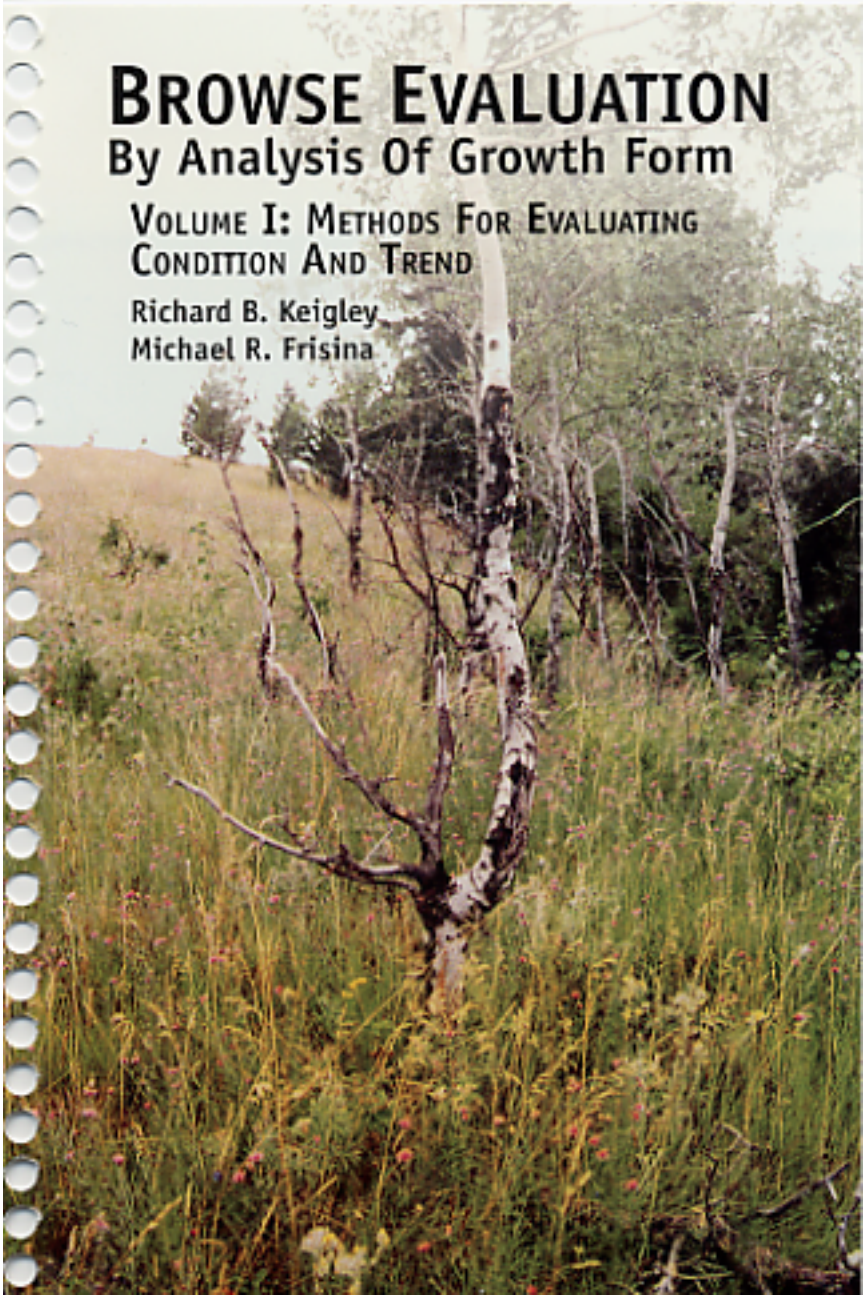
BROWSE EVALUATION
By Analysis Of Growth Form
VOLUME I: METHODS FOR EVALUATING CONDITION AND TREND
Richard B. Keigley
Michael R. Frisina

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By Analysis Of Growth Form

VOLUME I
Methods For Evaluating Condition And Trend

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Tree Tales: Of Past, Present, And Future

...could have been an alternative title for this book. The tree in the picture above records four phases of ecologic history dating back about 30 years. The growth forms of younger trees record current conditions. Knowledge of past and current conditions opens a window to the future.

Acknowledgements

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BROWSE EVALUATION
By Analysis Of Growth Form

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CHAPTER 1

INTRODUCTION

Land managers are often faced with the problem of describing the impact of ungulates on browse plants. A manager might ask the following questions:

1. How should I describe the current level of browsing?
2. Will trees and shrubs grow tall? Will they attain their typical stature?
3. Is the current situation unusual compared to the situation that prevailed historically?
4. If browsing currently prevents young plants from growing to their typical stature, how long will it be before the older, tall trees and shrubs die?

There are several existing methods of browse evaluation. This book describes a new method, one that is based on the effect that browsing has on the architecture—that is, the shape—of trees and shrubs.

Why is a new method warranted? In part, because previous methods are time consuming. Also, it is often difficult to interpret the results of surveys using previous methods.

An architecture-based survey can be conducted in as little as an hour. The interpretation of an architecture-based survey is straight forward. The focus: Will trees and shrubs grow to their typical stature?

Why is growth to typical stature important? Given the complexity of ecological systems, it would be impossible to foresee all of the implications of heavy ungulate use. But we can assume that full-statured trees and shrubs are fundamentally important to the ecosystem.

In Chapter 2 we describe the history of measuring browse utilization. Some of these methods describe certain aspects of browse-use more precisely than does the architecture-based method. But as we point out, it is often difficult to relate those measurements to specific ecologic impacts.

In Chapter 3 we present the general concepts. First we describe how woody plants grow in the absence of browsing. We then describe how browsing may alter a plant's architecture, and present four basic types of architecture that are produced by browsing:

1. Uninterrupted-growth type (produced by light-to-moderate browsing),

2. Arrested-type (produced by intense browsing),

3. Retrogressed-type (produced by a change from light-to-moderate browsing to intense browsing), and

4. Released-type (produced by a change from intense browsing to light-to-moderate browsing).

These architectures are produced during the time that the terminal leader grows within the browse zone. The effect of browsing on the terminal leader is retained in the architecture of the lower stem throughout the life of

the plant. By examining plants of different age, one can reconstruct the history of browsing that occurred at a site.

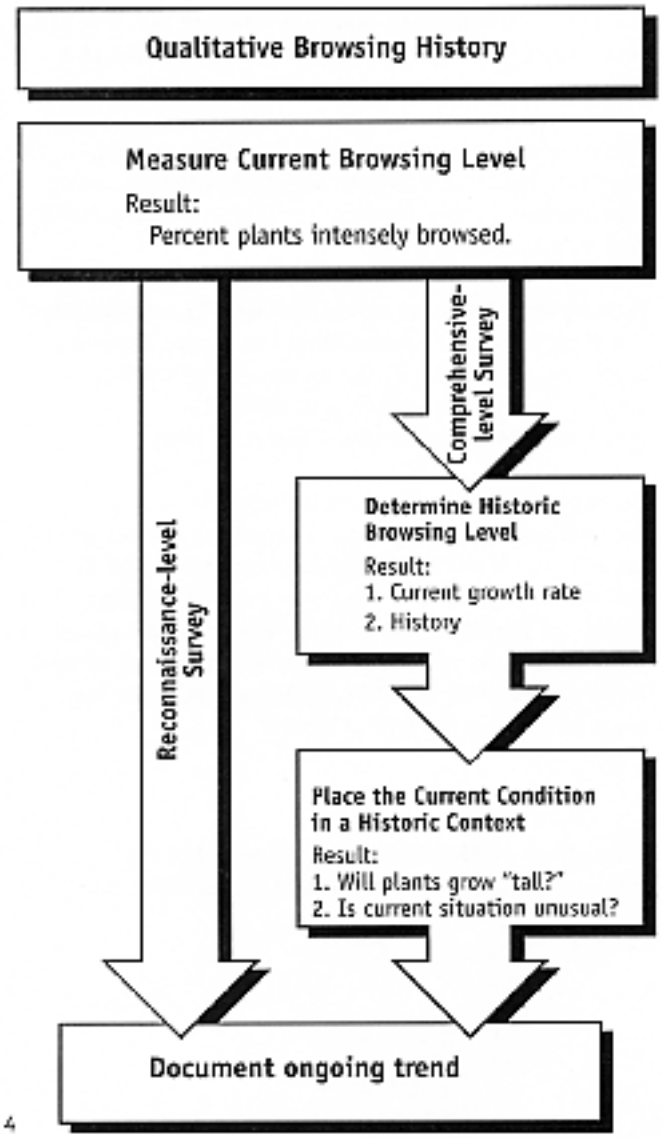
The remainder of the book, from Chapter 4 onward, describes how to conduct an architecture-based survey. Two levels of survey are described: reconnaissance-level and comprehensive-level.

A reconnaissance-level survey includes: 1) a qualitative browsing history, 2) determining the current browsing level, and potentially 3) the monitoring of short-term trends. It should be possible to conduct a reconnaissance-level survey in about an hour.

A comprehensive-level survey includes: 1) a reconnaissance level survey, 2) determing the net annual growth rate of some selected browse species, and 3) reconstructing the long-term year-by-year browsing history of the site. This additional information allows one to place the current situation in a historical context. As in the reconnaissance-level survey, a manager may elect to monitor short-term trends.

A flowchart on the following page describes the relationship between the different survey elements.

BROWSE SURVEY SEQUENCE



Suitable Browse Species

Most methods described in this book are suitable for browse species with relatively straight-growing primary stems. Some examples include aspen, pine, Douglas fir, spruce, willows, chokecherry, serviceberry, alder, and birch. The current browsing level can be classified for all such species.

Some methods of history reconstruction are based on the cluster of twigs that form in response to browsing in some species. Such clusters form in willow, aspen, chokecherry, serviceberry, alder and birch. Because conifer branches do not form similar twig clusters, the dating method cannot be applied to conifer species.

The methods are not appropriate for plants, such as sagebrush, that have a contorted growth habit.

The method works best for those species that typically grow taller than 2.5 m. We use growth to that height as a classification criterion. If the species does not typically grow to 2.5 m, the effect of browsing cannot be fully classified.

Recommended: *aspen, tall willows, chokecherry, serviceberry, birch, and alder.*

The long-term history reconstruction described in Chapter 6 could be based on aspen or conifers.

How To Use This Book

We assume that the reader has become familiar with the general architecture concepts described in Chapter 3 and has been assigned to conduct a comprehensive-level survey of some given area. As examples, we use a series of case studies that were conducted from the Wisdom District of the Beaverhead-Deerlodge National Forest.

We describe in Chapter 4 how to begin a survey with a qualitative browsing history. The history is described by placing symbols of the architecture-types along an approximate timeline. Suggested symbols are described in Appendix II.

The qualitative history provides an overview of the conditions that occur throughout the area. Based on those observations, the manager is better able to decide where to locate individual study sites.

Chapter 5 describes how to establish sample sites and classify the current level of browsing for a given species within the site. Twenty plants are classified as being either: 1) intensely browsed, or 2) light-to-moderately browsed. The data are recorded on the sample site's data sheet.

If one were conducting a reconnaissance-level survey, this is the only information that would be recorded on the site's data sheet. When conducting a comprehensive-level survey, stems from each of the 20 plants are classified and measured. In addition, sections are cut to determine age. For the sake of clarity, the height and age data are omitted from the data sheet presented in Chapter 5.

At this point a person conducting a reconnaissance-level survey would proceed to Chapter 8: Monitoring Short-term Trends. A person conducting a comprehensive-level survey would proceed to Chapter 6: Quantitative Browsing History.

In the beginning of Chapter 6 we focus on the situation that usually prompts the initiation of a survey: browsing was suspected to be intense. We describe methods of determining when the intense browsing might have begun and methods of determining the net annual growth rate over that period. This can be accomplished with browse species that produce a cluster of twigs in response to browsing. The data are collected at the same time that the plants are classified and on the Site Data Sheet.

In the latter part of Chapter 6 we describe how to reconstruct the long-term history of browsing at the site.

In Chapter 7, we describe how to determine the probability that the plants will grow to their typical stature. We use growth to 2.5 m as a criterion. If one wishes to incorporate this aspect into the survey, one must have selected a browse species that typically grows taller than 2.5 m.

We address the issue: Is the current situation unusual compared with the situation that prevailed historically. The answer to this question may provide guidance for long-range planning. We also address methods of assessing the rate of decline in structural diversity. The rate of decline may indicate how urgent it is to change management.

In Chapter 8 we describe a method of monitoring short-term trends. These measurement should provide feedback to managers who want to know as soon as possible the result of changes in management.

This book presents a method for evaluating condition and trend. A second volume on distinguishing between wildlife and livestock use is in progress.

CHAPTER 2

HISTORY AND DEVELOPMENT OF METHODS TO MEASURE BROWSE USE

Since the 1930s, land managers throughout the western United States have developed and utilized techniques for measuring and monitoring the effects of browsing by large wild and domestic ungulates on trees and shrubs.

Monitoring Effects Of Browsing

A method for collecting information necessary to manage rangelands and watersheds used by domestic livestock was developed by Nelson (1930). Nelson's approach utilized methods for mapping shrub cover and was the first to determine utilization levels by calculating percentages from differences between twig lengths before and after use. He also emphasized that the repeated removal of terminal and lateral buds by browsing animals can lead to reduced vigor and eventual death of plants. His methods were applied on a large scale in the U.S. Forest Service's Intermountain Region to determine how browse plants can be safely used as big

game winter food. The approach was also applied on the Kaibab National Forest and recommended as a possible means to determine relative abundance of game populations in areas where more reliable census techniques could not be applied (Locke 1930). Methods described by Nelson (1930) were adapted by Aldous (1945) for use in big game management and they became a widely used game management tool. They were later employed by the state of Utah with modifications by Smith and Urness (1962).

Key area concept

A number of accepted range survey methods were evaluated by Dasmann (1948) to determine those best suited for use in management of deer ranges. Dasmann described the key area concept, which emphasizes monitoring of plants in areas where animals naturally concentrate on winter ranges. This quote from Dasmann's paper describes his rational for the key area concept .." it follows where vegetation on such key areas is not overcropped, overcropping should not occur generally over the balance of the range." Dasmann recommended using forage utilization checks of key plants on key areas as the most direct and reliable method by which to direct deer management control programs. In a later publication, Dasmann (1951) described a series of methods designed to provide information needed to balance deer numbers against deer forage supply. He proposed eight different form classes in which individual browse plants could be placed as an index of the degree of past use and availability to browsing animals. Dasmann (1951) also provided a methodology for sorting out differences between use by deer and livestock.

Methods for monitoring condition and trend of browse ranges based on degree of utilization and magnitude of decadence were also developed by Cole (1958, 1959), Patton and Hall (1966), Wallmo et al. (1977) and others. Typically, the methods estimate utilization and place shrubs in one of several different form classes. Wildlife managers have attempted to use these methods to correlate deer population trend and production with changing range conditions resulting from utilization of shrubs on winter range.

In 1958 the Montana Fish & Game Department adopted the Cole (1958,1959) "key browse" method as a standard for monitoring deer winter range condition and attempted to base deer harvest management on data collected from these surveys (Mackie 1974). During the 1960s, game managers and biologists began expressing concern about inadequacies of the "key browse" method.

As a result, the Montana Fish & Game Department initiated a research project in 1967 to evaluate the method (Mackie 1972). An analysis of the Cole (1958, 1959) method by Mackie and Lonner (1977) revealed major inadequacies. They found great variability depending on sampling effort, differences between individual examiners in estimation of degree of utilization, and differences in perception as to form class.

The Cole (1958, 1959) method did not provide reliable measures of utilization, range condition, or trend (Mackie and Lonner 1977). There was little consistent correlation between deer population trend, fawn production, fawn survival, and measured key browse utilization, condition, and trend. None of the range evaluation procedures adopted for North America to help game managers keep

deer populations in balance with their habitat have demonstrated a measurable relationship between the habitat and its carrying capacity. Wallmo, et al (1977) proposed evaluating habitat carrying capacity on a nutritional basis.

Measuring Utilization

Many of the traditional methods for monitoring or evaluating the effects of browsing on habitat and animal carrying capacity include utilization measurements. A number of approaches were developed to improve accuracy. This section summarizes efforts to improve the accuracy of utilization measurements.

Methods

Methods for estimating utilization based on the total percentage of available twigs browsed were developed by Dasmann (1948), Cole (1959) and others. Stickney (1966) refined this approach by counting the number of twigs browsed on a sample of plants and applied regression analysis to estimate utilization. Others proposed deriving utilization estimates based on length measurements from browsed twigs (Nelson 1930, Julander 1937, Aldous 1945).

A method for determining utilization from the relationship between bitterbrush twig diameters and their lengths and weights using regression analysis was described by Basile and Hutchings (1966). A shrub utilization method based on the total weight of the plant was proposed by Schumtz (1983).

Comparison and evaluation of methods

A comparison of utilization measurements using twig-length methods with those based on numbers of twigs browsed concluded twig-length measurement data were more consistent among observers than estimates of number of twigs browsed (Jensen and Scotter 1977). However, measuring twig lengths required about four times as many man-hours as estimating percentages of browsed twigs, or counting the number of twigs.

Stickney (1966) similarly found that counting the number of twigs requires significantly less time than measuring twig lengths. Schuster (1965) found the best predictor of yields of deer browse was achieved by using a combination of twig numbers and length. Utilization levels based on number of twigs browsed were higher than utilization levels based on twig length measurements (Jensen and Scotter 1977).

Techniques depending on the number of browsed twigs, without regard to weight consumed, are generally restricted to establishing utilization at levels less than 60 percent of the weight (Jensen and Scotter 1977). For snowberry (*Symphoricarpus oreophilus*) estimating utilization from number of browsed stems becomes invalid at the 10 percent use level (Ruyle et al. 1983).

A main problem with estimating or counting the number of twigs browsed is an inability to provide adequate information to managers, as utilization frequently exceeds 50 percent on big game winter ranges which is beyond the accuracy level of the methodology.

Determining utilization from twig length measurements provides a relatively more precise value, but is very time consuming. Jensen and Urness (1981) found a strong correlation between utilization estimates based on twig lengths before and after browsing and an approach based on measuring twig diameters after browsing. Estimates based on twig weight were more accurate than those based on twig length (Rumble 1985, Provenza and Urness 1981).

Utilization and production was estimated using photographs of shrubs taken against a one-inch grid (Springfield 1974). Height, crown width, and crown area were used by Rittenhouse and Sneva (1974) to estimate production of big sagebrush. Lyon (1968) concluded shrub crown measurements when converted to an expression of volume and combined with twig production data can provide a quick and acceptably accurate method for measuring browse plants.

Since Nelson (1930) proposed incorporating utilization methods into the evaluation of condition and trend of browse ranges, land managers have tried to resolve inadequacies in linking measurable habitat attributes with habitat carrying capacity. No one has successfully established that connection (Mackie and Lonner 1977, Wallmo et al 1977).

Methods For Describing Browse Ranges

A variety of methods have been developed for describing shrubland plant communities. The various approaches

often describe plant communities in terms of density or number of plants per unit area, canopy coverage, frequency, and species composition. Some methods also include an estimate of production and describe soils and magnitude of soil erosion. There has been little standardization or general acceptance of a standard method. Many investigators have modified existing methods in attempts to improve accuracy or make them fit their specific investigative needs. In this section, a few of the more commonly used methods are briefly described.

Line intercept method

A method for sampling vegetation along a transect line was described by Weaver and Clements (1929). A streamlined approach was described by Canfield (1941 and 1942) This method for vegetation sampling is based on the measurement of all plants intercepted by the vertical plane along randomly located lines of equal length. A line transect with length and vertical dimension, but not width, is used. A direct intercept of the plant through the vertical plane is recorded. Density, composition, and ecological structure of the vegetation are also estimated.

The line intercept method is popular for measuring low shrubs and bunchgrass plants, but is a cumbersome method for measuring annuals. With modification, the line intercept method can be used to estimate utilization and forage volume. Recommendations for improving accuracy of the line intercept method were described by Hormay (1949).

Daubenmire canopy coverage method

Daubenmire (1959) described a method for measuring canopy coverage, species composition, and frequency of occurrence using a 20 X 50 cm frame placed along a line (tape). Daubenmire recommends a sample size of measurements from 40 frames along the transect line. Canopy coverage for each taxon is recorded by assigning one of six coverage classes (0-5, 5-25, 25-50, 50-75, 75-95, 95-100 %). An average coverage for the series of plots based on the midpoint of each class is used. The method was developed in the semi-desert, grassland, and forest vegetation of eastern Washington and has been applied in a wide variety of plant communities where plants are not much more than one meter tall. It is a relatively time efficient inventory method.

The 3-step method and 13-foot browse method

During the 1950s a method for inventorying vegetation and monitoring condition and trend on an allotment wide basis was developed for Forest Service lands (Parker and Harris 1959). A variety of site factors are measured using a three-quarter inch diameter ring at 100 points along a transect line. The method includes listing of perennial species, measuring vigor, and evaluating current erosion. General and close up photographs from permanent photo points are included in the method. Data are summarized using a score card.

The 13-Foot Browse Survey Method was developed by Snyder and South (no date) as a modification to methods in the Northern Region, US Forest Service, Wildlife Surveys Handbook.

The aforementioned methods were replaced by methods described in the Forest Services Draft Ecosystem Inventory and Analysis Guide (1972). However these historic methods are mentioned here because they still form the basis for shrub data in the files of many Ranger Districts.

Comparison and evaluation of methods

A comparison of 19 different variations of quadrant and plotless sampling techniques to estimate density revealed serious problems with accuracy (Lyon 1968). The number of plants per acre was estimated using the 19 different techniques. The results were compared to the known bitterbrush density on the study site. Many methods would not produce a correct answer with any sample size. All methods required unreasonably large samples to achieve acceptable precision. Several methods required more effort than counting all the plants on one or two acres. Lyon (1968) suggested that visual estimation techniques or non random sampling methods may provide a more realistic approach to sampling plant density.

The Daubenmire (1959) method yielded comparable results with the line-intercept approach (Hanley 1978). However, the line intercept method was recommended where a higher level of precision was required in measuring the density of shrubs.

Hutchings and Holmgren (1959) reported on biases associated with using small circular loops for sampling plant cover and offered modifications for reducing these inherent biases. An evaluation of the loop procedure of

the 3-Step Method found it to be reasonably well adapted for obtaining quantitative records of vegetation on range sites (Sharp 1954).

Summary

The Cole (1958, 1959) method does not provide a reliable measure for correlating deer habitat use with population trend. As a result, the Montana Fish & Game Department quit using Cole's method. A replacement approach was not developed.

Measuring utilization accurately is a time consuming process and, as reported by Mackie and Lonner (1977) and others, does not reflect range condition or trend.

Not all twigs on a plant are accessible to browsing animals. As a result, two different approaches for measuring utilization are typically used. One determines the percent of twigs browsed from the amount of plant production accessible to browsing animals. The other approach determines the percentage of twigs browsed from the total production of the plant, including that not accessible to browsing animals.

Fraas (1992) compared methods for measuring utilization of plant production accessible to browsing animals (Cole 1958, 1959 and Patton and Hall 1966) with methods designed to measure utilization of total plant production (Garrison 1953, Steinhoff 1959, Martinson 1960, Lay 1965). Fraas found that utilization measurements based on plant production accessible to browsing animals may not provide a relationship between browsing level and plant health.

In a four-year study involving several species, Garrison (1952) found a wide variation in annual production of shrubs.

Insect damage to plants can be significant and difficult to distinguish from deer browsing (Rayburn and Barkalow 1973).

Traditional methods for describing species composition, canopy coverage, frequency of occurrence, and density of browse plants on rangeland sites are useful for inventorying and monitoring browse ranges as long as interpretation of the results includes a realistic view of sampling precision inherent to the various methods. The USDA Forest Service Draft Ecosystem Inventory and Analysis Guide (1972) serves as one of the more comprehensive sources for range survey and inventory methods.

Since 1996 Montana Fish, Wildlife & Parks has considered adopting a method for evaluating browse condition based on growth form (Keigley 1997). In the remainder of this book, we describe how to conduct an architecture-based survey of browse condition.

CHAPTER 3

ARCHITECTURE CONCEPTS

Woody plants grow in a range of forms, from prostrate shrubs to tall trees, yet all share basic similarities in sequence of development. Tissue within buds differentiates to form a primordial stem with leaves. This tiny shoot may—or may not—elongate to produce a visible leafy shoot. There are several patterns of shoot development, some of which are restricted to tropical climates. We describe a pattern of preformed growth development common to cold climates. We then examine how browsing can affect plant development and produce growth forms that are strikingly different compared to that of an unbrowsed plant.

Stems, Branches, Leaders, And Buds

Trees and shrubs are composed of primary stems and lateral branches. Primary stems grow mostly vertically and are responsible for height growth. Lateral branches grow mostly horizontally. In this book we collectively refer to primary stems and lateral branches as "stems."

Stems elongate each year. We call the most-recently-produced segment "current-year-growth." A segment that was produced the year before current-year-growth is called "previous-year-growth." Older stem segments may be described by the growing season in which they were produced (e.g., 3-yrs ago).

A "terminal leader" is the current-year-growth at the tip of a primary stem. When using the architecture-based method of browse evaluation, we are primarily interested in the fate of terminal leaders. Trees typically have a single terminal leader, whereas shrubs typically have many.

Buds are embryonic stems. Buds develop in the axils of leaves. A leaf axil is the upper angle between the leaf stalk and the stem from which the leaf grows.

On a given stem, there will be one terminal bud and few to several lateral buds. In addition to the leaf axil position, buds may develop at other locations along the stem. Buds that were not produced in the leaf axil position are termed "adventitious" and often form in response to injury or unusual environmental conditions.

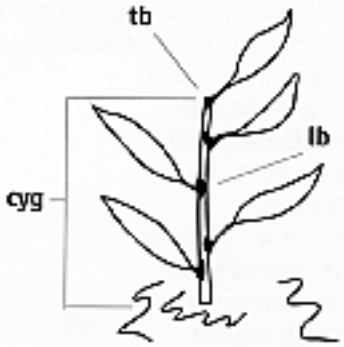
In temperate climates, buds typically undergo dormancy. Stems may elongate from a bud after a single season of dormancy. In this case, the stem that developed from that bud would be one year younger than the segment from which it developed. Stems may also elongate after more than one year of dormancy, in which case there will be a corresponding gap in age between current year growth and the segment on which the bud was borne. Buds that remain dormant for many years become covered by bark. On occasion, stems elongate from a bud during the growing season in which the bud was produced.

A Sequence Of Stem Production

In the figures below we follow the development of a stem through a three year period beginning with seed germination. Abbreviations: lb = lateral bud, tb = terminal bud, db = bud dormant for longer than one year, tbs = terminal bud scar, cyg = current-year-growth, pyg = previous-year-growth.

Later we will examine how browsing can alter the sequence of branch development.

Year 1



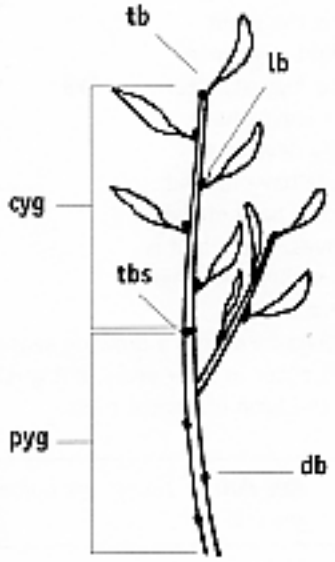
This figure shows how the plant might appear in late-August, after the leaves have fully developed. Buds have formed at the base of the leaves. Each bud is an embryonic stem. Once a stem elongates during a growing season, no further elongation will occur in later years, but girth will be added each year in the form of annual rings.

Key Point: *Leaves are borne only on current-year-growth.*

Year 2

In the second year of life, the miniature stem within the terminal bud (produced in year 1) elongates and its leaves expand. A ring (terminal bud scar) marks the position of the terminal bud from which the second year's growth developed. The stem segment that was current-year-growth in year 1 is now "previous-year-growth" (pyg). In addition, stems may develop from one or more lateral buds lower on the stem.

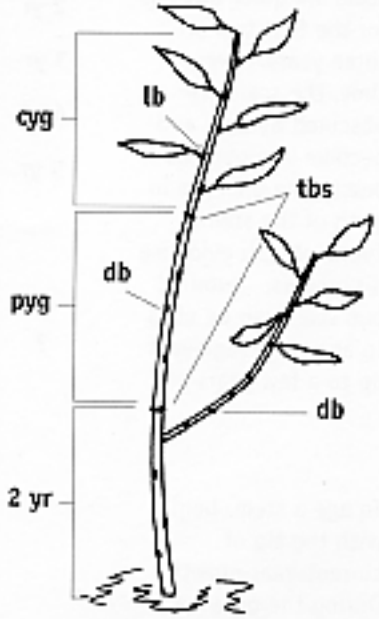
In this example, a single lateral branch developed while the rest of the buds produced the first year remained dormant. One cause of dormancy is a chemical growth regulator produced at the tip of the stem. The enforcement of bud dormancy is called apical dominance. Different plant species exert apical dominance to differing degrees. The ultimate shape of a tree or shrub is strongly influenced by the degree to which the apical dominance is exerted.



As in the first year, buds are produced in leaf axils. In northern climates there is typically a single annual growth cycle. On occasion, buds may develop into shoots the same year the buds were produced. One form of evidence of same-year-growth is the presence of a leaf-bearing lateral branch that developed from a segment that also bears leaves.

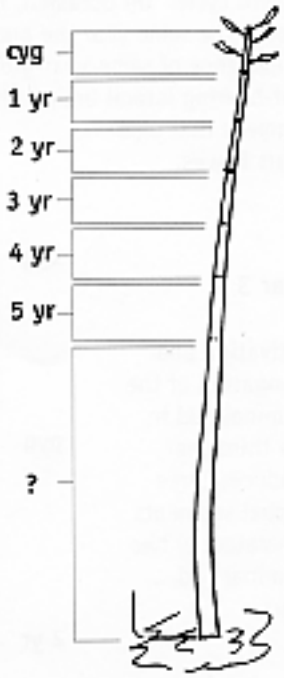
Year 3

Activation and elongation of the terminal bud in the third year produces three annual segments separated by two terminal bud scars.



Aging Of Stems From Bud Scars

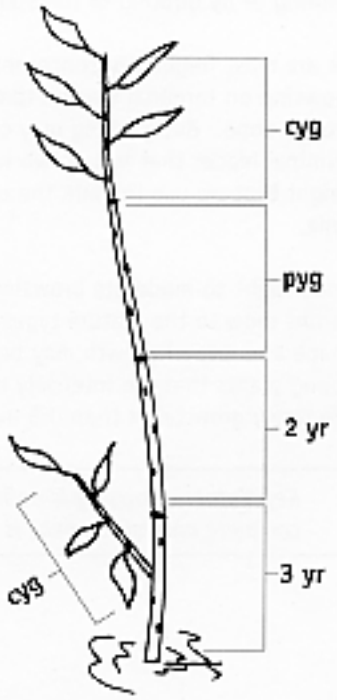
Terminal bud scars mark the point of origin for each year's leader growth. The scars are quite obvious for the first two or three years. Over time, the scars are obscured by bark and become less obvious due to the increase in girth of the stem. Eventually all evidence disappears. Terminal bud scars can be used to age stem segments up to a few years old.



To age a stem, begin with the tip of current-year-growth. During the growing season, this segment will have leaves. Move down the stem until a ring-like scar is encountered. The initial segment would be current-year-growth. To identify subsequent years, continue the process, until bud scars can no longer be identified.

Branches From Buds That Were Dormant For More Than One Year

In the previous example that described growth over three growing seasons, the lateral branch developed from a bud that was produced the preceding year. Branches may also develop from buds that have been dormant for two or more years. In the example below, the bud remained dormant for three years. As a result, current-year-growth emerges from a stem segment that is three years old. Development of branches from dormant buds is common in browsed plants.



Levels of Browsing Intensity

Key Point: *The method described by this book incorporates two levels of browsing intensity:*

1) Light-to-moderate, and
2) Intense.

Those levels and their combinations produce distinctive architectures. The architectures develop during the time that the terminal leader is vulnerable to being killed by pruning or by girdling of the stem below.

We are most frequently concerned with the effect of browsing on terminal leaders that grow within the browse zone. But girdling may cause the death of a terminal leader that has grown well beyond the 2.5 m height that we use to mark the upper limit of the browse zone.

Under light-to-moderate browsing, young trees and shrubs grow to the stature typical of their species. Their shape and rate of growth may be modified by herbivory. Young plants that are intensely browsed for their entire life rarely grow taller than 0.5 m.

Key Point: *Browsing is defined to be intense when a complete annual segment is killed.*

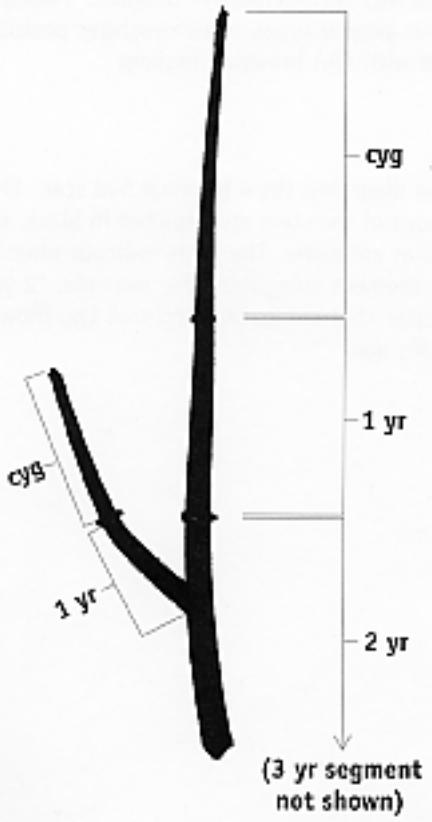
How Browsing Can Affect Stem Development

We are primarily concerned with the fate of stems that are responsible for height growth.

We begin this section by looking at four hypothetical possibilities. We will then examine how one of those possibilities might look in "real life" by comparing a photograph with an interpretive diagram. Finally, we will present four general types of architectures postulated to correspond with four browsing regimes.

In the diagrams: tbs = terminal bud scar. Live portions of the stem are depicted in black, dead portions are white. The years indicate when the stem segment elongated. For example, "2 yr" indicates that elongation occurred two growing seasons ago.

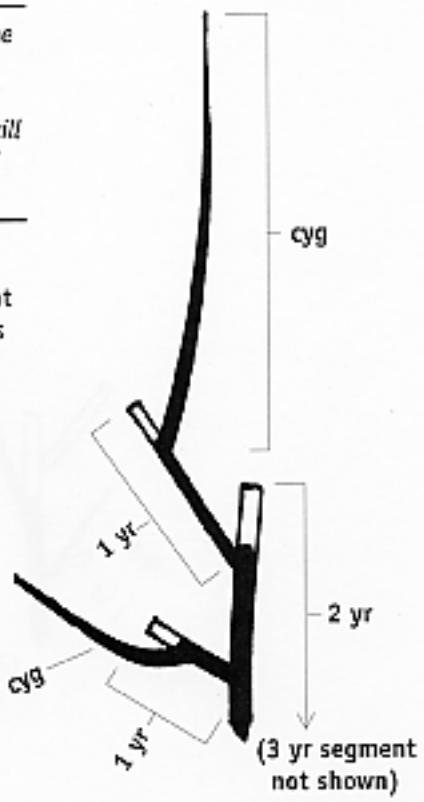
The plant below was not browsed at all. Each annual stem segment developed from the terminal bud of the preceding year's stem segment. As far as height growth was concerned, the lateral branch remained subordinate to the primary stem.



This plant was browsed each year, killing the tip of each annual stem segment. In contrast to the example at the left, each year's annual stem segment developed from a lateral (rather than terminal) bud located on the preceding year's stem segment. The lateral branch remained subordinate to the vertical stem.

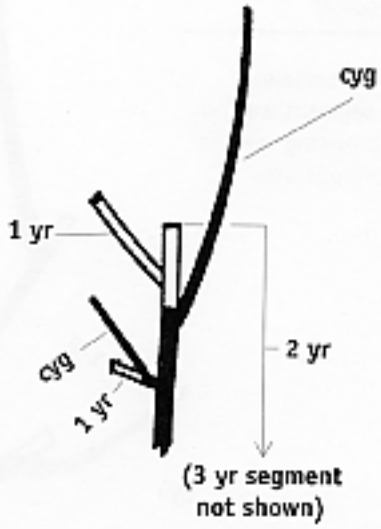
Key Point: *Only the tip of the annual segments died. Browsing did not kill a complete annual segment.*

Because a complete annual segment was not killed, browsing level is light-to-moderate.



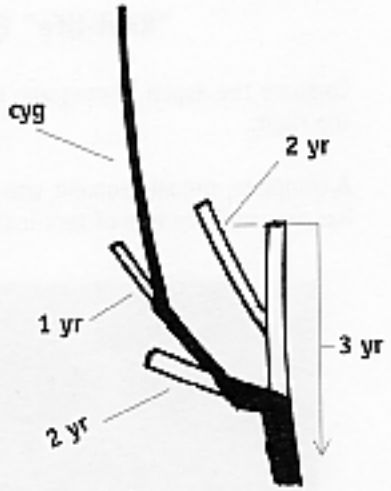
The plant below was browsed each year. In this case the entire 1-year-old segment was killed. Current-year-growth emerged from a dormant lateral bud located on the segment produced the first year. The lateral branch remained subordinate to the vertical stem.

Because a complete annual segment was killed, browsing level is intense.



In the plant to the right, browsing killed a complete annual segment. But in this case, current-year-growth did not develop from a dormant bud. Instead the lateral branch assumed dominance over the initial vertical stem.

Because a complete annual segment was killed, browsing level is intense.



(4 yr segment not shown)

Summary

We have diagramed three responses to browsing

1. New growth developed from previous-year-growth. A complete annual segment did not die. This indicates light-to-moderate browsing.
2. A complete annual segment died. New growth developed from a stem segment older than 1 year of age. This indicates intense browsing.
3. A complete annual segment died. A lateral branch took over the role of primary stem. This indicates intense browsing.

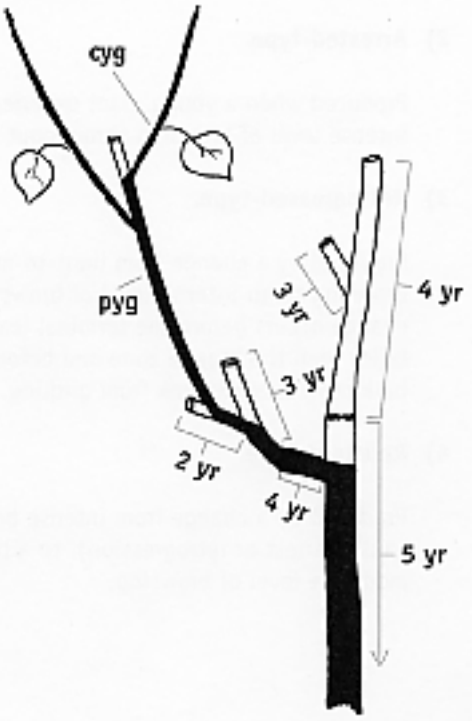
"Real-life" Example

Compare the aspen photograph below to the diagram to the right.

A complete annual segment was killed. A lateral branch has assumed the role of terminal leader.

This diagram is an interpretation of the photograph to the left. For clarity, leaves and some segments were omitted from the diagram. Cyg = current-year-growth. Pyg = previous-year-growth. Live stem segments are black, dead segments are white.

Because a complete annual segment was killed by browsing, this aspen would be classified as intensely browsed.



Architectures Produced By Browsing

Four basic architectures logically correspond with four browsing regimes:

1) **Uninterrupted-growth-type.**

   Produced when a light-to-moderate level of browsing occurs during the time that the terminal leader is vulnerable to being killed.

2) **Arrested-type.**

   Produced when a young plant experiences an intense level of browsing throughout its life.

3) **Retrogressed-type.**

   Produced by a change from light-to-moderate browsing to an intense level of browsing. The change occurs before the terminal leader grows taller than the browse zone and before a layer of bark protects the trunk from girdling.

4) **Released-type.**

   Produced by a change from intense browsing (that caused arrest or retrogression), to a light-to-moderate level of browsing.

Architectures Exhibited By Trees

a) Uninterrupted growth-type

b) Arrested-type

c) Retrogressed-type

d) Released-type

Architectures Exhibited By Shrubs

a) Uninterrupted growth-type

b) Arrested-type

c) Retrogressed-type

d) Released-type

Architecture Examples

This section introduces each architecture type. The examples show how the architecture types are expressed by both trees and shrubs.

In Chapter 5 (CURRENT LEVEL OF BROWSING) we describe the process of classifying individual plants.

Uninterrupted-growth-type Architecture

Uninterrupted-growth-type architecture is produced by light-to-moderate browsing for as long as the terminal leader is vulnerable to being killed by browsing. Young uninterrupted-growth-type individuals attain typical tree or shrub height, however their rate of growth and shape may vary due to herbivory.

Shrubs regularly replace older stems with younger ones. Because those young shoots must grow through the browse zone, shrubs remain sensitive to browsing throughout their lives.

After a tree grows taller than the browse zone and develops a protective armor of bark (that prevents girdling), it is no longer sensitive to an increase in browsing intensity.

The classification of a browse plant to uninterrupted-growth-type architecture is determined by a single criterion: As the terminal leader passes through the browse zone, it originates each year from previous-year-growth.

An uninterrupted growth-type tree

The straight stems of these aspen indicate that they experienced negligible herbivory as the terminal leaders grew through the browse zone. Most of each year's stem growth survived, producing an uninterrupted sequence of height growth.

An uninterrupted-growth-type shrub

These willows are composed of shoots of various height. The height of each shoot approximately corresponds with its age.

Stem segments were annually added to each shoot to produce an uninterrupted sequence of height growth.

Arrested-type Architecture

Arrested architecture is produced by chronic intense browsing. Young plants often escape browsing until they grow tall enough to be noticed by browsers. For example, snowpack may provide temporary protection. Once tall enough to be discovered, these plants would be hedged at a height defined to be "arrest-height."

Because of variation in plant vigor, topography, and annual snowpack thickness, arrest-height can vary from about 0.1 - 0.5 m. The classification of a given individual to arrested-type architecture is guided by two criteria:

1) at some point in time, browsing killed a complete annual segment of the primary stem, and

2) annual segments on shorter individuals would not have been killed by browsing. These shorter plants will develop arrested-type architecture when they grow too tall to be protected by snowpack.

The evaluation method described in this fieldbook only requires determining whether or not a plant is "intensely" browsed. Where intense browsing occurs, it is not necessary to distinguish between arrested- type and retrogressed-type architectures (the retrogressed-type architecture is described below). But such a classification can be made based on: 1) the age of the plant, and 2) the year that intense browsing began. In Chapter 6 (QUANTITATIVE BROWSING HISTORY) we describe how to determine plant age and the year that intense browsing began.

An arrested-type tree

These aspen were browsed to a height of about 20 cm. A complete annual segment was killed. Prior to that, these plants escaped intense herbivory, likely from protection by snowpack. As the aspen grew taller than the snowpack, they were exposed to intense herbivory.

Unless conditions change, these aspen are unlikely to grow much taller than 20 cm.

An arrested-type shrub

The shoots of these arrested-type birches have been browsed at a uniform height above ground level. Contrast this condition with the diverse stem heights that would be found on uninterrupted-growth type individuals. The uniform height of browsing indicates that the shrub experienced intense herbivory since establishment.

Retrogressed-type Architecture

Retrogressed-type architecture is produced when browsing level changes from light-to-moderate to intense:

During the initial period of light-to-moderate browsing, the young individual grows taller than arrest-height.

When browsing increases to intense, the upper stem (or stems) are killed by girdling or pruning.

Key Point: *Both the arrested- and retrogressed-type architectures are evidence of current intense browsing.*

Two classification criteria guide assignment:

1. Growth taller than arrest height, and
2. The death (from browsing) of a complete annual growth segment

Without determining plant age and year that browsing intensity increased, it may be impossible to distinguish tall arrested-type plants from short retrogressed-type plants.

For practical purposes, it is usually convenient to combine arrested- and retrogressed-type plants together. For the sake of discussions in the field, intensely browsed plants that clearly exceed arrest height can be assumed to have retrogressed-type architecture. A reasonable height threshold for separating arrested- from retrogressed-type plants is 75 cm.

A retrogressed-type tree

The total height of this aspen was 1.1 m, but all of the stem above 0.5 m was dead. Other aspen in the vicinity are browsed at 20 cm above ground level. Compared to those aspen, the tree below appears to have been less intensely browsed early in its life. When browsing increased, the upper stem was killed.

A retrogressed-type shrub

The shoots of this birch are terminated by clusters of twigs that occur at various heights above ground level. Those shoots must have grown to those heights during a period of light-to-moderate herbivory. At the end of that period, the shrub was composed of shoots of different heights, with height approximately corresponding with age. At this time, the shrub would be of uninterrupted-growth type architecture.

When herbivory increased to intense, elk (in this case) browsed the tips of shoots where they found them.

Released-type Architecture

Released-type architecture is produced when browsing changes from intense to light-to-moderate. The lower (surviving) stems of arrested- or retrogressed-type trees develop into trunks. In the case of shrubs, the resumption of shoot growth would leave dead clusters of twigs at an intermediate position along the shoot. There are 2 identification criteria:

1) The individual shows evidence of previous arrest or retrogression, and

2) The individual's terminal leader passed through the browse zone.

At what point do we reclassify an arrested- or retrogressed-type plant into the released-type category?

Plants continue to be classified as arrested- or retrogressed-type until previous-year-growth (i.e., 1-year-old wood) exceeds 2.5 m tall, which is approximately the upper limit of the browse zone.

A released-type tree

This aspen grew to 1.5 m tall when the upper stem was killed by herbivory. At that time, the aspen would be classified as having retrogressed-type architecture.

When browsing became less intense, a lower branch grew to become a trunk about 6 m tall.

The tree would be classified as having retrogressed-type architecture until the trunk grew taller than 2.5 m. This is measured to previous-year-growth.

A released-type shrub

A dead cluster of twigs occurs midway on this chokecherry shoot. The cluster was produced by intense herbivory. A subsequent decrease in herbivory allowed the terminal leader to grow beyond the browse zone.

Did A Moose Do It?

The focus of this book—browsing—may suggest that herbivory is responsible for everything we see. But not all death and disfigurement is due to ungulate browsing. Stream migration can leave willows in an excessively dry condition, while impoundment within beaver ponds can kill by flooding. Disease, insects, and parasites can kill a plant or alter its growth habit.

Three classes of evidence help distinguish the effects of browsing from other growth-form altering factors: 1) scar-type evidence, 2) developmental evidence, and 3) community level evidence.

Scar-type evidence

Unbrowsed branches should be terminated by a bud. The tip of the stem may die for reasons unrelated to browsing, but the bud should still be present. Browsing will remove the terminal bud leaving behind a blunt, perhaps shredded, stem. A search for terminal buds should occur early in the examination. Tooth marks may indicate girdling by herbivory. The absence of leaves during the growing season also indicates herbivory. Leaf stripping may leave longitudinal scars in the bark.

After stem death (from any cause), bark often peels and the stem may appear to have been girdled when actually it was not. A partially girdled stem can be identified by the ridge that develops at the edge of the

scar. The ridge develops because wood continues to be produced by the surviving cambium.

Developmental evidence

Clusters of twigs (hedging) have long been used as evidence of herbivory. The architectures described in this section are also evidence of herbivory.

Community-level evidence

If herbivory is uniform throughout an area, all individuals within an age class should have similar architectures. Plants of different age are affected by herbivory in different ways. In a community that contains a diversity of ages, a change in herbivory will produce correspondingly diverse effects, all indicative of the same history. In Chapters 4 and 6 (QUALITATIVE BROWSING HISTORY and QUANTITATIVE BROWSING HISTORY) we describe methods of reconstructing past levels of browsing.

CHAPTER 4

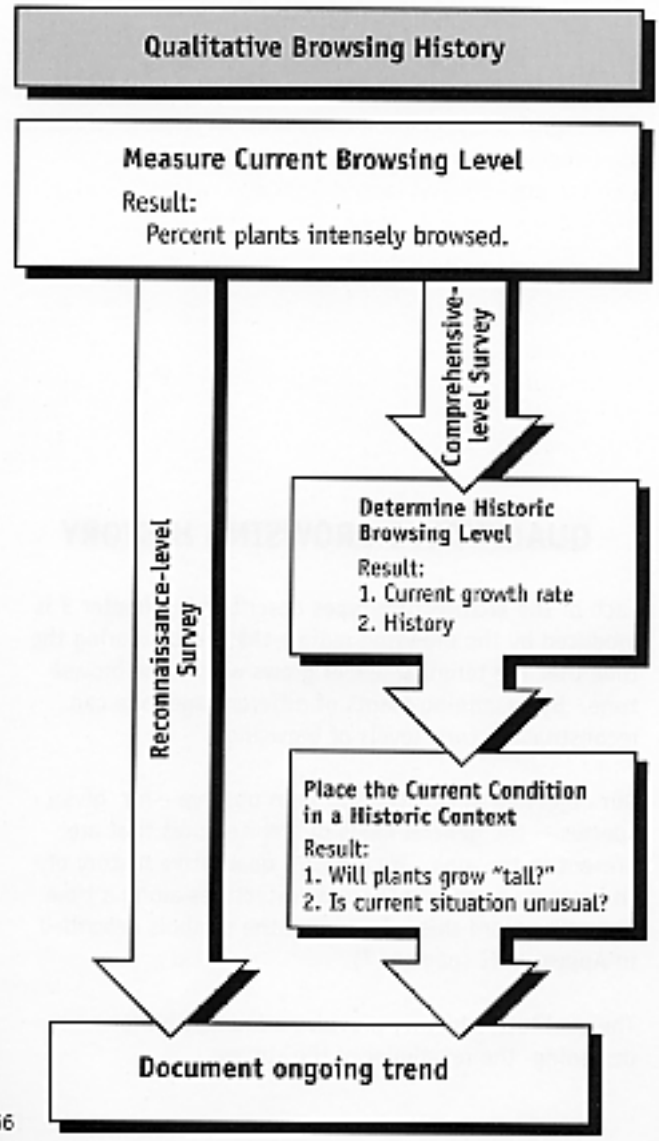
QUALITATIVE BROWSING HISTORY

Each of the architecture-types described in Chapter 3 is produced by the browsing regime that occurs during the time that the terminal leader grows within the browse zone. By examining plants of different age, one can reconstruct historic levels of browsing.

Our objective in this chapter is to observe—for given species— the general kinds of architectures that are present in the area. We depict a qualitative history of the area by arranging those architectures along a time line. We record this information the symbols described in Appendix II (page 147).

The qualitative history provides a foundation for designing the remainder of the survey.

BROWSE SURVEY SEQUENCE



A Qualitative History Of Light-to-moderate Browsing

In the 1996 photograph below, all aspen—from oldest to youngest—have uninterrupted-growth type architecture. Several ranged from one year to about 10 years of age. Trees in the background appear to be about 20-30 years of age.

The relationship between age and architecture in this stand indicates light-to-moderate browsing for at least the past 20-30 years.

Additional lines of evidence support this interpretation. When aspen is intensely browsed, ungulates also gnaw at the bark. The bark of these aspens is largely unscarred. In addition, none of the 20-30 year old trees were highlined. Trees are described as "highlined" when ungulates kill the lower branches by browsing all of the foliage within reach.

The first step in documenting the qualitative history is simply to note the architectures that are exhibited by individuals of different age. We record the observations by placing architecture symbols along a timeline. One end of the timeline we label "old, " the other we label "young." In Chapter 6 (QUANTITATIVE BROWSING HISTORY) we will describe methods of assigning timeline dates.

The aspen community illustrated on the previous page might be depicted as follows:

Based on the architecture types that are present, we can say that site appears to have been light-to-moderately browsed since the establishment of the oldest aspen. Based on the size of the aspen trunks, we could make a rough guess that the site has been light-to-moderately browsed for the past 20-30 years.

A Qualitative History That Documents An Increase In Browsing Intensity

The photograph on the facing page shows a large birch (*Betula occidentalis*) with retrogressed-type architecture. This plant by itself records a change from light-to-moderate browsing to intense browsing.

The four younger birches to the left of the larger birch had arrested-type architecture. The younger birches corroborate the history suggested by the larger birch.

The architectures are recorded on the timeline below.

Old **Young**

As in the previous case, we cannot assign actual dates on the timeline. But we know that the stems of this birch species do not live as long as the stems of aspen. As a result, the history that is recorded is correspondingly shorter. We might suspect that there has been an increase in browsing intensity within the past 20 years.

Case Study: Wisdom District, Beaverhead-Deerlodge National Forest

To get an overview of conditions in the general area, we reconstructed a qualitative history of three species: Geyer willow, aspen, and Douglas fir. At a given site, the total time required was less than five minutes.

Ungulates prefer some browse species over others. For example, Douglas fir is less-highly preferred compared to aspen. By noting the architectures of browse species that span the preference range, one can document the severity of the browsing impact that may occur. In this case study, aspen and Douglas fir were selected to bracket the preference range.

The placement of symbols along the timeline was based on rough estimates of age.

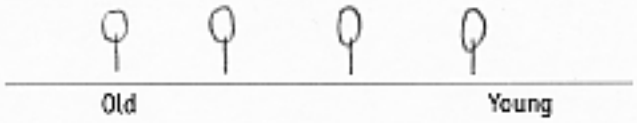
Symbols for each of the architectures are shown in Appendix II (page 147).

Architecture-based Survey
Qualitative History

Date: 3 Aug 97 Observer: R. Keigley

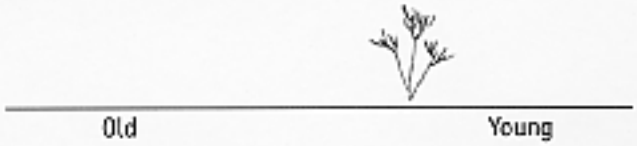
Sample area: 1 Sample site: 1

Species: Douglas fir



Species: Aspen

Species: Geyer Willow



CHAPTER 5

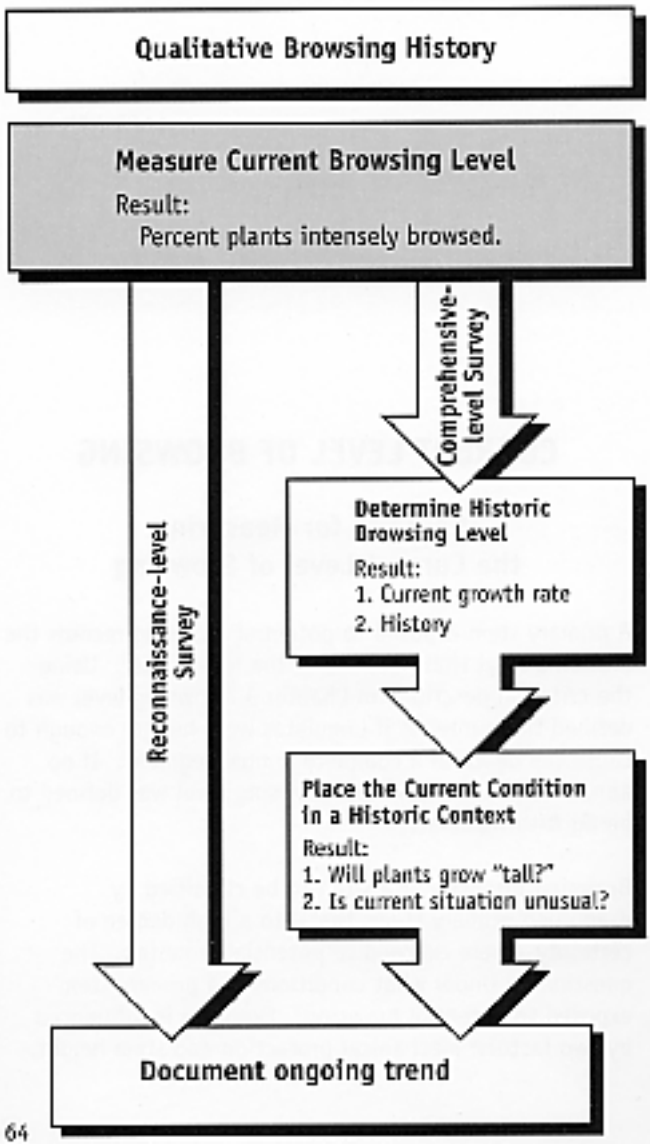
CURRENT LEVEL OF BROWSING

The Basis for Measuring the Current Level of Browsing

A primary stem exposed to potential browsing records the browsing level that occurred in the recent past. Using the criterion described in Chapter 3, browsing level was defined to be intense if ungulates were hungry enough to cause the death of a complete annual segment. If no annual segment was killed, browsing level was defined to be light-to-moderate.

Browsing intensity at a site can be classified by examining primary stems that—to a high degree of certainty—were exposed to potential browsing. The question is: Under what conditions is a primary stem exposed to potential browsing? Exposure is influenced by two factors: mechanical protection and stem height.

BROWSE SURVEY SEQUENCE



Mechanical protection

Young stems may be mechanically protected from browsing by older stems. The young stems are only exposed to browsing after they grow outside the protective cover of older stems.

Mechanical protection is especially important in the classification of shrubs. The shrub growth form is produced by the development of primary stems from the base of the plant. These primary stems develop throughout the life of the shrub. Young, unbrowsed stems are often intertwined among a thatch of branches and twigs killed by browsing.

If we were to base the browsing level of a shrub on a young, protected stem, we may erroneously conclude that the shrub was light-to-moderately browsed, when in fact the older stems (that protected the younger stems) were densely hedged by browsing. When classifying the browsing level of a tree or shrub, we must base that classification on primary stems that have not been mechanically protected by older shoots.

Stem height

Primary stems shorter than 150 cm tall are within reach of most ungulates. That height is used as the upper limit of a zone, within which, we can be fairly sure that ungulates would browse if they wanted to.

Young plants are seldom nipped off at ground level. The

lower limit of ungulate browsing appears to be influenced by snowcover. Often stems are cropped at about 20 cm high. But under some circumstances, stems appear to be protected until they are 40 - 50 cm tall.

One can be fairly certain that primary stems 50 - 150 cm tall are exposed to browsing.

But we cannot exclude stems shorter than 50 cm as indicators. On sites that have been heavily browsed for a period of years, all primary stems of young plants may be less than 50 cm tall.

In the next section we describe a step-by-step procedure for measuring current browsing level. Part of that procedure involves decisions on what and where to measure. Because of the influences of mechanical protection and stem height, some situations reflect current browsing level with more certainty than others. Three situations warrant special mention. Heights are measured to the top of previous-year-growth on the tallest primary stem.

Situation 1: Plants 50 - 150 cm tall are present.

Plants in this size range best indicate whether or not browsing will permit growth taller than 2.5 m.

Situation 2: Plants 50 - 150 cm tall are absent. Plants shorter than 50 cm are present. Tree-sized individuals are often present.

This situation occurs when plants on the site are intensely browsed for some years. The tree-sized individuals are a relic of an earlier period of light-to-moderate browsing and often are the parents of the short, heavily browsed plants. Snowcover may protect short plants from browsing. The uninterrupted-growth-type architecture of those protected plants would not reflect the current intense browsing.

Situation 3: Plants 50 - 150 cm tall are absent; taller plants are present. Plants shorter than 50 cm are often absent.

This situation often occurs in mature stands of willow. The taller willows usually have young terminal leaders around the perimeter that fall within the 50 - 150 cm size class. But there are potential problems with using these terminal leaders as indicators of current browsing level. For one, the stems may have been mechanically protected by the older stems. In addition, the stems may be mechanically protected by other willow shrubs growing immediately adjacent.

Steps for Determining Current Browsing Level

We describe a procedure for describing how current browsing level varies across a landscape. We present the survey results in the form of a map.

The procedure entails five steps:

1. Delineate the total survey boundary. Delineate sample areas within the total survey boundary.

2. Identify the browse species that is going to be surveyed.

3. Determine the location of sample sites within the survey area.

4. Select and classify the plants.

5. Summarize the results.

In practice, Steps 1 through 3 need to be considered concurrently. Obviously we need to begin with some idea of where the survey is going to take place (Step 1). But as a practical matter, we have to make sure that the sample area includes appropriate browse species (Step 2). At the same time, if we are going to interpolate levels of browse use across a landscape we need to insure that the selected browse species is well distributed (Step 3).

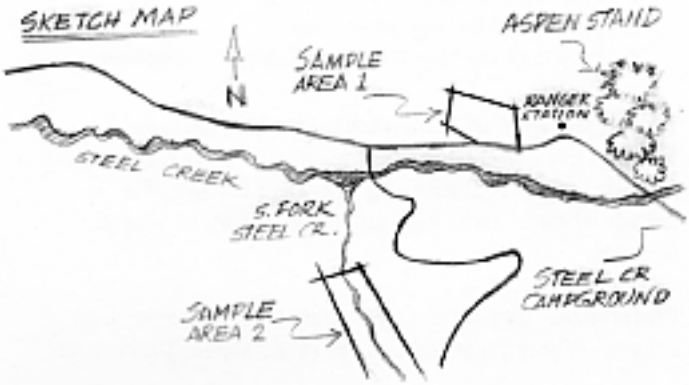
Step 1: Delineate the sample area

As a first step one should define the total boundary of the survey. Perhaps the total area encompasses an entire wildlife management area or grazing allotment.

But it may be difficult to visualize variation in ungulate use across very large areas. If so, the total survey area should be subdivided into smaller parcels. We refer to these smaller units as "sample areas."

Case study. This fieldbook describes examples taken from an architecture-based browse survey conducted on the Wisdom District of the Beaverhead-Deerlodge National Forest (Montana).

The map below defines the total survey area. Within that total area, two sample areas are delineated.



Step 2: Identify the browse species that will be surveyed

To use this method, you must be able to discern the sequence of stem development. This can be difficult for some species of browse. At the present time we have not adapted the method to sagebrush or bitterbrush.

The typical height of an unbrowsed plant is the second criterion. Given the limitation stated above, browse plants of any height can be classified. But when placing the current level in a historic context, we will use growth to 2.5 m as a benchmark height. To conduct a "comprehensive-type" survey, the plants must be capable of growing at least that tall.

Suitable plants include: aspen, cottonwood, willow, chokecherry, serviceberry, birch, and alder.

Within the limits described above, three basic things should be considered when selecting the species:

1. typical lifespan of individuals,
2. preference by ungulates, and
3. height of primary stems available for sampling.

Typical lifespan of individuals. Lifespan becomes a factor if the current browsing level is to be placed in a historic context. Shrubs will provide a history of a decade or two. Trees may provide a history of several decades.

Preference. Ungulates prefer some browse species over others. Highly preferred species (e.g., aspen, Drummond

willow) will be most sensitive to a change from light-to-moderate browsing to intense browsing. Once highly preferred species are intensely used at a site, less preferred species (e.g., alder, spruce) indicate the magnitude of the situation.

Height of primary stem. Three potential cases were described on pages 66-67. Most desirable is the situation where there are plants in the size class 50 - 150 cm tall as measured to previous-year-growth (Situation 1).

Note: *If the survey is to include a reconstruction of historic browsing levels, a site must also contain plants of diverse age. The selection of sites for history reconstruction is discussed on pages 116-119.*

Case study. Three species of willow grew in the sample areas identified in Step 1: Drummond willow (*Salix drummondiana*), Booth willow (*Salix boothii*), and Geyer willow (*Salix geyeriana*). Aspen (*Populus tremuloides*) grew nearby, but was not well distributed within the sample areas.

Although all three willow species were heavily used, Drummond willow appeared to be used most heavily, and Booth willow the least. Drummond willow was not as widely distributed as the Geyer and Booth willow. There were numerous Geyer willow (*Salix geyeriana*) in the 50 - 150 cm size class.

Geyer willow was tentatively selected as the species to monitor.

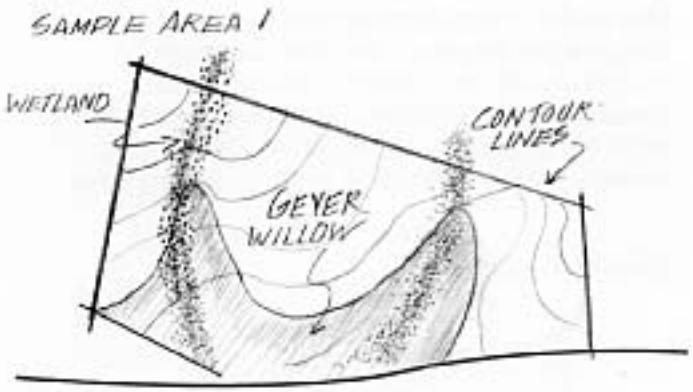
Step 3: Determine the location of sample sites within the study area

At this point in the process we have identified a sample area and, tentatively, a browse species. We could sketch a map of the distribution of that species using three mapping units:

> Mapping unit 1: Areas that contain plants that are between 50 - 150 cm tall. (The preferred case.)
>
> Mapping unit 2: Areas in which plants in the 50 - 150 cm size class are absent, but contain either: a) plants shorter than 50 cm tall (Situation 2 on page 66), or b) plants taller than 150 cm that have young primary stems in the 50 - 150 cm size class (Situation 3 on page 67).
>
> Mapping unit 3: Areas where primary stems of usable height are absent.

If the map of the sample area consists mostly of the third mapping unit, one should consider selecting another species for the survey.

Case study. The map on the facing page describes the distribution of Geyer willow stem heights in one of the sample areas. The shaded area delineates the areas in which the 50 - 150 cm size class grew. Shrubs in the 50 - 150 cm size class occurred throughout much of the sample area.



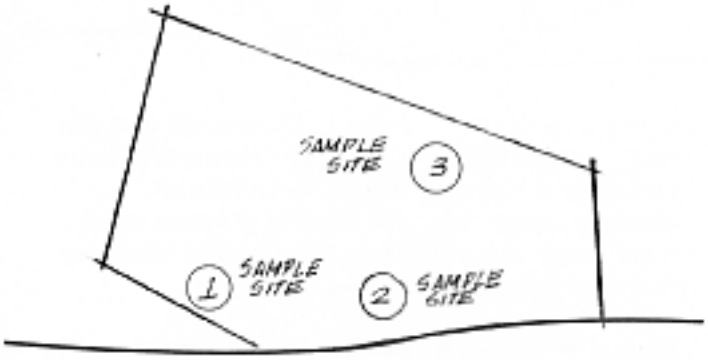
At this stage of Step 3, we have delineated the area that contains stems that are between 50 - 150 cm tall. In the final stage of Step 3 we identify the location of individual sample sites. The intensity of browse use at these sample sites will be used to interpolate conditions that occur between sample sites.

The size of sample sites will vary according to the density of the selected browse species. A site should contain 20 plants for classification. In the case study described in this book, sample sites ranged from about 250 - 500 m^2.

In the reconnaissance of the sample area, one may note that browse use is influenced by topography. For example, it may be found that browsing is more intense on southern exposures than on northern exposures. The availability of water may also influence browse use. The selection of sample sites should include this range of variation.

Case study. The reconnaissance of the sample area indicated that browse use was fairly consistent throughout, with no apparent difference due to topography. It was decided that three sample sites would be used to characterize the sample area. The location of the sample sites is shown on the map below.

SAMPLE SITES



Step 4: Classify the browsing level experienced by individual plants

The current browsing level of a plant is classified by examining a primary stem. The classification is accomplished in three stages:

1. Select an individual plant.
2. Select a primary stem on that plant.
3. Classify the primary stem.

Stage 1: Select individual plants. Select individual plants. About 20 plants should be classified at each sample site. Once one has an idea of how the plants are distributed throughout the sample site, the measurement of current browsing level should not take longer than about 30 minutes.

Note: *If the survey includes a historic perspective, other measurements will be taken at the same time. The total time required will increase correspondingly.*

Stage 2: From each plant, select a primary stem to classify. The selection of primary stems depends on the available size classes as described below.

If the plant is 50 - 150 cm tall (Situation 1 on page 66):

1. Examine the basal diameter of all shoots that make up the tree or shrub. Trees typically have a single primary stem, but browsing can produce a shrub-like growth form.

2. Select for classification the shoot with the largest basal diameter.

   The estimation of age does not have to be exact. All of the older shoots should have grown beyond the limit of the mechanical protection that is provided by associates. We simply want to exclude the use of young shoots that still may be mechanically protected.

If the plant is shorter than 50 cm (Situation 2 on page 66):

Mechanical protection should not be an important factor. Select the 20 tallest primary stems for classification.

If the plant is taller than 150 cm (Situation 3 on page 67):

Primary stems between 50 - 150 cm tall are used for classification. In practice only shrubs will have an assortment of primary stems to chose from. Mechanical protection could be a significant factor. Identify a side of the shrub that is not protected by a neighbor. Examine the zone from 50 - 150 cm high. Select a primary stem with previous-year-growth in this height range. Classify.

Stage 3: Classify the primary stem. The browsing level experienced by a primary stem is classified by examining the stem from ground level upward to current-year-growth.

Browsing will produce a dead stub that extends from the point where the stem was nipped down to the point where the following year's growth developed from a lateral bud (see page 31). The dead stubs should be examined for evidence of a terminal bud scar (a ring-like structure).

Key Point: *The presence of a terminal bud scar would indicate that an entire annual segment died. By definition, the primary stem would have experienced intense browsing.*

It is important to work upwards from ground level. In a case where a lateral branch assumed the role of a primary stem (after the tip of that stem was killed by browsing), one might miss evidence of that event if one began the examination at current-year-growth.

Case study. The data sheet on the next page presents the results of a site survey of current browsing level. The data are from Sample Site 1 of the Horse Pasture Sample Area.

I = intense, L/M = light-to-moderate. At this site, all sampled plants were intensely browsed.

In this example, only data for determining current level are shown. H_{pyc}, Collection number, L_c, A_y, and A_c are data that would be taken as part of a reconstruction of browsing history.

Date: Aug. 3 Observer: R. Keigley
Location: B-D NF, WB:D Steel Cr.
Sample area: 1 Sample site: 1
Species: Geyer willow

Observation number	Intensity level	Hpyg	Collection number	Lc	As	Ac
1	I					
2	I					
3	I					
4	I					
5	I					
6	I					
7	I					
8	I					
9	I					
10	I					
11	I					
12	I					
13	I					
14	I					
15	I					
16	I					
17	I					
18	I					
19	I					
20	I					

Step 5: Summarize the results

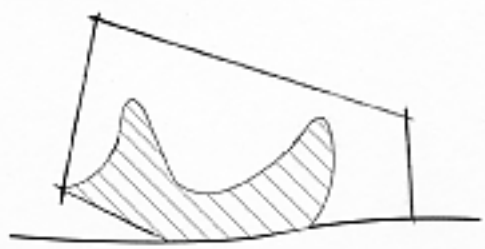
The current level of browsing can be reported in the form of a table. If multiple sample sites were surveyed, the results can be presented in map-form.

Case study. The table below reports results from the three sample sites in the Horse Pasture Sample Area.

Site	% Intensely browsed
1	100
2	100
3	100

The map below reports the intensity of use throughout the sample area. Geyer willow was intensely browsed throughout the sample area.

SKETCH MAP SAMPLE AREA 1



Salix geyeriana does not occur.

Salix geyeriana is intensely browsed.

Salix geyeriana is light-to-moderately browsed.
(Light-to-moderately browsed plants were not present.)

CHAPTER 6

QUANTITATIVE HISTORY OF BROWSING

In the previous chapter we described how plant architectures could be used to describe the current level of browsing at a site. Using the tools developed in that chapter, one would classify browse-use at a site as:

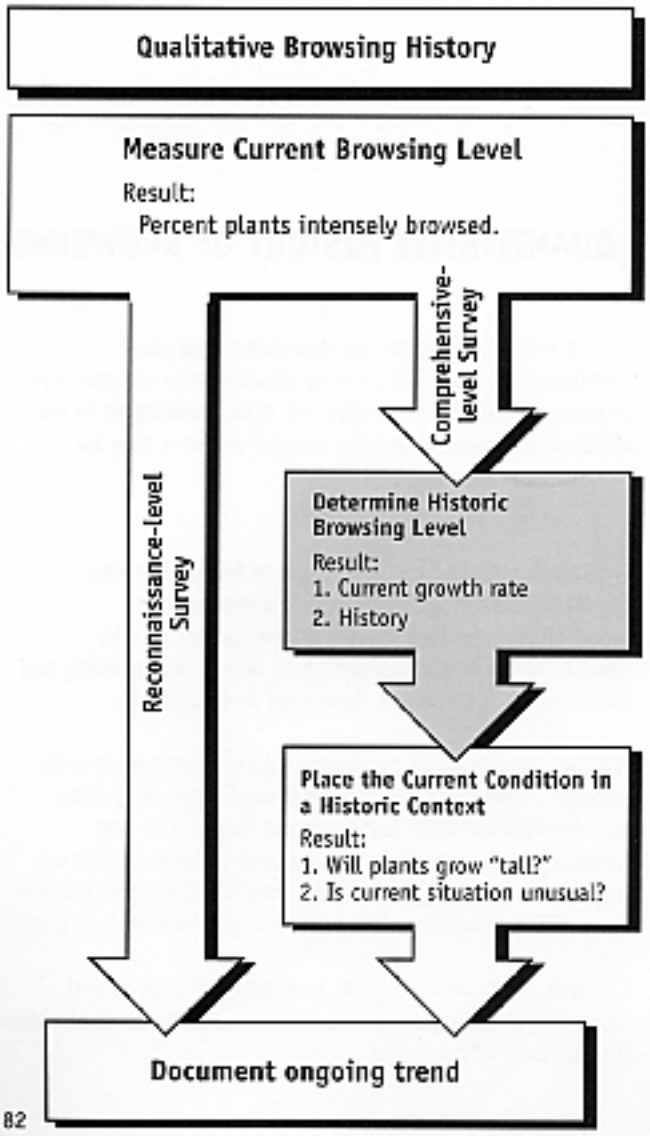
1) Intense, or
2) Light-to-moderate.

This book is based on two levels of browse survey: 1) reconnaissance, and 2) comprehensive. A reconnaissance-level survey would consist of the classification of current browsing level, and possibly the monitoring of trends as described in Chapter 8.

Why would one want to conduct a comprehensive level survey? Consider a hypothetical case. An early-June reconnaissance-level survey found that a site was intensely browsed. On a return visit in late-August we find numerous leafy stems reaching well into the browse zone. The vegetation is lush! Things don't look so bad!

Could it *really* be true that, over time, the trees and shrubs will only grow to be a few inches tall? Could this just be part of a natural cycle?

BROWSE SURVEY SEQUENCE



In This Chapter

A quantitative browsing history describes the actual years in which the browsing levels occurred. To accomplish this one must be able to determine the age of stems by counting annual rings—that is, from dendrochronology (pages 84-95).

The age of a live stem at a given height indicates the year in which that part of the stem was a terminal leader. The method of calculating that year is presented on page 96.

As an introduction to the potential uses of the architecture method, we describe the history recorded by a single released-type tree (pages 97-100).

Pages 100-108 describe how to determine when a current period of intense browsing began. With additional plant measurements, one can calculate the net annual growth rate that occurred during the period of intense browsing (pages 109-115). That net annual growth rate is used (in Chapter 7) to assess whether or not trees and shrubs are likely to grow to their typical stature.

Pages 116-124 describe a method of reconstructing a long-term history. In Chapter 7 we will use this long-term perspective to pose the question: *Is our current situation unusual?*

Note: *Symbols and formulas are summarized in Appendix III (pages 148-149).*

Annual Rings

In Chapter 3 we saw that a stem can be aged by counting terminal bud scars. But this method only works on stem segments that are a few years old. On older segments, the terminal bud scars become obscure as the stem increases in girth. The age of older stem segments can only be determined by counting annual rings.

The age determined by counts of annual rings is an estimate—an interpretation. There are many potential sources of error. But annual-ring-based ages are the only means of reconstructing a year-by-year history of browsing.

We briefly cover the following topics:

1. What is an annual ring?.
2. What do annual rings indicate?
3. Taking sections and cores.
4. Counting annual rings.

What is an annual ring?

An annual ring represents a year's worth of growth in the girth of a woody stem. Annual rings are produced by the cambium, a thin layer of tissue located close to the bark. The cambium produces phloem tissue on the side facing the bark and xylem tissue on the side facing the center of the stem.

As the xylem tissue accumulates each year, the stem increases in girth, and the cambium, phloem, and bark layers are pushed more distant from the center of the stem. One function of xylem is to conduct water from the soil to the uppermost branches.

Annual rings are found in the xylem. In conifers, the xylem tissue is largely composed of tracheids. The xylem of hardwoods is more diverse in composition. For example, hardwood xylem includes vessel elements, a cell type that is absent in conifers.

Vessels and tracheids are tube-shaped. In many species, the vessels and tracheids produced early in the growing season are larger in diameter than the cells produced later in the growing season. The xylem composed of large-diameter cells is called spring wood (or early wood); the xylem composed of small diameter cells is called summer wood (or late wood). This annual variation in cell size produces the bands commonly referred to as "annual rings."

Usually a single ring corresponds to one year's growth. But sometimes a seasonal weather pattern can, in a single growing season, produce what appears to be multiple annual rings. This within-year band is referred to as a "false ring" and is one potential source of error when estimating stem age. We will examine how to distinguish true annual rings from false rings.

What do annual rings indicate?

Counts of annual rings indicate the age of the stem. A count of annual rings taken from the base of the trunk indicates the age of the tree. If the tree was alive at the time the rings were counted, the annual rings can be used to calculate when the tree was established.

Key Point: *A count of annual rings at any point along a living stem can be used to calculate the year in which the given segment was a terminal leader. For example, the number of annual rings in a core taken at 2.5 m above ground level can be used to calculate the year in which the terminal leader grew out of the browse zone.*

Taking sections and cores

On large stems, the removal of a tree core should not cause harm. Where possible, coring is the method of choice. In the case of smaller stems, the age will have to be determined from a stem section.

Collection numbers. The ages of stems will be used with other plant measurements. To do that, one must keep track of where all the data came from. We document the identity of a specimen with a two part collection number. For example: 97-223. The "97" stands for the year in which we made the collection. The "223" stands for the individual sample. The numbers run in sequence starting with 1.

Cores. A core is taken with an increment borer that consists of three parts: a bit, an extractor, and a handle. The increment borer is a standard tool available from suppliers of forestry tools. In practice the bit is screwed into the tree by twisting the handle until the tip of the bit passes through the center rings of the stem.

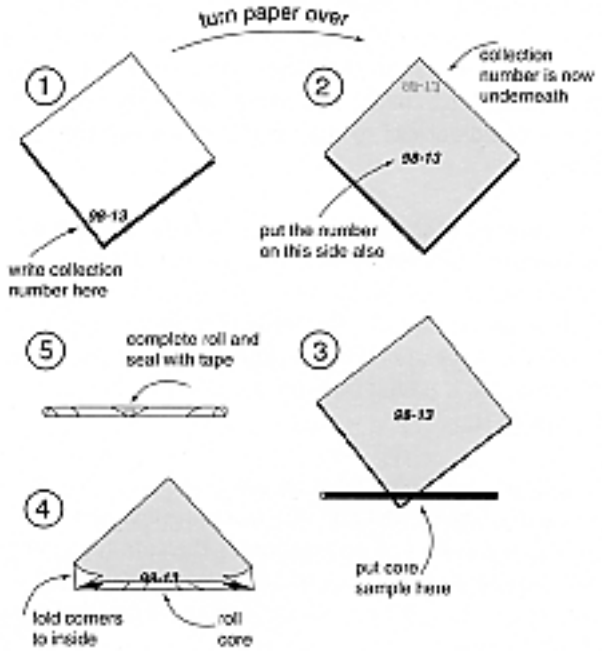
The center rings are seldom in the exact center of the stem. The asymmetry results because trees must counter the tendency to fall in the direction in which they lean. One has the best chance of finding the center rings if the stem is cored parallel to the direction in which the stem leans.

After coring to the desired depth, the extractor is fully inserted into the hollow bit. This pinches the core against the wall of the bit and seats the core into the teeth of the extractor. The bit is then backed out a turn or so. This separates the core from the remaining stem. The extractor is pulled from the bit drawing the core along with it.

The core is fragile and must be protected. Sometimes the core is fragmented and one must preserve the original sequence and orientation of the core fragments. Cores can be placed in plastic soda straws and sealed with tape or by pinching the ends of the straw that have been heated with a butane lighter.

But cores will not fit in many brands of soda straws. The authors have used the following alternative (see diagram on the next page). The core is placed diagonally on the corner of a square sheet of paper (to use a baseball

analogy, this corner would be home plate). The paper and core are then rolled until the core is in the center of the square (the core is aligned with third base, pitcher's mound, and first base). After folding the ends (first and third base) to seal the ends of the resulting tube, continue rolling to complete the protective case. Place a piece of tape on the remaining corner (second base).



The hole in the tree trunk produced by coring provides a potential entry for insects and pathogens. Plugs and sprays have been used to deter infestation and infection. But sprays and plugs may inhibit the tree's natural defenses. Many foresters leave the bore hole unplugged.

Sections. Stems up to about 3 cm diameter may be cut with lopping shears or hand pruners. Some models cut by pinching the stem against a flat anvil, while others (with two sharp blades) cut with a shearing action. Anvil-type cutters crush the stem and may make it difficult to see the rings. The rings from sections cut with shearing-type cutters can often be counted without further preparation.

Larger stem sections will probably have to be cut with a saw. Coarse-toothed saws leave a surface that will require treatment before the annual rings are countable. Even fine-toothed saws leave a rough surface.

Stem sections are relatively durable and can be transported in small envelopes.

Counting annual rings

Magnification. When we look at a core or section with the naked eye, we see the banding that is produced by the gradation between large-diameter cells (spring wood) and smaller diameter cells (summer wood). But what may appear to the naked eye to be a single ring may, under magnification, include two or more rings. (A reduced growth rate—narrow rings—is one result of intense browsing.) And while one can use an 8-to-10-power hand lens to examine the core in the field, a dissecting microscope is essential for an accurate count.

Orientation. To count annual rings one must determine which cells represent the annual cycle of spring wood

followed by summer wood. In a hardwood core we mostly distinguish annual cycles by looking for large-to-small-diameter patterns in vessel cells. To compare cell diameters, we look end-on into the vessel cells by rotating the core under the microscope until we have the proper orientation.

The core can also be oriented from its general appearance. The increment borer cuts the top and bottom of a vessel cell relatively cleanly but shreds the sides of the cell. The two surfaces of the core that are shredded mark the sides of the core on which the sides of the cell are exposed. The ends of the cell are exposed at a 90 degree rotation.

Preparation. Poorly sharpened cutting tools create a coarse surface that obscures the rings. Usually cores and sections must be prepared before rings are countable. Some biologists glue each core to a strip of wood and sand the core with progressively finer grades of sandpaper. While this technique protects the core from breakage, there are some disadvantages. First, the core may twist in the borer as it is being cut from the tree. As a result, the longitudinal orientation of the vessels changes from one end of the core to the other. If one glues the core to a strip of wood, one may not be able to reorient the core to look down into the vessel cells. Second, sanding may mash the sides of the cells thus preventing a view into the interior of the cell.

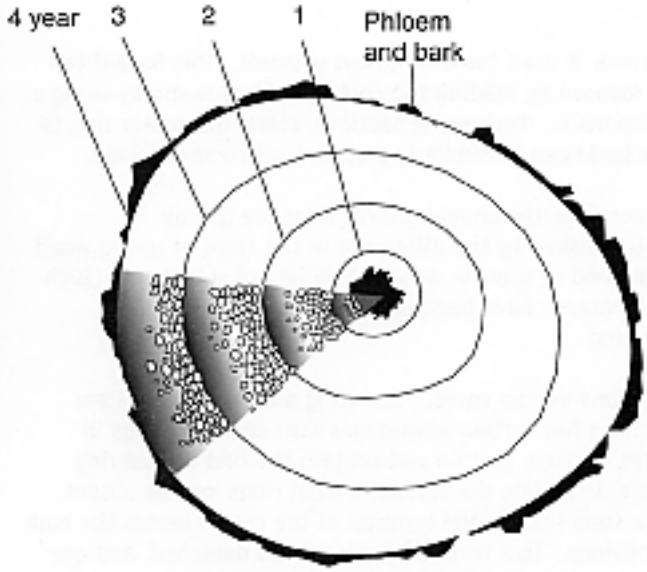
We have obtained excellent views by trimming the surface of the core or section with a sharp, single-edge razor blade under the dissecting microscope. There are the following disadvantages to this technique. First, the core may break. If this occurs, one must keep track of where the pieces came from so the core can be "reassembled."

Second, it is all too easy to cut yourself. This hazard can be reduced by holding the core with forceps and by using a sharp blade. Portions of sections (from the center ring to the bark) can be similarly prepared with a razor blade.

In conifers, the annual growth rings are mainly distinguished by the difference in the color of spring wood compared to summer wood. A variety of substances (such as kerosene) have been used to accentuate the color banding.

Sections versus cores. Counting annual rings in stem sections has certain advantages over counting rings in cores. A stem section will contain the first annual ring while, in a core, the earliest annual rings may be absent. In a stem section the location of the center versus the bark is obvious. In a core, the bark may be detached, and one may become confused as to which end of the core came from the center of the stem. We first describe how annual rings would be counted in a stem section and then explain how to handle the potential problems specific to cores.

Counting rings in sections. One should begin by identifying the annual ring that was produced in the first growing season. The central area of the stem typically contains two regions: one with a wavy border, and one with a border that is less irregular (see diagram on next page). The wavy border is the relic of the primary xylem that developed at the beginning of the first growing season. Outside the wavy region is the secondary xylem that we use to mark annual growth cycles. The roughly circular border of this second region marks the end of the first growing season and is counted as the first annual ring. One then counts the number of annual rings that developed after the first growing season.



As a stem ages, the older xylem in the interior of the stem becomes plugged with a variety of substances. Water is conducted in the younger xylem tissue. The non-conducting xylem is called "heartwood," the younger xylem "sapwood." The vessel elements of heartwood may become filled with a material that obscures the line that marks the transition between the summer wood of one year and spring wood of the next. When this occurs, annual rings must be distinguished by cell diameter alone, and often few cells can be clearly seen. It is a good idea to continually remind oneself that tree ring counts give an *estimate* of stem age.

A gradation in cell size (from spring wood to summer wood) is one indication of an annual ring. But as mentioned above, seasonal weather patterns can cause

cell-size transitions that falsely indicate an annual cycle. In hardwoods, false rings can be detected by the smoothness of the transition zone. When the cells are growing rapidly early in the growing season, there is a space between the outermost vessel borders of the large-diameter cells. When false rings form, these spaces are filled by smaller-diameter vessels. A trace of the transition would follow a zig-zag pattern. In contrast, there is not a large space between the outer borders of late-season vessels. When these cells stop growing at the end of the season, a relatively smooth line marks the limit of seasonal growth.

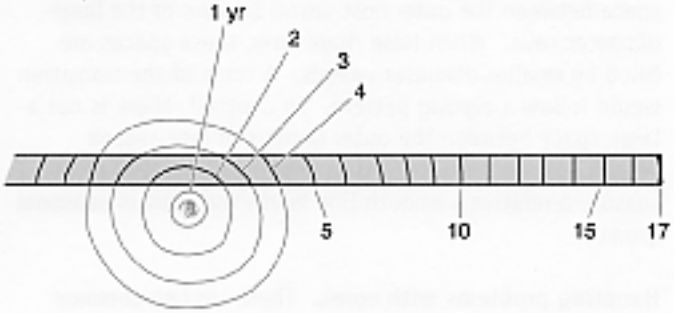
Handling problems with cores. There are two common problems:

1. The core may not contain the center rings. As a result, we are uncertain where to begin aging the core.
2. The core may be fragmented and the pieces disoriented. As a result, we may count rings that came from the opposite side of the tree (i.e., from past the center of the stem).

If the core came close to the center ring, one could estimate the number of rings that were missed. The estimation is made by drawing concentric circles using as a guide the width and shape of oldest annual rings that are visible.

Because young plants are seldom browsed for the first couple of years, the first few rings are usually relatively uniform in width. (Often one can get a sense of this variability if one has taken cores of similar age at the site.) In a core that missed the center by an estimated five years,

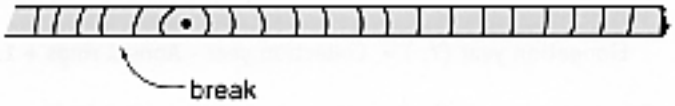
the error due to ring-width variability (during those early years) will likely be a year or so. Depending on the objectives of the survey, this level of confidence may be acceptable.

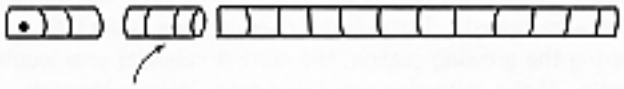


Fragmented cores pose two kinds of problems. First, if the core extends beyond the center rings, one may inadvertently include those annual rings when estimating the age of the stem. Second, if fragments are flipped end-to-end, the detection of large-to-small cell size transition becomes confusing. Obviously, it would be best to avoid breaking the core or, having done so, disturbing the orientation of the fragments. But these things happen. We describe some possible approaches to handling these problems.

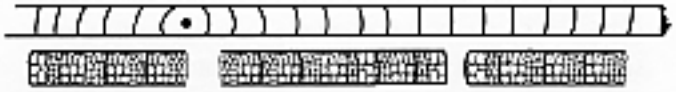
One can eliminate extraneous rings from the sample in the field by breaking the core off just beyond the center rings. If this is done, any fragments from the center-end of the core should have rings that curve. This curvature can be used for orientation. But there may be a disadvantage to breaking the core. Sometimes the rings on the distal side of the core can help one understand the ring pattern that occurs on the proximal side.

One can orient fragments end-to-end under the microscope by being consistent in how the core is placed on the microscope stage. The authors consistently place the center-end of a core to the left. This means that, within each annual ring, cell size should increase from left to right. Any fragment where rings are not curved can be reoriented from the pattern of cell-size transition. Fragments with curved rings can be reoriented using a combination of cell-size pattern and direction of curvature.





Can't be oriented correctly.
Curves are in wrong direction.



Transition in cell size is reversed. Fragment must be flipped end for end.

Calculating The Year Of Stem Elongation

While a primary stem increases in girth throughout its life, a given annual segment of the stem only elongates the year it is a terminal leader. The architectures described in this book are based on the effect that browsing may have had on the terminal leader. Browsing histories are reconstructed by determining when that effect occurred.

In other words, we must often determine the year in which a given primary stem segment was a terminal leader. The calculation is:

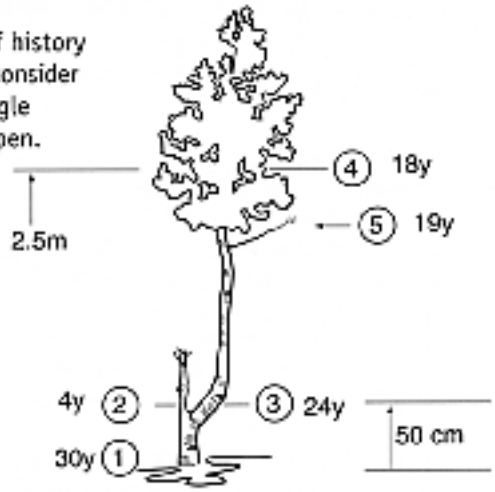
Elongation year (Y_E) = Collection year - Annual rings + 1.

Elongation year is the year the segment was a terminal leader. Collection year is the year in which the last annual ring was formed. If the core or section was collected during the growing season, the current calendar year would apply. If the collection was taken from January through about early May, the correct collection year would be the previous calendar year. For questionable samples, you should be able to tell if a complete annual cycle is present in the last ring.

To understand why 1 must be added to stem age, consider the case of a terminal leader. If a terminal leader was sectioned in mid-August of 1995, it would contain one annual ring. Because we are examining a terminal leader (that is current-year-growth), we know that the elongation year is 1995. That is,

1995 = 1995 (i.e., collection year) -1 (annual ring) +1.

The History Recorded By A Single Released-type Tree



As an example of history reconstruction, consider the case of a single released-type aspen.

As a first step, establish the qualitative history recorded by the tree. It is apparent that the dead, vertical stem was the initial trunk. That trunk grew to a height of 1.0 m before it died. Nearby, young aspen are currently being nipped at 20 cm above the ground, so browsing intensity must have been light-to-moderate when the terminal leader first grew into the browse zone.

Clusters of bite-marked twigs on the initial trunk's dead branches indicate that intense browsing was responsible for its death. The growth of the live trunk through the browse zone indicates a subsequent period of light-to-moderate browsing. Branches on the second trunk have been highlined, indicating a later period of intense browsing. These preliminary observations suggest that the tree experienced a four-stage browsing history: 1) light-to-moderate, 2) intense, 3) light-to-moderate, and 4) intense.

Next we examine how stem ages can be used to estimate when these transitions occurred. The circled numbers in the diagram correspond to the text sections below. Adjacent to the circled numbers are the stem ages estimated from cores and sections that were collected in July of 1994.

1. A core from 30 cm above the ground was used to estimate the age of the tree. This height is as close to the ground as one could easily core given the length of the increment borer handle. If the terminal leader had been nipped at 20 cm, a core at 30 cm would underestimate the tree's total age. But this stem did not fork, so the core at 30 cm provides a close estimate of total age. Using the formula described above, we estimate that this tree was established in 1965.

2. A section taken from the dead initial trunk at 50 cm above the ground contained 4 annual rings. Because the initial trunk grew to 1.0 m tall, we assume that browsing was light-to-moderate when the terminal leader grew through the 50 cm level. We might further assume that the primary stem grew to 50 cm tall the year after the tree was established. This would have occurred in 1966. From the four annual rings we know that the initial trunk lived four years before it was killed by browsing in 1969. Because clusters of twigs formed on the branches, we know that there was at least one year of intense browsing before the trunk was killed. We might estimate that this occurred in 1968.

3. A core taken at the base of the second trunk (at 50 cm) indicates the year in which the terminal leader began to grow through the browse zone. This core contained 24 annual rings, so height growth resumed in

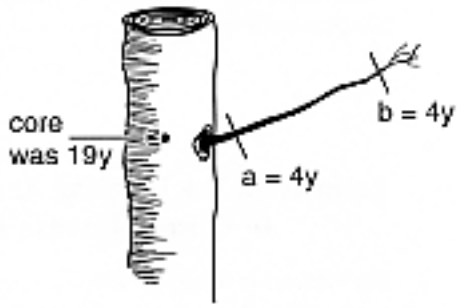
1971. That year marks a transition from intense browsing to light-to-moderate browsing.

4. From 50 cm to 2.5 m, the trunk did not fork indicating that browsing was light-to-moderate throughout that period of stem growth. A core taken at 2.5 m contained 18 annual rings. The trunk reached that height in 1977. From this we know that from 1971—the year of release—to 1977 browsing intensity was light-to-moderate. But we can see that the tree is highlined, so we know that the tree was intensely browsed some time after 1977.

5. This dead branch at 2.0 m above the ground provides a clue as to when browsing intensity might have changed from light-to-moderate to intense. The branch is terminated by a dense cluster of twigs indicating intense browsing. But before the dense cluster of twigs formed, the branch grew straight. This straight growth would only occur if the branch was not browsed.

We section this branch at two locations:
a) at the base of the branch, and
b) just below the cluster of twigs.

From the section at the base of the branch we can determine the total number of years that the branch survived. This branch lived a total of four years.



From the section at the base of the twig cluster we can determine when, in the life of the branch, the cluster of twigs formed. In this case, the branch took one year to grow from the trunk to the base of the twig cluster.

Because this branch was dead, we cannot determine with certainty the years in which it grew. But we can make an educated guess. While branches may develop from buds that have been dormant for more than one year, the tree's main branches often develop from buds that have been dormant a single year. If we assume this to be the case, we can estimate the year in which this branch grew from the annual rings in a core taken at the same level as the branch. This core contained 19 annual rings indicating that the terminal leader grew through 2.0 m tall in 1976. The branch would have been produced the following year in 1977.

After its initial growth in 1977, this branch experienced one year of straight growth (light-to-moderate browsing). The segment that developed during the 1978 growing season was browsed. If we observed that browsing in this area typically occurred in the winter, we could estimate that browsing intensity increased from light-to-moderate to intense in the winter of 1978.

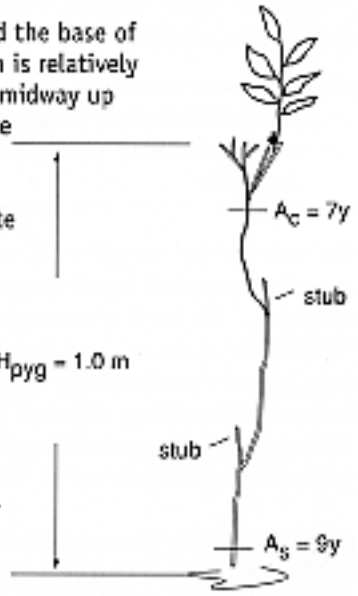
Estimating The Duration And Beginning Year Of Current Intense Browsing

The method is based on the cluster of twigs that is produced at the end of an intensely browsed stem.

Measurements and sections of the plant below were taken in August 1994. The section at the base of the primary stem contained 9 annual rings. The stem experienced 9 growing seasons, indicating that it first elongated in 1986.

Between ground level and the base of the twig cluster, the stem is relatively straight. The small stubs midway up the stem indicate that the segments produced in 1986 and 1987 were browsed. But no complete annual segment was killed. The primary stem experienced a light-to-moderate level of browsing in those years.

A section taken at the base of the cluster (A_c) contained 7 annual rings. This stem segment was a terminal leader in 1988.



From 1986 through 1988, the primary stem experienced a measurable net height-growth. But after the 1988 growing season, the situation changed. As in the preceding two years, a portion of the 1988 stem segment remained alive, so as in previous years, the 1988 segment experienced light-to-moderate browsing. But instead of growing markedly taller, the primary stem formed a cluster of twigs that has produced little net height growth since 1989.

Was the stem intensely browsed in 1989? With care it may be possible to identify the first (i.e., the oldest) annual segment that was killed by browsing. But while the reconstruction of a twig cluster's browsing history may be theoretically possible, it may be inordinately complicated to do so given the morass of dead twigs that may be present.

Key Point: *We use the year of twig cluster formation as an estimate of when the browsing level increased to intense.*

Our rationale for assigning the onset year may best be understood by considering the year-by-year history of the plant . The table on the adjacent page describes the number of annual rings that would be found on a stem segment produced during a given growing season. For example, the stem segment produced during the 1993 growing season would contain two annual rings and would be one year old in 1994.

We know that the stem segments produced in the 1986, 1987, and 1988 growing seasons were light-to-moderately browsed. The answer to the question *Was the segment intensely browsed?* can be answered "No." From 1989 through 1993, we answer that question with a "Possibly." Because we measure height to the tallest previous-year-growth, the current growing season should not be included. And if we are measuring plants in mid-summer, potential winter browsing is months away. The plant may—or may not—be browsed.

Year	Number of annual rings	Segment age in years	Intensely browsed
1994	1	cyg	NA
1993	2	1 (pyg)	Possibly
1992	3	2	Possibly
1991	4	3	Possibly
1990	5	4	Possibly
1989	6	5	Possibly
1988	7	6	No
1987	8	7	No
1986	9	8	No

Therefore, the stem experienced five "possible" years of intense browsing, or two years less than the age of the stem segment on which the cluster was borne.

The formula for the duration of the current period of intense browsing (D_I) is :

$$D_I = A_C - 2$$

where A_C is the age of the stem segment on which the cluster was borne.

In the example above:

$$D_I = 7 - 2$$
$$D_I = 5 \text{ y}$$

The formula for estimating the year that intense browsing began (Y_I) is:

$$Y_I = \text{Collection year} - A_C + 2$$

Put another way:

$$Y_I = \text{Collection year} - D_I$$

In the example above:

$$Y_I = 1994 - 5$$
$$Y_I = 1989$$

Selection of stems for measurement

The stems are among those selected for classification when determining the current level of browsing (see pages 63-67). Those stems met the following criteria:

1. the stem will be 50 - 150 cm tall, and

2. the stem will not have been mechanically protected by older stems.

Key Point: *There is an important new criterion: the twig cluster must contain at least one live twig.*

Among the full set of primary stems examined during an assessment of current browsing level, those that were light-to-moderately browsed would not be terminated by a cluster of twigs. The data pertaining to history reconstruction (H_{pyg}, L_c, A_s, and A_C) would only be

collected for those primary stems that were intensely browsed. Where intense browsing began one or two years ago, the formation of the twig cluster would be in the beginning stages. In this case, it is easy to distinguish the first annual segment that was killed by browsing. The L_t measurement would be taken at the base of that segment. (See diagram on page 111.)

Complications

Twig clusters. After a twig cluster forms, lateral branches may develop from dormant buds lower on the stem. If these branches develop much below the original cluster, it may become difficult to identify the base of the original cluster. As long as the original cluster can be distinguished and remains alive, the age relationships can be used to estimate the onset of intense browsing.

Limited time span. This method can only date the onset of intense browsing within the potential lifespan of an intensely browsed stem. This may be less than 15 years.

Over time, the oldest generation of intensely browsed stems on a shrub will die and may be replaced by younger stems. Or, the entire shrub may die. These younger stems will be intensely browsed when they extend beyond the protective canopy of the older, dead stems. These younger stems will develop twig clusters, but the date indicated by those clusters will not be accurate.

When the duration of intense browsing exceeds the limitations posed by this method, it may be possible to approach the problem from another direction. Namely, it may be possible to estimate when intense browsing began by determining when light-to-moderate browsing ended. The final section of this chapter describes such a method.

Case study

The data sheet on the adjacent page is a continuation of the sheet that was begun on page 78. In that case study, only the "Intensity level" column was completed. A reconnaissance-level survey would have determined "current browsing level" and perhaps continued to the trend monitoring described in Chapter 8.

Because we elected to conduct a comprehensive-level survey, additional measurements and samples were taken. The H_{pys} and L_c measurements were taken from the same stem that was used to classify intensity level. If a plant was classified as being light-to-moderately browsed, only the H_{pys} and A_s data would be needed.

Sections were cut from the base of the stem and just below the cluster of twigs. If the plant had been light-to-moderately browsed, the twig cluster data would not apply. Both sections were placed in a single envelope that was labeled with the collection numbers. The annual rings were counted under a microscope and recorded in the appropriate column. There is no need to have the separate envelopes for the sections. Once the rings are counted, the oldest section is the basal section.

Date: Aug. 3 Observer: R. Keigley
Location: B-D NF, W15:D Steel Cr.
Sample area: 1 Sample site: 1
Species: Geyer Willow

Observation number	Intensity level	Hpyg	Collection number	Lc	As	Ac
1	I	88	97-108	29	12	9
2	I	81	109	10	12	6
3	I	54	110	16	10	8
4	I	87	111	23	13	9
5	I	81	112	17	12	9
6	I	90	113	12	12	6
7	I	101	114	43	12	8
8	I	95	115	19	13	7
9	I	110	116	29	13	6
10	I	105	117	24	12	7
11	I	152	118	10	13	6
12	I	92	119	25	12	10
13	I	130	120	28	11	7
14	I	150	121	16	13	6
15	I	146	122	21	13	8
16	I	113	123	28	13	7
17	I	159	124	54	12	8
18	I	173	125	32	13	7
19	I	175	126	54	13	6
20	I	110	127	25	11	8

The data are entered into a spreadsheet in much the same form as they appear on the data sheet. (The H_{p92}, L_c, and A_s data will be used later.) In a spreadsheet area adjacent to the data block, a column is labeled "D_I." For each plant for which there are data (there would be none for light-to-moderately browsed plants), an estimate of the duration is calculated by: A_c - 2. The mean duration and standard error is calculated at the bottom of the column.

At this site, the mean duration of intense browsing was 5.4 ± 0.3 years (± SE). The samples were collected in 1997, therefore the beginning year of intense browsing is estimated to have been 1997 - 5.4 or 1992.

The beginning year was similarly estimated for two other sites in the sample area. The result:

Site 2. Duration: 6.2 ± 0.5 years (± SE). The estimated beginning year: 1991.

Site 3. Duration: 5.4 ± 0.1 years (± SE). The estimated beginning year: 1992.

Net Annual Height Growth Rate

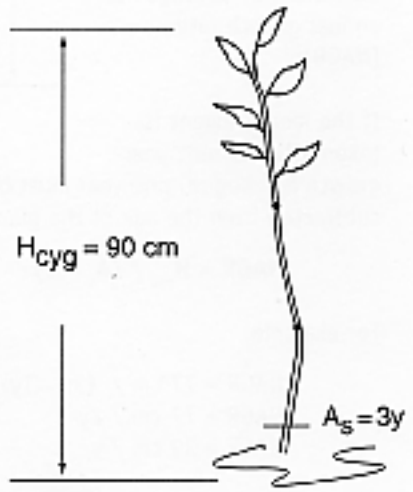
In the final chapter of this book, height-growth rate is used to assess the probability that plants will grow to their typical stature. In this chapter we describe methods of determining that rate.

First consider how one might measure the growth rate of an unbrowsed plant. At the end of the growing season we might measure the total height of the plant to the tip of current-year-growth, and divide that height by the age of the plant. Average annual growth rate (AGR) would be calculated by:

$$AGR = H_{cyg} / A_s$$

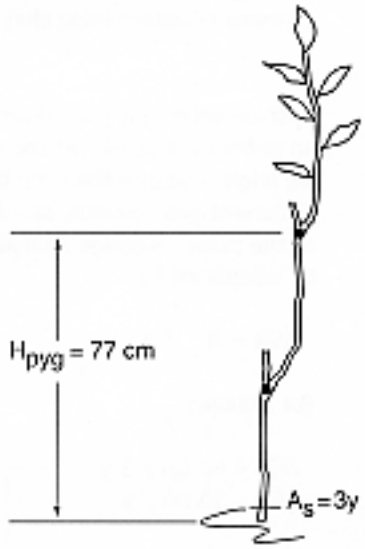
For example:

AGR = 90 cm / 3 y
AGR = 30 cm / y



Next consider the case of a light-to-moderately browsed plant. Depending on when we measure the height of the plant, current-year-growth may have been browsed. Growth rate data will be more consistent if height is measured to live previous-year-growth.

The height to live previous-year-growth excludes the dead stub that is above the point where current-year-growth developed. Because some of the stem was removed by browsing, we are not measuring the total length that the stem grew during the preceding growing season. We are measuring an average *net* annual growth rate (NAGR):



If the measurement is taken after current-year-growth has begun, one year must be subtracted from the age of the plant.

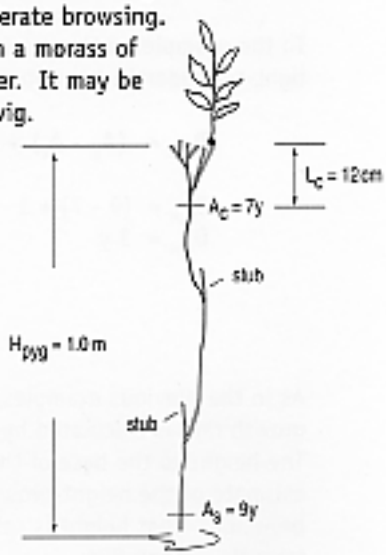
$$NAGR = H_{pyg} / (A_s - 1)$$

For example:

NAGR = 77 cm / (3y - 1y)
NAGR = 77 cm / 2y
NAGR = 39 cm / y

The intensely browsed plant below has a two part history: 1) an early period of light-to-moderate browsing, and 2) a subsequent period of intense browsing. We can estimate a net annual growth rate for both periods.

To calculate an average net annual growth rate for the early period of light-to-moderate browsing, one would ideally measure to the tip of the annual segment that last grew during light-to-moderate browsing. But this tip may be located in a morass of twigs that comprise the cluster. It may be difficult to find the correct twig.



Alternatively, one could measure height of the light-to-moderately browsed stem segments up to the base of the cluster. Because we exclude the segment length that lies within the cluster, this method of measurement underestimates the length of segments that grew during light-to-moderate browsing.

To calculate net growth rate we need to know the number of years that the stems grew under light-to-moderate browsing. The ages of the stem segments on the plant above are identical to the case presented on pages 101-102. From the table on page 103 we see that three annual segments are definitely known to have been light-to-moderately browsed.

The formula for calculating the number of years that the primary stem was light-to-moderately browsed ($D_{L\backslash M}$) is:

$$\mathbf{D_{L\backslash M} = (A_s - A_c) + 1}$$

In the example on the previous page, the duration of light-to-moderate browsing is:

$$\mathbf{D_{L\backslash M} = (A_s - A_c) + 1}$$

$$D_{L\backslash M} = (9 - 7) + 1$$
$$D_{L\backslash M} = 3\ y$$

As in the previous examples, the average net annual growth rate is calculated by dividing height by duration. The height to the base of the twig cluster is used as an estimate of the height-growth under light-to-moderate browsing. That height is calculated by subtracting L_c from $H_{p/s}$. Therefore:

$$\mathbf{NAGR_{L\backslash M} = (H_{p/s} - L_c) / D_{L\backslash M}}$$

$$NAGR_{L\backslash M} = (100\ cm - 12\ cm) / 3\ y$$
$$NAGR_{L\backslash M} = 88\ cm / 3\ y$$
$$NAGR_{L\backslash M} = 29\ cm / y$$

We estimate an average net annual growth rate for the period of intense browsing in a similar way. L_C is used as an estimate of the net height growth that has occurred since intense browsing began. Because L_C includes a portion of a light-to-moderately browsed segment, we know that it overestimates net height growth under intense browsing.

In the example above, the duration of intense browsing is:

$$\mathbf{D_I = A_C - 2}$$

$$D_I = 7 - 2$$
$$D_I = 5\ y$$

The average net annual growth rate is calculated by dividing L_C by duration.

$$\mathbf{NAGR_I = L_C / D_I}$$

$$NAGR_I = 12\ cm / 5\ y$$
$$NAGR_I = 2.4\ cm / y$$

Important Point: *$NAGR_{L|M}$* ***underestimates*** *the actual growth that occurred under light-to-moderate browsing. $NAGR_I$* ***overestimates*** *the growth that occurred during the period of intense browsing.*

Case study: The average growth rates at a site

On page 108, we described how a spreadsheet was used to calculate the duration of intense browsing. Adjacent to the block that contained the data, we added a column labeled "D_I" where we calculated the duration of intense browsing for each intensely browsed plant. We now add three additional columns to the spreadsheet: $D_{L\backslash H}$, $NAGR_I$, and $NAGR_{L\backslash H}$.

In the column labeled $D_{L\backslash H}$ we calculate a value for each plant using the formula:

$$D_{L\backslash H} = (A_L - A_C) + 1$$

In the column labeled $NAGR_I$, we calculate a value for each plant using the formula:

$$NAGR_I = L_C / D_I$$

In the column labeled $NAGR_{L\backslash H}$, we calculate a value for each plant using the formula:

$$NAGR_{L\backslash H} = (H_{999} - L_C) / D_{L\backslash H}$$

In each case, the spreadsheet formulas can be constructed by "pointing" to the appropriate values in adjacent columns.

Once a formula has been constructed for the first cell, the formula can be copied to all spreadsheet cells lower in the column.

If light-to-moderately browsed plants were present, those cells will contain zeros in the Duration column. Dividing by zero in the NAGR columns will produce an error message. The erroneous values should be deleted before computing the mean and standard error values at the bottom of the respective columns.

The table below presents the average net annual growth rates for each of the three sites in the sample area. The data for site 1 were described on page 107.

Site	$NAGR_{L/M}$	$NAGR_I$
1	15.6 ± 0.3 cm / y	4.9 ± 0.6 cm / y
2	24.6 ± 0.5 cm / y	3.5 ± 0.3 cm / y
3	16.4 ± 1.1 cm / y	3.7 ± 0.5 cm / y

The difference in growth rates (light-to-moderate compared with intense) should be interpreted with caution. Current intense browsing likely accounts—in part—for the fact that $NAGR_I$ is smaller than $NAGR_{L/M}$. But growth rate eventually declines with age, so some of the difference may be due to that effect. In Chapter 7 we will focus on the implications of low values of $NAGR_I$.

Reconstructing A Long-term History Of Browsing

The case studies in this book have focused on Geyer willow growing on a part of the Wisdom District of the Beaverhead-Deerlodge National Forest. In Chapter 7 we will place the willow's current situation in a historical context.

In Chapter 7 we will pose the question: *Is what we see today unusual compared to what has occurred in the past?* But for reasons explained below, we will shift our attention to another browse species. Three factors influenced that selection:

1. lifespan of individual stems.
2. age structure.
3. preference of the browse species by ungulates.

Stem lifespan

The architectural effect of past browsing is preserved in a plant's lower stem. A site's history can only go back as far as the age of the oldest stem. The longest browse-use histories will be based on species whose stems have a long lifespan. Compared with those of aspen and conifers, Geyer willow stems are short-lived.

Age structure

A site's browsing history is reconstructed by examining plants of different age. To avoid gaps in the historic record, all ages must be represented.

Important Point: *Trees and shrubs are established episodically. For example, on some sites fire is primarily responsible for inducing the growth of young aspen. The absence of a particular age class could be due to the absence of factors favorable for the development of young plants.*

We have seen that browsing can kill young plants. The absence of an age class could be due to browsing.

But without tangible evidence, one cannot distinguish between all of the possible reasons for which plants of a given age class are absent.

The historic record that is reconstructed below is restricted to periods for which there is direct evidence for a particular level of browsing. Periods where there is no evidence are left blank.

Preference by ungulates

Ungulates prefer to use some browse species such as aspen over others such as spruce. When browse use increases, highly-preferred species are intensely used before less-preferred species. When highly preferred species are depleted, the use of less-highly preferred species increases.

On a site that has been intensely used for decades, the youngest uninterrupted growth-type aspen may be many years old. Arrested-type aspen are typically short-lived. As a result, there may be no live middle-aged aspen. The browse-use history would contain a corresponding gap.

On the same site, spruce will likely have been intensely used more recently compared with aspen. As a result, there will be a smaller gap (or no gap) in the long-term history that is recorded by spruce.

Each of the above factors should be weighed when selecting the species that is ultimately used to depict the browsing history. The goal at this point should be reconstructing the longest history that contains the fewest possible gaps. Interpreting that history (in the final chapter) will account for the potential effect of browse preference by ungulates.

The following case study illustrates a method of long-term history reconstruction.

Case study

Conifers and aspen near the Wisdom District sample area were considered as potential subjects. The qualitative history described below required no more than a few minutes to take and indicated that aspen was the species of choice.

Preference. Conifers were present in a wide range of ages, all of which had uninterrupted-growth-type architecture. Young aspen in the sample area had arrested-type architecture. Older aspen close to the sample area had uninterrupted-growth type architecture. Because aspen and Geyer willow both experienced intense use, while conifers did not, aspen better indicates the past browsing of Geyer willow.

Age structure. The stems of the older aspen ranged rather evenly from about 0.25-to-1.5 meters in circumference. It appeared that a wide range of ages were present. It did not appear that there would be major gaps in the reconstructed history.

The long-term history was reconstructed in three stages:

1. Periods of light-to-moderate browsing were identified.

2. Periods of intense browsing were identified.

3. We looked for evidence that light-to-moderate browsing simultaneously occurred with intense browsing.

Identifying periods of light-to-moderate browsing. By definition, an uninterrupted-growth-type tree that has grown taller than the browse zone experienced light-to-moderate browsing as the terminal leader grew through the browse zone. The establishment year of the tree approximately marks the beginning of that period of light-to-moderate browsing that is recorded by that tree.

By finding the establishment year of all such individuals at the site, one can develop—for those trees—a composite picture of when light-to-moderate browsing occurred.

A tree was classified as uninterrupted-growth-type if the live stem did not fork from a dead vertical stem between ground level and 2.5 m. The dead vertical stem must also be one or more years old. While this was the criterion used for classification, two additional lines of evidence were considered when examining each tree:

1. The trunk was examined for straightness. The trunks of trees that have been browsed early in life often grow in a zig-zag fashion. The zig-zag growth results when the tip of the primary stem is browsed and subsequent growth develops from a lateral bud. As a result, current-year-growth diverges from previous-year-growth at a noticeable angle.

   The trunks of older trees at the site were quite straight. The trunks of some younger trees exhibited a zig-zag pattern, but none of these indicated that a complete annual growth segment had been killed by browsing.

2. The trunk was examined for a furrow that might have been produced by antler rubbing. An ungulate may partially girdle a young tree by antler rubbing. Virtually all young aspen in the area exhibited rubbing scars. If a tree increases markedly in girth after such an injury, the scar would be reduced to a furrow. Smooth-surfaced bark would indicate that injury did not occur.

While older aspen exhibited a range of injuries, all of these appeared to have occurred relatively recently. There was no evidence that older aspen experienced an early period of antler rubbing similar to that which has occurred in recent years. While antler rubbing is not the same as browsing, its recent appearance indicates a change in ungulate behavior at the site.

The combined evidence indicated that individuals classified as uninterrupted-growth-type truly experienced light-to-moderate use during their youth.

Tree age. It would be impractical and potentially harmful to core each uninterrupted-growth-type tree in the stand. Instead, ages were estimated using correlation, which determines the association between two variables.

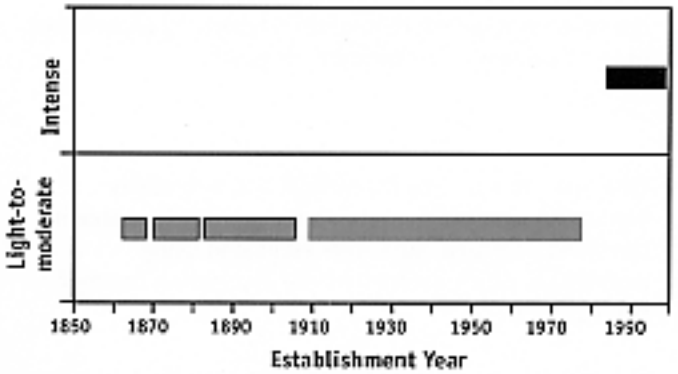
The correlation was developed from a sample of 10 trees in which: 1) circumference (C) was measured at 30 cm above ground level, and 2) age was determined from a core taken at the same height. The correlation model for the site:

$$\text{Age} = 3.87 + 0.79C \quad (r = 0.91,\ P < 0.0003)$$

The circumference of 136 uninterrupted-growth-type trees was measured. The establishment year was calculated for each tree.

The graph below plots level of browsing intensity on the Y-axis and year on the X-axis. On that graph, the establishment year of each light-to-moderately browsed tree marks a point in time in which light-to-moderate browsing occurred

Intensity of Aspen Browsing



Differences in site environment will cause trees of the same age to differ in girth. As a result, for some individuals the calculated establishment year will be inaccurate. But establishment year marks the beginning of a *period* of light-to-moderate browsing. For reasons described below, that period is estimated to be 5 to 10 years. This leeway somewhat mitigates the errors that may arise due to the inaccuracy of estimating age based on girth.

Identifying periods of intense browsing. Arrested-type aspen were aged from sections or terminal bud scars. All were established between 1987 and 1995. The years when the arrested-type plants established were plotted on the graph as years of intense browsing.

Check for simultaneous intense and light-to-moderate browsing. Two situations were checked for:

1. Did intense browsing also occur during the period of light-to-moderate browsing (1865-1974)?
2. Did light-to-moderate browsing also occur during the period of intense browsing (1987-1996)?

Released-type trees established from 1865-1974 would have been evidence of intense browsing during that time. Trees of this architecture type were not present. The straightness of the trunks and the absence of furrowing (due to antler rubbing) indicates that these trees did not experience the same level of use that occurs today. There is no evidence that intense browsing occurred during 1865 to 1974.

Since 1974 no aspen has grown to tree stature in the area. Except for individuals short enough to be protected by snowcover, all young aspen are intensely browsed. There is no evidence that aspen experienced light-to-moderate browsing during 1987 to 1996.

The reconstructed history. The historic record provided by aspen extends from 1865 to the present. However, there is a gap in the record from 1975 to 1986 that occurs because no living aspen established during that time. For several decades prior to 1975, browsing was light-to-moderate. After 1986 browsing was intense.

An aspen is very sensitive to intense browsing for a few years after establishment. For this reason it seems likely that the increase in browsing intensity occurred a few years after 1975, the establishment year of the youngest live aspen tree. An aspen would likely require 5 to 10 years of light-to-moderate browsing to become less-sensitive to intense browsing. This would place the increase in browsing level sometime in the mid-1980s.

The browsing history at the site can be characterized as follows. The historic record provided by aspen begins about 1865. Browsing was light-to-moderate from 1865 to the mid-1980s, after which browsing was intense. In Chapter 7, we will use this general picture of browsing history to place the current situation in the context of the site's long-term history.

CHAPTER 7

LONG-TERM CONTEXT

Placing the current situation in a long-term historical context is the final step in the evaluation process. Let's recap how we arrived at this point. An area was suspected to be heavily used by ungulates. We initiated a comprehensive-level survey. Data were collected that allow us to address the questions raised in the Introduction of this book:

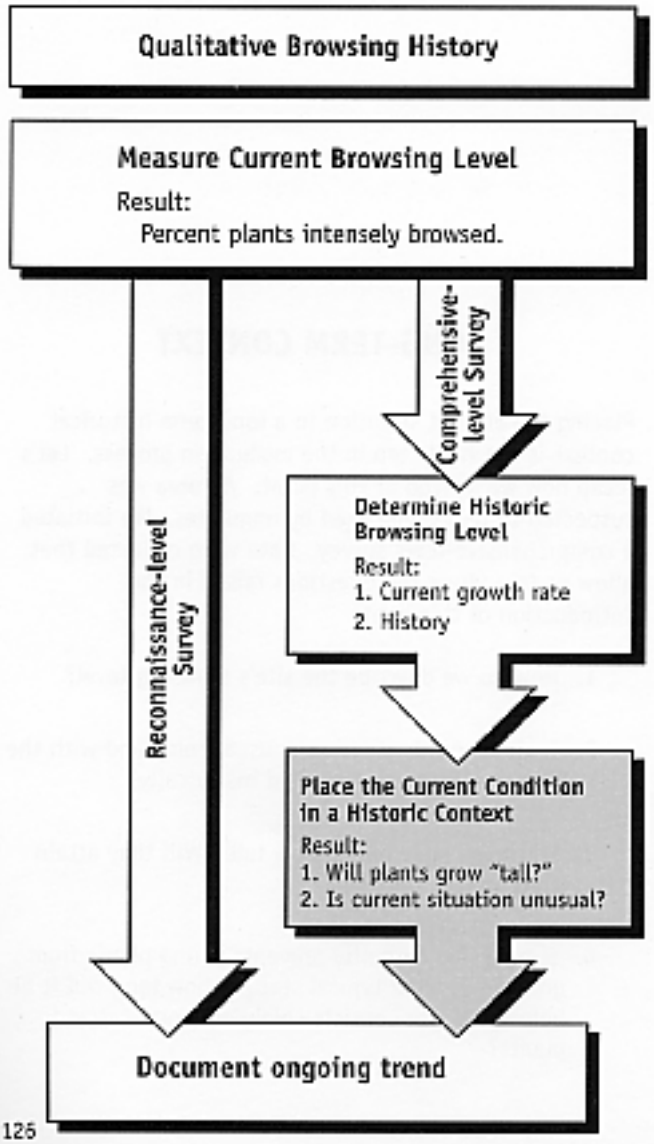
1. How do we describe the site's browsing level?

2. Is the current situation unusual compared with the situation that has prevailed historically?

3. Will trees and shrubs grow tall? Will they attain their typical stature?

4. If browsing currently prevents young plants from growing to their typical stature, how long will it be before the site consists solely of short-statured plants?

BROWSE SURVEY SEQUENCE



Is The Current Situation Unusual?

To answer this question, we examine the site's long-term history of browsing. To reconstruct that history, we selected the species that best portrayed the changes that occurred over the past century or so. A change in the level of use for any species has implications for all other browse species at the site.

In the Wisdom District case study, the long-term history was based on aspen. Aspen were intensely browsed for about the past 10 years, and light-to-moderately browsed for about the preceding century. The current level of aspen use is decidedly unusual compared with the level that prevailed historically.

A deviation from the historic browsing norm implies that other ecological processes are changing as well.

Will Trees And Shrubs Grow Tall?

In the previous chapter we calculated the net annual growth rate ($NAGR_T$) that has existed since intense browsing began. We also measured the height of previous-year-growth above ground level (H_{pyg}).

We use growth to 2.5 m as a criterion for release, because a retrogressed-type individual continues to be classified as retrogressed until it grows taller than 2.5 m. We calculate the height to release (H_R) by subtracting H_{pyg} from 2.5 m.

The number of years that would be required to grow to release height (y_R) is calculated by:

$$y_R = H_R / NAGR_1$$

Having calculated y_R, the question is: will the shoot survive long enough to grow that tall? This question can be answered in two ways. First, one could determine the maximum lifespan of other shoots growing in the area. If y_R is unreasonably large compared with that lifespan, it is doubtful that the heavily browsed stem will live long enough to grow to 2.5 m.

There is a simpler approach. Dead, intensely browsed primary stems indicate that the heavily-browsed stems do not survive long enough to grow to release height.

Case study

At Site 1 of the sample area, the average height of previous-year-growth was 115 cm. We calculate the height required to grow taller than 2.5 m (H_R) by:

$$H_R = 250 \text{ cm} - H_{PYG}$$
$$H_R = 250 \text{ cm} - 115 \text{ cm}$$
$$H_R = 135 \text{ cm}$$

We calculate the number of years required to grow to 2.5 m by:

$$y_R = H_R / NAGR_1$$
$$y_R = 135 \text{ cm} / 4.9 \text{ cm} / y$$
$$y_R = 28 \text{ y}$$

y_R for sites 2 and 3 were calculated to be 43 and 35 years respectively.

Many shrubs in the 0.5 - 1.5 m size class contained dead, intensely browsed primary stems. At the present growth rate, it does not seem likely that a primary stem could survive long enough to grow to 2.5 m tall.

Unless browsing level changes, the willow community will eventually consist of short heavily-browsed shrubs. The question is how much time will elapse before that occurs?

Estimating The Rate Of Decline In Structural Diversity

Consider the situation on the Wisdom District. At some time about 1991-1992, browsing intensity increased from light-to-moderate to intense. Some Geyer willow had grown taller than 2.5 m. But with a net annual growth rate ranging from 4-to-5 cm/y, it seems unlikely that willows in the 0.5 - 1.5 m size class will reach 2.5 m tall.

As the taller willows die, the structural diversity of the site will diminish. The willow component will then be limited to diminutive hedges. The rate at which structural diversity declines is determined by the longevity of tall willows present at the site. How long will the tall plants survive?

Tall coarse-barked trees may be relatively insensitive to the direct impact of browsing. Certain willows, such as Bebb willow, also develop a coarse bark. Individuals that are old enough to have coarse bark when intense browsing begins may survive for many decades. In these

cases, maturity confers a degree of protection from browsing.

But in the case of the typical willow growth habit where the shrub consists of many stems, maturity of the shrub may hasten the decline of structural diversity in the presence of intense browsing.

The rationale for the above interpretation is as follows. The stems of most willows are relatively short-lived. A shrub persists as an entity because older shoots are replaced by younger ones as they die. Tall shrubs can withstand intense browsing for several years. While ungulates may kill young shoots that emerge at the periphery of the shrub, young shoots in the middle are mechanically protected from browsing.

Young shoots may readily develop within the interior of a young, sparsely-stemmed shrub. But with age, the interior may become crowded and young stems may not be able to grow within the protective confines of the older stems. Shoots that develop along the less-crowded periphery are killed by browsing.

We are not aware of research that documents the lifespan of heavily-browsed willows and so we cannot estimate longevity in years. But if most of the tall willows on heavily browsed site are old and decadent, the conversion to a short-statured willow community may occur in the near future.

Summary Of Sample Area Condition

The condition of Sample Area 1 can be briefly summarized.

1. Douglas fir has been light-to-moderate browsed for several decades.

2. The record of aspen browsing extends from about 1865 to the present . Aspen was light-to-moderately browsed until the mid-1980s, after which, browsing increased to intense.

3. Geyer willow is currently intensely browsed. The intense browsing began about 1991.

4. The average net annual growth rate during the present period of intense browsing has been 4.0 cm / year. At that growth rate, the Geyer stems sampled in this survey will require an average of 35 years to grow to the release height of 2.5 m. Geyer stems do not live that long.

5. Unless conditions change, tall willows will be replaced by short hedges. Ultimately the willow component may be eliminated.

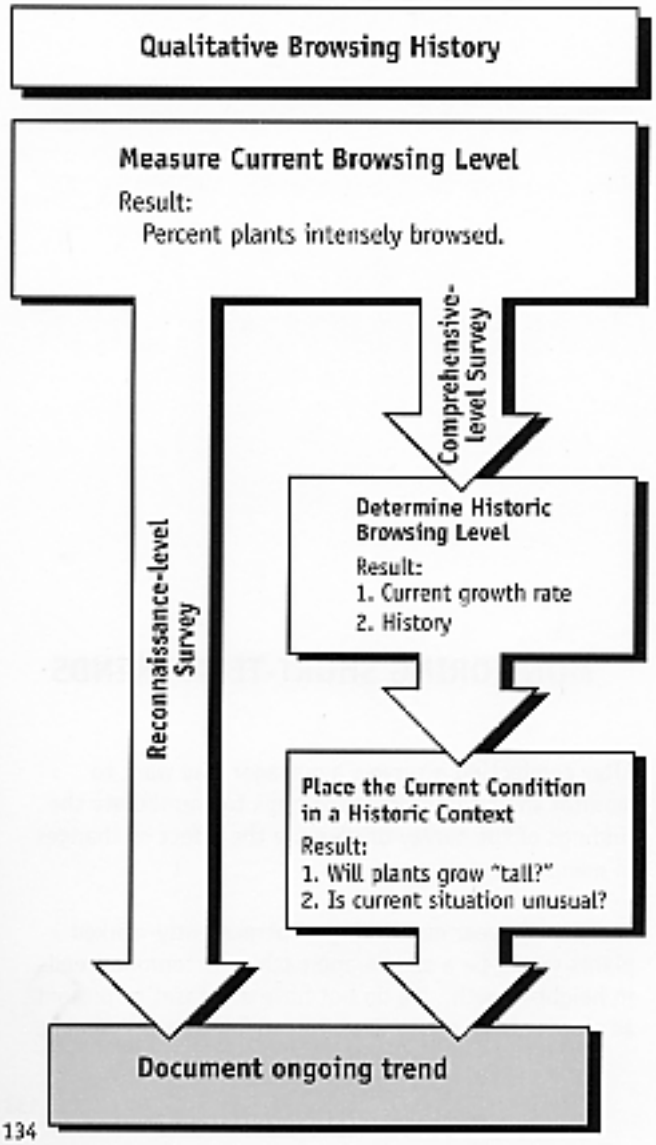
CHAPTER 8

MONITORING SHORT-TERM TRENDS

After conducting a survey, a manager may want to monitor short-term trends, perhaps to corroborate the findings of the survey or measure the effect of changes in management.

The year-by-year monitoring of permanently-marked plants would be a simple approach to determine trends in height-growth. We do not have a dataset to present as a case study, so we describe a hypothetical example.

BROWSE SURVEY SEQUENCE



A Hypothetical Case Study

An area was surveyed in the year 2006 and, as a result, the stocking rate was reduced prior to the following growing season. The survey indicated that intense browsing began in the year 2000 and that the average NAGR from 2000 through the year 2006 was 4 cm / y.

Plants were measured for H_{pvt} and permanently marked so they could be measured in subsequent years. As we are primarily interested in whether or not the plant is growing to typical stature, we would measure the tallest stem of the shrub. As a result, we may not measure the same stem each year.

Note that these are not the same stems that were classified during the survey. Those stems were cut and sectioned.

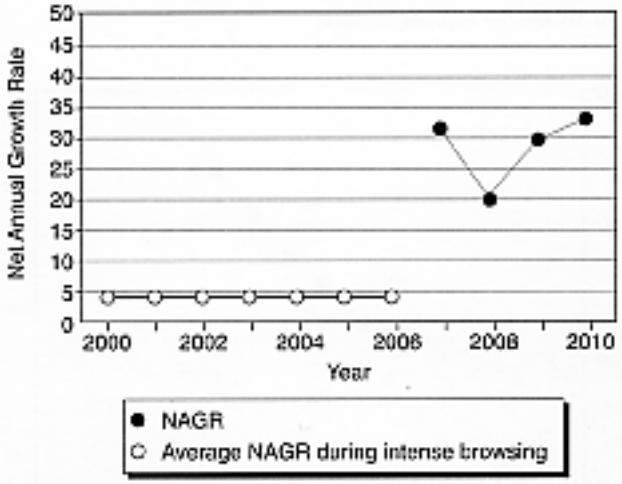
The hypothetical dataset is presented on the following page as it would appear in a spreadsheet. For the sake of clarity we limit the example to three plants; in practice one would use more samples.

The first column displays the year in which the data were taken. The next three columns labeled A, B, and C represent the plants from which the data were recorded. The next three columns were used to calculate the net annual growth rate (NAGR) for the respective plant. NAGR was calculated by subtracting the height in one year from the height in the preceding year. As a result, the year 2006 cells in the NAGR columns are blank. The right-most column was used to calculate an average NAGR for each year.

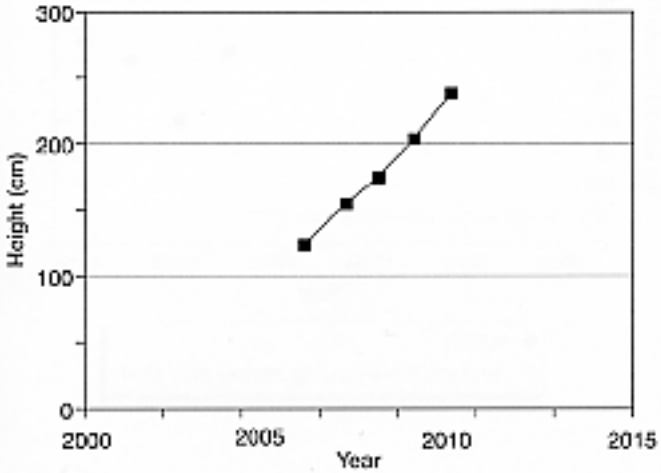
	PLANT HEIGHT			GROWTH RATE			
Year	A	B	C	A	B	C	Average NAGR
2006	75	120	170				
2007	100	150	210	25	30	40	32
2008	120	180	220	20	30	10	20
2009	140	210	260	20	30	40	30
2010	170	240	300	30	30	40	33

The growth rate data are presented in the graph on the adjacent page. The growth rate of 4 cm / y from the year 2000 - 2006 was the $NAGR_1$ determined during the comprehensive-level survey. The NAGR values from 2007 - 2010 were the annual average values measured during the short-term monitoring program.

From this graph it is apparent that the change in management affected growth rate. With values ranging between 20 and 30 cm, it seems quite likely that the shrubs in this stand would grow to typical stature.



Alternatively, one could plot the average height that was measured each year. Such a graph is shown below. However, height data will be biased by the plants that are selected. For example, if short plants (say 50 - 75 cm tall) had been selected for repeat monitoring, the corresponding average values would be lower. But the graph should still indicate whether or not the management is likely to result in the growth of trees and shrubs to typical stature.



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APPENDIX I

METRIC CONVERSION

1 m = 39.4 in = 3.281 ft
1 cm = 0.4 in

1 ft = 0.3048 m
1 ft = 30.5 cm
1 in = 2.54 cm

The following metric values were used in this book:

6.0 m = 20.0 ft
2.5 m = 8.2 ft
1.5 m = 4.9 ft
0.5 m = 1.6 ft
0.1 m = 0.3 ft

20 cm = 7.9 in
75 cm = 30.0 in

APPENDIX II

ARCHITECTURE SYMBOLS

Trees

Uninterrupted-growth type .....

Arrested-type .....

Retrogressed-type .....

Released-type .....

Shrubs

Uninterrupted-growth type .....

Arrested-type .....

Retrogressed-type .....

Released-type .....

APPENDIX III

SYMBOLS AND FORMULAS USED IN THIS BOOK

Symbols

A_c	Age of twig cluster (page 101)
A_s	Age of stem (page 101)
AGR	Annual growth rate (page 109)
D_I	Duration of intense browsing (page 103)
$D_{L/M}$	Duration of light-to-moderate browsing (page 112)
H_{cyg}	Height to current-year-growth (page 109)
H_{pyg}	Height to previous-year-growth (page 110)
L_c	Length of cluster (page 111)
NAGR	Net annual growth rate (page 110)
$NAGR_I$	Net annual growth rate during period of intense browsing (page 113)
$NAGR_{L/M}$	Net annual growth rate during period of light-to-moderate browsing (page 112)
Y_E	Year segment was a terminal leader (page 96)

Y_I Year intense browsing began (page 104)

y_R Number of years required to grow to 2.5 m tall (page 128)

Duration Formulas

$D_I = A_L - 2$

$D_{I\backslash N} = (A_L - A_C) + 1$

Growth Rate Formulas

$AGR = H_{avg} / A_L$

$NAGR_{I\backslash N} = (H_{avg} - L_C) / D_{I\backslash N}$

$NAGR_I = L_C / D_I$

Date Formulas

Y_E = Collection year - Annual rings + 1

Y_I = Collection year - A_C + 2

Y_I = Collection year - D_I

$y_R = H_R / NAGR_I$

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