Multiple Factors Affect Aspen Regeneration on the Uncompahgre Plateau, West-Central Colorado

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***Abstract**—In 1996, I inventoried over 90 aspen stands in 12 timber sales that had been clearcut >3 years previously. Units that regenerated adequately were larger, had higher slope angles, and had soils with a thick Mollic surface layer. Units that regenerated inadequately often had plant species that indicated high water tables. The factors associated with inadequate regeneration were high water tables, heavy browsing, soils with a thin Mollic surface layer, and logging practices that compact large portions of the unit. One of these factors alone often does not lead to inadequate aspen sprouting. Most often, inadequately regenerated aspen stands have two or more negative factors, so the factors act as cumulative stressors on aspen. It is important for managers to know soils, landforms, history, and behavior of animal populations in the area.*

Introduction

Aspen (*Populus tremuloides* Michaux[2]) grows in clones that form relatively distinct 1–3 ha (2–7 acres) groves of trees, all with the same genotype (Gullion 1985; Shepperd 1993a). Within such a stand, aspen reproduces entirely from root suckers. There is effectively no reproduction from seed, so clonal characteristics are more important than individual stem characteristics. Each stem is considered a ramet of the genet, embodied by the entire clone (Shepperd 1993a). Clones (genotypes) may differ in branching, stem color, phenology, and decay characteristics (Wall 1971).

As many as 50 to 100 stems may be connected by a single root system of as much as 17 m (56 ft) radius (Tew and others 1969; Tew 1970; Schier 1973; Schier and Zasada 1973), and these connections may persist for at least 15 years following a stand-replacing disturbance (Shepperd 1993a). Many complex, interrelated factors influence aspen regeneration. It is often not possible to separate the influences on aspen regeneration or to assign events such as a poor sprout crop to one or a few factors (Hildebrand and Jacobi 1990; Jacobi and others 1998). This paper explores these factors and presents a study conducted on the Uncompahgre Plateau in western Colorado.

Sprouting

Aspen sprouting is stimulated primarily by release from hormonal suppression; clearcutting does this nicely (Patton and Avant 1970; Hungerford 1988). Another primary factor, recently documented, is the thickness of the Mollic surface layer in the soil (Cryer and Murray 1992). In short, a Mollic surface layer is an upper layer (or layers) that is dark and organic-rich. In soil inventory, a Mollic surface layer >18 cm (>7 in) thick is called a *Mollic Epipedon*; in some soils, a thicker layer may be required before this term can be used (Soil Survey

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[2]Plant species names after Weber and Wittmann (1996).

Staff 1998). In the following discussion, I have used the term "Mollic surface layer" generally to apply to a dark, organic-rich surface layer of any thickness.

Many of the small sprouts in the understory of an aspen canopy are suppressed, and some of these will remain suppressed even if part of the canopy is removed. However, other small sprouts will release and grow to reach the new canopy or form another, lower canopy.

Because the implications of clonal growth and vegetative reproduction of aspen were not well understood by past authors, readers must use caution when interpreting older literature. In particular, the small sprouts in the understory of a mature aspen stand were incorrectly termed "reproduction," though they will never reach the overstory. For examples of such errors, see Dayton and others (1937) and Houston (1958).

The number of aspen sprouts decreases exponentially from the time of the disturbance that stimulated sprouting (figure 1; Crouch 1983 and 1986; Johnston and Hendzel 1985; Shepperd 1993a). Injuries to aspen sprouts can be caused by animals browsing the terminal leader, by the weight of snowpack, by trampling, by diseases, or by pocket gophers (Marston and Julander 1961; Smith and others 1972).

Hildebrand and Jacobi (1990) studied aspen regeneration failure after treatment in several sites in the Central and Southern Rocky Mountains. They documented failure of aspen regeneration associated with herbivore browsing pressure, greater than normal site moisture, and smaller cutting unit sizes. They also mentioned weather conditions—especially heavy snowpack and drought—as factors negatively influencing reproduction. They used several plant species as indicators of high water tables, notably cornhusk lily (*Veratrum tenuipetalum* Heller).

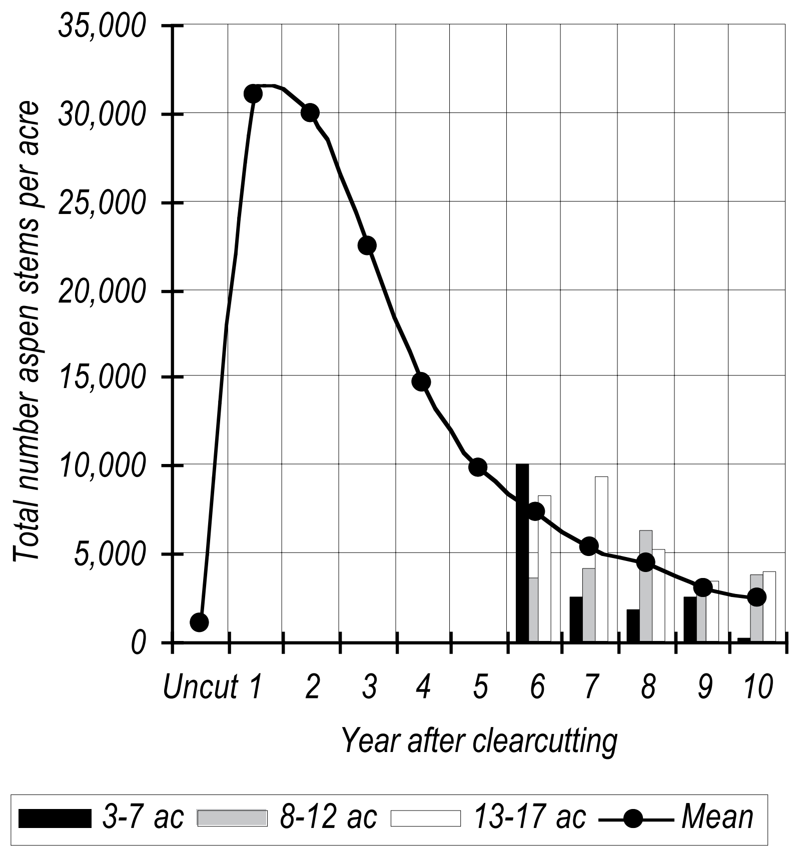

Figure 1—Number of aspen sprouts each year for 10 years following clearcutting in patches of several sizes (data from Crouch 1983 and 1986).

Jacobi and others (1998) focused on aspen regeneration failure on seven sites in western Colorado. They used two scenarios to describe aspen regeneration failure at their sites:

1. On moist sites, aspen root mortality occurs from excess soil moisture after deep, late spring snow packs, followed by summer drought, "predisposing aspen trees to infection by canker pathogens."
2. On dryer sites, drought conditions in spring and the following summer "predisposed aspen to infection by canker pathogens." At two sites, portions of the sites with poor regeneration had poor soil drainage at lower depths; there, shallow aspen rooting contributed to the drought stress.

In Minnesota, unexpectedly few root suckers sometimes develop following summer clearcutting (Bates and others 1998). Part of the absence may be assigned to clearcutting in the summer, when root carbohydrate reserves are low. In their growth chamber study, the authors documented a different contributing factor: reduced soil aeration following logging on poorly drained soils.

Big Game Use

The aspen stands in the study area are commonly used by elk and deer as summer range, providing forage, browse, and cover (Hess and Alexander 1986). Only two of the units inventoried were close to deer and elk winter range; most of the units were summer range.

After a stand is cut or burned, browsing by elk and other big game can eliminate a sprout crop completely, reduce the survival of sprouts to the depth of snow accumulation, or damage all sprouts so that all trees in a clone will have poor form for a long time (Krebill 1972; Komárková and others 1988; Romme and others 1995; White and others 1998; Suzuki and others 1999). Differences in protein content may cause the aspen trees in some clones to be browsed by elk more than others (McNamara 1973).

Elk use aspen stands preferentially and heavily after prescribed fire creates a sprout crop (Basile 1979; Canon and others 1987), but actually elk prefer serviceberry (*Amelanchier alnifolia*) over the aspen (Canon and others 1987). As Sampson (1919) suggested for cattle, when aspen sprouts in openings are destroyed so that a commercial stand cannot form, such destruction is an indicator of too many elk. Elk also eat blue wildrye (*Elymus glaucus*), asters, geranium, and meadow-rue (*Thalictrum fendleri*), common plants in aspen stands (Canon and others 1987).

Mule deer also browse aspen sprouts, but the effects are not as severe, because deer do not concentrate in such large numbers and apparently do not prefer aspen sprouts as much as elk do. However, deer can have significant effects in small areas (Smith and others 1972). Sprout crops disappear quickly if more than one species is browsing, such as cattle and deer together (Smith and others 1972), or if soils are light-colored, or if water tables are high in addition to browsing (Jacobi and others 1998).

Elk often gnaw the bark of mature aspen trees, which is sometimes unsightly but rarely fatal. Mortality or poor form in aspen caused by big-game browsing is usually a combination of browsing with other factors such as pathogenic fungi or injurious insects (Krebill 1972). The severity of browsing effects depends on how many animals use the area and for how long.

Livestock Use

Forage production ranges from moderate to high when stands are undepleted by continual herbivore use. Continued grazing reduces productivity markedly. Live understory vegetation production on aspen range in undepleted condition can range from 2,500 to 3,500 lb/ac/yr; in poor condition, 900 to 1,200 lb/ac/yr; and in depleted condition, 150 to 400 lb/ac/yr (Turner[3], Hess and Alexander 1986).

Cattle will use aspen stands near openings, either natural or human-made, much more than interior aspen stands. Aspen stands <0.3 km (<0.2 mi) from an opening may get used, depending on the quantity of forage left in the opening. Sheep, which can be herded to interior stands, can make more use of them than cattle.

Most of the species in aspen stands that are palatable to livestock are forbs. A few are shrubs, but there are relatively few palatable graminoids. Houston (1954) devised a range condition rating based on six criteria: four groups of plant species, soil cover (vegetation plus litter), and evident indicators of erosion. Another criterion he uses, "presence of aspen reproduction," is inappropriate given what we now know about clonal aspen reproduction processes.

Aspen sprouts are palatable to livestock, which can result in loss of some sprouts in regenerating clearcuts (Larson 1959). Sampson (1919) suggests that on aspen clearcuts in cattle range, if the aspen sprouts have been destroyed so that a commercial stand will not be formed, then the "range has been stocked beyond its normal carrying capacity." I suppose the same would apply to use by elk. In parts of Alberta, where aspen invades rangeland and reduces grazing capacity, "a single late grazing [by cattle] eliminated aspen regeneration" (Fitzgerald and Bailey 1984; also see Jones 1983 and Fitzgerald and others 1986).

Timber management and range management should be coordinated to ensure that aspen regeneration crops are not lost. Livestock damage is mostly (90%) due to browsing but also occurs because of trampling and rubbing (Sampson 1919). Size of treatment blocks (pastures, clearcuts, burned patches) is critical, with the very small blocks usually not surviving because of concentration of animal use (Mueggler and Bartos 1977).

Materials and Methods

In June, 1996, I was asked by the Grand Mesa, Uncompahgre, and Gunnison National Forests to conduct a regeneration survey of aspen stands in selected timber sales on the Uncompahgre Plateau in west-central Colorado (figure 2). The timber sales and stands had been selected because they were not meeting standards for aspen regeneration; the purpose of my work, then, was to determine why these stands were not meeting the standards. As part of my investigation, I noticed many aspen stands (other than the ones reported below) that were obviously meeting the standards. Since this study over-sampled stands that did not meet standards, the results reported below do not represent the true proportion of units and acres not meeting the standards. This study was designed to show those factors that lead to inadequate aspen sprouting.

Most of the aspen stands had not been surveyed for aspen regeneration before. Most of these stands had been cut for harvest 3–6 years previously, although some were as old as 13 years. Mostly they had been clearcut, especially the more recent cuts. The stands I was asked to survey were in 12 timber sales, all but three of which were on the Uncompahgre Plateau, a large northwest-to-southeast plateau in west-central Colorado, on the Ouray and Grand Junction Districts of the Uncompahgre National Forest. The other three sales were on the south slopes of the Grand Mesa, on the Paonia District of the Gunnison National Forest.

[3]Turner, George T. 1951. Evaluation of range watershed conditions of aspen and mountain grassland types in western Colorado. Unpublished Office Report, Typescript, 19 p.

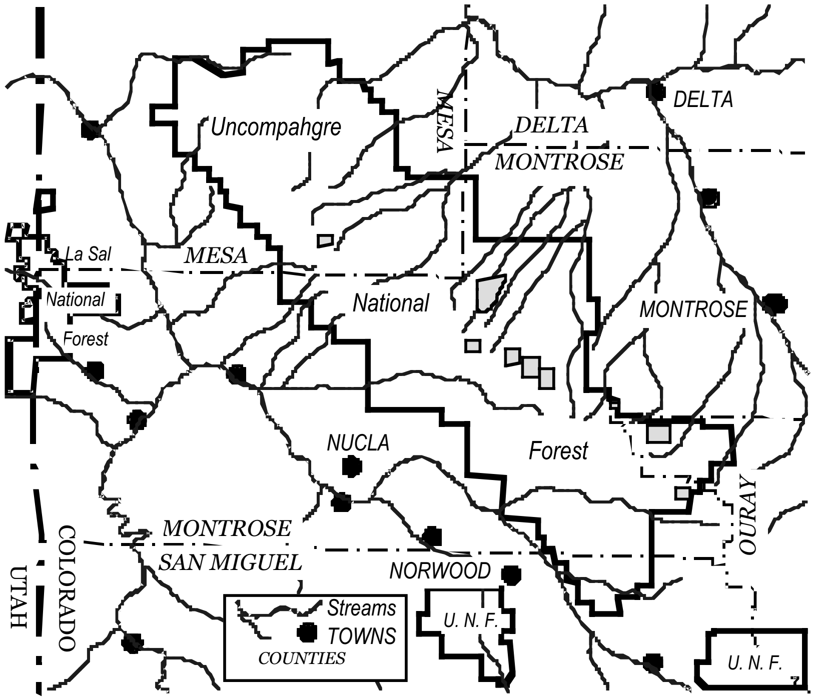

Figure 2—The Uncompahgre Plateau, the Uncompahgre National Forest, and the location of the timber sales studied. Study areas are in gray.

Before inventorying each clearcut, called a *unit* in timber sale terminology, I estimated the acreage of the unit. In each unit, I located three or more points methodically, usually by means of one or more parallel lines of equidistant points. The number of points in a unit was determined by the acreage of the unit: the minimum of three points was used for units of 0–4 acres, and one point was added for each additional 5 acres. The points were spaced at a regular interval from one another in multiples of 80 ft. Centered at each point was a 0.002-acre (0.0008 ha) circular plot. Within the plot, I tallied all tree stems (live or dead) by diameter and condition class.

For each group of trees within a plot with like characteristics, I recorded tree status (growing stock, cull, or dead); species; diameter at breast height (d.b.h., inches); total height (feet); tally; apparent age (years); and apparent damage-causing (or death-causing) agent. I used a form from the most recent appropriate handbook (USDA Forest Service 1993b).

For each unit (cut block) I recorded size (acres), shape, and location by means of a sketch map on which I located the sample points. I located each unit on an appropriate quadrangle map and on the maps for the recent soil survey (Hughes and others 1995). I observed and recorded signs of animal use, such as droppings, tracks, elk wallows, or cattle watering places. Often the animals themselves were observed, and I was able to also observe them eating aspen sprouts.

Calculations and Analysis

I determined whether each sample point was considered to be *stocked* according to the Forest Plan (USDA Forest Service 1993a). The Forest Plan standard that needed to be met was 1,200 stems per acre of growing stock (GS) stems, which are live, noncull stems (figure 3). In order to meet this standard, the plot at each point needed to have three or more live, non-cull stems. A *cull* stem is live but estimated to be incapable of forming an 8-foot log at maturity. Usually, they are more than two-thirds defective (from disease or damage), they

Figure 3—An example of abundantly adequate aspen regeneration in a medium-sized unit at a reasonable slope angle on good soils, with moderate livestock pressure. Harvested by clearcutting in 1988, 8 years before the photo was taken. Unit is 10 acres, on a 17% slope at 9,520 ft. Soil Map Unit 22, good for aspen regeneration. 6,700 growing stock stems/ac, growing 0.73 ft/yr, 100% of points stocked. Picture looking 350º magnetic (NNW), July 24, 1996.

have a dead top, or they are too deformed to compete in the canopy (USDA Forest Service 1993b).

I calculated number of growing stock stems per acre using:

$$G_a = \frac{G \times 500}{P}, \quad [1]$$

where G_a is growing stock stems per acre, G is the sum of growing stock stems counted, and P is the number of points in the unit.

Additionally, the forest plan requires that 75% or more of the sample points be stocked. There were some units where the whole unit had >1,200 growing stock stems/ac, yet <75% of their points were stocked; in many of these sites, the distribution of aspen was naturally patchy, coinciding with microsite variations in soils, landform, and water. One can easily visualize those sites being fully regenerated in a few years. For these reasons, I feel that it is better to estimate aspen regeneration success against the >1,200 growing stock stems/ac standard than to use the >75% points stocked requirement. In the following discussion, units are rated as having *adequate sprouting* if there are >1,200 growing stock aspen stems/ac. In my estimation, stands will be fully functional aspen stands for wildlife, watershed, and other values if they are adequate by this definition.

For calculation of the average height of aspen sprouts in a unit, I used the height of the tallest layer of growing stock stems in the plots, averaged across all the plots in the unit. Sometimes I used two layers for a plot if there were few stems in the tallest layer. I used the height of the tallest cull layer if there were no growing stock stems in that plot. I then calculated the average (mean) height of the tallest layers, weighted by the number of stems (tally) for each of those layers.

I used time since the clearcut that stimulated the sprouting as an estimate of age of an unit.

To calculate average slope azimuth for a group of units, I used a circular transformation as described in Zar (1984). First, the aspect *x*- and *y*-coordinates for each unit can be calculated:

$$x_i = (\sin[\alpha \times \frac{180}{\pi}] + 1) \times 100,\ x = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad [2]$$

$$y_i = (\cos[\alpha \times \frac{180}{\pi}] + 1) \times 100,\ y = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad [3]$$

where α_i= azimuth angle associated with measurement i. Then the average radius (r) and average azimuth angle (β) are calculated:

$$r = \frac{\sqrt{\left(\sum x_i\right)^2 + \left(\sum y_i\right)^2}}{100}, \qquad [4]$$

and

$$\beta = \cos^{-1} \frac{y}{r} \qquad [5]$$

The average radius (r) ranges $0 \leq r \leq 1$; $r = 1$ indicates a very tight clustering of azimuths about the average, and $r = 0$ indicates a very loose clustering.

I included data in the data set from a few units that had been surveyed by Les Choy in 1995 from the same sales. For those units, I visually checked the units to make sure the data were still valid in 1996. For data bases, I used Paradox®, Versions 8 and 9 (Corel 2000). To statistically analyze data, I used Statistix®, Version 2 (Analytical Software 1999).

Results and Discussion

For the 113 units in this study, the average unit sampled had 7,010 live stems per acre, of which 3,963 per acre were growing stock stems (table 1). In the units where sprouting was adequate, average height growth was 1.12 ft/yr; in units where sprouting was inadequate, average height growth was only 0.37 ft/yr, less than one-third (table 2).

Units where sprouting was adequate, but in addition >75% of the points were stocked, were larger, had taller sprouts, were on steeper slopes, and had a deeper Mollic surface layer. Interestingly, if a unit had inadequate sprouting, it invariably also had <75% points stocked, but not vice versa.

Slope Angle

In units with adequate sprouting, average slope was 12.5%; but in units with inadequate sprouting, average slope was only 6.4%, about half (table 2). Slope angle was positively correlated with number of aspen sprouts per acre, their height growth per year, and proportion of points stocked (table 3, figure 4), which indicates that slope angle is indeed an important predictor of aspen sprouting in this area, as indicated by Hildebrand and Jacobi (1990). Slope angle was negatively correlated with aspect y-coordinate; this means that northerly slopes are steeper on the Uncompahgre Plateau.

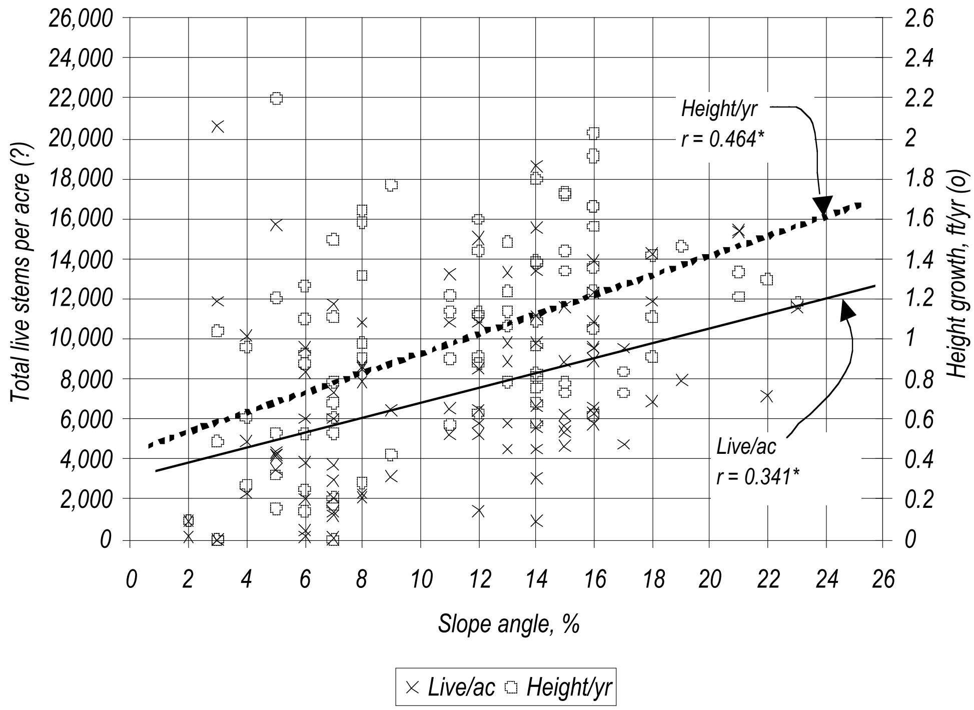

Figure 4—Height growth per year in aspen sprouts and number of live aspen stems per acre, as functions of slope angle. *Significant correlation, *a* <1%.

In all but two of the units with inadequate sprouting, slope angle was <10% (tables 4 and 5). One of these two remains a mystery, and the other was on a wet slope, with evidence of deep snow in winter. Low slope angle indicates that soil water may accumulate seasonally in these sites, in part because many of these sites have plant species indicating seasonally high water tables (table 6). Units with adequate sprouting but where slope was <9% were mostly marginal either in number of growing stock stems or number of points stocked (table 7).

Apparently, high water tables are most detrimental in the first few years following a clearcut, especially in combination with other negative factors such as heavy pressure by browsing animals. I suspect that just one high-water year is sufficient to accomplish complete mortality of an aspen sprout crop, although I saw complete mortality very seldom in this study. Because of natural self-thinning of the aspen sprouts, there is always some aspen sprout mortality, even in the absence of any negative factors. Mortality of all or most of the sprout crop apparently can occur 5 or more years after clearcut, in situations where the stress combination includes both high water table and aspen disease, and both are above some threshold of intensity. The threshold of intensity is probably higher in cases where the sprouts are more than 5 years old than it is in the first few years following the cut.

Browsing and Grazing

Most of the units with inadequate sprouting showed signs of being grazed or browsed heavily or very heavily: nine units by elk and four units by cattle (table 5). If I add units that were grazed moderately heavily by animals, there were 12 units with inadequate sprouting that had been grazed at least moderately heavily by elk, and six units by cattle. There were only two units with inadequate sprouting that were not grazed or browsed at least moderately heavily. This indicates that browsing pressure from animals is an important factor in predicting sprout mortality, but somewhat less important than seasonally high water tables. Both elk and cattle are involved here, but elk were about twice as important as cattle in this area.

Size of Units

Units with adequate sprouting averaged 24.3 acres; but units with inadequate sprouting averaged only 11.8 acres (table 2). Unit acreage is positively correlated with both growing stock stems/ac and percent of points stocked, which indicates that small units more often have inadequate sprouting (table 3).

The effects of heavy browsing or grazing on aspen sprouts are made more severe by units that are small. Small units are much more likely to be objects of concentrated use, especially by cattle, but by elk and deer as well. If the units are surrounded by closed-canopy forest, cattle use may be facilitated by a path through the forest in the form of an old haul road or skid trail. If there are many small units in a local area, the effects of heavy grazing or browsing are lessened, apparently because more forage and browse is available.

Small units are also more likely to have inadequate sprouting, because necessary logging facilities such as roads and landings take up a larger proportion of those units.

Soils

In units with adequate sprouting, average Mollic thickness was 32.3 cm (12.7 in); but in units with inadequate sprouting, average Mollic thickness was only 17.8 cm (7.0 in) (table 2). Mollic thickness is positively correlated with height growth of sprouts and number of points stocked (table 3, figure 5), which indicates that average Mollic thickness is an important predictor of adequacy of aspen sprouting. Average Mollic thickness is also positively correlated with aspect x-coordinate ("easterly-ness"), meaning that soils with a thicker Mollic layer are more often east-facing; this is expected, since winds are predominantly from the west, depositing deeper soil on easterly aspects. The positive correlation between average Mollic thickness and sprout age is probably due to more recent timber sales being located on soils expected to have better aspen sprouting, by conscious design of the timber managers.

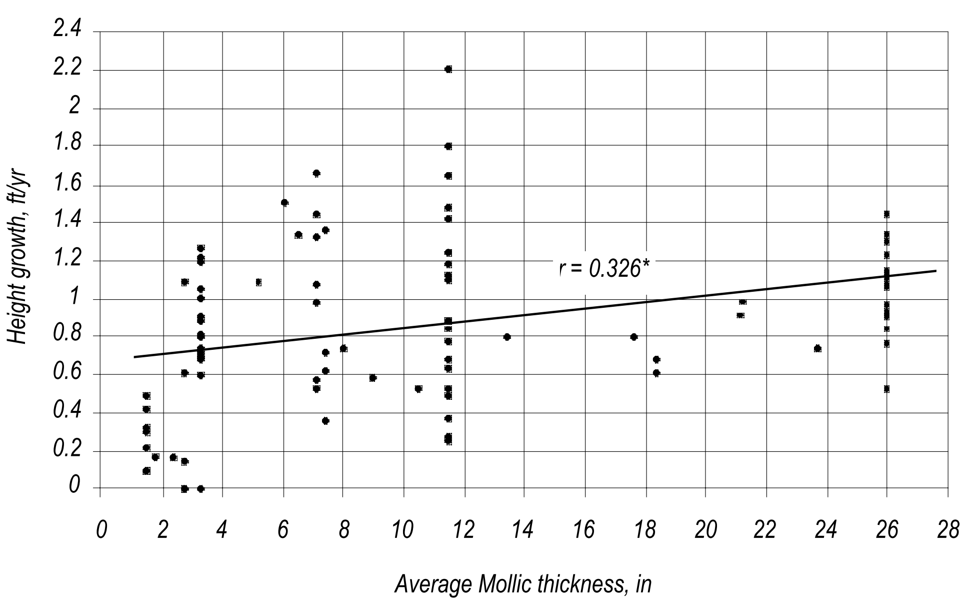

Figure 5—Height growth per year in aspen sprouts as a function of the thickness of the Mollic layer. *Significant correlation, *a* <1%.

Since soils were only superficially sampled for this study, I used the recent soil survey to evaluate soil map units for expected aspen sprouting (table 8; Hughes and others 1995). I used Mollic thickness, soil depth, soil temperature, and soil moisture as reported by Hughes and others (1995) to determine expected aspen regeneration quality for each soil map component (table 9), as implied in Cryer and Murray (1992). Based on table 9, I assigned each soil map unit a rating of "good" or "poor."

In the units with inadequate sprouting, soils were rated as poor for aspen regeneration (table 5). Also, about half of the units that came close to having inadequate sprouting had poor soils for aspen regeneration (table 7). These results confirm that soil is an important factor in determining potential for aspen sprouting.

The results by soil map unit were not as sharp as for unit size, slope, and stem size (table 9). *All* soil map units had adequate sprouting. The only soil map units that have >75% points stocked are 21 (Hapgood-Lamphier) and 22 (Hoosan-Lamphier-Leaps), although soil map units 25 (Lamphier-Hapgood) and 29 (Supervisor-Cebone) come close. These results indicate that soil map unit alone is insufficient for determining sprouting potential, yet soil map unit is still a useful criterion in combination with others.

Inadequate sprouting seems to be most certain with some combination of *more than one* of these negative factors, listed in priority order:

1. Seasonally high water tables, indicated by ≤ 9% slope, wet-site plants, and/or great snow accumulation.
2. Moderately heavy to heavy browsing by cattle or elk, sometimes made worse by small units <4 ha (<10 acres).
3. Soils with Mollic surface layer(s) <18 cm (<7 in) thick.
4. Logging practices that compact larger than normal portions of the unit, such as a large number of lateral haul roads or large, concentrated slash piles or landings. This may be complicated by small units in some places.

That more than one of these negative factors is necessary for inadequate sprouting is consistent with the hypothesis of Jacobi and others (1998) that these factors combine with one another to increase the amount of stress put on the aspen individuals. That is, these negative factors are in fact *stressors* that act additively (figure 6).

The hypothesis that increased stress is put on aspen by more than one negative factor is supported by the data in this study. The units where sprouting is inadequate or nearly inadequate are those where more than one negative factor is stressing the aspen. For sprouting to be inadequate, there could be as few as two negative factors, if those factors are especially intense (figure 7). There needs to be more than two negative factors if they are only moderately intense.

Is the stress of multiple factors brought to bear principally on the individual aspen stem, on the clone, or on some other unit? These data seem to show that stresses act both on the individual stem and on the clone. For example, browsing by animals leads to stress on the individual stems clipped by the animals, which leads to stress on the clone. This is indicated by the finding that live stems are one-third as tall in inadequate units as compared with adequate units. The height difference is likely due to animals browsing, since lightly browsed units have about the same height growth in all soil map units.

Areas where elk or cattle grazing or browsing pressure can be predicted are also at risk, but browsing is not as certain to lead to inadequate sprouting as seasonally high water tables are. Grazing and browsing pressure can usually be

Figure 6—Inadequate sprouting because of high water tables some years after cutting, as one stress factor in combination with the aspen disease Shepherd's Crook. Shepherd's Crook was found in several stands, but rarely was it responsible for significant mortality. Harvested by clearcutting in 1987, 9 years before the photo was taken. There are 2,940 live stems/ac, but only 375 GS stems/ac—most stems are dead or mostly dead culls. Jacobi and others (1998) studied this unit. Unit is 22 acres, on a 7% slope at 9,510 ft elevation. Soil Map Unit 15, considered good for aspen regeneration. Picture looking 291° magnetic (WNW), August 5, 1996.

Figure 7—Inadequate aspen regeneration because of low slope angle, heavy elk browsing, small unit size, and poor soils. Harvested by partial cutting in 1985, 11 years before the photo. Natural openings close by these units had no tree reproduction; in one of these openings, someone had dug a pond for watering animals, which had water in it in late season. It is likely that after 1985, the water table rose during one or more years. 125 GS stems/ac, growing 0.09 ft/yr, 0% of points stocked. Unit is 6 acres, on a 2% slope at 9,160 ft elevation. Soil Map Unit 27, considered poor for aspen regeneration. Picture looking 311° magnetic (NW), July 18, 1996.

predicted by asking the questions: "If a set of aspen clearcuts of a certain size and configuration are placed in a certain place, can we expect heavy use by elk (or deer)? Can we expect heavy use by cattle? Is this combined with other stress factors in the units to be cut?"

Overuse by elk is notable in several of the units in this study. An old timber haul road to several units in this study is now closed to motor vehicles to protect habitat. The elk population in this area has increased dramatically in recent years, and the aspen sprouting is suffering as a result. It is possible that the elk increase is due in part to fewer cattle here because of progressive changes in the management of the grazing allotment. But, the result in this area is that elk are being given preference and allowed to increase in numbers at the expense of aspen sprouting. Some kind of middle ground is desirable, where balance is achieved between elk herds and aspen regeneration, including consideration for other resources.

Browsing by cattle is an important factor in several units as well. For example, consider a unit that is divided into four parts by the pasture fence and the soil line that cross the unit (figure 8, figure 9, table 10). Elk use in this area is apparently at most moderate, even in intensity across all four parts.

In another unit of this study, an animal-proof exclosure was constructed in recent years in about a third of the unit. The fence is intact, and is apparently successful in keeping all herbivores out. In spite of poor soils for aspen regeneration in this unit, the sprouting was abundantly adequate *inside* the exclosure—though the sprouts are distributed in patches (figure 10). Outside the exclosure is an apparent disaster, with very heavy cattle pressure in the past, tapering off in recent years with improved grazing management, to which has been added intense pressure by elk, on soils unlikely to produce sprouting.

Soils that result in successful aspen regeneration can be predicted. Users should begin with a recent soil survey—in this case, Hughes and others 1995—and supplement this with field data as needed. A soil that usually results in poor aspen regeneration is an important negative factor leading to inadequate sprouting, but there are plenty of examples of units in this study that succeeded in spite of unlikely soils. It seems that unlikely soils are most important in combination with one of the other negative factors in high intensity. If a manager wishes to regenerate aspen on an unlikely soil for sprouting, other negative factors should be kept to a minimum such as low slope angles and grazing and browsing pressure. I recommend close coordination of timber management with wildlife and livestock management. Some modification of the previously preferred design may be required, such as changes of location, size, timing, and methods.

Local forest managers have incorporated many of these results into the site location and design of aspen timber sales. It has now become common practice to incorporate detailed soil, watershed, wildlife, and range management information into the location of proposed timber sales, as well as location and design of individual units.

Management of aspen is a multi-dimensional task; success often requires cooperation among many scientific disciplines and groups of partners. There are no substitutes for broad partnerships with common goals, consultation with interdisciplinary teams of scientists, and careful planning.

Figure 8—Fenceline contrast showing adequate aspen regeneration on the right side and very little on the left side. Unit was clearcut in 1987, 9 years before the photo was taken. The fence is a pasture division fence, with heavy grazing pressure (by cattle) on the left and light grazing pressure on the right. Pressure by elk is moderate on both sides, since the fence is a poor deterrent to them. The light line shows the boundary between Soil Map Unit 20, considered poor for aspen sprouting (left) and Soil Map Unit 21, considered very good for aspen sprouting (right). Aspen sprouting is barely adequate in the area left of the fence and right of the line. Circled numbers as in figure 9. Yellow-headed flower in abundance on the left side is orange sneezeweed (*Dugaldia hoopesii*), a noted increaser with livestock use. Picture looking east, July 29, 1996.

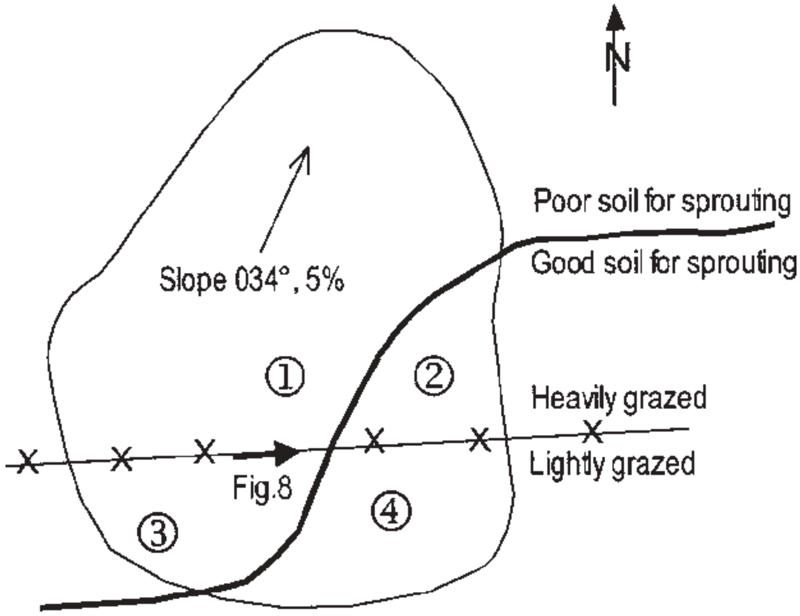

Figure 9—Diagram of Long Creek Sale, Unit No. 3. Photograph in figure 7, numbered zones in table 10.

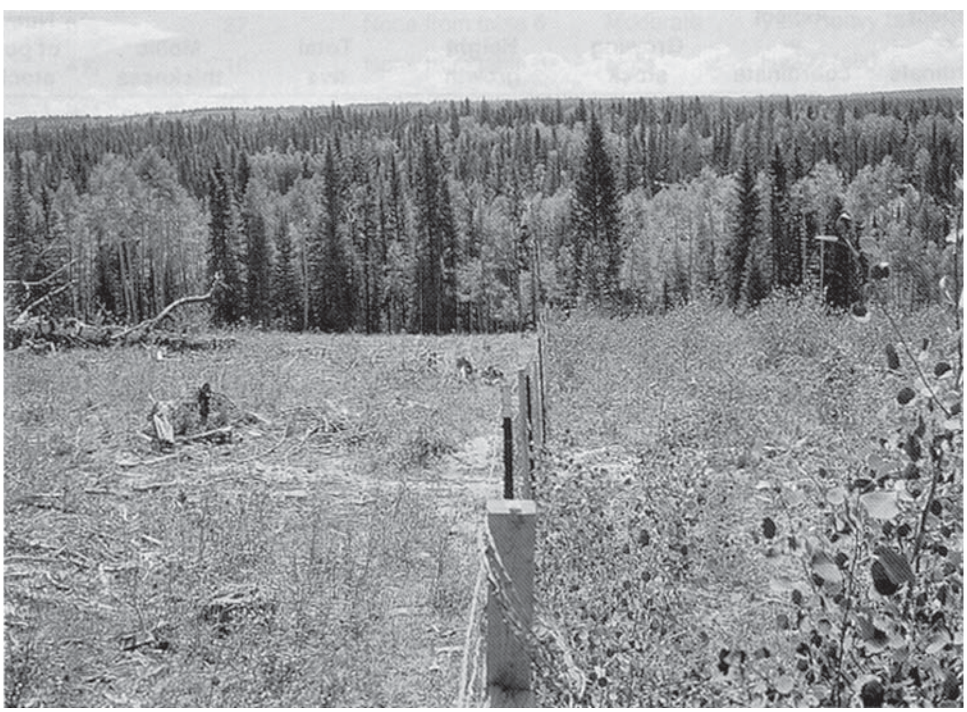

Figure 10—Fenceline in a unit of poor soils, contrasting between heavily grazed and browsed by elk and cattle (right), and protected from grazing and browsing (left). The area to the left of the fence (the exclosure) has been protected from all animal use by this 9-foot fence for the past few years. This unit was clearcut in 1993, 3 years before photo was taken; methods of harvest were designed to meet research objectives, so those methods were not the same as usual. The fence was built as a research demonstration. On the left, protected side, the aspen regeneration is noticeably patchy, but still regenerating successfully, with 11,300 GS stems/ac. On the right, unprotected side, the aspen regeneration is clearly inadequate, with only 670 GS stems/ac. Overall, the unit (including both inside and outside the exclosure) has 4,220 GS stems/ac, but only 56% of the points are stocked. The unit was mapped in Soil Map Unit 29, but by the photo and my observation these soils are light-colored on the surface and probably have poor potential for aspen sprouting. Unit is 30 acres, on a 14% slope at 8,960 ft elevation. Picture looking south-southwest from the northwest corner of the exclosure, August 29, 1996.

Table 1—Summary of aspen regeneration in 113 timber sale units.

	Average age, yr	Percent of points stocked	Growing stock	Live stems
			stems/ac	*per acre*
Averages ± SE	5.82 ± 0.25	64.81 ± 3.10	3,963 ± 300	7,010 ± 418

Table 2—Factors influencing aspen regeneration. Numbers are shown as mean ± Standard Error (*N*), where *N* is number of units (GS = growing stock).

Factor	>1,200 GS/ac and >75% points stocked	>1,200 GS /ac	<1,200 GS /ac and <75% points stocked	All units
Unit size, ac	25.2 ± 1.9 (61)	24.3 ± 1.6 (84)	11.8 ± 1.3 (29)	21.1 ± 1.4 (113)
Slope, %	12.9 ± 0.6 (55)	12.5 ± 0.6 (70)	6.4 ± 0.7 (20)	11.1 ± 0.6 (90)
Mollic thickness, in	13.9 ± 1.4 (42)	12.7 ± 1.1 (64)	7.0 ± 1.3 (29)	10.9 ± 0.8 (93)
Aspect x-coordinate	60.7 ± 4.5 (55)	59.9 ± 4.1 (70)	50.5 ± 7.4 (20)	57.8 ± 3.6 (90)
Aspect y-coordinate	57.8 ± 4.7 (55)	59.5 ± 4.1 (70)	80.2 ± 5.3 (20)	64.1 ± 3.5 (90)
Age, yr	5.5 ± 0.3 (61)	5.6 ± 0.3 (84)	6.3 ± 1.3 (29)	5.8 ± 1.4 (113)
Height growth, ft/yr	1.20 ± 0.05 (61)	1.13 ± 0.04 (84)	0.42 ± 0.05 (28)	0.95 ± 0.05 (113)

Table 3—Selected correlation coefficients: units for which aspect, slope, and soil are known. *N* = 70.

	Age	Aspect x-coordinate	Aspect y-coordinate	Growing stock	Height growth	Total live	Mollic thickness	Number of points stocked
				stems/ac	*ft/yr*	*stems/ac*	*inch*	
Aspect x-coordinate	–0.006							
Aspect y-coordinate	**0.235**	–0.116						
Growing stock, stems/ac	–0.054	0.089	0.008					
Height growth, ft/yr	–0.223	–0.018	–0.179	**0.516***				
Total live stems/ac	**–0.315***	–0.007	0.012	**0.670***	**0.412***			
Thickness Mollic layer, in	**0.374***	**0.284**	–0.200	0.159	**0.326***	0.020		
Number of points stocked	–0.070	0.024	–0.104	**0.806***	**0.630***	**0.703***	**0.279**	
Slope, %	0.020	–0.052	**–0.321***	**0.340***	**0.464***	**0.341***	**0.374***	**0.435***

Bold–Significant at 5%. **Bold***–Significant at 1%.

Table 4—Selected correlation coefficients: units surveyed in 1996. *N* = 90.

	Growing stock	Age	Percent of points stocked	Unit	Acres with inadequate sprouting
	stems/ac	*yr*		*acres*	
Age, yr	–0.290				
Percent of points stocked	**0.783***	**–0.236**			
Unit acres	**0.298***	0.025	**0.362***		
Acres with inadequate sprouting	**–0.515***	0.172	**–0.695***	–0.180	
Acres with adequate sprouting	**0.443***	–0.039	**0.562***	**0.938***	**–0.511***

Bold–Significant at 5%. **Bold***–Significant at 1%.

Table 5—Factors in units that had <1,200 growing stock stems/ac and <75% points stocked.

Unit	Slope angle(s)	Unit acres	Plant species from table 6 conspicuous	Cattle grazing/ browsing	Elk or deer grazing/ browsing	Soils for aspen regen.[a]	Comments
1, 2, 3	2%, 2%, 5%	6, 8, 5	PEFL15, ABBI2–dead saplings	Moderate	Very heavy (elk)	Poor	Natural openings with ponds in area; major elk range; poor soils
4, 5	3%, 8%	6, 9	BRAR	Heavy	Light	Poor	Much human activity, open road through units; poor soils
6, 7, 8, 9, 10	7%, 5%, 8%, 9%, 7%	8, 10, 16, 8, 12	ABBI2-dead saplings, AGROS2	Moderately heavy	Moderately heavy (elk)	Poor	Elk activity heavy in some units; poor soils
11	4%	21	LIPU6, HESP6, SESE2	Light	Heavy (elk)	Poor	Poor soils
12	3%	10	LIPU6, HESP6, SESE2	Heavy	Moderately heavy (elk)	Poor	See comments for Unit 15; poor soils
13	12%	13	HESP6	Light	Moderate (elk)?	Good	The only mystery yet remaining
14	7%	22	VETE4	Light	Moderate (elk)?	Good	Documented site: death of sprout crop from combined high water and shepherd's crook (Jacobi and others 1998)
15	7%	32	None from table 6	Heavy	Moderately heavy (elk)	Poor	This and unit 12 are the only openings in heavily grazed cattle range; poor soils
16	14%	7	VETE4, SESE2, CAUT, SALU2	Moderately heavy	Heavy (elk)	Good	Slump blocks, scarps, ponds common in and around unit; snow depths considerable, snow damage common
17	7%	4	None from table 6	Moderate	Heavy (elk)	Good	Much mortality and cull damage from shepherd's crook
18	6%	27	None from table 6	Moderate	Very Heavy (elk)	Good	Major elk range
19	4%	10	None from table 6	Light	Heavy (elk)	Poor	Major elk range; poor soils
20	6%	10	None from table 6	Moderate	Heavy (elk)	Mostly poor	Major elk range; heavy, mostly (2/3) poor soils

[a]Rating according to the criteria in table 9.

Table 6—Plant species indicating seasonally high water tables.

Code[a]	Growth form	Species name[b]	Common name
ABBI2	Sapling	*Abies bifolia* (*A. lasiocarpa*)	Subalpine fir, saplings dead from high water (poor form, twisted, many lower branches)
AGROS2	Grass	*Agrostis* species	Bentgrasses
CACA4	Grass	*Calamagrosis canadensis*	Bluejoint reedgrass
CAUT	Grasslike	*Carex utriculata*	Beaked sedge
BRAR	Forb	*Breea arvense*	Canada thistle
DECE	Grass	*Deschampsia cespitosa*	Tufted hairgrass
HESP6	Forb	*Heracleum sphondylium*	Cow-parsnip
LIPU6	Forb	*Ligularia pudica*	Groundsel
PEFL15	Shrub	*Pentaphylloides floribunda*	Shrubby cinquefoil (called potentilla in trade)
SALU2	Shrub	*Salix lutea*	Yellow willow (and other shrub willows)
SESE2	Forb	*Senecio serra*	Butterweed groundsel
VETE4	Forb	*Veratrum tenuipetalum*	False-hellebore, cornhusk lily (sometimes called skunk cabbage in error)

[a]After USDA Natural Resources Conservation Service (1997).
[b]After Weber and Wittmann (1996).

Table 7—Factors in units that had >1,200 growing stock stems/ac but were <9% slope angle.

Unit	Slope angle(s)	Unit acres	Plant species from table 6 conspicuous	Cattle grazing/ browsing	Elk or deer grazing/ browsing	Soils for aspen regen.[a]	Comments
A, B	7%, 5%	18, 12	BRAR, DECE, CACA4	Moderately heavy	Light	Poor	Poor soils mostly; both units close to inadequate
C	4%	11	None from table 6	Moderate	Moderate (elk)	Good	Some conifers left; compaction by timber haul roads—no aspen sprouting there
D	5%	7	POTR5—this year's sprouts	Moderately heavy	Moderately heavy (elk)	Poor	Poor soils; unit close to inadequate
E	5%	10	None from table 6	Very heavy (2/3 of unit)	Moderate (elk)	Good	Pasture division fence separates heavily grazed cattle pasture (lower 2/3 of unit) from lighter-grazed pasture; line between good/poor soils also divides unit; most of unit (lower 2/3) inadequate, especially number of points stocked
F, G	8%, 7%	90, 45	VETE4, BRAR, ABBI2—dead saplings	Heavy only around edges, light in middle	Light	Good	Large units; compaction from timber haul roads and slash piles, especially in unit G; unit F is great success, unit G obviously success outside roads and slash piles
H, I	7%, 6%	60, 60	None from table 6	Moderately heavy	Heavy (elk)	Good	Logging design included too many lateral haul roads, increasing area compacted and reducing aspen sprouts; both units close to inadequate on number of points stocked
J	7%	33	None from table 6	Light	Heavy (elk)	Poor	Elk use is on tops of tall sprouts; elk were standing on snow; Poor soils
K, L	6%, 6%	16, 9	None from table 6	Heavy	Heavy (deer and elk)	Good	Low-elevation sites, near deer-elk winter range; unit L inadequate in number of points stocked
M	8%	36	None from table 6	Heavy only at edges	Heavy (deer and elk)	Good	Low-elevation sites, near deer-elk winter range
N	6%	5	None from table 6	Light	Heavy (elk)	Poor	Small unit, 5 ac; many conifers left; shepherd's crook in sprouts; poor soils
O, P	5%, 3%	8, 12	PEFL15, DECE, VETE4	Light	Light	Poor	Small units, 8-12 ac; shepherd's crook conspicuous in sprouts; poor soils
Q	8%	32	None from table 6	Moderate to heavy	Moderately heavy (elk)	Both	East ½ is nearly flat, with heavy cattle pressure and poor soils, poor sprouting; west ½ is 16% slope, light cattle pressure, moderately heavy elk pressure, good sprouting
R	3%	38	ABBI2—dead saplings	Light	Heavy (elk)	Poor	Many sprouts bent with snow damage; poor soils

[a]Rating according to the criteria in table 9.

Table 8—Summary by Soil Map Unit.

SMU[a]	No. units	Acres	Points stocked	Growing stock	Total live	Average height	Height growth	Slope
				stems/ac	*stems/ac*	*ft*	*ft/yr*	*%*
13 & 15	3.0	44.0	52.5%	1,938	3,944	5.9	0.7	10.8
20	11.3	214.9	52.1%	2,875	5,247	4.2	0.7	8.6
21 & 22	8.6	206.8	83.5%	4,971	7,923	6.5	0.9	11.0
25	11.2	354.5	72.5%	3,475	5,006	12.6	1.1	12.0
27	8.5	104.3	47.6%	1,816	9,278	2.0	0.4	5.7
29	30.1	684.5	71.2%	4,391	8,583	5.1	1.0	9.2
31	20.4	245.0	58.3%	3,183	6,651	3.8	0.9	3.1

[a]See table 4 for explanation of the Soil Map Unit codes, from Hughes and others 1995.

Table 9—Assignment of Soil Map Units to aspen regeneration classes.

SMU	Soil component	Taxonomic class	Mollic thickness	Aspen regeneration	Comments
			inch		
	Chilson	Lithic Argiboroll, Clayey, Mixed	5	Poor	Very clayey, shallow
13	Delson	Typic Argiboroll, Fine, Montmorillonitic[a]	11	Moderate	Very clayey, warm
	Beenom	Lithic Argiboroll, Loamy, Mixed	8	Poor	Clayey, shallow
	Delson	Typic Argiboroll, Fine, Montmorillonitic[a]	11	Good	Very clayey, warm
15	Kubler	Pachic Argiboroll, Fine, Montmorillonitic[a]	33	Very good	Very clayey, warm
	Showalter	Aridic Argiboroll, Clayey-Skeletal, Montmorillonitic[a]	11	Good	Very clayey, warm, dry
20	Gralic	Typic Cryorthent, Loamy-Skeletal, Mixed, Nonacid	<2	Poor	Shallow
	Grenadier	Dystric Cryochrept, Loamy-Skeletal, Mixed	4	Mostly poor	Shallow and cold
21	Hapgood	Pachic Cryoboroll, Loamy-Skeletal, Mixed	17	Very good	
	Lamphier	Pachic Cryoboroll, Fine-Loamy, Mixed	35	Very good	
	Hoosan	Pachic Cryoboroll, Fine, Mixed	22	Very good	
22	Lamphier	Pachic Cryoboroll, Fine-Loamy, Mixed	35	Very good	
	Leaps	Typic Cryoboroll, Fine, Montmorillonitic[a]	14	Good	
25	Lamphier	Pachic Cryoboroll, Fine-Loamy, Mixed	35	Very good	
	Hapgood	Pachic Cryoboroll, Loamy-Skeletal, Mixed	17	Very good	
27	Overgaard	Typic Cryoboralf, Fine, Mixed	<2	Poor	Clayey, shallow
	Olathe	Lithic Cryochrept, Loamy, Mixed	<2	Poor	Shallow
29	Supervisor	Typic Cryoboroll, Loamy-Skeletal, Mixed	11	Good	
	Cebone	Boralfic Cryoboroll, Fine, Montmorillonitic[a]	12	Moderately good	Very clayey
	Ula	Mollic Cryoboralf, Fine-Loamy, Mixed	7	Moderate	Clayey at depth
31	Agneston	Typic Cryoboralf, Loamy-Skeletal, Mixed	<2	Poor	Clayey, Shallow
	Pendergrass	Lithic Cryorthent, Loamy-Skeletal, Mixed, Nonacid	<2	Poor	Shallow

[a]Now called "Smectitic."

Table 10—Zones in Long Creek Sale, Unit 3 (see figure 9).

Zone no.	Cattle grazing intensity	Soil	Aspen sprouting
1	Heavy	Poor	Very few, all culls, heavily browsed
2	Heavy	Good	Large number, mostly culls, heavily browsed
3	Light	Poor	Moderate sprouting, barely successful
4	Light	Good	Vigorous sprouting, very successful

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