

Mountain Big Sagebrush Age Distribution and Relationships on the Northern Yellowstone Winter Range

Carl L. Wambolt
Trista L. Hoffman

Abstract—This study was conducted within the Gardiner Basin, an especially critical wintering area for native ungulates utilizing the Northern Yellowstone Winter Range. Mountain big sagebrush plants on 33 sites were classified as large (≥ 22 cm canopy cover), small (< 22 cm canopy cover), or dead and then aged by counting growth rings. Large and small plants averaged 32 and 6 years old, respectively. Nearly half of the small plants were 5 years old, the result of optimal conditions for establishment in 1988, the year large wildfires burned much of Yellowstone National Park. Dead plants averaged 41 years of age. A bimodal peak in establishment of mountain big sagebrush corresponded with two large reductions in the Northern Yellowstone elk population.

Introduction

Big sagebrush (*Artemisia tridentata* Nutt.) grassland comprises the largest vegetation type in the Western United States (Colbert and Colbert 1983) dominating 60 million ha (Beetle 1960). Since the 1930s, control of sagebrush has been a primary objective of many land managers, with the intent of improving herbaceous production for livestock (Best 1972). However, big sagebrush is recognized as valuable forage and cover for many wild ungulates, (Kufeld and others 1973; Welch and Peterson 1981; Wambolt and McNeal 1987; Ngugi and others 1992; Wambolt 1996, 1998), birds, (Best 1972; Reynolds 1981; McAdoo and others 1989), and other wildlife (Mullican and Keller 1986). Ironically, some land managers are increasingly engaged in reducing big sagebrush, often for the stated purpose of benefiting wildlife.

There is much conjecture about the dynamics of big sagebrush production, including the relationship with age. Some believe that big sagebrush declines in production or vigor after a certain age (West and others 1984), but details and the interrelationships with environmental factors related to possible declines are unclear. Decadence, degradation, and senescence are terms commonly used in the literature (Roughton 1972; Evans and Young 1978; Sinclair 1984) and in management plans relating to big sagebrush

(Anonymous 1979, 1982; Petroni 1991), but their relevance to big sagebrush is vague. Our objective was to obtain an understanding of the age distribution of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* [Rydb.] Beetle) over a range of environmental conditions on 33 sites on the Northern Yellowstone Winter Range (NYWR).

Methods

Study Area

The study was conducted in the Gardiner Basin of the NYWR adjacent to Yellowstone National Park (YNP) in southwestern Montana (fig. 1). Along the Yellowstone River annual precipitation averages 305 mm. The nearby benchlands receive 406 mm of precipitation. Half of the annual precipitation is in the form of snow and June is the wettest month. The Gardiner Basin is a natural winter range for ungulates due to the orographic effects on precipitation of mountain peaks up to 3,353 m (Wambolt 1996). Elk (*Cervus elaphus nelsoni*) and mule deer (*Odocoileus hemionus hemionus*) are the important ungulates on the study area.

Glacial scouring and deposition have been strong influences on the soils. Parent materials include granites and limestones deposited by glaciers as well as basalts and breccias. The soil regolith in the study area may range from a few cm in areas scoured by glaciers to over 1.5 m in depositional areas. Mollisols are the dominant soil order. Soil textures are most commonly loams and sandy loams (Wambolt and McNeal 1987).

Four sagebrush taxa, basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), Wyoming big sagebrush (*A. t.* ssp. *wyomingensis* Beetle and Young), mountain big sagebrush, and black sagebrush (*A. nova* Nels.), occur sympatrically but with varying frequency. Mountain big sagebrush is the dominant on the majority of the area. Threadleaf rubber rabbitbrush (*Chrysothamnus nauseosus* ssp. *consimilis* [Green] Hall & Clem.), mountain low rabbitbrush (*C. viscidiflorus* ssp. *lanceolatus* [Nutt.] Hall & Clem.), narrowleaf low rabbitbrush (*C. v.* ssp. *viscidiflorus* var. *stenophyllus* [Hook] Nutt.), and gray horsebrush (*Tetradymia canescens* D.C.) occur throughout the sagebrush-dominated portions of the area.

Bluebunch wheatgrass (*Agropyron spicatum* [Pursh.] Scribn.) and Idaho fescue (*Festuca idahoensis* Elmer) are the principal grasses found as sagebrush understory. Other common grasses are prairie junegrass (*Koeleria macrantha* Ledeb.), needle-and-thread (*Stipa comata* Trin. & Rupr.), and Indian ricegrass (*Oryzopsis hymenoides* [R. & S.] Ricker).

In: McArthur, E. Durant, Fairbanks, Daniel J., comps. 2001. Shrubland ecosystem genetics and biodiversity: proceedings; 2000 June 13–15; Provo, UT. Proc. RMRS-P-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Carl L. Wambolt is Professor of Range Science and Trista L. Hoffman was a Graduate Assistant, Department of Animal and Range Sciences, Montana State University, Bozeman, MT 59717.

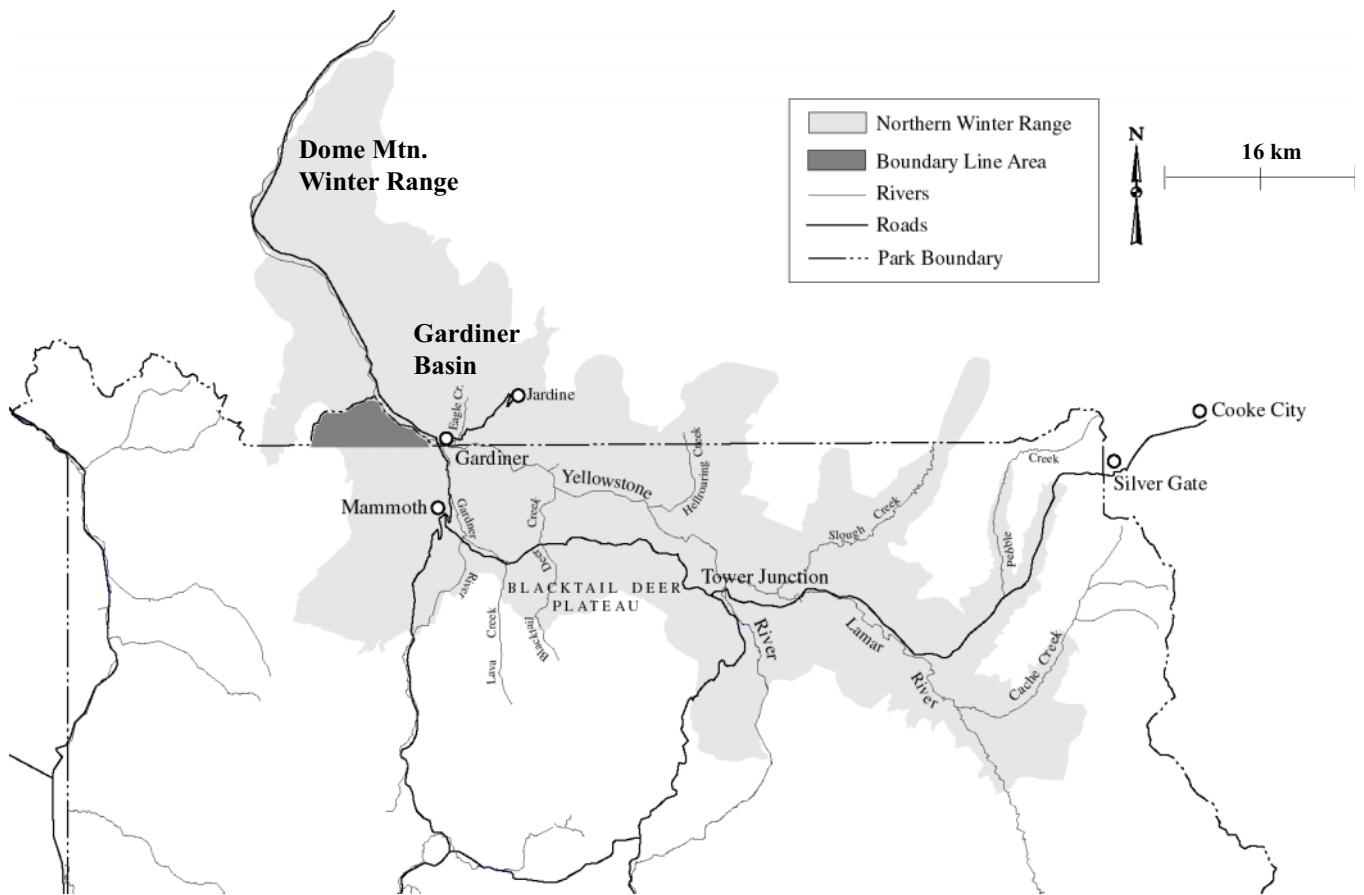


Figure 1—The Northern Yellowstone Winter Range. This study was conducted north of Yellowstone National Park in the Gardiner Basin. That area is especially important for wintering ungulates.

Sampling

Each study site was a stand of mountain big sagebrush that was relatively homogenous in characteristics such as slope, aspect, and elevation. Confirmation of the mountain big sagebrush subspecies was made in the lab using an ultraviolet light (Stevens and McArthur 1974). Each study site was at least 0.25 ha in size (40 x 60 m) and ranged up to 3 ha.

Measurements of plant parameters began near the end of June 1993. The majority of sagebrush growth for the year occurred before this time. Long shoots and leaves were fully elongated, and an annual growth ring was well established in the stem xylem. Therefore, measurable production increases by sagebrush plants were not expected over the remainder of the summer. The plant parameters recorded included browse form class, percent cover of live and dead sagebrush, density of large, small and dead plants, percent dead crown, age, and production of winter forage.

Browse form classes used were described by Wambolt and others (1994). Plants that receive repeated heavy browsing develop a dense canopy and a hedged appearance. Lightly browsed plants have a more open canopy with linear growth due to the annual extension of terminal leaders. Usually, all of the plants on a site exhibited nearly the same browse form class.

At each site, two line transects, 30 m long, were established with the slope to measure cover. The transects were parallel to one another and 10 m apart. Belt transects of 60 m² were established to obtain the other parameters by measuring 1 m on each side of the line transect. Measurements from the transects were pooled.

A plumb bob was used to determine live and dead cover to the nearest cm along the line transects. Live cover included any leaves, leaders, stems or seedheads that intercepted the line transect. Dead cover referred to the intercept of dead sagebrush branches elevated above the ground.

Plant density was determined by counting all sagebrush plants rooted within the belt transect. Plants were divided into large, small and dead categories. A large plant measured >22 cm across the widest portion of its crown. This minimum measurement was adapted from the sagebrush production models used (Wambolt and others 1994). Plants <22 cm were not considered to be significant contributors to site production, but were important as representatives of the younger age classes. Dead plants were separated from woody litter by the requirement of at least one main stem still rooted in place, and some portion of the stem remaining above the ground. An ocular estimate of the percentage of dead crown area was made for each large sagebrush. Estimates were made to the nearest 10 percent.

Production was defined after Wambolt and others (1994) as the amount of sagebrush forage available to wildlife during winter. Production measurements were made on 10 large plants per line transect. The 10 plants were those rooted closest to 3 m increments along the 30 m belt transect. Four measurements were recorded for each plant to model production. The major axis referred to the longest horizontal line between living plant tissue across the plant crown. The minor axis was a similar line perpendicular to the major axis. Two additional axes were measured perpendicular to one another and set at 45° angles to the intersection of the major and minor axes. The modeled forage production per plant was multiplied by the density of large plants to determine the mass of sagebrush forage available on a per ha basis.

Each of the 20 plants measured for production (10 plants x 2 transects) was cut at the base and transported to the lab for aging (total of 660 large plants). Twenty small immature plants (<22 cm across the widest portion of their crown) were collected in the same manner for aging at each of the 33 sites (total of 660 small plants). Twenty dead plants per site were also collected, but because dead plants were uncommon and often not found near the 3 m marks, these plants were collected by walking through the site and cutting the first 20 plants encountered. Often, dead stems were rotted or colonized by ants and had to be discarded, thus, on some sites, it was not possible to collect 20 specimens.

Annual growth rings were counted in cross-sections (Ferguson 1964; Taha 1972). Sagebrush cross-sections were sanded smooth and a fresh razor was used to take a thin veneer off the surface. This removed the surface pores that were filled with sawdust or impurities and clarified the annual growth rings. A light coating of vegetable oil was sometimes used to highlight rings before counting with a 10x hand lens under a full spectrum light.

Results and Discussion

The age distribution of large mountain big sagebrush is shown in figure 2. Ages of individual large plants ranged from 5 to 88 years with an average age of 32 years. Because no large plants were less than 5 years old, it appears that 5 years are required for a mountain big sagebrush plant to reach an age where it is large enough to have a crown >22 cm at the widest portion. Roughton (1972) excluded all plants less than 9 years old in his discussion of sagebrush age classes. When mountain big sagebrush is burned, recovery to pre-burn levels of forage production is a slow process and requires almost a decade for shrubs to attain any notable level of production (Roughton 1972). Further, frequent burning of sagebrush should be expected to reduce sagebrush forage production (Watts and Wambolt 1996).

The population of sagebrush in the study area is relatively young. The age classes with the largest number of individual plants were between 25 and 35 years old. When plants were grouped as stands (20 plants measured per stand), the average stand age (n = 33) ranged from 18 to 45 years with an average overall stand age of 32 years in 1993 (table 1). Therefore, the average stand age was identical to the average individual age. Only 12 percent of the individuals exceeded 50 years of age, and 5 percent were older than 60 years.

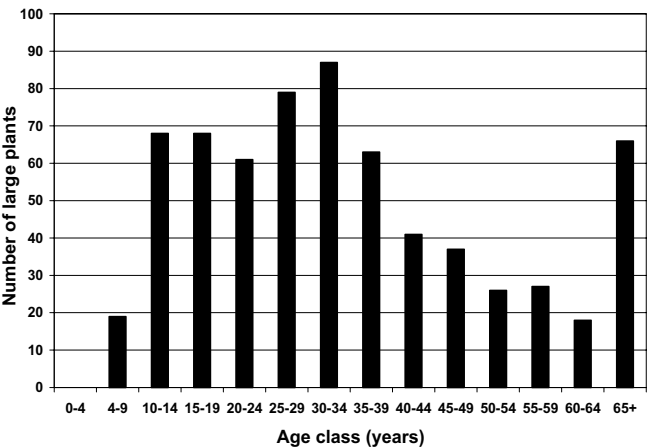


Figure 2—Age distribution of 660 large (>22 cm across widest portion of crown) mountain big sagebrush plants from 33 sites in 1993.

While big sagebrush have been reported to live as long as 200 years (Ferguson 1964), the oldest plant we recorded was a dead individual of 109 years. The oldest living plant was 88 years of age. In areas such as southwest Montana and southern Idaho where most sagebrush stands have been treated in various manners in attempts to improve livestock forage, the majority of mountain big sagebrush have been aged at 11 to 20 years with the next most common age class 21 to 30 years (Brown 1982). Although the length of time since the last disturbance (such as fire) was not discussed, Brown (1982) found only 3 percent of plants were older than 50 years. In Nevada, the average longevity of big sagebrush (subspecies not considered) was estimated at 30 to 40 years (Wallace and Romney 1972). The oldest big sagebrush plant (subspecies not considered) observed by Roughton (1972) in Colorado was 72 years old. On two sites, he found that 60 to 75 percent of shrubs were between 5 and 35 years of age (the 0 to 4 year age class was excluded). By excluding age classes below 9 years, he found that the majority of sagebrush on a third site was between 50 and 59 years old. He described this age structure as “decadent” even though thousands more

Table 1—Averages and ranges of plant characteristics for 33 mountain big sagebrush sites.

	Mean	Standard deviation	Maximum	Minimum
Percent live line cover	14.2	0.1	38.8	3.0
Percent dead line cover	5.5	0.0	15.0	0.1
Density large plants/m ²	0.9	0.3	1.5	0.4
Density small plants/m ²	1.0	1.0	4.0	0.1
Density dead plants/m ²	0.2	0.1	0.7	0.1
Winter forage (g/plant)	127.6	73.6	330.1	34.8
Percent deadcrown	22.5	7.2	43.2	11.1
Age large stand	32.2	6.4	45.0	18.0
Age small stand	6.1	0.5	25.0	1.0
Age dead stand	40.7	7.5	56.0	20.0

plants were observed between 1 and 9 years old than all the other age classes put together. This description seems misleading because thousands of young replacement plants were not considered. Although the sagebrush stands apparently had begun a cycle of self-rejuvenation as described by Lommasson (1948), stands were described by Roughton (1972) as if the young members were of no consequence.

In the Gardiner Basin of the NYWR, every site measured had young age classes well represented with the majority of plants less than 50 years old. Because none of the 33 sites have been drastically disturbed (as with fire, spraying, and so forth), this relatively young condition has maintained itself, with sagebrush plants establishing, maturing, dying and being replaced in a relatively short period of time (around 50 years) in the absence of human intervention as expected from a climax dominant. This indicates that burning or other disturbances are not necessary to maintain sagebrush stands in a productive state.

Dead mountain big sagebrush plants also provided evidence that mountain big sagebrush stands turn over relatively rapidly without intervention. The average age of dead plants was 40.7 years (table 1). This does not precisely establish the age at which mountain big sagebrush are likely to die because plants with rot were excluded from the sample. However, the estimate comes from 440 observations, which indicates that turnover by age 41 is not uncommon. Lommasson (1948) reported 40 years as the stand age at which old mountain big sagebrush plants begin to senesce, thereby breaking down and creating natural openings in which young plants may establish. Recruitment by seedlings in closed stands of mountain big sagebrush occurs only infrequently due to intraspecific competition (Meyer 1994). However, patterns of seedling establishment are not always clearly related to natural openings associated with aging stands. They may also be influenced by environmental factors such as soil moisture or seed production (Tyrrell and Crow 1994).

The year of establishment for small mountain big sagebrush individuals is shown in figure 3. Such small plants do not contribute notably to the production by mountain big sagebrush in the study area. Occasionally plants that were over 20 years old and still small were found in areas with adverse growing conditions such as very dry, shallow soils on exposed ridgetops.

Individual small mountain big sagebrush plants ranged from 1 to 25 years old. Nearly one-half of 660 small plants sampled were 5 years old (germinated in 1988) when sampled in 1993. This age dominated on all 33 sites. When small plants were grouped as stands (20 plants per stand), the average age ($n = 33$) ranged from 4 to 11 years with an overall average age of 6 years (table 1).

Crisp and Lange (1976) proposed a model for age structure of shrubs that under hypothetical natural conditions, mortality is highest in young and old individuals, with reduced mortality in mature, but relatively young plants. A sharp decline would occur early after germination, followed by a period of reduced mortality. Eventually, mortality rates would again increase after plants reached a critical age.

The average stand establishment dates of large and small mountain big sagebrush plants are shown in figure 4. Data were collected from different populations and should not be combined to form a continuous age structure. The

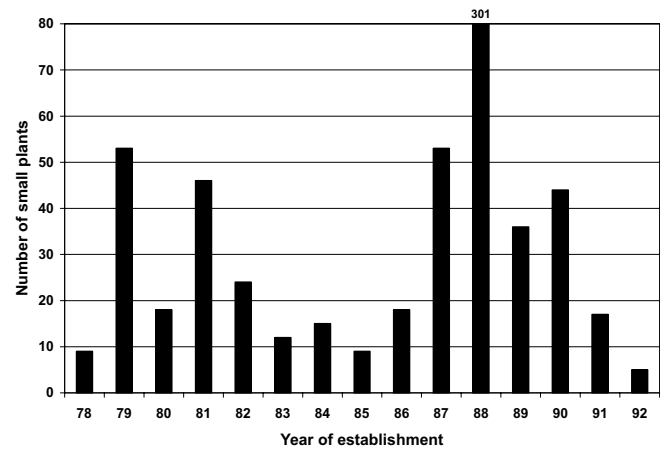


Figure 3—Year of establishment for 660 small (<22 cm across widest portion of crown) mountain big sagebrush plants from 33 sites.

survivorship curve (fig. 4) from this study area is quite different from the hypothetical change described in Crisp and Lange (1976). Within the age distribution for large plants, several stands have average ages that date to the late 1940s and early 1950s. Stand ages do not pre-date the 1940s because, as a whole, mountain big sagebrush in this area were found to average 41 years (table 1). The stands at the older end of the curve are probably approaching the lifespan of mountain big sagebrush. This lifespan is influenced in part by the large ungulate populations that have been present since these plants germinated.

In the late 1950s and early 1960s, mountain big sagebrush establishment generally increased, reaching a peak in 1961 (fig. 4). This event was followed by a general decrease in recruitment by the late 1960s. This is inconsistent with the hypothesis that decreased mortality is observed in mature

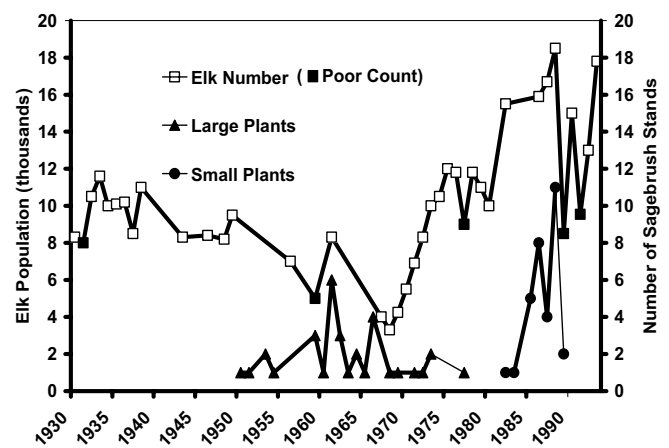


Figure 4—Large (>22 cm across widest portion of crown) and small (<22 cm) mountain big sagebrush stands average establishment date and elk winter counts on the Northern Yellowstone Winter Range.

but relatively young plants (Crisp and Lange 1976). Assuming that plants germinate and establish equally each year and that survival followed the hypothetical curve described by Crisp and Lange (1976), then many more site ages should have been observed in the late 1960s and early 1970s. However, by the 1970s, establishment of mountain big sagebrush is extremely low.

According to the hypothetical age distribution model (Crisp and Lange 1976), small mountain big sagebrush should have high mortality rates that perhaps slow as the plants get older and begin to mature. Because nearly half of the small plants measured were 5 years old, their distribution also contrasts with the hypothetical model. Establishment peaks dramatically in 1988. This type of establishment was not found during other years.

The bimodal curve of the age distribution of mountain big sagebrush corresponds to two distinct reduction events for the Yellowstone elk population (Tom Lemke, unpublished report, Montana Fish, Wildlife & Parks, Houston 1982). Removals of 6,365 animals in the winter of 1955 and 1956 (mostly from outside YNP) and of 5,135 (mostly from within YNP) in the winter of 1961 to 1962, primarily by shooting, cut the elk population approximately in half each year (Houston 1982). During the winter of 1988 and 1989, snow conditions, coupled with habitat loss from the large Yellowstone fires the previous summer, resulted in approximately a 40 percent loss of the herd (Tom Lemke, unpublished report, Montana Fish, Wildlife & Parks).

Declines in the elk herd that occurred during these two periods of sagebrush establishment may partially explain the difference between the curves in this study and the hypothetical curve. A reduction in herbivory and trampling may have increased establishment and survival of mountain big sagebrush, while declines occurred when elk populations were high.

Episodic germination due to other environmental conditions may also play a role in determining the age distribution observed in this study. Daubenmire (1975) found that in basin big sagebrush (*Artemisia tridentata* Nutt ssp. *tridentata*), recruitment of seedlings may be delayed for years until favorable moisture conditions occur for germination and establishment. Humphrey (1984) found similar results, although big sagebrush subspecies was not considered. Microtopographic characteristics of the seedbed and precipitation timing are critical for germination of mountain big sagebrush (Booth and others 1990; Young and others 1990). Successful emergence of mountain big sagebrush seedlings may depend on the amount and timing of spring snowpack (Meyer 1994). In addition, weather conditions, especially early drought are the primary factors in causing seedling mortality (Meyer 1994), although seedlings may be able to withstand water shortages by early summer (Booth and others 1990).

Temperature and precipitation records from the years 1977 to 1992 show unusual climatic conditions that may have contributed to the large number of plants that germinated in 1988 (table 2). The late summer of 1987 was one of the wettest in the 15 year interval. This moisture corresponded with a period of mountain big sagebrush flowering and seed production. An increase in water availability during late summer has been shown to increase the growth of reproductive tissues of big sagebrush (Evans and Black

Table 2—Precipitation extremes during the 15 year period between 1977 and 1992.

Month	Precipitation	15 year ranking
<i>mm</i>		
1987		
July	910	Wettest
August	410	4 th wettest
1988		
April	490	2 nd wettest
May	920	Wettest
June	120	Driest
July	240	3 rd driest
August	36	Driest

1993). The spring of 1988 was also one of the wettest of the 15 years sampled, but was followed by a drought in the summer and fall. A moist spring would promote seed germination of many plant species, but a summer drought would likely hamper growth of competing plants. Mountain big sagebrush, which is drought tolerant relatively soon after emergence (Booth and others 1990), would likely have higher survival rates.

The age structure of large and small plants includes two major episodes of establishment. The event in the late 1950s and early 1960s may be accounted for in part by the dramatic declines in the elk population. Detailed climatic conditions for this period were not found. In 1988, unusual climatic conditions coupled with an approximately 40 percent reduction in the Yellowstone elk herd may have created an ideal situation for mountain big sagebrush establishment.

References

Anonymous. 1979. Timber resource plan, Ochoco National Forest. U.S. Department of Agriculture, Forest Service, Prineville, OR, (EPA: May 7, 1979). 239 p.

Anonymous. 1982. Proposed livestock grazing management for the Sierra Planning Area, California. U.S. Dept. of the Interior, Bureau of Land Management, Bakersfield, CA, (EPA: May 13, 1982). 117 p.

Beetle, A. A. 1960. A study of sagebrush—the section *Tridentatae* of *Artemisia*. Wyoming Agricultural Experiment Station Bulletin. 368. 83 p.

Best, L. B. 1972. First year effects of sagebrush control on two sparrows. *Journal of Wildlife Management*. 36: 534–544.

Booth, G. D.; Welch, B. L.; Jacobson, T.; 1990. Seedling growth rate of 3 subspecies of big sagebrush. *Journal of Range Management*. 43:432–436.

Brown, J. K. 1982. Fuel and fire behavior prediction in big sagebrush. U.S. Department of Agriculture, Forest Service Research Paper INT-290: 1–10.

Colbert, T. A.; Colbert, M. A. 1983. Revegetating with sagebrush—Who's right? *Rangelands*. 5:33–35.

Crisp, M. D.; Lange, R. T. 1976. Age structure, distribution and survival under grazing of the arid-zone shrub *Acacia burkittii*. *Oikos*. 27:86–92.

Daubenmire, R. F. 1975. Ecology of *Artemisia tridentata* ssp. *tridentata* in the State of Washington. *Northwest Science*. 49:24–35.

Evans, R. A.; Young, J. A. 1978. Effectiveness of rehabilitation practices following wildfire in a degraded big sagebrush-downy brome community. *Journal of Range Management*. 31:185–188.

- Evans, R. D.; Black, R. A. 1993. Growth, photosynthesis and resource investment for vegetative and reproductive modules of *Artemisia tridentata*. *Ecology*. 74:1516–1528.
- Ferguson, C. W. 1964. Annual rings in big sagebrush. University of Arizona Press. 95 p.
- Houston, D. B. 1982. The northern Yellowstone elk, ecology and management. Macmillan Publishers, New York.
- Humphrey, L. D. 1984. Patterns and mechanisms of plant succession after fire on *Artemisia*-grass sites in southeastern Idaho. *Vegetatio*. 57:91–101.
- Kufeld, R. C.; Wallmo, O. C.; Freddma, C. 1973. Foods eaten by the Rocky Mountain elk. *Journal of Range Management*. 26:106–113.
- Lommasson, T. 1948. Succession in sagebrush. *Journal of Range Management*. 1:19–21.
- McAdoo, J. K.; Longland, W. S.; Evens, R. A. 1989. Nongame bird community responses to sagebrush invasion of crested wheat-grass seedlings. *Journal of Wildlife Management*. 53:494–502.
- Meyer, S. E. 1994. Germination and establishment ecology of big sagebrush: Implications for community restoration. Symposium on management, ecology and restoration of intermountain annual rangelands, Boise, ID. U.S. Department of Agriculture, Forest Service. General Technical Report INT GTR-313: 244–251.
- Mullican, T. R.; Keller, B. L. 1986. Ecology of the sagebrush vole (*Lemmyscus curtatus*) in southeastern Idaho. *Canadian Journal of Zoology*. 64:1218–1223.
- Ngugi, K. R.; Powell, J.; Hinds, F. C.; Olson, R. A. 1992. Range animal diet composition in southcentral Wyoming. *Journal of Range Management*. 45:542–545.
- Petroni, M. A. 1991. Gravelly sagebrush. Final Environmental Impact Statement. U.S. Department of Agriculture, Forest Service, Beaverhead National Forest, Ennis, MT.
- Reynolds, T. D. 1981. Nesting of the sage thrasher, sage sparrow, and Brewer's sparrow in southern Idaho. *Condor*. 83:61–64.
- Roughton, R. D. 1972. Shrub age structures on a mule deer winter range in Colorado. *Ecology*. 53:615–625.
- Sinclair, A. W. J. 1984. The economics of utilizing decadent interior cedar and hemlock. Technical Report. Forest Engineering Research Institute. Canada, Point Claire, Québec. 59:50 p.
- Stevens, R.; McArthur, E. D. 1974. A simple field technique for identification of some sagebrush taxa. *Journal of Range Management*. 27:325–326.
- Taha, F. K. 1972. The role of some environmental and man-made factors on big sagebrush (*Artemisia tridentata* Nutt.) reinvasion. M.S. Thesis, Montana State University, Bozeman, MT. 80 p.
- Tyrrell, L. E.; Crow, T. R. 1994. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. *Ecology*. 75:370–386.
- Wallace, A.; Romney, E. M. 1972. Radioecology and ecophysiology of desert plants at the Nevada Test Site. U.S. Atomic Energy Commission. Technical Information Document 25954.
- Wambolt, C. L. 1996. Mule deer and elk foraging preference for 4 sagebrush taxa. *Journal of Range Management*. 49:499–503.
- Wambolt, C. L. 1998. Sagebrush and ungulate relationships on Yellowstone's northern range. *Wildlife Society Bulletin*. 26:429–437.
- Wambolt, C. L.; McNeal, A. F. 1987. Selection of winter foraging sites by elk and mule deer. *Journal of Environmental Management*. 25: 285–291.
- Wambolt, C. L.; Creamer, W. H.; Rossi, R. J. 1994. Predicting big sagebrush winter forage by subspecies and browse form class. *Journal of Range Management*. 47:231–234.
- Watts, M. J.; Wambolt, C. L. 1996. Long-term recovery of Wyoming big sagebrush after four treatments. *Journal of Environmental Management*. 46:95–102.
- Welch, B. L.; Peterson, J. C. 1981. In vitro digestibility among accessions of big sagebrush by wild mule deer and its relationship to monoterpenoid content. *Journal of Range Management*. 34:497–500.
- West, N. E.; Provenza, F. D.; Johnson, P. S.; Owens, M. K. 1984. Vegetation change after 13 years of livestock grazing exclusion of sagebrush semi desert in west central Utah. *Journal of Range Management*. 37:262–264.
- Young, J. A.; Evans, R. A.; Palmquist, D. E. 1990. Soil surface characteristics and emergence of big sagebrush seedlings. *Journal of Range Management*. 43:358–366.