetative spread - stem layers rarely (sprouts ??)
drought enduring
flowers - Jul-Sep
seeds/lb. - 1,760,000 to 2,500,000
fire intolerant
range - Rocky Mountains (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 4600-10,000 ft.
moisture regime - semi-dry
soils - deep, well-drained, pH ~7.0
soil moisture - udic
soil temperature - cryic

2) Response to Fire

Fire return intervals in mountain big sagebrush communities historically were 12-15 years (Miller and Rose 1999). Plants are easily killed by fire in all seasons by even light intensity fires (Blaisdell *et al.* 1982). Mountain big sagebrush will not resprout. But this taxa can rapidly reestablish itself from seed under the typically more mesic conditions of *vaseyana* sites (Harniss and Murray 1973). Seedlings on burned-over areas arise both from seed introduced into the area from an adjacent unburned seed source and from seed stored in the soil that remains viable after burning. Seed present in the upper soil layers can be stimulated during low to moderate severity fires (Hironaka *et al.* 1983, Mueggler 1956). Reproductive maturity may occur in 3 to 5 years. Preburn density and cover may be achieved in 15 to 20 years under favorable conditions (Hironaka *et al.* 1983).

Mesic site conditions and fuel discontinuities may result in unharmed mountain big sagebrush plants or groups of plants within light and moderately severe burns. Whereas the normally mesic site conditions often preclude severe burns, severe wildfires are more likely to occur on steep, south slopes during hot, dry summers. Such severe fires leave few unburned plants and consume most of the seed stored in the litter and upper soil. These sites also are highly susceptible to invasion by exotic plants.

Rapid reestablishment and growth of sagebrush is aided by: 1) reduction in bunchgrasses, 2) suitable soil surface moisture conditions for seedling establishment, and 3) the tendency of soil stored seed to be stimulated by fire. Natural establishment of seedlings may be slow where severe burns occur on steep slopes because of unstable soil surface conditions, intense surface temperatures, and poor moisture conditions. It may

take 30 years or more before preburn densities and coverages of mountain big sagebrush are regained on severe burns. Rapid reestablishment is more likely on sandy or gravelly soils which are well suited for supporting sagebrush but have poor potential for herbaceous plants. Sagebrush returns slowly on fine-textured soils with good potential for production of herbaceous species (Blaisdell *et al.* 1982, Hironaka and Winward 1983).

3) Response to Browsing

This taxa is relatively palatable and provides an important source of browse for wintering big game (Hironaka *et al.* 1983). Effects of browsing are not known.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986). Up to 90% canopy reduction can be obtained with 2,4-D, dicamba, picloram or clopyralid. The latter compound is preferred where this sage occurs with bitterbrush (*Purshia tridentata*) or serviceberry (*Amelanchier* sp.). Clopyralid has relatively minor effects on members of the Rosaceae (Whisenant 1986).

***Artemisia tridentata vaseyana (form spiciformis*) -** subalpine big sagebrush

1) General Characteristics

evergreen
habit - 2-4 ft. tall
vegetative spread - stem layers
drought enduring
flowers - Jul-Sep
seeds/lb. - (?)
fire tolerant
range - Colorado, northcentral Wyoming, southeastern Idaho, central Utah (see McArthur and Plummer 1978, Schultz 1986, McArthur and Goodrich 1986)
elevation - 8800-10,000 ft.
moisture regime - semi-dry
soils - basic, deep
soil moisture - udic

soil temperature - cryic
soils - deep

2) Response to Fire

Winward (1985) reports that this form will resprout following fire, which is especially significant as it is the only member of the big sagebrush group with this capacity. No other information on this taxa is available.

3) Response to Browsing

No information.

4) Response to Mechanical Treatment

No information.

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986).

Artemisia tridentata wyomingensis - Wyoming big sagebrush

1) General Characteristics

evergreen
habit - basally branched, rounded, uneven topped, 4-38 in. tall
vegetative spread - none
drought enduring
flowers - late Jul-Sep
seeds/lb. - 1,215,000 to 3,000,000
fire intolerant
range - Wyoming Basin east to Montana, Wyoming, Colorado, Idaho and southwestern North Dakota (see McArthur and Plummer 1978, Schultz 1986, www.fs.fed.us/database/feis/)
elevation - 5000-7000 ft.
moisture regime - dry
soils - dry, shallow, well-drained, gravelly, fine-textured silt-loams
soil moisture - aridic-xeric
soil temperature - mesic-frigid

2) Response to Fire

Wyoming big sagebrush is readily killed by fire. If the foliage is exposed to a minimum temperature of 194 degrees F (90 degrees C) for a period of at least 30 seconds, the plant will die. In essence, any fire passing through a plant will cause mortality (Britton and Clark 1985) although Peters (pers. comm.) reports plants surviving burning of lower branches in Montana.

Site productivity affects the ease with which big sagebrush will burn. Highly productive sites have greater plant density and more biomass which, in turn, provides fuel to carry a fire. Among the three major subspecies of big sagebrush, mountain big sagebrush (ssp. *vaseyana*) is most flammable, basin big sagebrush (ssp. *tridentata*) is intermediate, and Wyoming big sagebrush is least flammable (Britton and Clark 1985).

Prolific seed production and high rates of germination enable them to reestablish rapidly after fire. Wind-, water-, and animal-carried seed contribute to regeneration on a site (Goodwin 1956, Tisdale and Hironaka 1981). Soil-stored seed is thought to be important in the reestablishment of mountain big sagebrush (ssp. *vaseyana*) (Mueggler 1956). On-site seed storage permits rapid reestablishment even where most shrubs in an area are eliminated.

Postfire reestablishment of Wyoming big sagebrush has not been widely documented. Several years may be required for seedling establishment to occur on xeric Wyoming big sagebrush sites (Clifton 1981, Wambolt and Payne 1986, West and Hassan 1985, Young and Evans 1978). During years of low precipitation, few sagebrush plants can become established, and it may take many years before reinvasion takes place. In the Great Basin, these sites are at very high risk for permanent degradation as a result of invasion by exotic plants. Even under favorable conditions, site recovery may take 60-100 years (Kaltenecker, pers. comm.).

3) Response to Browsing

This taxa is important for wintering big game animals and sage grouse but the effects of browsing are not known (Hironaka *et al.* 1983).

In a central Wyoming study, grazing was shown to have a pronounced effect on the longevity of a Wyoming big sagebrush control effort. On plots which had been sprayed but not grazed, sagebrush remained in a reduced state for 14 to 17 years. Fourteen years after spraying, the number of young plants was about 30 percent less than on the untreated plots. The number of mature plants was about 50 percent below that measured on the control. After 17 years, the number of young plants on sprayed and grazed plots was much greater than that for unsprayed and grazed, or sprayed and ungrazed areas. The increase in sagebrush cover and concomitant decrease in forage began 5 years after

treatment. Part of the measured decrease in forage production may be due to the tendency of livestock to utilize the treated areas more heavily, reducing the vigor of understory plants (Johnson 1969).

4) Response to Mechanical Treatment

Mechanical or chemical treatments are generally most suitable for *wyomingensis* sites because there often is insufficient fine fuels to allow for controlled burns (Hironaka *et al.* 1983).

5) Response to Herbicides

All varieties of *Artemisi*a are readily killed by herbicides (Pechanec *et al.*1965, Tisdale and Hironaka 1981, Western States Sage Grouse Committee 1982, Monsen and Shaw 1986, Whisenant 1986). In a central Wyoming study, plots which had been sprayed but not grazed, has sagebrush in a reduced state for 14 to 17 years. Fourteen years after spraying, the number of young plants was about 30 percent less than on the untreated plots. The number of mature plants was about 50 percent below that measured on the control. After 17 years, the number of young plants on sprayed and grazed plots was much greater than that for unsprayed and grazed, or sprayed and ungrazed areas. The increase in sagebrush cover and concomitant decrease in forage began 5 years after treatment. Part of the measured decrease in forage production may be due to the tendency of livestock to utilize the treated areas more heavily, reducing the vigor of understory plants (Johnson 1969).

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APPENDICES

A. Palatability (ranked by Roger Rosentreter, botanist with BLM Idaho State Office)

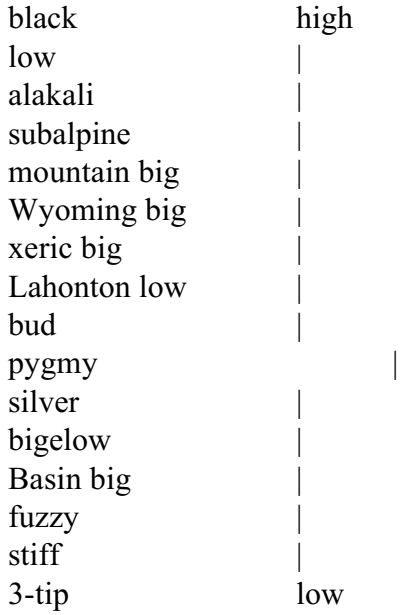

Fig. 1. Ordination of major sagebrush taxa against gradients of soil temperature and soil moisture (reprinted by permission from West and Young 2000).

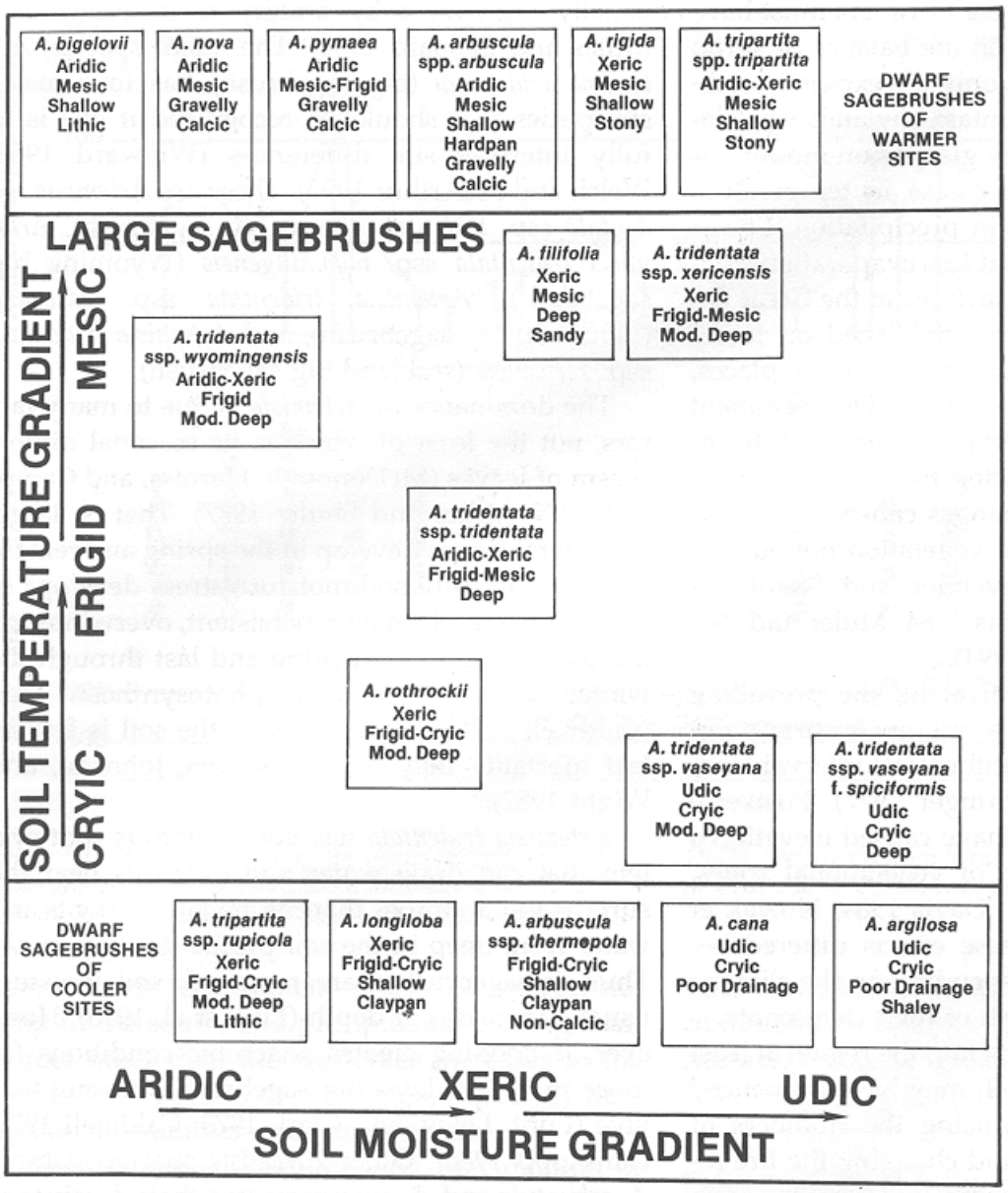

Fig. 2. See figure caption (reprinted by permission from West and Young 2000).

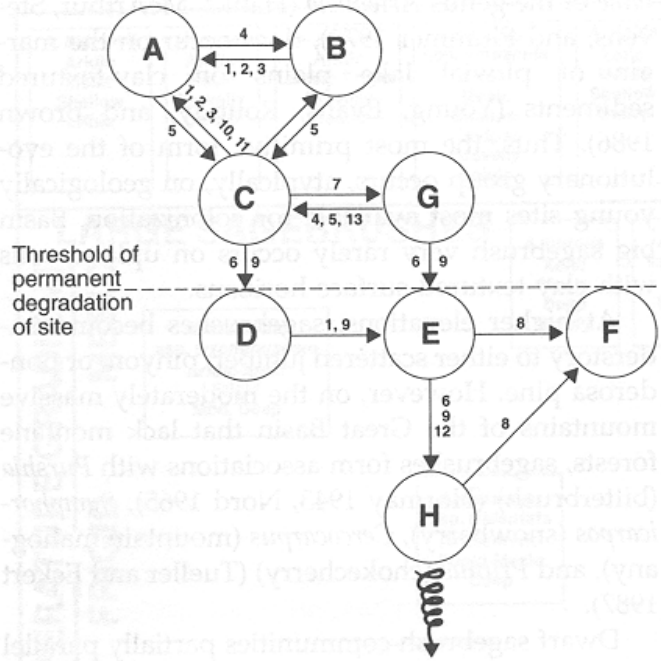

Figure 7.4. Major pathways of progressive and retrogressive succession in lower-elevation sagebrush steppe and Great Basin sagebrush vegetation. Community Types (circles) A-Herb-dominated phase of pristine (without livestock impact) sagebrush steppe; B-Shrub-dominated phase of pristine sagebrush steppe, all growth forms present; C-Denser, larger sagebrush with remnants of native, perennial herbs, after moderate livestock grazing but no episodes of recent fire. Aroga, *poor soil aeration, snow mold or vole girdling damage to shrubs; D. Densest, largest sagebrush, understory dominated by introduced annuals, after lengthy, heavy grazing. E-Cheatgrass medusahead other introduced annuals (e.g. bur buttercup) dominate F. Introduced perennial grass (crested wheatgrass, Russian wildrye, etc.) monocultures or polycultures with seeded shrubs and forbs. G-Herbicide-induced native grasslands. H-Weedy, introduced biennials and perennials such as yellow starthistle, leafy spurge, knapweeds, etc. dominate. Force (arrows) 1. Wildfire. 2.* Aroga *moth 3. Much wetter than average years. (Promotes snow mold, poor soil aeration and vole girdling.) 4. Cessation 1, 2, and/or 3. 5. Moderates livestock grazing. 6. Lengthy, heavy livestock grazing. 7. Herbicides applied to kill broad-leaved plants. 8. Tillage followed by seeding. 9. Accelerated soil erosion. 10. Prescribed burning. 11. Sheep, deer, and/or elk use in fall or winter. 12. Further weed invasion. 13. Interseeding of native shrubs and forbs.*