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Title: SEASONAL RESPONSE OF BITTERBRUSH TO BURNING AND CLIPPING IN EASTERN OREGON

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Bitterbrush [Purshia tridentata (Pursh) DC] plants were burned or clipped, fall and spring, under different soil moisture conditions on two sites in east-central Oregon. Treatments on plants of an erect growth form on the Juniperus/Artemisia-Purshia site resulted in 38% of the fall-clipped and 40% of the spring-clipped plants sprouting. None of the unwatered fall-burned plants sprouted, nor did any of the fall-burned plants that were watered 24 hours prior to burning. Ten percent of the plants that were watered after fall-burning and 30% of the spring-burned plants sprouted.

On the Pinus/Purshia site treatments on plants of a lower-growing, decumbent form of bitterbrush resulted in 69% of the fall-clipped and 90% of the spring-clipped plants sprouting. None of the unwatered, fall-burned plants sprouted although 20% of the plants watered prior to fall-burning and 10% of the plants watered after fall-burning sprouted. Fifty percent of the spring-burned plants sprouted.

Within sites, sprouting of clipped plants on either site did not appear to be related to plant size, age, or soil moisture. Burning was more damaging on both sites than clipping and fall-burning more damaging than spring-burning.

Seasonal Response of Bitterbrush to Burning and Clipping in Eastern Oregon

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INTRODUCTION

Intensive management of western rangelands and forests has increased rapidly during the past several decades. Unfortunately, early shrub management on these rangelands and forests kept pace more by trial and error than by sound ecological investigation. Fortunately, increasing concern for the ecological role of shrubs in western ecosystems, deteriorating big game habitat, and non-consumptive values on rangelands and forests have encouraged a healthy reexamination of our understanding of and attitude toward our indigenous western shrubs.

More recently, interest in prescribed burning has increased. However, if fire is to be employed in vegetation management with any success, burning effects on both desirable and undesirable vegetation will have to be sufficiently understood to allow achievement of specific burning objectives.

This study was conducted in eastern Oregon to (1) compare fall and spring burning effects on bitterbrush, (2) compare effects of burning on bitterbrush in two different plant communities, (3) determine the effects of different soil moisture regimes on fall-burned bitterbrush plants, and (4) compile an annotated bibliography on bitterbrush.

The thesis reported here utilizes the format of a journal article in the Journal of Range Management. The journal article follows a detailed literature review on the ecology of bitterbrush. The final chapter is an annotated bibliography of bitterbrush.

LITERATURE REVIEW

Antelope bitterbrush [Purshia tridentata (Pursh) DC.] is one of the most widely distributed western shrubs. Hormay (1943) placed its range at 138 million ha in 11 western states and southern British Columbia. It is found from the northern portion of Arizona and New Mexico northward to southern British Columbia, and from the Cascade-Sierra Mountain Range eastward to western Montana, Wyoming and Colorado. In Oregon it grows in all counties east of the Cascade Mountains and locally in Jackson County (Stanton 1959). Hormay (1943) reported that in California bitterbrush grows east of the Cascade and Sierra Mountains between 1067 and 3353 m. Nord (1965) revised its upper limit in California to 3505 m. In Oregon, Stanton (1959) reported its elevational range from 61 m near the Columbia River to about 1980 m in the Paulina Mountains. Alderfer (1977) revised its upper limit in Oregon to 2164 m on Hart Mountain. At its northern limits in the Kootenai and Okanogan Valleys of British Columbia it occurs between 305 and 610 m.

Bitterbrush grows in pure stands (Stanton 1959) but more commonly in association with various genera of trees, shrubs, forbs, and grasses. Franklin and Dyrness (1973) for example, described 18 habitat types in Oregon in which bitterbrush was a major component. Since bitterbrush grows extensively under a wide variety of climatic and environmental conditions, it would be expected to grow in a great variety of plant communities. However, certain plants appear most frequently with bitterbrush. Trees commonly reported to be growing with bitterbrush include Pinus contorta, P. jeffreyi, P. monophylla, and P. ponderosa.

Other trees include *Juniperus occidentalis*, *Populus tremuloides*, *Pseudotsuga menziesii* and probably others (Stanton 1959; Yeager 1960; Nord 1965).

Shrubs growing with bitterbrush vary widely. In California bitterbrush is most frequently found with *Artemisia tridentata*, *Atriplex canescens*, *Cercocarpus ledifolius*, *Chrysothamnus nauseosus*, *C. viscidiflorus*, *Eriogonus* spp., *Grayia spinosa*, *Lygodesmia spinosa*, *Opuntia* sp., *Prunus andersoni*, *Ribes* spp., *Rosa* spp., and *Symphoricarpos* spp. (McKeever and Hubbard 1960; Nord 1965). In Idaho, McConnell and Dalke (1960) observed that many of the same associates were found, but that *Symphoricarpos albus* and *Ceanothus velutinus* became more common with increases in elevation. At 2400 m in Colorado, bitterbrush occurs frequently with *C. montanus* and *A. tridentata* on south slopes and with *Physocarpus malvaceus* on north slopes. In Oregon many of these same associates are found with bitterbrush (Franklin and Dyrness 1973). However, at higher elevations bitterbrush is found with, and eventually yields to *C. velutinus* and *Arctostaphylos patula*.

Many grasses and grass-like plants grow with bitterbrush. Common associates include *Agropyron spicatum*, *Bromus mollis*, *B. tectorum*, *Festuca idahoensis*, *Koeleria cristata*, *Oryzopsis hymenoides*, *Poa pratensis*, *P. sandbergii*, *Sitanion hystrix*, *Stipa columbiana*, *S. comata*, *S. occidentalis*, *S. thurberiana*, *Carex geyeri*, and *C. rossii* (Daubenmire 1952; Stanton 1959; Dyrness 1960; Nord 1965; Dealy 1966). Although *F. idahoensis* is frequently listed as one of the most common grasses growing in association with bitterbrush, Nord (1965) reported *S. hystrix* was the only grass species always found in bitterbrush stands in California.

Antelope bitterbrush is one of two species in an exclusively North American genus of the rose family (Rosaceae). It has been described as a rigid, freely branching but sometimes depressed shrub, 0.6 to 2.5 m tall, or rarely a small tree up to 15 m in canopy diameter. Leaves are deciduous, cuneate, and deeply three-toothed at the apex with the middle lobe rounded. The leaves are 5 to 20 mm long, greenish above and grayish-tomentose beneath, with the margins generally revolute. Flowers are solitary on short lateral twigs. The calyx tube is funnelform and six to eight mm long with stipitate-glandular and tomentose lobes that are ovate-oblong. There are five petals which are oblong-obovate to spatulate, yellow to pale yellow or white, and five to nine mm long with 18 to 30 stamens well exserted in one row. The fruit is pubescent, cartilaginous, short-stipulate, ellipsoid-fusiform achene, and the thick style (one, rarely two) is persistant. The seed is black, six to eight mm long, without endosperm and with the radicle inferior (Stanton 1959; Nord 1965; Hitchcock and Cronquist 1973). Bitterbrush may be identified in older manuals in the genus Kunzia or Tigarea. It is also locally known as antelopebrush, quininebrush, black sage, deerbrush, greasewood, or buckbrush (Nord 1965).

Bitterbrush reproduces mainly from seed. Seed is produced by plants that are at least 30 cm tall and three years old on favorable, competition-free sites (Nord 1965). In many native stands, plants may require ten years or more to produce seed. Seeds drop a few days after maturity which ranges from early June at low latitudes and elevations to mid-September at higher latitudes and elevations in California (Nord 1965). Blaisdell (1958) reported seven years data on bitterbrush in

Idaho during which seed ripening occurred on July 17, and dissemination was completed by August 2. Nord (1965) delineated seed ripening in California and observed that good seed crops generally occur in seasons where subsequent leader growth is about eight cm or more. Seed maturation depends on local climatic conditions. Holmgren and Basile (1959) reported that in Idaho seed ripened in July at 915 m elevation, and about one month later at 1525 m. In Oregon, Stanton (1959) reported ripe seed in mid-June at 91 m elevation, and five to six weeks later at 1525 m.

Bitterbrush also reproduces vegetatively by stem layering and sprouting. Nord (1965) noted that the two factors apparently responsible for stem layering were soil moisture, and size and growth form of the plant. On burned-over areas, layering was related to soil texture, with nearly three times more plants layering on fine than on coarse-textured soils. Nord (1965) also reported that layering was more common at higher elevations. Nord's observation was reinforced by Alderfer's (1977) description of a high elevation, decumbent, layering form in Oregon.

Bitterbrush also sprouts. Mechanical damage or fire frequently top-kills plants. Subsequent sprouting appears to be dependent on season of damage, soil moisture, soil texture, growth form, genetic influence of crossing genera, and local growing conditions. Sprouting normally originates from numerous adventitious buds located near the base of the main stem or from a callus of meristematic tissue which develops beneath the bark and encircles the stem (Blaisdell and Mueggler 1956; Stanton 1959).

Variable phenotypic expressions may result from the genotypic influence of several other plants. Smith (1964) reported early recognition of introgression between Stansbury cliffrose (*Cowania stansburiana*) and bitterbrush. At the southern portion of its range bitterbrush commonly intergrades with Stansbury cliffrose and desert bitterbrush (*P. glandulosa*) (Plummer *et al*. 1957; Thomas 1957; Stutz and Thomas 1964; Nord 1959, 1965). Stutz and Thomas (1964) considered desert bitterbrush to be a stabilized segregant from the hybridization products of cliffrose and bitterbrush.

Stutz (1974) described avenues by which new species originate, including gene flow through sexual recombination. In Oregon, Alderfer (1977) suggested geographic routes for gene flow resulting in four distinct bitterbrush ecotypes and many intermediate types. Chromosome studies, however, invariably resulted in a diploid number of 2N=18 (Alderfer 1977).

Longevity in bitterbrush has been widely reported and varies considerably. Nord (1965) reported a bitterbrush plant 162 years old. Many authors have reported plants in excess of 100 years, although most stands are much younger. Hormay (1943) considered the normal life span of bitterbrush to be 60 to 70 years.

Bitterbrush grows on a wide variety of soils. In California, Nord (1965) reported stands on soils developed from granitic, basaltic, rhyolitic, or pumiceous parent materials, or on sedimentary sandstone and shale rock. In general, bitterbrush is most frequently found on young, deep to very deep, coarse-textured, well-drained soils (Driscoll 1964; Nord 1965). Bitterbrush is also a pioneer species on recent volcanic deposits in Idaho (Eggler 1941) and California (Nord 1965) and codominant with ponderosa pine (Pinus ponderosa) on a 27-year-old mud flow in California (Dickson and Crocker 1953). Nord (1963) reported that bitterbrush often invades disturbed areas long before other plants appear and for many years may provide the only form of soil cover and protection.

Bitterbrush is apparently intolerant of saline conditions, and is generally absent on clay loams or other clay textures, or where claypan or hardpan is within about 60 cm of the soil surface (Nord 1965). Alderfer (1977), however, reported bitterbrush growing on clay soils in Oregon. Bitterbrush is also absent or rare in otherwise climatically suitable areas where depth is restricted, or poorly drained and slowly permeable, or in areas subject to periodic flooding, slow runoff, or where a high water table is within 30 cm of the surface (Nord 1965; Dealy and Geist 1978). Soils with slightly acid reactions support better stands of bitterbrush (Nord 1965) although it also grows on basic soils (Plummer et al. 1968). Nord (1965) noted that bitterbrush was absent on sandy soils that are mildly alkaline or calcareous within 90 to 120 cm of the surface. Sabinski and Knight (1978), working in Grand Teton Park, were not able to isolate any textural trend to separate bitterbrush stands from big sagebrush (Artemisia tridentata Nutt. spp. vaseyana Rydb.) but speculated that bitterbrush was able to grow with big sagebrush where the amount of silt at 10 to 20 cm decreased and sand at that depth increased. Sabinski and Knight (1978) did not report soil reaction or indicate a calcareous nature.

Available soil moisture is important for bitterbrush, particularly in areas where precipitation is marginal or where soil textural conditions either retain too little moisture or hold it at high tensions. Hubbard (1956) and Nord (1965) reported that available soil moisture is the critical factor in germination, survival, and growth of bitterbrush. Although seedlings may extend root systems to depths of 50 cm or more the first growing season (Hormay 1943) and ultimately to depths of 5.5 m or greater (McConnell 1961), adverse moisture conditions induced by soil conditions (Nord 1965), drouth (Hormay 1943), or competition (Holmgren 1956) may affect plant growth and survival. Although bitterbrush may exist as a xerophyte or phreatophyte (Nord 1965), the largest plants are found where the water table is 4.6 to 7.6 m below the soil surface (Hormay 1943; Nord 1965).

Bitterbrush value as a browse plant was recognized as early as 1909 (Hormay 1943). Early work by the University of Nevada showed crude protein levels of 13% in young leaves and twigs which was 82% digestible (Hormay 1943). Hormay also noted that in Utah, early experiments revealed 15% crude protein in leaves and twigs in June, and 10% in September. Dietz et al. (1958) found comparable winter protein levels of nearly 11% in Colorado. In Oregon, Hickman (1975) found protein levels for June and September of about 17 and 10% respectively. Hickman's digestibility values, however, were considerably lower than those of the Nevada study, peaking at 40% in July. Bissell et al. (1955) tested the digestibility of foods commonly eaten by deer in California. They found that bitterbrush was the only tested browse species capable of sustaining deer as a single food supply for prolonged periods. In only one study was protein level found inadequate. Smith (1957) reported a crude protein value of 2.7% on winter range in Utah.

Other nutritive values have also been found satisfactory for livestock and wildlife maintenance diets. Hickman (1975), for example, found December crude fiber values of 22.5%, crude fat of 5%, and calcium of 0.6% on critical deer winter range in southern Oregon.

Although bitterbrush propagates primarily by rodent-cached seed (Hormay 1943; Nord 1959; West 1968; Stuth and Winward 1976), a wide range of enemies affect germination and survival. Furniss (1972) listed over 80 species of insects suspected of damaging bitterbrush. Although most affect leaves, no portion of the plant is immune to attack. Tent caterpillars (Malacosoma sp.), cutworms (Lycophotia sp.), wireworms (Elatridae sp.), and grasshoppers (Melanoplus sp.) have been the most damaging (Nord 1965). Diseases have also been responsible for plant damage, frequently attacking entire stands. Krebill (1972) listed eight diseases known or suspected of damaging bitterbursh. Included were rots, cankers, a parasitic plant, and the widespread problem of damping-off.

Rodents and larger browsing mammals also feed on bitterbrush. Rodents most frequently attack seed supplies. Nord (1965) cited a planting test in which rodents took up to 87% of the seed. Nord also reported observations of a seeding trial in California in which rodents systematically mined drill rows searching for seed. The most commonly involved rodents include kangaroo rats (Dipodomys sp.), deer mice (Peromyscus sp.), chipmunks (Eutamias sp.), golden mantle and antelope squirrels (Citellus spp.), pocket mice (Perognathus sp.), shrew (Sorex sp.), and pack rats (Neotoma sp.) (Nord 1965).

While rodents most often attack seeds, larger mammals feed heavily on aerial plant organs. Jackrabbits (Lepus californicus), deer (Odocoileus sp.), and domestic livestock (Bos sp. and Ovis sp.) often browse heavily on bitterbrush (Cook 1954; Holmgren and Basile 1959; McKeever and Hubbard 1960; Anderson et al. 1968; Ferguson 1968). On heavily used sites overbrowsing may affect plant survival and generally creates a low, compact, tightly hedged appearance (McConnell and Smith 1977). To maintain stands in good condition, Hormay (1943) recommended a maximum of 60% use of current twig growth. Garrison (1953) recommended 60 to 65% use on the best sites, and 50% use of drier sites.

Nitrogen fixation by bitterbrush has been investigated. In 1958 Wagle described nodules growing on the roots of bitterbrush in California. Wagle and Vlamis (1961) in a follow-up study reported that nodulated plants growing in low nitrogen soils of basaltic origin grew better than non-nodulated plants on the same soil. The nodules contained a symbiotic organism that the authors speculated may have had the ability to fix atmospheric nitrogen. After speculation on nitrogen fixation by bitterbrush (Allen and Allen 1965; Becking 1970), Krebill and Muir (1974) described Frankia purshiae, the endophyte found in bitterbrush nodules, and discussed its possible role in nitrogen fixation. Farnsworth (1976) then compiled an extensive list of nodulated shrubs and presented information to support possible contributions by non-legumes to local nitrogen budgets. Most recently Dalton and Zobel (1977) conducted an intensive investigation into the role of bitterbrush nodulation. In greenhouse-grown seedlings from 12 sources in several western states, all nodules exhibited the ability to reduce acetylene except the group of plants from Bryce Canyon, Utah. These plants may be genetically different and not adapted to the endophyte found in Oregon soils. The same report indicated that soil temperature and plant age were important in determining the degree and effectiveness of nodulation and that moisture stress and seasonal and diurnal temperature variation had highly variable effects. The authors noted, however, that xylem pressure potentials in the range of -25 bars greatly reduced nodule activity both in the field and in the greenhouse. Nitrogen accretion calculated by Dalton and Zobel was only 0.057 kg N/ha·yr on a site where bitterbrush contributed 25.2% of the vegetative cover.

Despite its weak potential to fix nitrogen, bitterbrush occasionally responds to nitrogen fertilization, and the role of nodulation is not clear. Klemmedson and Ferguson (1969) grew bitterbrush seedlings in soil taken from three depths on a site that normally supported bitterbrush. They added different amounts of nitrogen and found that nitrogen caused a bitterbrush yield decline when grown in soil from the surface layer, but a slightly increased yield in soils from 15 to 40 and 40 to 90 cm depths. On granitic soils proven to be deficient in nitrogen for barley, adding nitrogen resulted in negative or no response by bitterbrush. Klemmedson and Ferguson also reported that when total nitrogen in bitterbrush plants reached about 2.0%, yield declined.

Dendrochronological techniques have been used in several studies involving bitterbrush. Dendrochronology is the systematic study of tree-rings applied to dating past events and evaluating climatic history (Fritz 1965). In temporate ecosystems woody plants often exhibit annual growth rings or xylem layers resulting from seasonally active cambial growth followed by reduced growth or dormancy during the winter period. Roughton (1962) presented an extensive review of dendrochronology and age determination in woody plants in which shrubs, including bitterbrush, were emphasized. Roughton reported that various techniques have been satisfactorily used to age woody plants. The four basic techniques used are growth-ring counts, estimated age classes, bud-scar and branching-node counts, and growth-ring analysis. Only the first and last methods are considered sufficiently reliable in age investigations, and they are not absolute. Problems frequently encountered include false rings produced by severe, fluctuating weather during a growing season or by defoliation, missing rings or rings too narrow to be discernable resulting from stagnation, dormancy during the growing season, or growth that is neither annual nor seasonal in nature. Other problems include incomplete rings due to intermitant cambial growth, and missing portions of plant stems caused by insects, girdling, frost, mechanical damage, or decay.

In early work on bitterbrush, Hormay (1943) reported that stems form one growth ring per year and can be readily aged within two to three years by counting rings in a section through the main stem at ground level. Ferguson (1959) examined bitterbrush stems and found them to be highly sensitive and readily dated despite irregular stem forms. Although some rings were small or nearly absent, or contained false layers in larger rings, Ferguson noted that neither characteristic detracts from datability in bitterbrush.

Roughton (1972) applied different age-determination techniques to various shrubs in Colorado and reported that bitterbrush plants were readily aged by cross-dating xylem layers, and that growth-ring analysis was more accurate than annual ring-counts. Adams (1975) examined 355 bitterbrush plants near Silver Lake, Oregon. He reported that bitterbrush exhibited growth-ring patterns consistent with chronologies for _Pinus ponderosa_ and _Juniperus occidentalis_. Of 355 plants, only 23% were alive, yet only 7% were not dated. Twelve plants were not readable and 14 were too decayed to be reliable.

McConnell and Smith (1963) used annual ring-counts to relate bitterbrush plant age to maximum stem diameter. This site-specific technique accounted for 86% of the variation among plant ages, thus providing a reliable method of quickly estimating bitterbrush age. Since the size of shrubs in general may be a function of plant density and favorableness of site conditions (Beetle 1960), estimation techniques are not sufficiently precise for ecological investigation into plant ages.

McConnell and Smith (1963, 1977) sanded stem cross-sections near the root crown, then examined the sections under a low-power microscope. They reported that a stain of boiled linseed oil and terpentine mixture resulted in increased ring clarity. To aid in visual ring clarity, Roughton (1972) applied a light coating of kerosene. Other solutions useful as stains may include phloroglucin (Stewart 1930).

Location of a section for ring analysis has been reviewed by Roughton (1962). Aerial plant portions above the root crown, and root systems, are generally unreliable indicators of plant age and reliability decreases with increased distance from the root crown. Although the root crown near the soil surface generally provides the specimens most likely to contain the maximum number of rings, samples taken from the base of the largest stem or root were usually not statistically different than root crown ages if the plants had not been subjected to fire or other destructive treatment (Roughton 1962).

Possibly because of the extensive range, climatic and environmental conditions under which it grows, bitterbrush response to burning is highly variable. Although most bitterbrush reproduces from seed (West 1968) it is commonly felt that fire destroys bitterbrush by removing both the existing stand and the seed source. Most reports discussing the response of bitterbrush to burning are results of wildfires and not well documented with respect to soil textural characteristics, soil moisture, phenological stage of development, weather conditions, or other environmental conditions which may influence post-fire recovery.

In California, Nord (1965) reported highly variable post-burn recovery, where five of 13 wildfires resulted in at least 5% sprouting while on one burn, sprouting exceeded 25%. Hormay (1943) noted that in only one instance did substantial sprouting occur; a January wildfire in northeastern California resulted in over 25% sprouting. In general, Hormay stated that hundreds of thousands of acres of bitterbrush have been destroyed by fire. Countryman and Cornelius (1957) reported a complete absence of bitterbrush regeneration six years after a wildfire although it constituted 91% of the vegetal cover adjacent to the burn. Leopold (1950) emphasized the highly variable response by noting that in the Truckee River Canyon of eastern California logging and recurrent fires stimulated extensive growth of bitterbrush, but a few miles toward Reno fires seemed to eliminate bitterbrush.

Southern Idaho is frequently described as an area where bitterbrush sprouts well following fire. Blaisdell (1950, 1953) reported that burning destroyed sagebrush (Artemisia sp.) but bitterbrush sprouted. The year following burning, 49, 43, and 19% of burned plants sprouted on light, moderate, and heavy burns respectively. These results occurred on basaltic soils in a 41 cm precipitation zone. Similar results were obtained at the U. S. Sheep Station near Dubois, Idaho where annual precipitation is only 28 cm. At Dubois, nearly all the plants sprouted after a small burn of light intensity in the fall of 1945 but only 25% sprouted on a large burn of heavy intensity in the fall of 1947. Blaisdell and Mueggler (1956) burned or severed bitterbrush plants five cm above ground level in Idaho. They found that 50 and 72% respectively of burned and severed plants sprouted, and that sprouting occurred as late as 13 months after treatment. Also, mortality was high on sprouted plants. Twenty-six percent of sprouted plants died during the 12-month period. Thirty-three percent of burned plants that sprouted died compared to 21% of the severed plants.

Driscoll (1963) found in Oregon that sprouting ability was related more to soil factors than to burn intensity. On northerly slopes, stands of bitterbrush supported by loose, coarse-textured, nonstony soils without cinders or pumice had the highest frequency of sprouting. In one such area, 80% of the burned plants sprouted. Driscoll also noted that bitterbrush on these sites frequently layered, and that plants which sprouted did so from the layer but never from the parent plant. Weaver (1957) observed that in the *Pinus ponderosa* zone of Oregon, bitterbrush rapidly and heavily invaded after logging but that it was readily killed by fire. On areas where it dominated ground cover, it had not reestablished 18 months after a wildfire, although grasses, pine, and manzanita were well established.

Less information on burning response is available from other areas. In central and northern Utah, Blaisdell and Mueggler (1956) observed that only limited sprouting occurs. Daubenmire (1970) stated that bitterbrush in Washington is nearly always killed by steppe fires. In the Great Basin in general, Billings (1952) noted that bitterbrush is eradicated by fire since it rarely rootsprouts in that region and its seeds are not particularly mobile. Billings, however, did not clarify sprout origin in that bitterbrush seldom if ever has been reported to sprout from the root system proper.

It is possible that bitterbrush, which is frequently an early successional species and apparently grows best on coarse, relatively infertile soils, may have a narrower ecologic amplitude than is currently believed. Applied nitrogen, for example, is frequently detrimental to bitterbrush (Klemmedson and Ferguson 1969, 1973). Because burned vegetation often results in a flush of total nitrogen in the soil (Vlamis *et al*. 1955; Vlamis and Gowans 1961), the plants may be harmed in direct proportion to the fuel load and accompanying increase in soil nitrogen. Any attempt to improve soil growing conditions by fertilization may be either directly toxic to bitterbrush or indirectly harmful by stimulating competing plants.

Bitterbrush responds better to mechanical top removal than to burning. Blaisdell and Mueggler (1956) severed plants five cm above ground level and compared subsequent sprouting to that of burned plants. Seventy-two percent of the severed plants sprouted compared to 50% for burned plants. Mueggler and Blaisdell (1958) compared effects of rotobeating, railing, spraying, and burning sagebrush range. Burning severely harmed bitterbrush while spraying resulted in a 250% increase in production after three years. The authors suggested that rotobeating helped bitterbrush and that railing had no effect, although bitterbrush on these plots was too sparse to draw definitive conclusions.

Judicious topping rather than completely severing the plant appears beneficial. Ferguson and Basile (1966) and Ferguson (1972) recommended removing part of the aerial plant crown to stimulate growth and make foliage more available to browsing animals. Ferguson (1972) recommended mechanically removing 30 to 50% of the aerial crown to stimulate growth. After four years, Ferguson reported that none of the plants treated in this manner had died, and no detrimental effects on shrub longevity, nor increase in damage from insects or disease, were observed. Shrubs increased production immediately, and four years later were still producing more than the control plants.

Timing of bitterbrush defoliation may also be important. Menke (1974) reported that defoliating bitterbrush during late spring and summer at the fruit developing or seed shatter stages was most harmful and these plants required more than one year for recovery of vigor and total nonstructural carbohydrate reserves. Hyder and Sneva (1962) and

Sneva and Hyder (1966) reported that spraying resulted in a similar response. Bitterbrush sprayed with 2.0 lb/A of 2,4-D resulted in mortality of 9 to 23% over five spray dates, and a mean crown reduction of about 40%. Spraying at any date defoliated bitterbrush and recovery was related to the earliness of spraying and the length of growing season remaining after spraying. Blaisdell and Mueggler's (1956) data also showed timing of defoliation to be important, because in general, spring clipping was more harmful than fall clipping.

Seasonal Response of Bitterbrush to Burning and Clipping in Eastern Oregon

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Highlight

Bitterbrush [*Purshia* *tridentata* (Pursh) DC.] plants were burned or clipped, fall and spring, under different soil moisture conditions on two sites in east-central Oregon. Treatments on plants of an erect growth form on the *Juniperus*/*Artemisia*-*Purshia* site resulted in 38% of the fall-clipped and 50% of the spring-clipped plants sprouting. None of the unwatered fall-burned plants sprouted, nor did any of the fall-burned plants that were watered 24 hours prior to burning. Ten percent of the plants that were watered after fall-burning and 30% of the spring-burned plants sprouted.

On the *Pinus*/*Purshia* site treatments on plants of a lower-growing, decumbent form of bitterbrush resulted in 69% of the fall-clipped and 90% of the spring-clipped plants sprouting. None of the unwatered, fall-burned plants sprouted although 20% of the plants watered prior to fall-burning and 10% of the plants watered after fall-burning sprouted. Fifty percent of the spring-burned plants sprouted.

Sprouting of clipped plants on either site did not appear to be related to plant size, age, or soil moisture. Burning was more damaging on both sites than clipping and fall-burning more damaging than spring-burning.

Recent interest in prescribed burning makes plant response to fire of vital concern to both land and wildlife managers. Controversial chemicals may be restricted and the recent increases in fossil fuel costs may encourage the use of fire in vegetation management on forests and rangelands. Therefore, it is imperative that resource managers know how plants will respond to fire, especially the desirable plants which the treatment is designed to enhance.

Bitterbrush [Purshia tridentata (Pursh) DC.] is a desirable browse species for both domestic livestock and wildlife (Nord 1965) but its response to burning has been variable. In eastern Idaho it sprouted freely, although sprouting varied inversely with intensity of the burn (Blaisdell 1950, 1953). Driscoll (1963) found that sprouting in central Oregon was related more to soil factors than burn intensity. Sprouting after fire also varied widely in California where five of 13 wildfires were followed by 5% sprouting, and 25% sprouting occurred on one burn (Nord 1965). Limited sprouting occurred in northern and central Utah (Blaisdell and Mueggler 1956). In Washington, Daubenmire (1970) noted that bitterbrush was nearly always killed by steppe fires. Hormay (1943) stated that hundreds of thousands of acres of bitterbrush have been destroyed by fire, and Billings (1952) contended that bitterbrush in the western Great Basin was permanently erradicated by fire.

Mechanical top removal appears to be less damaging to bitterbrush than burning. In fact, Ferguson (1972) recommended removing 33 to 50% of the aerial crown to stimulate growth. Mueggler and Blaisdell (1958) reported that rotobeating and railing were less damaging than burning. Blaisdell and Mueggler (1956) burned and severed bitterbrush plants five cm above ground level monthly, May through October. They found that 50 and 72% respectively of burned and severed plants sprouted, that sprouting occurred as late as 13 months after treatment, and that late-season treatment was generally more detrimental than spring treatment.

Since bitterbrush at different locations may exhibit genetic influence of Stansbury cliffrose (Cowania stansburiana) (Thomas 1957) or desert bitterbrush (P. glandulosa) (Nord 1959), both of which sprout abundantly, isolating specific factors which control sprouting is difficult. However, certain environmental conditions have been implicated in sprouting. This study was conducted to isolate some controllable environmental factors which may be responsible for the variation in bitterbrush response to burning and clipping.

Study Areas and Methods

Two study areas representing different plant communities were selected for study. Site I is located about 30 km northwest of Burns, Oregon at 1555 m elevation. Characteristic vegetation is the Juniperus/Artemisia-Purshia association (Fig. 1) described by Driscoll (1964). Bitterbrush growing on this site is similar to one of the columnar forms described by Alderfer (1977) and is distinctly different than the growth form on site II. None of the treated plants on site I were layered. Site I soils are Lithic Xerollic Paleargids over silica and limestone coated fractured bedrock (Dyksterhuis et al. 1969).

Site II is located 42 km north of Riley, Oregon at 1585 m elevation. Characteristic vegetation on site II is similar to the Pinus ponderosa/Purshia tridentata (Fig. 2) association described by Daubenmire and Daubenmire (1968). Bitterbrush on this site is a lower growing, decumbent form that layers infrequently. Site II soils are a loamy-skeletal, mixed, frigid family of Lithic Argixeroll residium overlying rhyolite (U. S. Forest Service 1977). Soil texture on both sites

Fig. 1. Erect bitterbrush growth form on site I. Light colored shrub in foreground is _Artemisia tridentata_

Fig. 2. Decumbent bitterbrush growth form on Site II. Bitterbrush density is greatest in Pinus ponderosa openings and reduced where pine regeneration is well established.

is similar (Table 1). Both soils are shallow, averaging about 36 cm to bedrock.

Both sites are located within the High Lava Plains physiographic province of Franklin and Dyrness (1973) and on the western fringe of the Great Basin. Annual precipitation on both sites is similar averaging about 30 cm. Most of the precipitation occurs as snow during the winter months. Snow persists about two weeks longer on site II due to the over-story canopy of ponderosa pine, and bitterbrush phenological development correspondingly initiates about two weeks later than on site I.

A total of 80 bitterbrush plants on each site were randomly selected with ten each assigned to eight treatments: fall clip, fall clip then water, spring clip, fall burn, fall burn then water, water then fall burn, spring burn, and control. Fall treatments were applied during the first week of August, 1977 when 95% of the achenes had been shed. Spring treatments were applied on March 30, 1978 on site I and April 13, 1978 on site II when the first leaf on each twig was approximately 30% expanded. Earlier spring treatment was prohibited by deep snow and impassible terrain.

Air temperature, relative humidity, and wind speed during treatment were determined with a battery operated fan psychrometer and a hand-held anamometer (Table 2). To produce uniform intensity on all burn treatments, plants were burned individually in a plant burner similar to that described by Wright _et al_. (1976). The burner was calibrated to attain a soil surface temperature of about 260°C at 45 seconds. Water treatments were applied 24 hours prior to, or immediately

Table 1. Soil characteristics at two depths (cm) for two bitterbrush sites in eastern Oregon. Values are mean percentages by weight with ranges in parentheses.

	Site I		Site II	
	0 - 5	5 - 29	0 - 10	10 - 38
Clay (%)	24.8 (20.3 - 26.0)	38.9 (36.2 - 41.1)	25.1 (23.9 - 26.0)	29.1 (27.3 - 30.8)
Silt (%)	45.4 (34.0 - 54.6)	50.8 (48.2 - 55.3)	50.0 (49.0 - 51.0)	50.8 (49.5 - 52.3)
Sand (%)	29.8 (19.6 - 40.5)	10.3 (7.0 - 11.7)	24.9 (23.0 - 27.1)	20.1 (19.7 - 20.7)
< 2 mm (%)	37.7 (31.7 - 42.3)	43.6 (28.9 - 52.4)	61.3 (53.3 - 69.9)	48.8 (41.7 - 55.9)
2 mm - 1.27 cm (%)	45.1 (37.8 - 48.3)	34.1 (26.7 - 37.8)	20.9 (19.9 - 21.9)	30.0 (24.0 - 36.1)
> 1.27 cm (%)	17.2 (11.6 - 20.0)	22.3 (9.9 - 44.4)	17.8 (10.8 - 24.8)	21.2 (20.1 - 22.3)
Organic matter (%)	7.2 (1.7 - 10.7)	3.1 (2.2 - 4.8)	3.5 (2.9 - 4.1)	2.2 (2.0 - 2.3)

Table 2. Weather conditions during four burning periods on two bitterbrush sites in east-central Oregon.

	Fall Burns		Spring Burns	
	Site I	Site II	Site I	Site II
Treatment date	8/3/77	8/5/77	3/30/78	4/13/78
Temperature (°C)	29	27	12	10
Relative humidity (%)	14	22	69	36
Wind speed (km/hr)	<8	<8	<8	<8

after burning to simulate a five cm storm. Water was applied in a fine mist with a calibrated positive displacement pump. With the post-burn water treatments, water was applied one minute after the flame subsided and two minutes after flaming was initiated. Water was restricted to approximately the area of the plant burner by circular metal rings embedded into the soil surface.

Based on size, 50 additional plants estimated to cover the age range exhibited on each site were measured and clipped on October 17, 1977 on site I, and Decmeber 15, 1977 on site II. These plants had dropped their leaves and appeared dormant on the dates they were clipped. These 50 plants from each site were sectioned and aged by growth ring examination (Roughton 1972) under a 10X binocular microscope to determine if sprouting ability was related to plant age or size. Stump activity of the 50 additional plants cut for age determination on each site was also examined and results were recorded in August and September 1978. Also, plants sprouting in the 50 additional measured, clipped, and aged group were classified in five-year intervals and tested with chi-square analysis to detect age differences in sprouting response. Measurements of plant height, eliptical crown area, calculated crown volume, maximum stem diameter, stem circumference, and calculated average stem diameter were correlated with plant age.

Soil texture on each site (Table 1) was determined by the hydrometer method (Bouyoucos 1962) and soil moisture was determined gravimetrically (Gardner 1965). Also, soil moisture retention curves at tensions of 0.1 to 15 bars were developed for each site using Tempe cells and a pressure-plate apparatus (U. S. Salinity Laboratory Staff 1954).

The 80 treated plants were observed monthly on each site during the growing season following treatment and each plant with visible sprouts was recorded. The number of live plants in each of the basic eight treatments was subjected to chi-square analysis to detect statistical differences.

Results and Discussion

Fall-burned plants were more severely damaged than spring-burned plants (Table 3). None of the unwatered, fall-burned plants sprouted on either site compared to 30% sprouting of spring-burned plants on site I and 50% on site II. These results are similar to those of Blaisdell and Mueggler (1956) who also showed fall burning to be more detrimental.

Plants that were watered 24 hours prior to fall burning also responded poorly despite 12 to 16% soil moisture content in the upper five cm compared with 4 to 7% under the unwatered plants. These soil moistures correspond to 3.73 cm of available water on site I and 4.37

Table 3. Response of 260 bitterbrush plants (% alive or sprouted) on two sites in east-central Oregon.

	Site I					Site II				
	Treatment date	Observation date				Treatment date	Observation date			
		6/1	7/1	8/1	9/1		6/1	7/1	8/1	9/1
Fall clip	8/2/77	60	60	60	60	8/4/77	20	40	40	40
Fall clip then water	8/3/77	20	30	40	40	8/5/77	40	50	50	50
Spring clip	3/30/78	10	10	30	40	4/13/78	80	90	90	90
Fall burn	8/3/77	0	0	0	0	8/5/77	0	0	0	0
Water then fall burn	8/3/77	0	0	0	0	8/5/77	0	20	20	20
Fall burn then water	8/3/77	0	10	10	10	8/5/77	0	10	10	0
Spring burn	3/30/77	0	20	20	30	4/13/78	0	40	50	40
Fall clip and age	10/17/77	-	-	30	30	12/15/77	-	-	78	78
Control		100	100	100	100		100	100	100	100

cm on site II pre-watered treatments, compared with 2.07 and 2.72 cm on the unwatered treatments respectively. Although several reports have suggested that soil moisture is important for sprouting of fall-burned plants, it may not be the controlling factor. Only on site II did any of the pre-watered treatment plants sprout.

Many of the plants watered immediately after burning were expected to sprout since: (1) none of the plant skeletons were consumed indicating a fire of low to moderate intensity, (2) heat was removed immediately by water, (3) soil moisture approached 12 to 16% within 24 hours, and (4) the literature indicated that fires extinguished by water may result in substantial sprouting. However, only one plant watered after burning sprouted on each site, indicating that factors in addition to soil moisture and duration of applied heat were involved.

Spring-burned plants sprouted better than fall-burned plants on both sites. This result could be attributed to several factors. First, spring soil moisture was 27 to 30%, two-fold that of the pre-watered fall burns and about six-fold greater than the unwatered fall burns. Possibly available soil water may be more important than surface soil wetness, because the pre-watered treatment only infiltrated to an average depth of 15 cm, far short of the effective root zone for most mature bitterbrush plants. In contrast, soil during the spring burns was near field capacity through the entire soil profile (Table 4). Second, air temperature was 29 and 27°C during the fall burns on sites I and II respectively, compared to 12 and 10°C during the spring burns. Plants with higher initial temperatures would be expected to attain higher maximum temperatures and suffer greater cambial and bud damage,

Table 4. Available soil water (cm) at time of treatment for each soil profile on two bitterbrush sites.

	Available soil water (cm)	
	Site I	Site II
Field capacity (0.1 bar)	11.80	18.97
Spring treatments	10.74	14.08
Watered fall treatments	3.73	4.37
Unwatered fall treatments	2.07	2.72
15-bar tension	4.69	4.62

since lethal temperature effects on plants are a function of maximum temperature and also the period of heat duration (Hare 1961). Third, plant physiological development may be critical. McConnell and Garrison (1966) reported that nonstructural carbohydrates were lowest in late June and early July, and that root material had greater seasonal change in carbohydrate resources than top material.

It is not known how much carbohydrate material is necessary to initiate and support sprout growth on bitterbrush, but in view of the dry growing season of 1977, bitterbrush reserves on these sites may have been below normal. Also, since burned plants sprout late in the growing season, a combination of sprouting requirements plus mid-season moisture stress may have reduced plant capacity to sprout and sustain growth. In most cases (Blaisdell and Mueggler 1956; Nord 1965) early burns are less damaging to bitterbrush than summer or fall burns. It is difficult, therefore, to determine whether soil moisture, air temperature, physiological stage of development or some combination of factors is responsible for greater spring sprouting.

Growth form may also be important. Driscoll (1963) reported that many layered plants sprouted from the layer but never from the parent plant. Although plants on neither site were layering, the lower growing form on site II possessed many more branches near ground level. All of the burned plants that sprouted on both sites did so from masses of dormant buds near the axils of existing branches close to ground level, but not from the stem proper as was reported in Idaho (Blaisdell and Mueggler 1956). Thus, the decumbent form had more buds from which to sprout. Sprouting frequently occurred at more than one branch base which contributed more photosynthetic tissue for plant recovery. Lower growing, profusely branched plants may be more likely to sprout than plants of the erect form on site I where few if any branches were near ground level.

Clipped plants sprouted more frequently than burned plants (Table 3). Further, except for the fall clip treatment, response paralleled that of the burned plants. The decumbent form on site II sprouted more frequently than the erect form on site I, and spring-clipped plants sprouted more frequently than fall-clipped plants.

If soil moisture is important in sprouting of fall-clipped plants, then watered plants should have shown a positive response, especially in view of the abnormally dry fall of 1977. However, there was no difference between the watered and unwatered plants that were fall-clipped (Table 5). Again, available soil water in the root zone may be more important than surface soil wetness.

Table 5. Chi-square values of treatment results within two bitterbrush sites in eastern Oregon.

		FCTW[2]	SC[3]	FB[4]	WTFB[5]	FBTW[6]	SB[7]	CONT[8]
Site I	FC[1]	0.200	0.200	5.952*	5.952*	3.516	0.808	2.813
	FCTW		0.000	2.813	2.813	1.067	0.000	5.952*
	SC			2.813	2.813	1.067	0.000	5.952*
	FB				0.000	0.000	1.569	16.200**
	WTFB					0.000	1.569	16.200**
	FBTW						0.313	12.929**
	SB							7.912**
Site II	FC	0.000	3.516	2.813	0.238	1.067	0.000	5.952*
	FCTW		2.143	4.267*	0.879	2.143	0.000	4.267*
	SC			12.929**	7.272**	9.800**	2.143	0.000
	FB				0.556	0.000	4.267*	16.200**
	WTFB					0.000	0.879	10.208**
	FBTW						2.143	12.929**
	SB							4.267*

[1]FC = Fall clip.

[2]FCTW = Fall clip then water.

[3]SC = Spring clip.

[4]FB = Fall burn.

[5]WTFB = Water then fall burn.

[6]FBTW = Fall burn then water.

[7]SB = Spring burn.

[8]CONT = Control.

Values followed by a single asterisk indicate that compared treatment results are significantly different at the 5% level and those followed by a double asterisk at the 1% level.

On site II, 90% of the spring-clipped plants sprouted. Since soil moisture and phenological development were similar on both sites at time of treatment, growth form may be more important than either soil wetness or stage of development when treatments during one season are considered. Specifically, branching habit and proximity of lower branches to the soil surface may be critical. Other studies reporting clipping response of bitterbrush (Garrison 1953; Blaisdell and Mueggler 1956; Ferguson and Basile 1966; Ferguson 1972) have shown different responses to season of treatment and that partial top removal actually stimulated twig growth. However, these reports did not compare more than one growth form and did not describe the treated growth form adequately to predict response on a different growth form.

Post-treatment mortality was high in southern Idaho (Blaisdell and Mueggler 1956) where 33% of the burned plants and 21% of the clipped plants had died within 16 months of treatment. In this study none of the clipped plants that sprouted had subsequently died although 13 months had elapsed since the fall treatments and six months since the spring treatments. Two of the 80 burned plants had died, however.

Blaisdell and Mueggler (1956) reported that 39% of the treated plants sprouted from callus tissue and 24% from existing buds near ground level. Of the 240 treated plants in this study 98 sprouted, but only two sprouted from callus tissue (Fig. 3). Both of these plants were clipped and both were of the erect growth form on site I. Subsequent removal of the bark for closer examination on one of these plants killed the buds. On most clipped plants intact bark in the basal area afforded the opportunity for development of callus tissue

Fig. 3. Two of 98 treated plants that sprouted did so from callus tissue which developed under the bark near ground level. Burned plants probably could not sprout in this manner because the bark was heavily charred. The arrow on the stump indicates the location of callus tissue sprouts.

while most of the burned plants were badly charred to ground level. This development supported the contention of Blaisdell and Mueggler (1956) that burns of lower intensity which left plant stems near ground level protected either by bark or soil would result in more plants sprouting. They found that less severely burned plants frequently sprouted from callus tissue.

Age of the plant, at least throughout the normal life span, is apparently not critical in ability to sprout. Seedlings or immature plants, and older, decadent plants would normally be expected to sprout less frequently than healthy, mature plants because poorly developed root systems or large proportions of non-functioning vascular systems normally lower resistance to damage. However, on site I bitterbrush plants sprouted over an age range of 15 to 92 years (Fig. 4) despite obvious stem damage and deformities on older plants. Plants which died ranged from 22 to 118 years. Although the stand was much younger, site II plants responded similarly with respect to age. Sprouting plants ranged from 9 to 31 years while plants that died ranged from 13 to 38 years. Chi-square values of 21.50 with 21 degrees of freedom on site I and 6.37 with six degrees of freedom on site II were not significant.

McConnell and Smith (1963) measured, severed, and aged bitterbrush plants on several different sites. They found site specific, high correlations between maximum stem diameters and plant age. They recommended periodic reevaluation of the relationship to maintain high reliability of estimations of plant age from stem measurements. Reevaluation necessarily involves cutting plants to obtain maximum stem diameter measurements. On these sites stem circumference or average

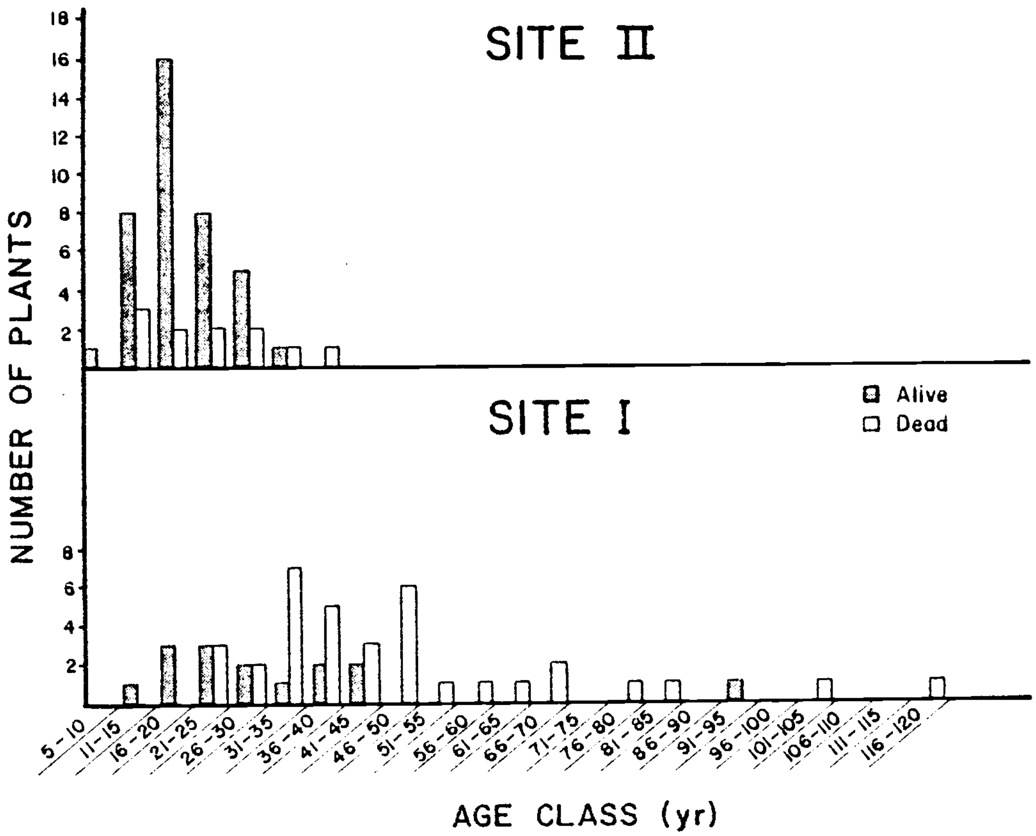

Fig. 4. Sprouting and non-sprouting bitterbrush plants by age group (yrs) after clipping 50 plants over the apparent age range on two bitterbrush sites. Plant ages ranged from 15 to 118 years on site I and from 8 to 38 years on site II, indicating a low fire frequency on these sites.

stem diameter calculated from circumference measurements provided correlations similar to that of maximum diameter (Table 6). Use of circumference measurements provides a rapid method of estimating plant age non-destructively once the age-circumference relationship is known. Although measurements on aerial portions of bitterbrush plants provide an indication of age they are most affected by browsing, annual weather conditions, growth form, and site conditions. Stem measurements taken near the root crown are least affected, and provide the most reliable indication of age.

Management Implications

Bitterbrush stands are often burned by wildfires or prescribed burns, or damaged by mechanical brush control or logging practices. In planning such treatments or evaluating their effects on bitterbrush, consideration should be given to necessity for treatment, bitterbrush growth form, type of treatment, and season of application.

Burn treatments are difficult to predict or evaluate because fall-burned plants generally will not sprout until well into the following growing season whereas fall-clipped plants will begin sprouting within two weeks of treatment. Similarly, spring-burned plants sprout later than spring-clipped plants and externally appear dead. Also, many plants may sprout but suffer subsequent mortality.

Since bitterbrush is frequently a weak sprouter and reproduces primarily from seed, planned treatments should leave islands of healthy plants to provide an adequate seed supply for reestablishment. Rodents may cache seed up to 300 m from the source but 60 m is considered the

Table 6. Correlation matrix of several measured attributed of bitter-brush on two sites in east-central Oregon.

		HT[2]	CA[3]	CV[4]	MSD[5]	ASD[6]	CI[7]
Correlation coefficients— Site I	AGE[1]	0.6234	0.4985	0.5067	0.8371	0.8357	0.8357
	HT		0.7271	0.7513	0.6309	0.6406	0.6410
	CA			0.9708	0.4777	0.5058	0.5056
	CV				0.4994	0.5278	0.5276
	MSD					0.9932	0.9587
	ASD						0.9999
Correlation coefficients— Site II	AGE	0.5316	0.4949	0.4319	0.7941	0.7855	0.7851
	HT		0.7630	0.6550	0.3367	0.3823	0.3831
	CA			0.9253	0.3843	0.4227	0.4213
	CV				0.2956	0.3201	0.3198
	MSD					0.9658	0.9655
	ASD						0.9999

[1]AGE = Plant age from stem growth-ring counts.

[2]HT = Plant height to nearest cm.

[3]CA = Crown area calculated according to $\pi d_1 d_2/4$.

[4]CV = Crown volume calculated according to HT x CA.

[5]MSD = Maximum stem diameter to nearest mm.

[6]ASD = Average stem diameter calculated from circumference measurements.

[7]CI = Stem circumference measured to nearest mm.

maximum distance for rapid establishment. Because sprouted plants and newly established seedlings are particularly susceptable to damage, consideration should be given to several years of full protection. Additionally, flowering occurs on previous growth so at least two seasons are required for flowering and seed production following severe treatment.

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Ferguson, C. W. 1959. Growth rings in woody shrubs as potential aids in archaeological interpretation. The Kiva 25:24-30.

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Wagle, R. F. 1958. Early growth in bitterbrush and its relation to environment. PhD Thesis. Univ. California, Berkeley. 271 p.

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A Bibliography of Bitterbrush [*Purshia tridentata* (Pursh) DC.] Annotated from 1967 to 1978

by

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Foreword

Bitterbrush [*Purshia tridentata* (Pursh) DC.] is one of the most widely distributed shrubs in western North America. Its value as a browse species has been recognized for over half a century. Recent concern for the ecological significance of shrubs in natural ecosystems and the serious depletion of many big game winter ranges has led to extensive investigation of bitterbrush.

This bibliography is the result of a literature review conducted during a course of graduate study at Oregon State University. It contains information that should be of interest to both the academic and nonacademic communities.

This annotated bibliography primarily contains references published after 1967, since extensive reviews were completed earlier. In 1964 Frederick C. Hall compiled an unpublished literature review of bitterbrush that circulated primarily in Region 6 of the U. S. Forest Service. Joseph V. Basile published an annotated bibliography of bitterbrush in 1967 as U. S. Dep. Agr. Forest Serv. Res. Pap. INT-44 from the Intermountain Forest and Range Experiment Station. To compile as much information as possible under one cover, the references cited by Basile and Hall are listed collectively in the Appendix. Appreciation is extended to J. V. Basile and F. C. Hall for permission to reproduce portions of their manuscripts.

ADAMS, A. W. 1972. Dendrochronology as a tool in planning wildlife habitat manipulation. In: Proc. Fifty-Second Annu. Conf. West. Assoc. State Game and Fish Comm. 52:321-330.

A total of 355 bitterbrush plants were partially excavated, and severed below ground level. Specimens were cross-sectioned, sanded, and examined for age structures. Twelve plants were not readable and 14 were too decayed to be reliable. Thus only 7% were unusable although only 23% of the plants were alive at time of collection. Plant ages ranged from four to 127 years.

ADAMS, A. W. 1975. A brief history of juniper and shrub populations in southern Oregon. Oregon State Wildl. Comm. Wildl. Res. Rep. 6. Oregon State Wildl. Comm., Corvallis. 33 p.

Summarizes age structure analysis in bitterbrush to reconstruct past populations of shrubs on critical winter deer range in southern Oregon. No significant differences in average density of either live or dead bitterbrush between communities was detected. Live plants averaged 58 years and dead plants 71 years. Plant establishment during the last 50 years has been poor, although if they became established, plants lived a normal life span of about 71 years. Juniper invasion is suspected as a major cause of bitterbrush reduction.

ALDERFER, J. M. 1977. A taxonomic study of bitterbrush [*Purshia tridentata* (Pursh) DC.] in Oregon. MS Thesis. Oregon State Univ., Corvallis. 197 p.

Trends for cliffrose gene flow in bitterbrush were traced through northeastern Oregon and along the eastern front of the Cascades, resulting in four distinct bitterbrush ecotypes. A low, layering ecotype growing under lodgepole pine, an ecotype similar in habit but differing in morphological characteristics on Hart Mountain, a tall, massive ecotype growing on deep soils near Janesville in northern California, and a similar columnar form growing near Durkee in northeastern Oregon, were described. Paper chromatography suggested cliffrose genes in certain populations. In all cases a diploid chromosome number of 2N=18 was found. Also, germination studies indicated that a 15 to 20 minute thiourea treatment yielded higher germination than the previously recommended five minute treatment.

ANDERSON, A. E., D. E. MEDIN, and D. C. BOWDEN. 1972. Mule deer fecal group counts related to site factors on winter ranges. J. Range Manage. 25:66-68.

Counts during 1963-1965 of mule deer fecal groups were related to 32 site factors on a Colorado winter range from 1740 to 2682 m elevation. Bitterbrush density and utilization accounted for the greatest variation in fecal group counts, and was the major food species.

ANDERSON, A. E., D. E. MEDIN and D. C. BOWDEN. 1972. Mule deer numbers and shrub yield-utilization on winter range. J. Wildl. Manage. 36:571-578.

Counts of mule deer fecal groups were related to mean forage yields and mean utilization of three shrubs, including bitterbrush. There was no snigificant correlation between indices of deer numbers and mean yield or utilization of bitterbrush. Mean yield and utilization were also not significantly correlated.

BARNEY, M. O., and N. C. FRISCHKNECHT. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27:91-96.

Bitterbrush occurred on three of nine burn age-classes. It resprouted following fire but did not invade as quickly as little rabbitbrush or snakeweed.

BASILE, J. V. 1967. An annotated bibliography of bitterbrush [Purshia tridentata (Pursh) DC.). U. S. Dep. Agr. Forest Serv. Res. Pap. INT-44. Intermountain Forest and Range Exp. Sta., Ogden. 27 p.

Annotates 221 references to bitterbrush through 1967.

BAYOUMI, M. A., and A. D. SMITH. 1976. Response of big game winter range vegetation to fertilization. J. Range Manage. 29:44-48.

Twig growth, seed production, and leaf and twig crude protein content of bitterbrush increased with each increment of applied nitrogen in the range of 33.6 to 168 kg/ha. Applied phosphorus had no effect on yield or utilization. In winter, elk preferred shrubs on fertilized plots.

BECKING, J. H. 1968. Nitrogen fixation of non-leguminous plants. In: Symposium of nitrogen in soil. Institute for Soil Fertility, Groningen, Netherlands. p. 47-74.

Bitterbrush is mentioned as a non-leguminous, nitrogen-fixing plant.

BECKING, J. H. 1970. Plant-endophyte symbiosis in non-leguminous plants. Plant and Soil 32:611-654.

Reviews literature on nitrogen fixation by non-leguminous plants in six taxonomic orders including Rosales, to which bitterbrush belongs.

BECKING, J. H. 1976. Actinomycete symbioses in non-legumes. In: W. E. Newton and C. J. Nyman (Eds). Proc. First Internat. Symp. on Nitrogen Fixation. Washington State Univ. Press, Pullman, p. 581-591.

Cytology, morphology, and taxonomy of actinomycete symbionts and their host plants, including bitterbrush, are discussed.

BLACKBURN, W. H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resources Res. 11:929-937.

Simulated rainfall was used to study infiltration and sedimentation rate on 28 sites within five watersheds in Nevada where the shrub layer included bitterbrush. Infiltration and sedimentation data are presented for each plant community and watershed.

BLAUER, A. C., A. P. PLUMMER, E. D. McARTHUR, R. STEVENS, and B. C. GIUNTA. 1975. Characteristics and hybridization of important intermountain shrubs. I. Rose Family. U. S. Dep. Agr. Forest Serv. Res. Pap. INT-169. Intermountain Forest and Range Exp. Sta., Ogden. 36 p.

Describes bitterbrush and its hybridization with cliffrose and desert bitterbrush. Also summarizes literature relating to bitterbrush distribution and habitat.

BOND, G. 1976. Observations on the root nodules of *Purshia tridentata*. Proc. Royal Soc. of London 193:127-137.

In greenhouse studies nodulated plants of bitterbrush grew satisfactorily in nitrogen-free water culture and fixed up to 40 mg of nitrogen per plant up to 16 months after planting. Acetylene assays confirmed nitrogenase activity by nodules but not by roots. Microscopic studies of nodules showed that their structure resembled that of other non-leguminous nodules.

BOYD, R. J. 1954. Effects of seed treatments upon the germination of certain browse species of Colorado. Abstract of MS Thesis submitted to Colorado A & M College. J. Range Manage. 9:170.

Germination of bitterbrush seed stratified for 70 days at -1 to 5°C was 82.5% compared to 1% for untreated seed. Acid scarification in concentrated sulfuric acid for 50 minutes resulted in 83.5% germination.

BURRELL, G. C. 1977. Bitterbrush (Purshia tridentata) in the winter ecology of the Entiat mule deer herd. MS Thesis. Univ. Washington, Seattle. 73 p.

Food habits of the Entiat mule deer herd appeared to be related to bitterbrush density. Where there was a high density of bitterbrush, deer ate primarily bitterbrush. As bitterbrush density, or the availability of preferred bitterbrush leaders decreased, mule deer ate other forage species. Fawns ate less bitterbrush than did the mature herd. Although bitterbrush is a preferred species, deer diets may shift to other highly preferred species when bitterbrush is not available. Thus a decline in bitterbrush productivity may not be a limiting factor for the Entiat mule deer herd.

BUWAI, M. 1975. Plant vigor, herbage yield, and total nonstructural carbohydrates of several range species as influenced by defoliation treatments and rest periods. Diss. Abs. 36:1532.

Bitterbrush was most affected by late season defoliation. Defoliation appeared more detrimental to herbage yield and vigor than to total nonstructural carbohydrate levels. Herbage yield and vigor had not recovered after 14 to 26 months of rest. Heavy defoliation was more detrimental than moderate defoliation, and multiple defoliations more detrimental than single defoliations.

CALIFORNIA FOREST PEST CONTROL ACTION COUNCIL. 1970. Forest pest conditions in California, 1969. California Div. Forest., Sacramento. 21 p.

Cankers are responsible for heavy losses of bitterbrush on over 30,000 acres in northern California and southern Oregon. Early plant symptoms include the formation of swellings by twig dying and later limb or branch dying. Six possible pathogenic fungi have been cultured from the cankers.

COLWELL, R. N. 1968. Remote sensing of natural resources. Sci. Amer. 218:54069.

Solar infrared aerial photography can be used to distinguish sagebrush from bitterbrush on rangelands. Bitterbrush appears bright red while the sagebrush is dark.

DALE, A. 1968. Comparative wood anatomy of some shrubs native to the northern Rocky Mountains. U. S. Dep. Agr. Forest Serv. Res. Pap. INT-45. Intermountain Forest and Range Exp. Sta., Ogden. 73 p.

A taxonomic key based on xylem characteristics of 55 woody species is presented. Photomicrographs were used to determine vessel distribution, perforation plates, rays, and axial parenchyma. Photomicrographs and synopses of characters used in the key are presented for each species, including bitterbrush.

DALTON, D. A., and D. B. ZOBEL. 1977. Ecological aspects of nitrogen fixation by Purshia tridentata. Plant and Soil 48:57-80.

Acetylene reduction was used to assay nodule activity in both field and greenhouse plants. Maximum rates were observed at 20°C. Reduction rate increased linearly for five hours then declined in exised nodules, ceasing after 19 hours. Nodule activity declined in water stressed plants, essentially ceasing when xylem pressure potentials reached -25 bars. Only 46% of bitterbrush plants were nodulated and it was suggested that low soil temperature and poor moisture conditions were responsible. Total calculated nitrogen accretion rate was 0.057 kg N/ha/hr on a site where bitterbrush contributed 25.2% of vegetal cover.

DAUBENMIRE, R. 1970. Steppe vegetation of Washington. Washington Agr. Exp. Sta. Tech. Bull. 62. Washington State Univ., Pullman. 131 p.

Describes several habitat types in which bitterbrush dominates the shrub layer. Several Purshia-Festuca stands did not contain bitterbrush which was apparently removed by fire. It was concluded that bitterbrush is nearly always killed by a steppe fire.

DAUBENMIRE, R. 1972. Annual cycles of soil moisture and temperature as related to grass development in the steppe of eastern Washington. Ecology 53:419-424.

The annual cycle of soil moisture use and recharge was examined in several climax communities including Purshia/Stipa. Soil temperatures were measured at 50 and 100 cm, and data were related to phenologies of dominant grasses. Plant community distribution was found to be related more to differences in soil moisture and temperature than to chemical composition or profile characteristics of the soil.

DAUBENMIRE, R., and J. B. DAUBENMIRE. 1968. Forest vegetation of eastern Washington and northern Idaho. Washington Agr. Exp. Sta. Tech. Bull. 60. Washington State Univ., Pullman. 105 p.

Describes a Pinus ponderosa-Purshia tridentata habitat type. Most of this forest is an edaphic climax on sandy or stony soils. Fire eliminates only the bitterbrush but extensive movement of its achenes by rodents and birds ensures prompt reinvasion of burned areas.

DEALY, J. E. 1970. Survival and growth of bitterbrush on the Silver Lake deer winter range in central Oregon. U. S. Dep. Agr. Forest Serv. Res. Note PNW-133. Pacific Northwest Forest and Range Exp. Sta., Portland. 5 p.

After two years in a four-year-old bitterbrush plantation, response was greater from browsing protection than from elimination of plant competition. Response was more evident in crown size than in plant height.

DEALY, J. E. 1971. Habitat characteristics of the Silver Lake mule deer range. U. S. Dep. Agr. Forest Serv. Res. Pap. PNW-125. Pacific Northwest Forest and Range Exp. Sta., Portland. 99 p.

Bitterbrush contributes significantly to six of 21 ecosystems described.

DEALY, J. E., and J. M. GEIST. 1978. Conflicting vegetational indicators on some central Oregon scablands. J. Range Manage. 31: 56-59.

On two sites where bitterbrush and low sagebrush occurred together, bitterbrush was not a reliable indicator of site conditions because landscapes that appeared to be uniform were actually highly variable with respect to internal soil characteristics.

DEITSCHMAN, G. H., K. R. JORGENSEN, and A. P. PLUMMER. 1974. Bitterbrush. In: Seeds of woody plants in the United States. U. S. Dep. Agr. Handbook 450. p. 686-688.

Summarizes information on bitterbrush including collecting, cleaning, and storage of seeds.

DIETZ, D. R. 1968. Chemical composition and digestibility by mule deer of selected forage species, Cache la Poudre range, Colorado. Diss. Abs. 1968:3122B.

Seasonal trends in proximate composition of several browse species including bitterbrush are presented and discussed. In feeding trials with mule deer fawns, adding pelleted lucerne to bitterbrush lowered percentage of digestibility and TDN content, but improved palatability and weight gains.

DRYER, D. L., and E. K. TROUSDALE. 1978. Cucurbitacins in Purshia tridentata. Phytochemistry 17:325-326.

In a study designed to isolate the germination inhibitor in bitterbrush, two triterpenes, both cucurbitacins, were identified. Neither cucurbitacin was active as an inhibitor. The mother liquors from the fractions containing these triterpenes retained seed germination inhibitory activity. Normally limited to the Cucurbitaceae, Cruciferae, and Scrophulariaceae families, cucurbitacins in bitterbrush account for the very bitter taste of bitterbrush seeds.

EDGERTON, P. J., B. R. McCONNELL, and J. G. SMITH. 1975. Initial response of bitterbrush to disturbance by logging and slash disposal in a lodgepole pine forest. J. Range Manage. 28:112-114.

On pumice soils in central Oregon, timber harvest practices resulted in moderately to heavily disturbed soils on 75% of the area and bitterbrush crown cover was reduced by 71%. Despite damage, bitterbrush responded quickly to more favorable growing conditions. Current twig growth doubled, and large numbers of seedlings were established on disturbed soils.

EPPS, G. A. VAN. 1974. Shrub seed production - a potential enterprise. Utah Sci. 35:21-23.

Production of seed from several shrub species, including bitterbrush, is discussed. Various aspects of growing shrubs for seed are emphasized.

EVANS, R. A., and J. A. YOUNG. 1977. Bitterbrush germination with constant and alternating temperatures. J. Range Manage. 30:30-32.

Germination of bitterbrush seeds was greatest with cold night temperatures in the optimum range of 2 to 5°C for stratification. Warm daytime temperatures of 10 to 40°C gave relatively high germination when nighttime temperatures were in the stritification range. Thiourea treatment expanded the number of temperature regimes that gave maximum germination, and also increased amount of germination at all temperature ranges.

EVERETT, R. L., and R. O. MEEUWIG. 1975. Hydrogen peroxide and thiourea treatment of bitterbrush seed. U. S. Dep. Agr. Forest Serv. Res. Note INT-196. Intermountain Forest and Range Exp. Sta., Ogden. 6 p.

Seeds of bitterbrush were exposed to 12 different germination-stimulating treatments. In subsequent germination trials overall emergence was 10% greater than in untreated controls. Soaking in 1% H_2O_2 and shaking for three, five, or seven hours during exposure gave the best results. It was suggested that H_2O_2 treatments may reduce frost damage to seedlings since only a few seedlings emerged at one time.

EVERETT, R. L., R. O. MEEUWIG, and J. H. ROBERTSON. 1978. Propagation of Nevada shrubs by stem cuttings. J. Range Manage. 21:426-429.

Stem cuttings of 54 Nevada shrub species were tested for rooting capacity. Four percent of 110 total bitterbrush cuttings sprouted.

EVERETT, R. L., R. O. MEEUWIG, and R. STEVENS. 1978. Deer mouse preferences for seed of commonly planted species, indigenous weed seed, and sacrifice foods. J. Range Manage. 31:70-73.

Captive deer mice from three western plant communities were fed seed from 18 grass, forb, and shrub species. Mice consumed seed equal to one-third of their body weight daily. Bitterbrush was the most preferred seed accounting for 10.2 to 30.7% of mice diets in five trials. The lowest value was obtained in the last trial where bitterbrush seed was coated with alpha-naphthy-thiourea, a rodent pesticide repellent.

FARNSWORTH, R. B. 1976. Nitrogen fixation in shrubs. In: H. C. Stutz (Ed). Wildland shrubs: symposium and workshop. Brigham Young Univ., Provo. p. 32-71.

Discusses evidence for and the role of nitrogen fixation in several shrubs, including bitterbrush.

FERGUSON, C. W. 1959. Growth rings in woody shrubs as potential aids in archaeological interpretation. The Kiva 25:24-30.

Bitterbrush stems contain a highly sensitive ring pattern that can readily be dated despite irregular stem forms. Small or nearly absent rings, or false layers in larger rings do not detract from datability of ring sequences. Sensitivity of bitterbrush growth layers makes it an ideal species for ecological studies.

FERGUSON, R. B. 1968. Survival and growth of young bitterbrush browsed by deer. J. Wildl. Manage. 32:769-772.

On two sites near the Payette River in southwest Idaho, browsed bitterbrush plants were compared to protected plants. On one site there was no difference, but on the other site survival of protected shrubs was 20% greater than unprotected plants. Mean surface area of protected plants was 1.6 to 3.4-fold greater than that of browsed plants, and young shrubs moderately browsed each winter remained smaller than unbrowsed shrubs.

FERGUSON, R. B. 1972. Bitterbrush seedling establishment as influenced by soil moisture and soil surface temperature. J. Range Manage. 25:47-49.

Bitterbrush seeds exposed to field conditions for 80 days following seed dispersal exhibited reduced viability. Exposure of seeds to dry heat for periods up to 15 hours did not reduce germination percentage until temperature exceeded 80°C. Seedling survival and growth were significantly affected by both artificial watering and slope exposure.

FERGUSON, R. B. 1972. Bitterbrush topping: shrub response and cost factors. U. S. Dep. Agr. Forest Serv. Res. Pap. INT-125. Intermountain Forest and Range Exp. Sta., Ogden. 11 p.

Following mechanical removal of 30 to 50% of bitterbrush crowns, annual twig growth increased considerably, then gradually decreased over a four-year period. After four years twig growth remained greater than on untopped shrubs, however. No detrimental effects on shrub longevity or increased insect attack or disease damage resulted from topping. Using chain saws, costs of $9.00 to $21.00 per acre can be expected on stands of similar density.

FERGUSON, R. B., and M. A. MARSDEN. 1977. Estimating over-winter bitterbrush utilization from twig diameter-length-weight relations. J. Range Manage. 30:231-236.

Methods are described for estimating mean utilization of individual twigs by both length and weight. Caution should be used when extrapolating techniques outside southern Idaho.

FERGUSON, R. B., and S. M. MONSEN. 1974. Research with containerized shrubs and forbs in southern Idaho. In: R. W. Tinus, W. I. Stein, and W. E. Balmer (Eds). Proc. North Amer. Containerized Forest Tree Seedling Symp. Great Plains Agr. Council Pub. 68. p. 349-358.

A potting mixture of shredded peat moss, horticultural vermiculite, and several supplemental nutrients was used to grow bitterbrush seedlings. When supplemented with a slow-release fertilizer (18-6-12), potted seedlings had greater emergence, larger plants at one month, and larger and taller plants at two months. Thus, the benefits of fertilizing seemed to be primarily in larger, more robust seedlings at planting time. Also, reasonable success was achieved in suppressing damping-off by using a mixture of Benlate and Dexon applied as a drench immediately after sowing seed and again at the beginning of germination.

FRANKLIN, J. F., and C. T. DYRNESS. 1973. Natural vegetation of Oregon and Washington. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. PNW-8. Pacific Northwest Forest and Range Exp. Sta., Portland. 417 p.

Describes 18 habitat types or associations in Oregon of which bitterbrush is a major component.

FRANKLIN, J. F., and C. T. DYRNESS. 1969. Vegetation of Oregon and Washington. U. S. Dep. Agr. Forest Serv. Res. Pap. PNW-80. Pacific Northwest Forest and Range Exp. Sta., Portland. 216 p.

See Franklin and Dyrness, 1973.

FURNISS, M. M. 1972. A preliminary list of insects and mites that infest some important browse plants of western big game. U. S. Dep. Agr. Forest Serv. Res. Note INT-155. Intermountain Forest and Range Exp. Sta., Ogden. 16 p.

Lists 82 species of insects and mites known or suspected of utilizing or damaging bitterbrush.

FURNISS, M. M., and R. G. KREBILL. 1972. Insects and diseases of shrubs on western big game ranges. In: C. M. McKell, J. P. Blaisdell, and J. R. Goodin (Eds). Wildland shrubs - their biology and utilization. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. INT-1. Intermountain Forest and Range Exp. Sta., Ogden. p. 218-226.

Summarizes literature on insect and disease enemies of four western shrubs, including bitterbrush.

GIUNTA, B. C., D. R. CHRISTENSEN, and S. B. MONSEN. 1975. Interseeding shrubs in cheatgrass with a browse seeder-scalper. J. Range Manage. 28:398-402.

In seeding trials over a five-year period at 1737 m elevation, four browse species were sown in different scalp widths in dense cheatgrass. Scalp width had a highly positive effect on shrub survival after five years, with the greatest response shown by bitterbrush. Herbage production per plant was not affected by scalp width but total production per plot increased as a result of an increase in number of plants per plot.

HALL, F. C. 1964. Literature review of bitterbrush (Purshia tridentata). Unpublished manuscript. U. S. Dep. Agr. Forest Service. Pacific Northwest Region (6), Portland. 48 p.

Provides an extensive review of bitterbrush literature including 109 references.

HANSEN, R. M., R. C. CLARK, and W. LAWHORN. 1977. Foods of wild horses, deer, and cattle in the Douglas Mountain area, Colorado. J. Range Manage. 30:116-119.

In an area of moderate occurrence, bitterbrush contributed less than one percent to the diets of wild horses and cattle, and one percent for deer. Diets were determined from microscopic analysis of fecal material collected during the summer of 1975 but without regard to season of production.

HANSEN, R. M., and B. L. DEARDEN. 1975. Winter foods of mule deer in Piceance Basin, Colorado. J. Range Manage. 28:298-300.

Bitterbrush, big sagebrush, and Utah serviceberry contributed 14% of deer diets on a pinyon-juniper-sagebrush site in early December and nine percent in March. On a pinyon-juniper site, these three species contributed 41 and 12% during the same periods. Shrub contribution generally decreased and tree utilization generally increased through the winter period.

HARNISS, R. O., and R. B. MURRAY. 1973. 30 years of vegetal change following burning of sagebrush-grass range. J. Range Manage. 26:322-325.

During August, 1936, 460 acres of sagebrush-grass range on the Upper Snake River Plains near Dubois, Idaho were burned. In 1936, bitterbrush occurred only on the heavily burned plots. By 1948, small amounts had appeared on unburned plots. In 1966, bitterbrush had also appeared on lightly burned and moderately burned plots. The increase of bitterbrush might be related to the area's history of use or to weather factors that allowed invasion of a dense sagebrush stand.

HARPER, L. W. 1970. The use of thiourea for laboratory germination of antelope bitterbrush seed. Proc. Assoc. Official Seed Analysts 60:127-131.

Seeds of bitterbrush were soaked from two to 512 minutes in one, two, or four percent thiourea solutions and germinated under three temperature conditions. Soaking for 128 minutes in two percent solution gave the best results. However, toxic symptoms increased with thiourea concentration and soaking time. Germination of seed soaked in tap water for 48 hours on blotters moistened with 0.2% thiourea, 0.2% KNO_3, or both, was 78.7, 9.0, and 19.5% respectively.

HEIT, C. E. 1970. Germinative characteristics and optimum testing methods for twelve western shrub species. Proc. Assoc. Official Seed Analysts 60:197-205.

Information is presented on optimum germination procedures and testing methods for various shrub species including bitterbrush.

HICKMAN, O. E. 1975. Seasonal trends in the nutritive content of important range forage species near Silver Lake, Oregon. U. S. Dep. Agr. Forest Serv. Res. Pap. PNW-187. Pacific Northwest Forest and Range Exp. Sta., Portland. 32 p.

Seasonal trends in moisture content, crude protein, crude fiber, crude fat, ash, calcium, phosphorus, apparent digestibility, and calcium:phosphorus ratio are reported for bitterbrush along with seven grass or grasslike plants, four forbs, and five other shrubs.

HUBBARD, R. L. 1956. The effects of plant competition on the growth and survival of bitterbrush seedlings. U. S. Dep. Agr. Forest Service. California Forest and Range Exp. Sta. Res. Note 109, Berkeley. 9 p.

Bitterbrush seedling mortality was about equal until July 13 under negligible, light, and heavy levels of competition. Mortality at that date was attributed primarily to cutworms and other insects. At the end of the first growing season, heavy competition from native vegetation and crested wheatgrass resulted in higher mortality than either light or negligible competition. At the end of the third growing season, over half of the seedlings in the heavy competition plots were dead, compared to about 21% in light and negligible competition plots.

(see also HUBBARD, R. L. 1957. The effects of plant competition on the growth and survival of bitterbrush seedlings. J. Range Manage. 10:135-137.)

HUDSON, R. J., D. M. HERBERT, and V. C. BRINK. 1976. Occupational patterns of wildlife on a major East Kootenay winter-spring range. J. Range Manage. 29:38-43.

Whitetail deer preferred lower ground with a high shrub density, while mule deer preferred more open shrub communities, especially bitterbrush, in rugged country at high elevations. Cattle grazing had little effect on the distribution of wildlife. Partial correlation analysis applied to 14 environmental parameters appeared useful for quantifying habitat use behavior and for resolving some ambiguities of overlapping habitat preferences.

HULL, A. C., Jr. 1974. Species for seeding arid rangeland in southern Idaho. J. Range Manage. 27:216-218.

Forty-eight of 90 tested species failed completely. Bitterbrush had an average rating of very poor or less.

HULL, A. C., Jr., and M. K. HULL. 1974. Presettlement vegetation of Cache Valley, Utah and Idaho. J. Range Manage. 27:27-29.

Explorers and early settlers in Cache Valley found abundant grass and little sagebrush. Bitterbrush was the second most abundant shrub.

ISKANDER, F. D. 1974. Factors affecting feeding habits of sheep grazing foothill ranges of northern Utah. Diss. Abs. 35:1146.

Sheep grazing was heaviest around shrubs, and sheep oriented themselves towards conspicuous objects while grazing. Presence of big sagebrush decreased utilization of neighboring bitterbrush.

JENSEN, C. H., and G. W. SCOTTER. 1977. A comparison of twig-length and browsed-twig methods of determining browse utilization. J. Range Manage. 30:64-67.

Bitterbrush and cliffrose were used to compare two methods of determining browse utilization. Estimating the percentage of browsed twigs or calculating percentages from counts of browsed and unbrowsed twigs provided higher utilization than measuring twig lengths. Eastimating percentages of browsed twigs resulted in high individual bias in heavy-use areas while calculating percentages of utilization from twig length measurements provided equal sensitivity throughout the zero to 100% range. Twig measurement data were more consistant among observers than estimates. Measuring twig lengths required about four times more man-hours than estimating percentages or counting twig numbers.

JENSEN, C. H., A. D. SMITH, and G. W. SCOTTER. 1972. Guidelines for grazing sheep on rangelands used by big game in winter. J. Range Manage. 25:346-352.

Sheep grazed at two intensities on 12 areas of big game winter range at 1737 to 1890 m elevation, during six different periods, selected bitterbrush after mid-July. Bitterbrush availability to game was reduced in proportion to percentage used by sheep. Bitterbrush was the most abundant and desirable forage and was not impaired by any of the grazing systems used.

JENSEN, H. 1942. A study of seasonal variation of the composition of forage plants of southeastern Oregon. MS Thesis. Oregon State Univ., Corvallis. 40 p.

Discusses nutritional data for five grass species and bitterbrush. Crude protein levels in bitterbrush ranged from a high of 14.09% in June to a low of 7.51% in December, 1938. Crude protein for 1941 varied less, from a high of 11.17% in May to a low of 8.65% in October.

JENSEN, N. E. 1972. Pinyon-juniper woodland management for multiple use benefits. J. Range Manage. 25:231-234.

Silvicultural and regeneration practices including stump culture, pruning, thinning, weeding, and tube stock planting were initiated to improve Christmas tree, juniper fence post, and forage production, wildlife habitat, and soil and watershed values. Overstory removal effectively released bitterbrush, increasing the number of twigs by 42% and leader growth by 100% over the control area. Bitterbrush cover increased by 28%.

JOHNSON, A. H., and G. A. SMATHERS. 1976. Fire history and ecology, Lava Beds National Monument. In: Tall Timbers Fire Ecol. Conf. 15. Tall Timbers Res. Sta., Tallahassee. p. 103-115.

Today this forest is filled with an understory of mountain mahogany and antelope bitterbrush. Although these two shrubs were components of the original community, frequent fires held them in check. Excessive density of these shrubs not only reduces pine reproduction but also greatly increases the fuel loadings and therefore the possibility of a conflagration which might destroy the entire community.

KLEMMEDSON, J. O., and R. B. FERGUSON. 1969. Response of bitterbrush seedlings to nitrogen and moisture on a granitic soil. Soil Sci. Soc. Amer. Proc. 33:962-966.

Bitterbrush seedlings were grown in pots in granitic soil taken from a bitterbrush site in southern Idaho. Soils from depths of 0-15, 15-40, and 40-90 cm were used with nitrogen supplements of 0, 34, and 100 kg/ha and two moisture regimes. Nitrogen caused seedling yields to decrease on the upper two layers, but to increase on soil from the 40 to 90 cm layer. The high moisture regime reduced adverse effects of added nitrogen on seedlings grown in the surface layer, but increased the adverse effect on seedlings grown in lower soil layers. Subsequently, bitterbrush responded negatively or gave no response to added nitrogen in soils proven to be deficient in nitrogen for barley. Yields of bitterbrush decreased when nitrogen in plants reached about two percent.

KLEMMEDSON, J. O., and R. B. FERGUSON. 1973. Effect of sulfur deficiency on yield and nitrogen content in bitterbrush (*Purshia tridentata*) seedlings on granitic soils. Soil Sci. Soc. Amer. Proc. 37:947-951.

Bitterbrush seedlings were supplemented NPK, NPS, or NPKS, in soils which showed slight to marked sulfur deficiency. Weight of bitterbrush seedlings was significantly lower on NPK treatments than on NPS or NPKS treatments, but total nitrogen was 2.07% compared with 1.15% when sulfur was included. Subsequent additions of sulfur suggested that bitterbrush can grow satisfactorily on soils that are very low in nitrogen and sulfur, but less satisfactorily on soils where sulfur is much less available than nitrogen. It was recommended that where bitterbrush is grown on granitic soils and where fertilization is contemplated, that available nitrogen and sulfur be properly balanced.

KREBILL, R. G. 1972. Preliminary annotated list of diseases of shrubs on western game ranges. U. S. Dep. Agr. Forest Serv. Res. Note INT-156. Intermoutain Forest and Range Exp. Sta., Ogden. 8 p.

Lists root rot, root-stem cankers, a parasitic plant, damping-off, dieback, drought, and frost as injurious to bitterbrush.

KREBILL, R. G., and J. M. MUIR. 1974. Morphological characterization of Frankia purshiae, the endophyte in root nodules of bitterbrush. Northwest Sci. 48:266-268.

Histological analyses were made of root nodules of bitterbrush collected in Idaho and Utah. Hypertrophied parenchyma cells in the cortex of nodules contained an endophyte characterized by obovoid vesicles connected to ends of narrow hyphae. The taxon Frankia purshiae Becking is recommended for this endophyte.

KUFELD, R. C. 1973. Foods eaten by the Rocky Mountain elk. J. Range Manage. 26:106-113.

Forty-eight food habit studies were surveyed to summarize data on plants normally eaten by Rocky Mountain elk. Bitterbrush was rated as a highly valuable plant in winter and fall.

KUFELD, R. C., O. C. WALLMO, and C. FEDDEMA. 1973. Foods of the Rocky Mountain mule deer. U. S. Dep. Agr. Forest Serv. Res. Pap. RM-111. Rocky Mountain Forest and Range Exp. Sta., Fort Collins. 31 p.

Ninety-nine food habit studies were surveyed to summarize data on plants normally eaten by mule deer. Bitterbrush use was rated heavy during winter, summer, and fall, and moderate during spring.

LANGHAM, J. M. 1971. Nitrogen in relation to plant succession on intradune cobble flats, with emphasis on germination and growth. Diss. Abs. 32:2655.

Four seral communities were described on advancing dunes near the Hanford Atomic Reservation in Washington, including a Purshia

tridentata/Chrysothamnus nauseosus stage and a P. tridentata/Poa sandbergii stage. Seeds of four late-seral pioneer species, including bitterbrush, were germinated in pots containing control, low, and high nitrogen levels. Bitterbrush germinated best in low nitrogen pots with N levels similar to dunes in late seral stages.

LAVIN, F., and T. N. JOHNSON, Jr. 1977. Species adapted for planting Arizona pinyon-juniper woodland. J. Range Manage. 30:410-415.

Bitterbrush was rated fair/good for planting on only one of ten sites in central Arizona. The successful site was at 1981 m with 43 cm annual precipitation and a mean annual temperature of 9°C on Jacques loam soil.

LAYCOCK, W. A. 1961. Improve your range by heavy fall grazing. Nat. Woolgrower 51(6):16, 30.

Mentions that sheep seldom eat shrubs in the spring, except the flowers of bitterbrush.

LAYCOCK, W. A. 1967. How heavy grazing and protection affect sagebrush-grass range. J. Range Manage. 20:206-213.

Bitterbrush production decreased on good and poor condition range under fall or spring grazing, and also within exclosures. The large decrease in production was probably caused by damage from tent caterpillars in 1958-1960. In 1960 almost all bitterbrush plants were completely defoliated. By 1964 many were partly or completely dead.

LAYCOCK, W. A. 1969. Exclosures and natural areas on rangelands in Utah. U. S. Dep. Agr. Forest Serv. Res. Pap. INT-62. Intermountain Forest and Range Exp. Sta., Ogden. 44 p.

Bitterbrush is a major component in ten of 529 exclosures and natural areas in Utah.

LESPERANCE, A. L., P. T. TUELLER, and V. R. BOHMAN. 1970. Symposium on pasture methods for maximum production in beef cattle: competitive use of the range forage resource. J. Anim. Sci. 30:115-121.

Rumen samples indicated that cattle selected 80% grass when available, but shifted to some browse, primarily bitterbrush, in the fall. Deer selected browse on summer and winter ranges to about the same extent that cattle selected grass, although deer tended to select three to five browse species while cattle concentrated on one site-specific species. Some late autumn competition existed between deer and cattle for bitterbrush.

LYON, L. J. 1968. An evaluation of density sampling methods in a shrub community. J. Range Manage. 21:16-20.

Nineteen variations of quadrat and plotless sampling techniques were used to estimate density of bitterbrush in a population with known parameters. All methods needed unreasonably large samples to give acceptable precision, many methods would not produce a correct answer with any size sample, and several methods required more effort than counting all plants. Visual estimation techniques or non-random sampling methods may be the most realistic approach to density sampling.

McARTHUR, E. D., B. C. GIUNTA, and A. P. PLUMMER. 1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 32:28-33.

Shrub species valuable for browse production, including bitterbrush, are described. A table of 34 species is presented showing value for restoration of rangeland and soil stabilization, and the vegetation types to which they are best suited.

McCONNELL, B. R., and J. G. SMITH. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23:208-212.

Shrubs, mostly bitterbrush, increased production about 2.2 kg/ha for each 30.5 cm increase in pine spacing, and about 1.1 kg/ha for each one percent decrease in pine canopy.

McCONNELL, B. R., and J. G. SMITH. 1970. Some effects of grazing intensity on bitterbrush dispersion. J. Range Manage. 23:92-94.

Fenceline comparisons in a uniform habitat showed bitterbrush density was reduced by heavy grazing but not affected by moderate use. Large increases in mean area per plant under heavy grazing did not alter overall form of random population dispersion. Inclusion of

one-year-old plants on moderately used areas caused aggregation of the population but not on the heavily used areas. Contrasting reaction probably resulted from a differential pattern of seedling mortality due to different amounts of herbaceous understory in the two shrub populations.

McCONNELL, B. R., and J. G. SMITH. 1971. Influence of grazing and age on crown characteristics in bitterbrush. U. S. Dep. Agr. Forest Serv. Res. Note PNW-146. Pacific Northwest Forest and Range Exp. Sta., Portland. 4 p.

Changes in average crown diameter and percentage of dead crown were related to bitterbrush age on moderately and heavily grazed ranges. There was a significant difference in average crown diameter under different grazing levels but differences between percentages of dead crown area were not significant.

McCONNELL, B. R., and J. G. SMITH. 1977. Influence of grazing on age-yield interactions in bitterbrush. J. Range Manage. 30:91-93.

Significant relationships were found between yield and age of bitterbrush. Plants that were heavily grazed during the spring and early summer produced more forage than plants that were moderately grazed during late summer and fall. Under heavy grazing, plant longevity was reduced and fewer plants survived until the age of maximum production. Consequently only 88 kg/ha of air-dry forage were produced under heavy early grazing compared with 172 kg/ha under moderate late-season grazing.

MARTIN, R. E. 1978. Fire manipulation and effects in western juniper. In: R. E. Martin, J. E. Dealy, and D. L. Caraher (Eds). Proc. Western Juniper Ecol. and Manage. Workshop. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. PNW-74. Pacific Northwest Forest and Range Exp. Sta., Portland. p. 121-136.

Discusses plant succession in juniper ecosystems with and without periodic fire. Also reports that on burns with high soil moisture, up to 30% of bitterbrush sprouted, but never more than 10% were left the second year.

MEDIN, D. E., and R. B. FERGUSON. 1972. Shrub establishment on game ranges in the northwestern United States. In: C. M. McKell, J. P. Blaisdell, and J. R. Goodin (Eds). Wildland shrubs - their biology and utilization. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. INT-1. Intermountain Forest and Range Exp. Sta. Ogden. p. 359-368.

Principles and procedures of seeding game ranges are discussed. In an example of seeding success, a ten-year-old bitterbrush seeding near Boise produced over 620 lb of oven-dry twig material per acre in a stand with about 700 plants per acre.

MENKE, J. W. 1974. Effects of defoliation on carbohydrate reserves, vigor, and herbage yield for several important Colorado range species. Diss. Abs. 35:632.

Amounts and distributions of rainfall on an intermountain shrubland type in northern Colorado that caused increased seasonal growth resulted in lower seasonal total available carbohydrate storage. Bitterbrush was detrimentally affected by defoliation during late spring and summer at fruit development or seed shatter stages. Multiple defoliations were more detrimental than most single defoliations at any phenological stage. Plant vigor and herbage yield were more easily depressed than carbohydrate reserve storage.

(see also MENKE, J. W. 1974. Effects of defoliation on carbohydrate reserves, vigor, and herbage yield for several important Colorado range species. PhD. Diss. Colorado State Univ., Fort Collins. 311 p.)

MONSON, S. B., and D. R. CHRISTENSEN. 1976. Woody plants for rehabilitating rangelands in the intermountain region. In: H. C. Stutz (Ed). Wildland shrubs: symposium and workshop. Utah State Univ., Logan. p. 72-119.

Discusses shrub management in the intermountain region. Describes plant selection criteria, recent developments in plant selection, use of bare-root and containerized planting stock and wildland disturbances. Bitterbrush is discussed throughout.

NEAL, D. L., and H. R. SANDERSON. 1975. Thiourea solution temperature and bitterbrush germination and seedling growth. J. Range Manage. 28:421-423.

Seed collections were treated in thiourea solutions at 18 temperatures ranging from -1 to 93°C. Normal germination and seedling growth occurred following treatments between 16 and 60°C. Below 16°C germination rate declined slightly but seedling growth was normal. Seedling deformities began to appear above 60°C, and germination declined rapidly. Deformities consisted of annual cracks around the hypocotyls and detached root caps.

NORD, E. C., and C. M. COUNTRYMAN. 1972. Fire relations. In: C. M. McKell, J. P. Blaisdell, and J. R. Goodin (Eds). Wildland shrubs - their biology and utilization. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. INT-1. Intermountain Forest and Range Exp. Sta., Ogden. p. 88-97.

Discuss fuel loading, arrangement, moisture content, heat content, and chemical composition of several shrubs. Moisture content of living fuel was related to ash content. Bitterbrush foliage and current leaders had 147% moisture content in May, smaller foliage and stems had 131%, and ash content was 3.8% on a dry matter basis.

PEEK, J. M., F. D. JOHNSON, and N. N. PENCE. 1978. Successional trends in a ponderosa pine-bitterbrush community related to grazing by livestock, wildlife, and to fire. J. Range Manage. 31:49-53.

A ponderosa pine/bitterbrush community near the Salmon River, Idaho, was determined to be a seral stage of a Douglas fir/snowberry habitat type. Bitterbrush density was similar outside and inside a big game exclosure, but twig production was 12 times greater outside. Utilization by big game of this vegetation has maintained the productivity of bitterbrush and retarded succession to climax.

PERRY, D. A., and J. E. LOTAN. 1977. Regeneration and early growth on strip clearcuts in lodgepole pine/bitterbrush habitat type. U. S. Dep. Agr. Forest Serv. Res. Note INT-238. Intermountain Forest and Range Exp. Sta., Ogden. 7 p.

A lodgepole pine/bitterbrush habitat type near West Yellowstone, Montana is described as exceptionally droughty and nutrient poor.

PFISTER, R. D., and R. DAUBENMIRE. 1975. Ecology of lodgepole pine (Pinus contorta Dougl.). In: D. M. Baumgartner (Ed). Management of lodgepole pine ecosystems Symp. Proc. Washington State Univ. Coop. Ext. Serv., Pullman. p. 27-56.

Bitterbrush is the shrub layer dominant in four of 11 recognized climax lodgepole pine communities. Environmental conditions include well-drained pumice soils, seasonally wet pumice soils, obsidian sands, frost pockets, and subalpine climates.

PHILLIPS, T. A. 1970. The status of antelope bitterbrush in the Cassia Mountain area of southern Idaho. Range Improvement Notes 15(4):1-15. U. S. Dep. Agr. Forest Service. Intermountain Region, Ogden.

Bitterbrush age-form classes indicated that less than 1% were seedlings, 5% were young, 65% mature, and 30% decadent. Ring counts on four distinct sites indicated that plants on canyon rims averaged ten years older than plants on toe slopes, canyon slopes, and ridgetops. This was attributed to greater natural fire protection on canyon rims. On the four sites, plant ages ranged from four to 130 years with an average of 45 years. About 18% of all plants layered. It was suggested that three consecutive years of above normal moisture may be required for effective leader growth, seed production, and establishment. Historically, bitterbrush was able to reproduce and become established under extremely heavy grazing pressure. Fire has killed more bitterbrush than all other agents combined. Little or no reestablishment has occurred on most burns, although date of burning may be important in recovery.

PLUMMER, A. P., D. R. CHRISTENSEN, and S. B. MONSEN. 1968. Restoring big-game range in Utah. Utah Div. Fish and Game Pub. 68-3, Ephraim. 183 p.

Discusses principles and procedures of successful range restoration with guides for seeding specific vegetal types. Describes precipitation zones and soils to which bitterbrush is adapted. Recommends that low, layering forms be used for stabilizing and beautifying roadcuts and exposed sites. Low, layering forms also

recover much better after burning; in some areas recovery has been virtually 100% but this is unusual.

PLUMMER, A. P., D. R. CHRISTENSEN, R. STEVENS, and N. V. HANCOCK. 1970. Improvement of forage and habitat for game. In: Proc. Fiftieth Annu. Conf. West. Assoc. State Game and Fish Comm. 50:430-441.

Hand planting of bitterbrush has been replaced by seed dribblers mounted on crawler tractors which drop seed in cleat marks. Bitterbrush is an important artificially established species on restored game ranges. Ten principles for successful seeding are listed.

PLUMMER, A. P., D. R. CHRISTENSEN, R. STEVENS, and K. R. Jorgensen. 1970. Highlights, results, and accomplishemnts of game range restoration studies. Utah State Div. Fish and Game Pub. 70-3, Logan. 94 p.

Summarizes results of studies on species selection, site determination, germination techniques, site preparation and planting, and protection of plantings. Bitterbrush is mentioned throughout.

REGELIN, W. L., R. M. BARTMAN, D. W. REICHERT, and P. H. NEIL. 1976. The influence of supplemental feed on food habits of deer. U. S. Dep. Agr. Forest Serv. Res. Note RM-316. Rocky Mountain Forest and Range Exp. Sta., Fort Collins. 4 p.

Tame mule deer exposed to unlimited amounts of concentrated feed selected the same forage species, in similar proportions, as did deer that received no supplemental feed. Of the nine species which comprised 93% of all bites taken, bitterbrush contributed 39.1%.

RICHENS, V. B. 1967. Characteristics of mule deer herds and their range in northeastern Utah. J. Wildl. Manage. 31:651-666.

On the Daggett winter range, bitterbrush was an important supplemental mule deer food. It accounted for 6.9% of rumen weight although it comprised only 0.6% of the total ground cover. By age classes, 92.2% of bitterbrush plants were mature, 6.1% young, 1.3% decadent, and 0.4% seedlings.

RICKARD, W. H. 1968. Field observations on the altitudinal distribution of the side-blotched lizard. Northwest Sci. 42:161-164.

Mentions bitterbrush as a major shrub component below 630 feet elevation on a north facing slope in the Rattlesnake Hills of southeastern Washington. Bitterbrush did not occur at elevations from 630 to 3450 feet.

ROUGHTON, R. D. 1962. A review of literature on dendrochronology and age determination of woody plants. Colorado Dep. Game and Fish Tech. Bull. 15. Colorado Coop. Wildl. Res. Unit, Fort Collins. 99 p.

Reviews literature on dendrochronological and age determination techniques for three shrubs, including bitterbrush. Over 550 references are reviewed.

ROUGHTON, R. D. 1972. Shrub age structures on a mule deer winter range in Colorado. Ecology 53:615-625.

Shrub age structures were determined by sampling in selected communities and aging individual plants by growth-layer analysis. Prepared specimens of bitterbrush were easily aged by cross-dating xylem growth layers.

RUMSEY, W. B. 1971. Range seedings versus climax vegetation on three sites in Idaho. J. Range Manage. 24:447-450.

On a loamy, 41 to 56 cm precipitation site of the Lantonia soil series, seedings yielded an average of 4785 kg/ha compared to about 2464 kg/ha on native range. Climax vegetation on this site is dominated by bitterbrush in the shrub layer.

RUPP, M. S. 1970. Root distribution of _Artemisia tridentata_ and _Purshia tridentata_ in sandy soils of south-central Washington. Diss. Abs. 30:3052B.

Radioactive I^{131} was injected into the soil to measure and delineate root systems of bitterbrush, big sagebrush, and Sandberg bluegrass.

SABINSKE, D. W., and D. H. KNIGHT. 1978. Variation within the sagebrush vegetation of Grand Teton National Park, Wyoming. Northwest Sci. 52:195-204.

In one of four described communities, bitterbrush occurs with big sagebrush. It was suggested that bitterbrush is able to grow with big sagebrush where silt decreases and sand increases at the 10 to 20 cm soil depth.

SERGURA-BUSTAMANTE, M. 1970. Ecology of bitterbrush [Purshia tridentata (Pursh) DC.] in the Silver Lake deer winter range, Oregon. Diss. Abs. 30:4459B-4460B.

Analysis of six plant communities, four of which contained bitterbursh, showed that the occurrence of bitterbrush was not affected by elevation and that it occurred on slopes but not at the tops or bottoms of slopes, or on flat lands. Bitterbrush was absent from soils with a high content of surface gravel, and with high pH and exchangeable sodium.
(see also SEGURA-BUSTAMANTE, M. 1970. Ecology of bitterbrush [Purshia tridentata (Pursh) DC.] in the Silver Lake deer winter range, Oregon. PhD Thesis. Oregon State Univ., Corvallis. 269 p.)

SHERMAN, R. J., and W. W. CHILCOTE. 1972. Spatial and chronological patterns of Purshia tridentata as influenced by Pinus ponderosa. Ecology 53:294-298.

In central Oregon pine forests, bitterbrush reproduces almost exclusively from seed and frequently from caches of seed made by rodents. Fire exclusion has caused a decrease in suitable litter-free sites for seed caches and may result in a decline of bitterbrush. Bitterbrush is not fire resistant but is fire dependent.

SILVESTER, W. B. 1976. Ecological and economic significance of the non-legume symbioses. In: W. E. Newton and C. J. Nyman (Eds). Proc. First Internat. Symp. on Nitrogen Fixation. Washington State Univ. Press, Pullman. p. 489-506.

Nitrogen fixation by non-leguminous plants, including bitterbrush, is discussed.

SILVESTER, W. B. 1977. Dinitrogen fixation by plant associations excluding legumes. In: R. W. F. Hardy and A. H. Gibson (Eds). A treatise on dinitrogen fixation. Section 4, Agronomy and Ecology. John Wiley & Sons, New York. p. 141-190.

The ecological importance of nitrogen fixation by non-leguminous plants, including bitterbrush, is reviewed.

SNEVA, R. A., and D. N. HYDER. 1966. Control of big sagebrush associated with bitterbrush in ponderosa pine. J. Forest. 64: 677-680.

A mixed stand of big sagebrush and bitterbrush was sprayed with 2 lb/A of 2,4-D on five dates over three years. May treatments, when Sandberg bluegrass heads were in late boot, resulted in 95% sagebrush mortality and 10% bitterbrush mortality. Bitterbrush crown area was reduced by 25%. After flower eruption, bitterbrush damage increased. Since all bitterbrush leaves were killed at each spray date, recovery was directly related to earliness of spraying and length of growing season remaining after spraying.

STARK, N. 1966. Review of highway planting information appropriate to Nevada. Desert Research Institute. Univ. Nevada, Reno. p. 54.

Summarizes available information applicable to planting bitterbrush on roadsides in Nevada.

STELZER, M. J. 1968. The Great Basin tent caterpillar in New Mexico: life history, parasites, disease, and defoliation. U. S. Dep. Agr. Forest Serv. Res. Pap. RM-39. Rocky Mountain Forest and Range Exp. Sta., Fort Collins. 16 p.

At elevations above 8000 feet, quaking aspen is the favored host of the caterpillar. Between 1800 and 3500 feet, infestations are most serious on cottonwood and willow. Mentions 11 other trees and shrubs, including bitterbrush, on which the caterpillar feeds.

STEWART, W. D. P. 1967. Nitrogen-fixing plants. Sicence 158:1426-1432.

Discusses the role of bacteria, blue-green algae, root-nodulated angiosperms, and root-nodulated gymnosperms in nitrogen fixation. Notes that nitrogen fixing angiosperms are characteristic pioneer plants of areas low in combined nitrogen and therefore these plants have a competitive advantage. Includes Purschia [Purshia] as a root-nodulated angiosperm that needs to be tested for nitrogen fixation.

STUTH, J. W. 1975. Livestock, deer, and logging interactions in the lodgepole pine-pumice region of central Oregon. Diss. Abs. 36: 1995-1996.

Bitterbrush was the only species utilized by deer in both logged and non-logged areas. Utilization was least in July and increased on logged areas during August. Overall utilization was seven to ten times higher on logged than on non-logged areas. Cattle use of bitterbrush on fringes of non-logged areas increased during August and reached 75% of the diet by the end of the grazing season. Sheep used bitterbrush on both logged and non-logged areas. Logging decreased numbers of bitterbrush plants but yields were 287 to 397 lbs/A on logged vs. 223 to 297 lbs/A on non-logged areas.

(see also STUTH, J. W. 1975. Livestock, deer, and logging interactions in the lodgepole pine-pumice region of central Oregon. PhD Thesis. Oregon State Univ., Corvallis. 175 p.)

STUTH, J. W., and A. H. WINWARD. 1976. Logging impacts on bitterbrush in the lodgepole pine-pumice region of central Oregon. J. Range Manage. 29:453-456.

Production of bitterbrush in logged areas was approximately the same or greater than in adjacent nonlogged areas even though an average of 43% of the bitterbrush plants were lost during logging. Plants in logged areas had leader growth 2.5 cm longer than in nonlogged areas. Plants taller than 40 cm were most frequently damaged by logging, and plants 20 to 40 cm tall accounted for the greater production response following logging.

STUTH, J. W., and A. H. WINWARD. 1977. Livestock-deer relations in the lodgepole pine-pumice region of central Oregon. J. Range Manage. 30:110-116.

Bitterbrush gradually replaced maturing forbs in the diets of deer during July. Bitterbrush was the most important forage species in the diets of cattle, sheep, and deer using the lodgepole pine/bitterbrush/western needlegrass communities. Fall was the peak consumption period for bitterbrush by cattle and deer, while sheep consumed large quantities throughout the summer grazing season.

STUTZ, H. C. 1972. Genetic improvement in crop species as contrasted with possibilities in shrubs. In: C. M. McKell, J. P. Blaisdell, and J. R. Goodin (Eds). Wildland shrubs - their biology and utilization. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. INT-1. Intermountain Forest and Range Exp. Sta., Ogden. p. 139-143.

Although bitterbrush and Stansbury cliffrose cross freely, at least 23 different characteristics distinguish these two species. So common is the hybridization and backcrossing that essentially no population of bitterbrush in Utah is free of introgression from cliffrose. Only two recombination products of crossing have found adaptive environmental niches, however.

STUTZ, H. C. 1974. Rapid evolution in western shrubs. Utah Sci. 35: 16-20, 33.

Describes the sexual recombination process responsible for generation of new species. Although cliffrose and bitterbrush belong to separate genera, they hybridize quite commonly in nature, producing a highly fertile hybrid. It was suggested that the lower palatability of cliffrose to sheep creates an intense, selective advantage and allows cliffrose to spread its genes northward into bitterbrush populations.

STUTZ, H. C., and L. K. THOMAS. 1964. Hybridization and introgression in *Cowania* and *Purshia*. Evolution 18:183-195.

Describes crossing strategies between two distinct genera and suggests that desert bitterbrush (*Purshia glandulosa*) is a stabilized segregant from the hybridization product of Stansbury cliffrose (*Cowania stansburiana*) and antelope bitterbrush (*P. tridentata*).

THORNTON, J. F. 1960. Managing Great Basin juniper-sage-bitterbrush rangelands for big game and livestock on national forests in California. Amer. Soc. Range Manage. Abs. 13:59.

Forage management on juniper-sagebrush-bitterbrush range should include both livestock and game. Competition for bitterbrush can be minimized by grazing sheep in the spring and leaving most of the season's growth for deer.

TIEDEMANN, A. R., G. O. KLOCK, L. L. MASON, and D. E. SEARS. 1976. Shrub plantings for erosion control in eastern Washington - progress and research needs. U. S. Dep. Agr. Forest Serv. Res. Note PNW-279. Pacific Northwest Forest and Range Exp. Sta., Portland. 11 p.

Bitterbrush seedlings were planted on two forest sites in eastern Washington on colluvial subsoil from granodiorite parent material. Other soils were decomposed granodiorite, volcanic ash, and "popcorn" pumice. Organic matter content was low and slopes ranged from 40 to over 70%. Bitterbrush survival appeared to be affected by elevation differences between source and planting site. Seedling size at planting time should be tall enough to withstand inundation by ravelling, loose soil material, yet the root system should be small enough to allow hand planting with minimum site disturbance.

TINGEY, W. M., C. D. JORGENSEN, and N. C. FRISCHKNECHT. 1972. Thrips of the sagebrush-grass range community in west-central Utah. J. Range Manage. 25:304-308.

Four bitterbrush sites in Tooele County, Utah, yielded three species of thrips feeding on bitterbrush litter. These three species were found feeding on foliage of other plant species, however, and one species - Frankliniella occidentalis Pergande - was considered a potential pest on rangelands.

TRLICA, M. J., M. BUWAI, and J. W. MENKE. 1977. Effects of rest following defoliations on the recovery of several range species. J. Range Manage. 30:21-27.

Following 90% defoliation, bitterbrush made good recovery after 14 to 26 months rest. Heavy defoliation during the fruit development stage resulted in shorter twigs than plants defoliated at other stages. A rest period of 14 to 26 months was not sufficient for complete recovery of vigor, herbage yield, and total nonstructural carbohydrates. Live crown cover following rest was less than control plants if bitterbrush had been defoliated at any of four phenological stages. Defoliation at the fruit development or seed shatter stages was most harmful.

U. S. FOREST SERVICE. 1976. Some important native shrubs of the West. U. S. Dep. Agr. Forest Service. Intermountain Forest and Range Exp. Sta., Ogden. 16 p.

Fourteen native shrubs, including bitterbrush, are described and illustrated with emphasis on their position in the plant community, their value on wildlands, and their cultivation and potential for future use.

URNESS, R. J., A. D. SMITH, and R. K. WATKINS. 1977. Comparison of _in vivo_ and _in vitro_ dry matter digestibility of mule deer forages. J. Range Manage. 30:119-121.

Percent digestibility using _in vivo_ and _in vitro_ techniques was lower for bitterbrush than most other shrubs tested. _In vivo_ results were higher than those from _in vitro_ methods.

WALLMO, O. C., L. H. CARPENTER, W. L. REGELIN, R. B. GILL, and D. L. BAKER. 1977. Evaluation of deer habitat on a nutritional basis. J. Range Manage. 30:122-127.

Average winter cellulose content of several shrubs, including bitterbrush, was 19 to 32%. Lignin content was 18 to 25%. Average digestibility of twigs in February was 34%.

WARD, A. L. 1971. _In vitro_ digestibility of elk winter forage in southern Wyoming. J. Wildl. Manage. 35:681-688.

Rumen fluid from elk and cattle was used to determine _in vitro_ dry matter digestibility of dried forage samples collected from November through March. Bitterbrush digestibility using elk inoculum was 23.3 to 30.3% and using inoculum from a steer on a lucerne diet was 22.2 to 24.7%. Digestibility values were highest in the March samples.

WARING, R. H. 1969. Forest plants of the eastern Siskiyous: their enviornmental and vegetation distribution. Northwest Sci. 43:1-17.

In the eastern Siskiyou Mountains of southern Oregon and northern California, Jeffrey pine occurs on extremely infertile soils derived from perodotite or serpentinite. These soils are high in iron and magnesium and low in phorsphorus, potassium, nitrogen, and calcium. These soils are also shallow and generally droughty. Bitterbrush occurs infrequently on rocky sites within the Jeffrey pine type.

WEBSTER, S. R., C. T. YOUNGBERG, and A. G. WOLLUM. 1967. Fixation of nitrogen by bitterbrush [Purshia tridentata (Pursh) DC]. Nature 216:392-393.

Four-month old bitterbrush seedlings grown in a sandy soil with high natural nodulation potential were separated from nodules and the nodules were exposed to N^{15}. Using 0.02 atmospheric percent of excess N^{15} as positive evidence of nitrogen fixation, all samples resulted in 0.051% or greater.

WEST, N. E. 1968. Rodent-influenced establishment of ponderosa pine and bitterbrush seedlings in central Oregon. Ecology 49:1009-1011.

In montane forests of central Oregon, about 90% of bitterbrush seedlings develop in clusters. Clusters originate from unrecovered caches of seed made by small rodents.

WRIGHT, H. A. 1972. Shrub response to fire. In: C. M. McKell, J. P. Blaisdell, and J. R. Goodin (Eds). Wildland shrubs - their biology and utilization. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. INT-1. Intermountain Forest and Range Exp. Sta., Ogden. p. 204-207.

Reviews literature on effects of fire on several plants including bitterbrush.

WRIGHT, H. A. 1978. The effect of fire on vegetation in ponderosa pine forests. Texas Tech. Univ., Range and Wildl. Info. Series No. 2, College of Agr. Sciences Pub. T-9-199. Texas Tech. Univ., Lubbock. 21 p.

A state-of-the-art review of fire effects on plants is presented, including bitterbrush, in five climax and four seral ponderosa pine communities.

WRIGHT, H. A., and C. M. BRITTON. 1976. Fire effects on vegetation in western rangeland communities. In: Use of prescribed burning in western woodland and range ecosystems Symp. Proc. Utah Agr. Exp. Sta., Logan. p. 35-41.

A review of fire effects on several plants, including bitterbrush, is presented.

WRIGHT, H. A., L. F. NEUENSCHWANDER, and C. M. BRITTON. 1978. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities. U. S. Dep. Agr. Forest Serv. Gen. Tech. Rep. Intermountain Forest and Range Exp. Sta., Ogden. (In Press).

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On a site that had been chained and seeded with crested wheatgrass and bitterbrush, bitterbrush sustained minor damage when one-leaf pinyon saplings were individually treated with picloram or karbutilate, provided the bitterbrush plants were not rooted beneath the tree canopy.

YOUNG, J. A., and R. A. EVANS. 1976. Stratification of bitterbrush seeds. J. Range Manage. 29:421-425.

Temperatures above 5°C were too warm, and below o°C too cold, for bitterbrush stratification. The optimum temperature for the longest duration was 2°C. Any departure from optimum temperature and moisture regimes prolonged time required for stratification or negated any effect of the stratification treatment.

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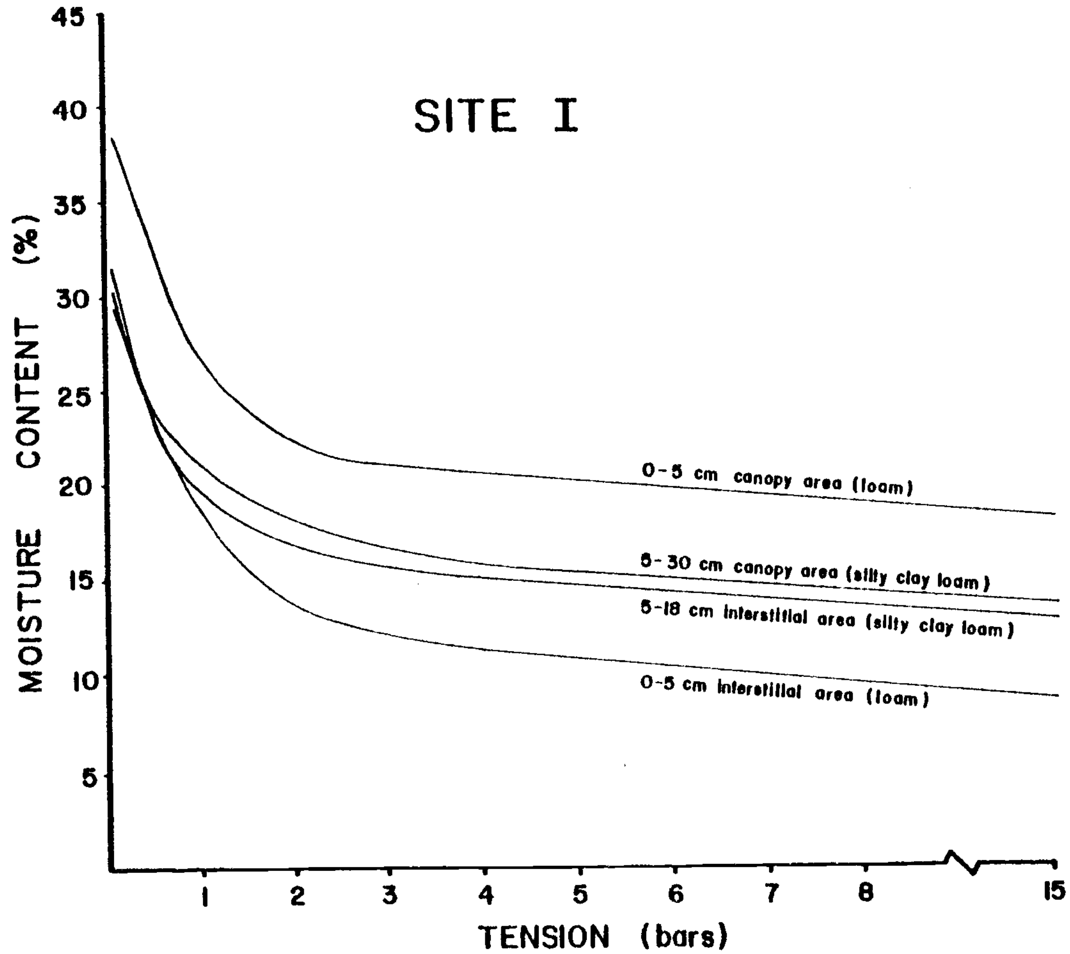
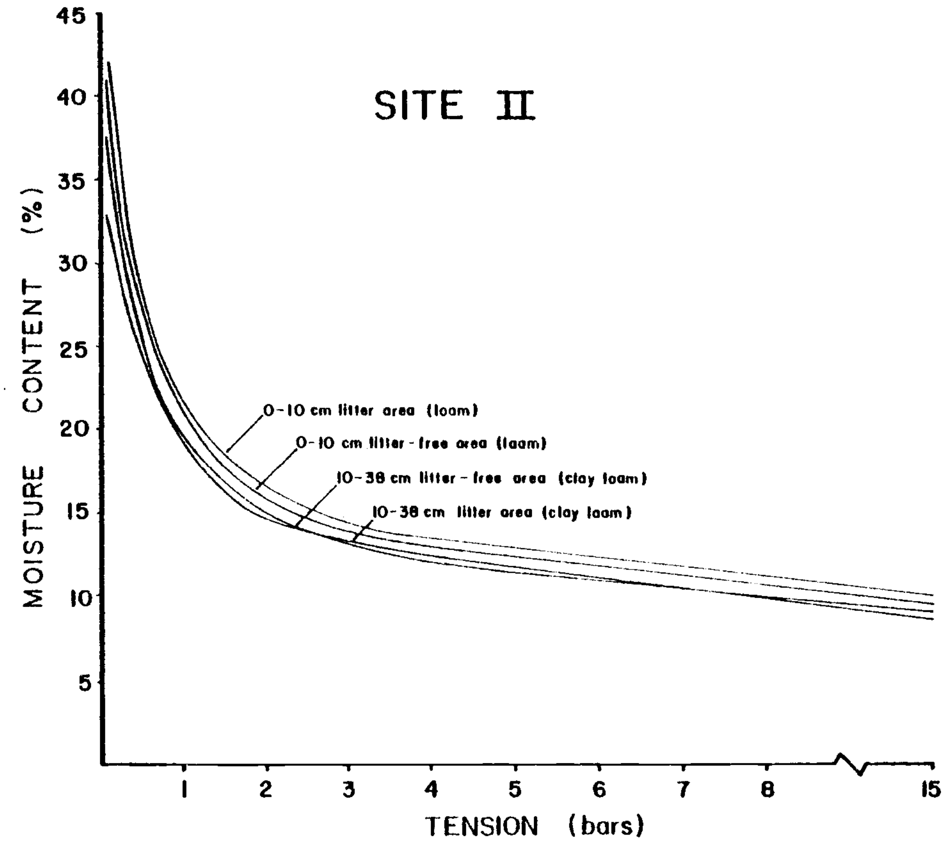
APPENDICES

APPENDIX A

SOIL MOISTURE RETENTION CURVES FOR BITTERBRUSH SITES I AND II


SITE I
MOISTURE CONTENT (%)
45
40
35
30
25
20
15
10
5
TENSION (bars)
1
2
3
4
5
6
7
8
15
0-5 cm canopy area (loam)
5-30 cm canopy area (silty clay loam)
5-18 cm interstitial area (silty clay loam)
0-5 cm interstitial area (loam)


SITE II
MOISTURE CONTENT (%)
45
40
35
30
25
20
15
10
5
0-10 cm litter area (loam)
0-10 cm litter - free area (loam)
10-38 cm litter - free area (clay loam)
10-38 cm litter area (clay loam)
1
2
3
4
5
6
7
8
15
TENSION (bars)

APPENDIX B

ATTRIBUTES OF 50 CLIPPED PLANTS ON BITTERBRUSH SITES I AND II

MEASURED ATTRIBUTES OF 50 CLIPPED PLANTS ON SITE I

			Aerial parameters			Stem parameters		
Plant no.	Alive or Dead	Age (yrs)	Major axis (cm)	Minor axis (cm)	Height (cm)	Maximum diameter (mm)	Circum- ference (mm)	Calculated ave. dia. (mm)
1	D	32	98	81	108	49.2	141.3	45.0
2	A	17	97	67	74	25.6	79.4	25.3
3	A	20	71	60	20	24.1	66.7	21.2
4	A	17	55	44	39	32.3	101.6	32.3
5	D	49	153	94	107	46.5	146.1	46.5
6	D	101	170	114	163	160.6	427.0	135.9
7	D	40	140	103	97	52.1	152.4	48.5
8	D	39	210	122	138	43.6	134.9	43.0
9	D	31	91	83	42	31.4	98.4	31.3
10	D	30	155	121	95	59.7	152.4	48.5
11	A	92	220	178	176	70.9	193.7	61.6
12	D	48	104	99	96	43.3	128.6	40.9
13	A	37	123	93	75	36.2	95.3	30.3
14	D	47	87	70	57	45.1	136.5	43.5
15	D	58	145	75	212	70.9	196.9	62.7
16	D	53	122	67	91	38.3	96.8	30.8
17	D	47	186	132	119	38.9	119.1	37.9
18	D	38	70	56	52	28.6	87.3	27.8
19	A	42	136	106	147	71.1	193.7	61.6
20	D	35	85	48	66	71.9	200.0	63.7
21	D	48	66	32	78	64.9	192.1	61.1
22	A	21	116	89	32	21.6	65.1	20.7
23	D	79	94	88	104	55.4	144.5	46.0
24	D	118	225	156	178	175.7	444.5	141.5
25	D	69	135	110	84	55.8	168.3	53.6
26	A	43	99	64	67	43.2	120.7	38.4
27	D	26	120	89	75	34.2	93.7	29.8

Continued

Plant no.	Alive or Dead	Age (yrs)	Aerial parameters: Major axis (cm)	Minor axis (cm)	Height (cm)	Stem parameters: Maximum diameter (mm)	Circum-ference (mm)	Calculated ave. dia. (mm)
28	A	27	116	76	66	37.5	108.0	34.4
29	D	24	90	61	72	27.7	84.1	26.8
30	D	41	124	116	91	33.7	104.8	33.4
31	D	40	166	137	119	52.2	142.9	45.5
32	D	83	145	140	167	71.2	195.3	62.2
33	D	68	358	211	220	88.8	261.9	83.4
34	D	31	53	51	42	27.1	74.6	23.7
35	D	50	195	134	178	46.2	136.5	43.5
36	D	23	150	141	149	23.7	69.9	22.2
37	D	35	157	128	196	51.8	134.9	43.0
38	A	15	44	28	57	13.7	41.3	13.1
39	A	27	134	106	88	33.2	87.3	27.8
40	D	62	99	68	159	74.8	188.9	60.1
41	A	23	84	63	65	14.4	39.7	12.6
42	A	38	105	102	53	23.9	74.6	23.7
43	D	44	62	43	43	26.7	79.4	25.3
44	D	38	123	110	91	44.7	139.7	44.5
45	D	22	123	92	67	35.7	101.6	32.3
46	D	41	93	81	60	33.2	87.3	27.8
47	D	34	79	70	47	26.8	77.8	24.8
48	A	22	82	30	41	13.3	41.3	13.1
49	D	32	87	46	42	45.0	103.2	32.8
50	A	34	154	139	97	31.6	79.4	25.3

MEASURED ATTRIBUTES OF 50 CLIPPED PLANTS ON SITE II

			Aerial parameters			Stem parameters		
Plant no.	Alive or Dead	Age (yrs)	Major axis (cm)	Minor axis (cm)	Height (cm)	Maximum diameter (mm)	Circum- ference (mm)	Calculated ave. dia. (mm)
1	D	17	63	46	25	19.2	49.2	15.7
2	D	21	210	192	90	23.2	73.0	23.2
3	A	25	141	109	50	25.9	81.0	25.8
4	D	31	118	86	61	38.7	109.5	34.9
5	D	28	97	75	63	36.6	101.6	32.3
6	A	21	103	74	51	24.8	68.3	21.7
7	A	19	130	103	60	21.0	63.5	20.2
8	A	26	108	86	50	30.7	81.0	25.8
9	A	20	113	97	71	18.5	57.2	18.2
10	A	25	126	84	45	29.9	85.7	27.3
11	A	15	73	43	30	11.3	28.6	9.1
12	A	15	62	58	29	13.9	38.1	12.1
13	D	16	65	50	37	19.2	54.0	17.2
14	D	38	194	182	83	43.9	114.3	36.4
15	A	18	122	96	55	20.9	63.5	20.2
16	D	26	50	48	27	36.2	82.3	26.3
17	A	17	47	30	37	13.0	31.8	10.1
18	A	25	92	89	50	42.8	111.1	35.4
19	A	19	45	40	31	13.5	41.3	13.1
20	A	26	169	104	77	32.0	95.3	30.3
21	D	25	115	68	50	39.7	115.9	36.9
22	A	18	92	68	60	22.4	63.5	20.2
23	A	9	50	36	34	7.2	22.2	7.1
24	A	20	103	83	60	19.5	60.3	19.2
25	A	21	81	72	38	39.1	95.3	30.3
26	A	12	81	71	51	16.7	31.8	10.1
27	A	17	89	86	65	19.6	38.1	12.1

Continued

Plant no.	Alive or dead	Age (yrs)	Aerial parameters: Major axis (cm)	Minor axis (cm)	Height (cm)	Stem parameters: Maximum diameter (mm)	Circum- ference (mm)	Calculated ave. dia. (mm)
28	A	18	48	34	35	25.8	80.2	25.5
29	A	26	70	59	58	19.1	50.8	16.2
30	A	31	102	85	57	40.3	103.2	32.8
31	A	25	82	67	54	23.2	69.9	22.2
32	D	15	47	28	39	14.1	42.9	13.6
33	D	13	55	46	43	13.7	42.9	13.6
34	A	20	64	45	34	18.2	57.2	18.2
35	A	22	85	56	62	32.5	101.6	32.3
36	A	27	112	111	71	21.2	66.7	21.2
37	A	18	59	55	32	16.0	47.6	15.2
38	D	13	29	28	39	12.8	33.3	10.6
39	A	18	147	114	58	19.8	6.19	19.7
40	A	11	44	41	39	9.2	28.6	9.1
41	A	13	57	57	50	8.2	22.2	7.1
42	A	26	116	86	63	21.9	68.3	21.7
43	A	14	89	62	47	10.5	31.8	10.1
44	A	16	72	66	34	26.4	73.0	23.2
45	A	21	53	52	26	26.9	76.2	24.2
46	A	15	71	49	32	22.2	69.9	22.2
47	A	20	95	68	52	32.3	101.6	32.3
48	A	16	128	105	42	27.2	76.2	24.3
49	A	15	105	74	35	20.8	65.1	20.7
50	A	18	52	35	35	16.7	47.6	15.2