

Browse Evaluation of Tall Shrubs Based on Direct Measurement of a Management Objective

Richard B. Keigley and Michael R. Frisina

Abstract—The monitoring of Geyer willow was based on the following management objective: *Browsing will prevent fewer than 50 percent of Geyer willow shrubs from growing taller than 3 m.* Three questions were addressed: (1) Is browsing a potential factor? (2) If so, can young plants grow taller than 3 meters? (3) If not, is browsing the dominant factor? All shrubs were intensely browsed. With a post-browsing growth rate of 5.0 cm per yr, no shrub could grow 3 m tall. Analyses of stem growth rate excluded dominant roles for climate and plant vigor. Browsing and stem age were the dominant factors that limited growth to 3 m tall.

Introduction

The stature and density of trees and shrubs across the landscape is a major influence on the potential diversity and abundance of wildlife. On winter range, wild ungulates require access to the high quality forage (Cooke 2002; Renecker and Schwartz 1997; Schmidt and Gilbert 1978; Schwartz and Renecker 1997; Short 1981). Shrubs are among the most nutritious food sources on winter ranges (Peterson 1995; Young and Clements 2002). Shrubs and trees provide nesting sites and other habitat components for both resident and migratory birds, with many species having particular plant height and cover requirements (DeGraaf and others 1991). To maintain desired wildlife populations, land managers must provide habitat of appropriate quality, and structural diversity is an important aspect of habitat quality.

Ungulate browsing can potentially alter the structural diversity of a plant community (Kay 1990; Lovaa 1970; Rasmussen 1941; Wagner 2006). By preventing young plants from attaining full stature, protracted heavy browsing can move a community of trees and shrubs toward an herbaceous meadow-like condition that is less suitable as winter range (Kay and Walker 1997). Livestock grazing and ungulate

browsing can reduce the nesting success and abundance of neotropical migratory birds (Ammon and Stacey 1997; Bowman and Harris 1980; Jackson 1992, 1993; Knopf and others 1988). When the maintenance of ungulate winter range and bird-nesting opportunities are management objectives, browsing must be limited to a level at which structural diversity is preserved. A problem that managers face is that of distinguishing between harmful and benign levels of browsing (Keigley and Frisina 1998).

In addition to the potential influence of herbivory, climate and other environmental factors affect the height to which plants can grow (Harper 1977; Kozlowski 1991). While the level of herbivory may be regulated by reduction of ungulate population size, environmental factors are generally not under management control. For that reason, the development of an appropriate management strategy requires that environmental effects be distinguished from the effects of ungulate use. Big game and livestock exclosures are an established method for distinguishing between the effects of ungulates and the environment (Kay 1990; Thompson 2002). However exclosures have often not been constructed at areas of interest. Once an exclosure is constructed, a number of years is required before the differences inside and out become apparent. Therefore, managers ideally require an approach that distinguishes between the effects of browsing and environment without the use of exclosures.

We use a case study to describe a method for determining if browsing pressure is having an adverse effect on structural diversity. The method can be applied in areas where exclosures have not been constructed. The evaluation process begins with the definition of a management objective and the selection of an indicator species. Although we believe that the method can be applied to short-growing shrubs, the results are clearest when applied to trees or shrubs capable of growing at least 3 m tall.

Methods

Study Area

The study took place on a portion of the 22,743 ha Mt. Haggin Wildlife Management Area located in southwest Montana about 19 km south of the town of Anaconda (45° 58' N, 113° 4' W). The study area consists of a combination of wet and dry meadows. Willows (*Salix* spp.) are common along numerous stream courses and in wide riparian created by beaver dams. Elevation of the study area is about 1,900 meters; annual precipitation is about 51 cm (Frisina 1992).

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Richard B. Keigley is a Research Ecologist, USGS Northern Rocky Mountain Science Center, Bozeman, MT; email: richard_keigley@usgs.gov.

Michael R. Frisina is a Range-Habitat Coordinator, Montana Fish Wildlife & Parks, Butte, MT; email: mfrisina@mt.gov.

Prior to 1976, the area was privately owned (Newell and Ellis 1982). Domestic livestock grazed pastures continuously and intensively; willow was sprayed, dozerpiled, and burned to create more grassland for livestock. In 1976, the Montana Department of Fish, Wildlife and Parks (MFWP) purchased the land and established Mt. Haggin Wildlife Management Area to provide public recreational opportunities and habitat for wildlife (Frisina 1982). Efforts to reduce willow stopped. Populations of moose (*Alces alces*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) increased (Frisina 1982; Kuntz 1993). Recently whitetail deer (*Odocoileus virginianus*) began using the study area during the summer.

Moose are the only large ungulates present on the study area during winter; they concentrate in willow bottoms as snow accumulates. Browsing of willows by moose has been a concern of MFWP for several years (Frisina and Keigley 2004; Keigley and others 2002a,b; Keigley and Fager, in press). Deer, elk, and antelope inhabit the area during snow-free months when herbaceous plants are generally preferred and all habitat types are available for foraging. After establishment of the wildlife management area, livestock numbers were reduced (Frisina 1992). A rest-rotation grazing system was established in 1984, in which cattle are allowed access to a pasture during the growing season once every third year (Frisina 1992; Frisina and Keigley 2004).

Management Objective

A measurable management objective provides the basis for the design of a monitoring program (Elzinga and others 1998). We adopted the following as a management goal: *Browsing will permit some young plants to attain their potential stature, their growth being primarily limited by local environmental conditions.* The management goal was refined to a measurable management objective by including: (1) the browse species to be monitored, (2) the potential height of those plants, and (3) the number that must be capable of growing to that potential height. The purpose of testing for the attainment of the objective is to either eliminate or isolate browsing as the dominant factor that influences habitat quality.

Indicator Species

We selected Geyer willow (*Salix geyerianna*) as the species to monitor. The species was widely distributed throughout the study area. A study that reconstructed the browsing history of Geyer willow at Mt. Haggin found that, at about 1985, browsing pressure increased from a light-to-moderate level to an intense level (Keigley and others 2003). Some plants encountered in this study were more than 5 m tall (fig. 1). Shorter plants were heavily browsed and had a hedge-like appearance. The tall shrubs attained their height when browsing pressure was less intense. From these observations we concluded that lightly browsed Geyer willow had the potential for growing to about 5 m tall.

Although Geyer willow has the potential for growth to 5 m at Mt. Haggin WMA, we used 3 m as the benchmark height in the management objective. We assumed that at 3 m tall, a stem had grown above the browse height of moose and its

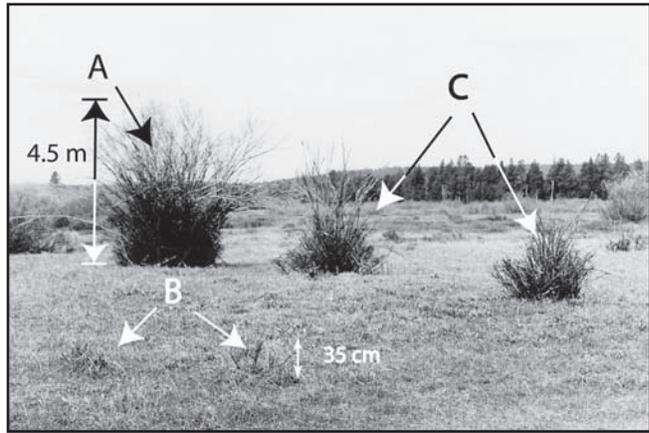


Figure 1—Over the past four decades, the moose population at Mt. Haggin WMA increased, causing a corresponding increase in browsing pressure. The taller Geyer willow shrubs in the background grew to about 4.5 m tall when browsing pressure was low. Shrubs of intermediate height grew for a time when browsing pressure was low; their growth stopped when browsing pressure increased. The short willow shrubs in the foreground were established after browsing pressure increased to an intense level. Site conditions on which these plants grow are similar. The tall shrubs indicate the height potential for this area.

growth would no longer be subject to influence by browsing. Finally, to make the objective measurable, we defined the required number to be 50 percent; individual management agencies may wish to set different thresholds. The complete management objective was: *Browsing will prevent fewer than 50 percent of Geyer willow shrubs from growing taller than 3 m; the growth of those shrubs will be primarily limited by local environmental conditions.* It is important to note that this objective focuses on the effect of browsing. Other factors, such as site condition and inter- and intraspecific competition could prevent growth of Geyer willow shrubs to 3 m tall.

Having defined a management objective, selected an indicator species, and determined that the species was capable of growth to 3 m tall, we proceeded to monitor for attainment of the management objective.

Monitoring Method

General Approach—Monitoring was accomplished by addressing three questions in the following order:

1. Is browsing a potential influence that could prevent young plants from growing through the browse zone? If browsing is not a potential influence on height growth, the management objective was attained and further analysis was not necessary.
2. If browsing is a potential influence, are 50 percent of the sampled plants likely to grow to 3 m tall? If so, the management objective was attained.

3. If 50 percent of the sampled plants are unlikely to grow to 3 m tall, was browsing the dominant factor that limited height growth? If browsing was found to be the dominant factor, the management objective would not be attained.

Site and Sample Selection—During the summer of 2005 we sampled 20 Geyer willow shrubs at each of 10 study sites. Three sites were located within the Sullivan Creek corridor and seven sites within the Deep Creek corridor. Sampling was restricted to shrubs 50 to 150 cm tall as measured to the base of current-year-growth. This height-range criterion was selected because shrubs less than 50 cm tall may be protected from browsing by snowcover, while shrubs taller than 150 cm may escape browsing by livestock and deer. To grow taller than 3 m, young shrubs must grow through the 50 to 150 cm browse zone. Individual shrubs were selected for measurement by walking a transect line, stopping at five-pace intervals, and finding the closest shrub meeting the above criteria.

Within each site, conditions such as soil type and moisture appeared homogeneous. Stem growth rates were compared by ANOVA to assess variation in growing conditions across sites.

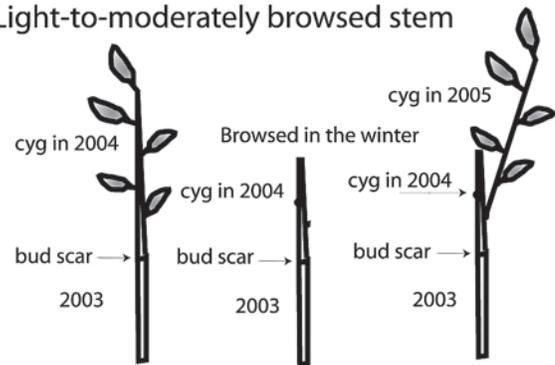
Question 1: Is Browsing a Potential Influence?—This question was addressed by: (1) classifying the browsing level of sampled shrubs into two categories (light-to-moderate and intense), and (2) by determining the percentage of shrubs that were intensely browsed. The browsing level of a shrub was determined from the examination of stems. An individual stem was classified as light-to-moderately browsed if, throughout the life of the primary stem, a given year's annual growth segment developed from the segment produced the preceding year (fig. 2a). Two situations led to a stem being classified as intensely browsed. First, a stem was classified as intensely browsed if at some point in the life of the stem a complete annual segment was browsed and had died, thus causing the next year's terminal leader to develop from an annual segment older than the preceding year (fig. 2b). Secondly, a stem was classified as intensely browsed if: (1) the initial primary stem was browsed, and (2) a complete annual increment within that segment was dead, thus causing a lateral branch to be responsible for subsequent height growth (fig. 2c). In this case it is possible for a stem to be classified as intensely browsed yet meet the condition that each year's annual growth segment developed from the segment produced the preceding year.

A shrub was classified as intensely browsed if at least one stem comprising the shrub was intensely browsed. The shrub was classified as light-to-moderately browsed if all stems were light-to-moderately browsed. At a given site, browsing was assumed to be a potential influence if at least 50 percent of the shrubs were intensely browsed. If browsing was determined to be a potential influence at a site, additional samples and measurements were taken to address questions 2 and 3 above. It is important to note that shrub condition is not based solely on the assessment of percent intensely browsed.

Collection of Samples and Measurements for Questions 2 and 3—Using the protocol described above, 20 shrubs were selected for measurement and sampling at

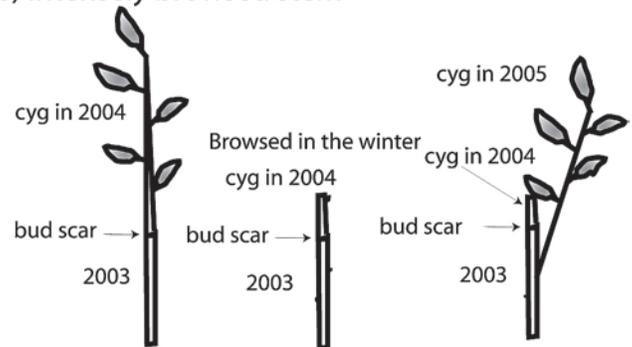
each site. From each shrub, the following live stems were selected for measurement: (1) the oldest, and (2) the tallest. Heights of those stems were measured to the base of current year growth (H_{BCYG}). The selection criteria could be met by a single stem or by two separate stems.

a) Light-to-moderately browsed stem



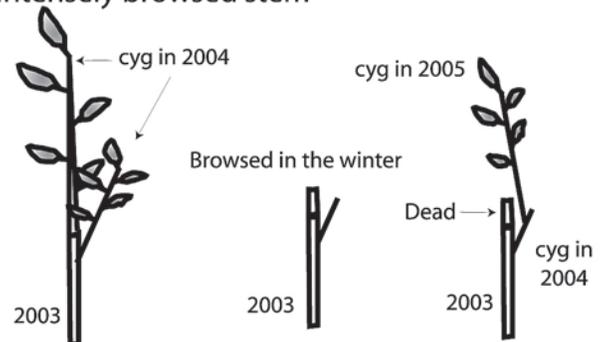
Current-year-growth consistently develops from segment produced the previous year.

b) Intensely browsed stem



Current-year-growth develops from segment produced prior to the previous year. A complete annual segment dies.

c) Intensely browsed stem



A complete annual segment of primary stem died. Branch assumed role of primary stem. Current-year-growth consistently developed from segment produced the previous year.

Figure 2—Criteria for classifying the browsing level of individual stems into two categories: intense or light-to-moderate. A shrub was classified as intensely browsed if a single stem was intensely browsed.

The oldest live stem was selected using girth at the base as a surrogate for age. Older stems were selected because young stems growing within the protective canopy may not have been exposed to browsing; because of this protective effect, the behavior of the shrub over the long term is best characterized by the condition of older stems. The measurement of the tallest height was used to assess recent changes in height that may have occurred.

The oldest stem was examined from tip to base to determine if it was browsed at any point in its life. If the oldest stem was not browsed, the shrub was recorded as unbrowsed. If the selected stem was browsed, the length from the base of the stem to the browsed tip was measured (H_{BB}) (fig. 3). The browsed stem was then cut at ground level. The effective height of the stem that grew after the first browsing event (H_{AB}) was calculated as:

$$H_{AB} = H_{BCYG} - H_{BB}$$

Sections were cut from the base of the stem and from the highest living part of the unbrowsed length of stem (see fig. 3). The annual rings in these sections were counted; the ages of those sections were designated A_S and A_L respectively. Typically, above the point where A_L was cut was a section of stem that had died after browsing. That section was examined for bud scars to determine the number of years over which the now-dead stem segment had grown; that period was designated A_D .

The number of growing seasons over which the unbrowsed stem grew (Y_{BB}) was calculated as:

$$Y_{BB} = (A_S - A_L + 1) + A_D$$

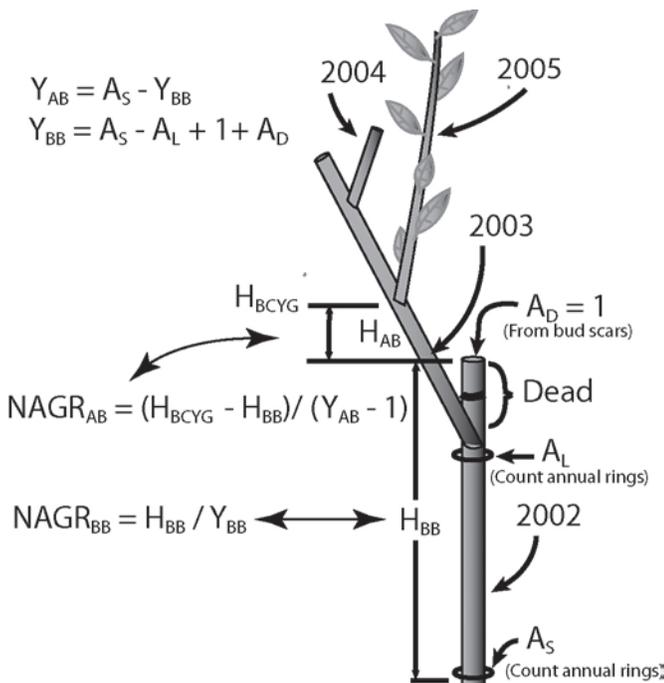


Figure 3—Samples and measurements taken to determine the pre- and post-browsing growth rates ($NAGR_{BB}$ and $NAGR_{AB}$, respectively).

The number of growing seasons that occurred after the first browsing event (Y_{AB}) was calculated as:

$$Y_{AB} = A_S - Y_{BB}$$

The net annual growth rate that occurred before the browsing event ($NAGR_{BB}$) was calculated as:

$$NAGR_{BB} = H_{BB} / Y_{BB}$$

The net annual growth rate that occurred after the first browsing event ($NAGR_{AB}$) was calculated as:

$$NAGR_{AB} = (H_{BCYG} - H_{BB}) / (Y_{AB} - 1)$$

One was subtracted from Y_{AB} because height measurements were made to the base of current year growth.

To determine the lifespan of browsed stems, each shrub was examined for the presence of dead stems that had been browsed. Where present, the oldest dead stem was selected for sampling, using girth at the base as a surrogate for age. The height of each dead stem was measured to its tip (H_D) and a section taken from its base; the age of the dead stem was determined from a count of annual rings (A_D). The ages of these stems were used as an estimate for the lifespan of the live stems sampled. Linear and curvilinear correlation procedures were run to determine the model that best fit the height on age relationship.

Question 2: Are 50 Percent of the Sampled Plants Likely to Grow to 3 m Tall?—This question was first addressed by examining the long-term trend of the shrub based on the growth characteristics of the oldest stem.

Because browsing was not a growth-limiting factor for unbrowsed stems, such stems were treated as capable of growing to 3 m tall. In the case of browsed stems, this question was addressed by determining, for each stem, the net annual growth rate that occurred after the first browsing event ($NAGR_{AB}$) and an estimated lifespan (Y_L). Using those values we then determined if the respective stems would live long enough to grow from H_{BCYG} to 3-m (fig. 4).

The number of years required to grow to 3 m (Y_{300}) was calculated as:

$$Y_{300} = (300 - H_{BCYG}) / NAGR_{AB}$$

Based on the correlation model that best fit the age and height relationship of dead stems, the lifespan of the browsed live stems (Y_L) was estimated based on their respective heights. The estimated remaining-years-of-life (Y_R) was calculated for each browsed stem as: $Y_R = Y_L - A_S$. The surplus or deficit in lifespan was calculated by subtracting Y_R from Y_{300} . If Y_R was greater than Y_{300} , the stem was deemed likely to grow to 3 m tall. If fewer than 10 shrubs at a site were found to be unlikely to grow to 3 m tall, the analysis proceeded to Question 3. In addition, we conducted a similar test in which it was assumed that all stems could live to the age of the oldest dead stem found during the study. The test using maximum age was used as further clarification of the ability of plants to attain 3 m tall.

The growth of the oldest live stem characterizes a long-term history of the shrub. If growing conditions remained constant over the life of the shrub, older stems would generally be taller than younger stems, and the history documented by the older stems would accurately characterize the growth

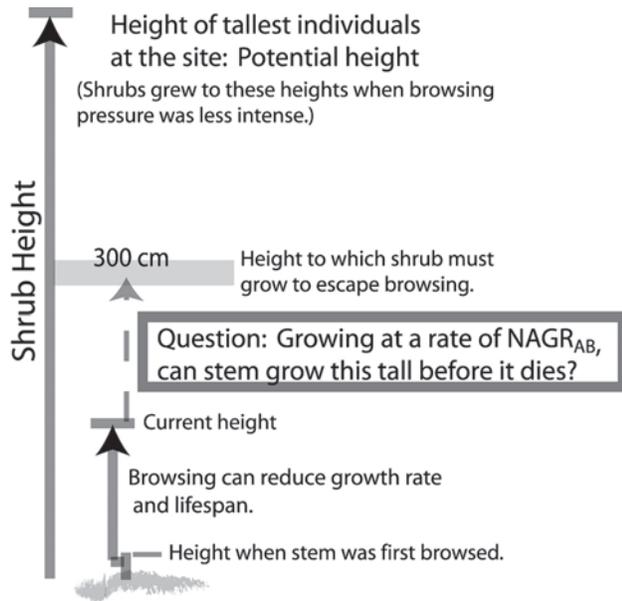


Figure 4—The rationale for assessing whether a stem could grow to 3 m tall.

of the shrub within the 50 to 150-cm zone. But if growing conditions markedly improved from some adverse state, young vigorous stems, may become taller than the older, physiologically stressed stems, and the growth of older stems may not accurately characterize potential growth to 3 m tall. We tested for changes in growing conditions by comparing the height of the tallest stem on each shrub to the height of the oldest stem ($H_{TALL} - H_{OLD}$). A positive value would indicate an improvement in growing conditions. If there was a positive difference that exceeded 2 years of growth at the pre-browsing growth rate, we assumed that the shrub would be able to attain 3 m tall ($H_{TALL} - H_{OLD} > 2 * NAGR_{BB}$).

Question 3: Is Browsing the Dominant Factor That Limits Height Growth?—Many factors can potentially affect stem growth rate, including browsing, climate, plant vigor, and stem age. We began the process of assessing the potential dominance of the browsing factor by comparing $NAGR_{BB}$ to $NAGR_{AB}$; the comparison was done by the Mann-Whitney test. We then evaluated the potential roles of climate, plant vigor, and stem age.

To assess the potential relationship between stem growth rate and climate, we first determined the mean number of years in which stems grew before the first browsing event (Y_{BB}). Based on that mean, we constructed a running average annual precipitation using Wise River 3WNW climate data (station 249082). Mean $NAGR_{BB}$ values were calculated for stems established during a given year; only years having three or more values were used. The mean $NAGR_{BB}$ values and the running precipitation averages were then plotted to determine if a correspondence existed. $NAGR_{BB}$ values were plotted on establishment year; running averages were plotted on initial year over which the average was taken.

If there was no correspondence in trends, we assumed that climate was not a dominant factor in determining stem growth rate.

A regression of $NAGR_{AB}$ on A_S was used to test for a possible age-related reduction in the post-browsing growth rate. A negative correlation would indicate an age-related influence.

In evaluating the potential role of vigor, we assumed that vigorous plants would have high values of $NAGR_{BB}$ compared to less vigorous plants. If vigor played a dominant role in the post-browsing growth rate, then there should be a positive correlation between $NAGR_{AB}$ and $NAGR_{BB}$. We tested for that correlation by regression.

We examined the role of browsing: (1) by comparing mean pre- and post-browsing growth rates, and (2) by comparing the pre- and post-browsing variances of those growth rates. If browsing played a dominant role, the mean $NAGR_{AB}$ should be less than $NAGR_{BB}$, and dominant roles for climate, age, and vigor would have been excluded. Our rationale for comparing variances as a test for browsing dominance was as follows. Prior to browsing, stem growth rate would be influenced by plant vigor and environmental factors. If none of these factors were dominant across the landscape, growing conditions would be diverse, thus resulting in large variation among $NAGR_{BB}$ values. The introduction of a landscape-wide dominant-factor (that is, browsing) would cause growth rate to decline to a relatively constant value compared to the pre-browsing rates. We compared variances by the Levene test; a difference in variance would suggest the effect of a landscape-wide dominant factor.

Results and Discussion

The first step of data analysis was to address Question 1: Is browsing a potential factor that could prevent young plants from growing through the browse zone? All shrubs at all sites were intensely browsed, thus exceeding the 50 percent threshold set prior to the survey.

Having deemed that browsing was a potential factor, we proceeded to address Question 2: Are young plants likely to grow through the browse zone? The grand mean net annual growth rate after the first browsing event ($NAGR_{AB}$) was 5.0 ± 0.3 cm / year (\pm SE). The means and standard errors for individual sites ranged from 2.2 ± 0.9 cm / year to 9.4 ± 1.6 cm / year. The maximum observed $NAGR_{AB}$ for an individual stem was 26 cm/year. Sixteen stems had negative or zero growth rates, the base of current year growth respectively being lower than, or equal to, the height that the stem was when first browsed. Because these stems did not have a positive growth rate, they were excluded from consideration when determining if the browsed stem would grow taller than 3 m.

Dead stems were found in 195 out of 200 sampled shrubs. The grand mean lifespan of the browsed dead stems was 11.6 ± 0.3 years (\pm SE). The mean lifespan at different sites ranged from 9.4 ± 1.0 years to 14.0 ± 1.0 years. In some cases, the age of the old live stem of a shrub exceeded the age of the old dead stem. This finding indicates that the estimated lifespan of live stems was conservative. The maximum observed lifespan was 22 years.

A logarithmic model provided the best fit for correlating lifespan with height ($N = 195$, Adjusted $R^2 = 0.11$, $P < 0.0001$). Mechanical protection is likely responsible for the positive correlation between lifespan and stem height. Stems growing in the interior of taller shrubs would enjoy a longer period of protection from browsing, during which they could branch and develop greater photosynthetic potential compared to shorter, younger stems that are killed by browsing. The variation of observed values from predicted values could be due to many factors including disease, frost damage, plant vigor, and local site conditions.

We found that by growing at a rate of its measured $NAGR_{AB}$, no stem would grow out of the browse zone within the respective lifespan estimated by the logarithmic model (fig. 5a). If it were assumed that all shrubs could live to the maximum observed lifespan of 22 years, 14 (7.0 percent) of the shrubs would live long enough to grow to 3 m tall (fig. 5b).

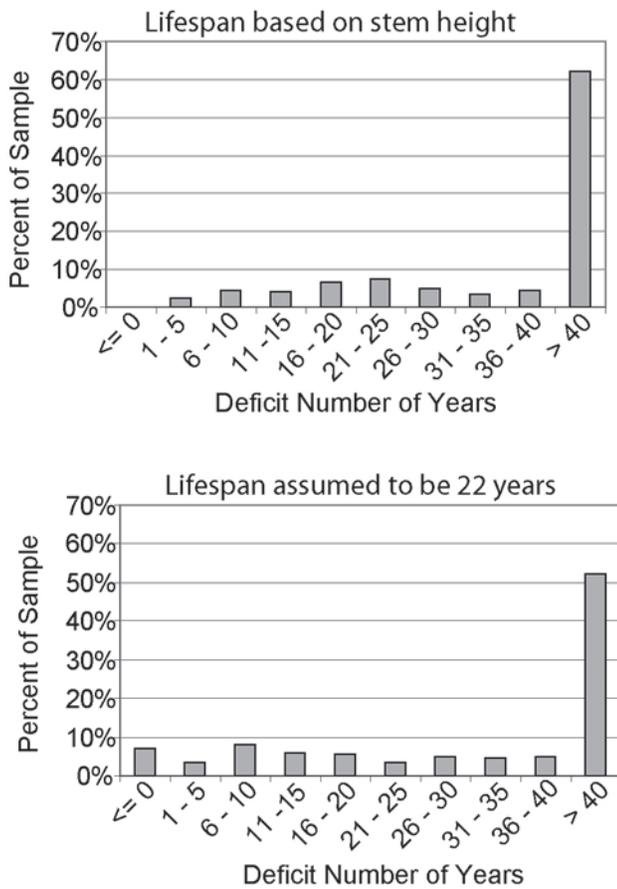


Figure 5—Frequency diagram showing the deficit number of years required to grow to 3 m tall. The upper graph depicts the deficit using estimated lifespan based on stem height. Over 60 percent of the sample would require more than 40 years to attain 3 meters. The lower graph depicts the deficit assuming that all shrubs could attain the age of the oldest dead stem sampled during the study (22 y); seven percent (14 plants) would live long enough to grow to 3 meters, while over 50 percent would not. In either case, less than 50 percent of the browsed shrubs are likely to grow to 3 m tall.

At no site were 50 percent of the plants likely to grow to 3 m tall using lifespan based on either the correlation model or on the maximum observed age. Based on the characteristics of the older stems, growth to 3 m was deemed unlikely.

The comparison of the height of young tall stems with the height of old stems suggests a recent slight improvement in growing conditions. Younger stems had overtopped older stems in 65.5 percent of the shrubs. But only 8.5 percent of the stems had exceeded the height of their respective older stems by two annual growth increments (that is, equal to twice the respective $NAGR_{BB}$). The slight improvement in growth was consistent with monitoring conducted elsewhere on the Mt. Haggin Wildlife Management Area (Keigley and Fager, in press). Based on both a long-term and short-term perspective, no site met the 50 percent threshold of growth to 3 m tall.

Having determined that shrubs are unlikely to grow through the browse zone, we addressed Question 3: Is browsing the dominant factor that limits height growth? The mean $NAGR_{BB}$ for all sites was 19.0 ± 0.3 cm / year (\pm SE). The variance of $NAGR_{BB}$ across sites was homogeneous; there was no significant difference in $NAGR_{BB}$ between sites ($P = 0.149$). We concluded that between-site environmental condition was not a significant factor in stem growth rate.

In an analysis of pooled data, the variances of $NAGR_{BB}$ and $NAGR_{AB}$ were heterogeneous (Levene test, $P < 0.001$). The mean $NAGR_{AB}$ of all sites (5.0 cm/year) differed significantly from the mean $NAGR_{BB}$ (Mann-Whitney test, $P < 0.001$). We examined how climate plant vigor, stem age, and browsing might have contributed to the reduction in growth rate.

On average, stems grew 2.9 ± 0.1 years before being browsed. Based on this period, we constructed a 3-year running average precipitation. A plot of $NAGR_{BB}$ and precipitation showed no similarity, suggesting that between-year differences in precipitation had little effect on stem growth (fig. 6). Given the proximity to flowing surface water, it is likely that all stands received subsurface moisture throughout the growing season, thus moderating any effect that precipitation might have.

The stem growth rate of plants diminishes as stems reach maturity and cease growing taller, so an age-related decline in growth rate was expected to occur in our sample. The question was: Was an age-related decline the dominant influence on the post-browsing growth rate? There was a negative correlation between stem age and $NAGR_{AB}$ indicating an age-related effect (Adjusted $R^2 = 0.03$, $P = 0.009$) (fig. 7). If we examine the maximum growth rate that occurred within each year, $NAGR_{AB}$ diminishes with age; no stem older than 14 years of age had a post-browsing growth rate that exceeded 6.8 cm/year. In contrast, the post-browsing growth rates of some young stems were extremely low, some having negative values. For these stems, age could not have been the cause of low initial growth rates. We concluded that age was a significant factor for stems having high initial post-browsing growth rates but age did not exercise landscape-level dominance.

We anticipated that stems that grew vigorously before browsing would continue to grow vigorously after browsing, although perhaps at a reduced rate. This relationship would be documented by a positive correlation between $NAGR_{AB}$ and $NAGR_{BB}$. In fact there was a negative correlation

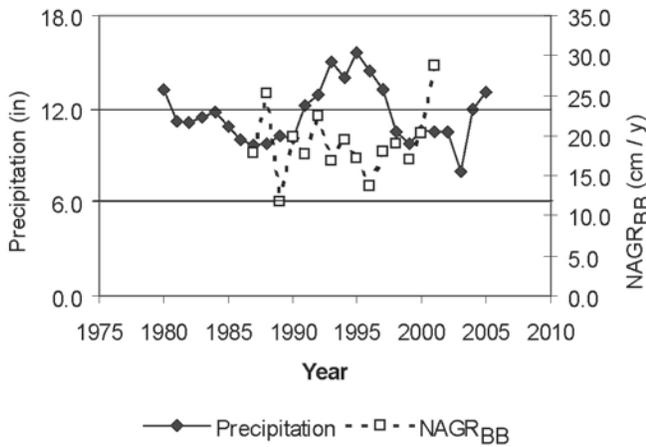


Figure 6—Three-year running average annual precipitation and pre-browsing growth rate. Annual precipitation values are plotted on the initial year of the 3-year-mean; the pre-browsing growth rates are plotted on the establishment year of the stem. The trends do not correspond with one another, indicating that climate was not a dominant factor. Proximity to flowing water likely reduces the effect of between-year variation in precipitation.

between $NAGR_{AB}$ and $NAGR_{BB}$ ($b = -0.14$, Adjusted $R^2 = 0.05$, $P = 0.001$) (fig. 8). We concluded that pre-browsing vigor did not result in an enhanced post-browsing growth rate compared to less vigorous plants, and that vigor was not a dominant factor.

The significant difference between pre- and post-browsing mean growth rates (19.0 versus 5.0) was consistent with a browsing effect. The significant reduction in post-browsing variance (93.1 versus 34.5, $P < 0.001$) was consistent with the onset of a landscape-level dominant factor, namely browsing.

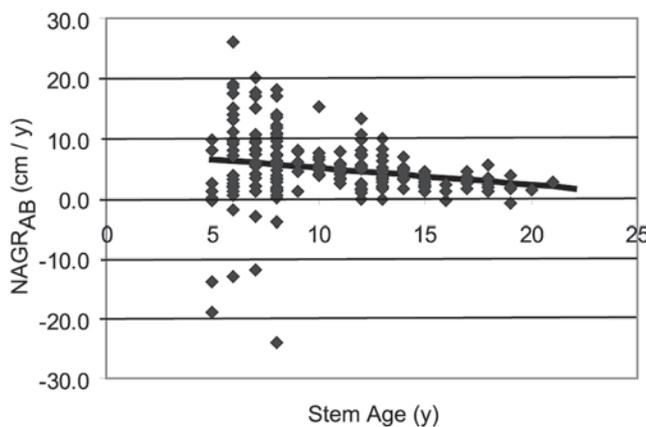


Figure 7—Relationship between stem age and post-browsing growth rate. There was a significant negative correlation ($P < 0.01$). Although some young plants had a low post-browsing growth rate, the maximum post-browsing growth rate within each year diminishes with age.

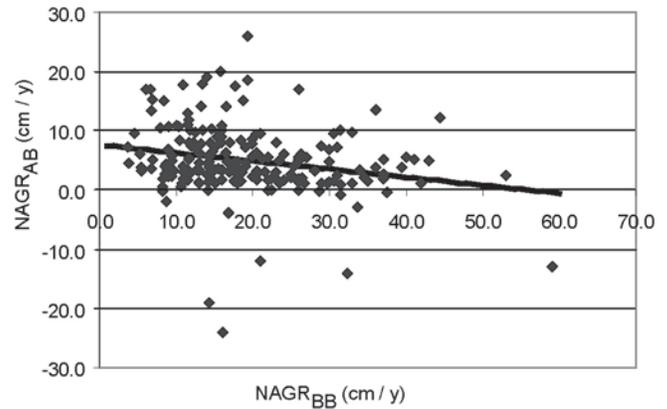


Figure 8—Relationship between pre- and post-browsing growth rates. If plant vigor exerted a dominant influence on growth rate over the life of the plant, one would expect a positive correlation between growth rates. There was a significant negative correlation ($P = 0.001$).

Having excluded climate and vigor as dominant factors, we concluded that browsing, in combination with age, dominated the growth of Geyer willow at the Mt. Haggin WMA. Because of the age-related decline in post-browsing growth rates, the respective values of $NAGR_{AB}$ that were measured at the time our study will decline over the remaining life of the stems, further supporting our interpretation that stems will not live long enough to grow to 3 m tall.

In summary, we conducted a four-part process that consisted of (1) defining a management objective, (2) selecting an indicator species, (3) determining its potential stature, and (4) monitoring for the attainment of the objective. We concluded that the management objective was not attained: browsing will prevent more than 50 percent of the plants from growing taller than 3 m.

Our approach is distinctive in how monitoring relates to the management objective. Over the past decades, land managers have monitored browsing level using form class (Cole 1958, 1959; Dasmann 1951; Wallmo and others 1977) and percent twigs browsed (Aldous 1945; Julander 1937; Nelson 1930; Stickney 1966). While form class and utilization can indicate that browsing has a minor or major effect on plant growth, neither form class nor utilization has intrinsic ecologic value. It is the condition of plants that is of intrinsic value. Form class and utilization are indirect measures of current and future plant condition. The assessment of habitat variables using indirect measurement is one of the primary weaknesses in wildlife-habitat research (Morrison and others 1998).

In contrast, the management objective we described has intrinsic ecologic value. If browsing pressure is maintained at a level that allows some plants to attain full stature, then it can be assumed that browsing does not have a significant negative effect on characteristics such as structural diversity and fruit production. The process described above directly tests for the attainment of a management objective that has intrinsic ecologic value.

Our approach is also distinctive in that the effect of browsing can be isolated without the use of big game and livestock exclosures. In the absence of exclosures, land managers have had to accept the possibility that climate and other factors played a dominant role in controlling the condition of browse plants. The analysis of stem growth rate provides a means of assessing the role of those factors without experimentally isolating the plants from browsing.

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