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Restoration of Aspen in Different Stages of Mortality in Southern Utah

Seth Ray Ohms
Utah State University

RESTORATION OF ASPEN IN DIFFERENT STAGES OF MORTALITY

IN SOUTHERN UTAH

by

Seth Ray Ohms

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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Approved:

Dale L. Bartos Major Professor	John C. Malechek Committee Member
Michael R. Kuhns Committee Member	Thomas L. Kent Dean of Graduate Studies

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ABSTRACT

Restoration of Aspen in Different Stages of Mortality

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Seth Ray Ohms, Master of Science

Utah State University, 2003

Major Professor: Dr. Dale L. Bartos
Department: Forest, Range, and Wildlife Sciences

Aspen clones of an aspen-dominated community in Southwestern Utah are declining, some having experienced high mortality coupled with insufficient regeneration. The objectives of this study were to (1) determine if decadent, non-regenerating mature aspen stands could be regenerated through disturbance of the auxin/cytokinin hormone relationship by clearcutting; (2) determine the extent of ungulate use of regenerating aspen ramets. Clearcuts were made in late summer of 2001 in 10 different clones that exhibited various levels of decline on a continuum from relatively healthy to extremely deteriorated. Nested wildlife/livestock exclosures were constructed in each clearcut plot, as well as in a corresponding uncut control plot. In the fall of 2002, regenerating suckers were counted. In addition, vigor and ungulate utilization of these suckers were measured in the wildlife and livestock exclosures, as well as in an unprotected portion of the clearcut and control plots.

Regeneration of the clearcut plots ranged from none in the most decadent clones, to 75,000 stems/ha in the least decadent clone, and was significantly greater than the control plots. Vigor, as measured by height of the suckers, was 1.5 to 2.1 times greater in the clearcut plots than in the control plots. Seventy-three percent of the suckers in the unprotected portion of the plots were heavily browsed, while only 12% were not browsed. Successful regeneration of aspen clones is heavily dependent upon clone decadence. Unregulated browsing pressure may limit the clone's ability to successfully restock and remain on the landscape.

(99 pages)

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Dr. Dale Bartos, my major professor, has been very supportive, and his profound experience with aspen systems was a wonderful asset. I also express sincere gratitude to Drs. John Malechek and Michael Kuhns, who served on my committee. The statistical expertise and assistance from Dr. David Turner were indispensable. I would like to thank them for their support and guidance. Special recognition is given to Dr. James Bowns; his superior mentoring abilities have inspired me to pursue this and higher degrees. I deeply admire and respect him.

I thank State Senator Thomas Hatch and the Utah Agricultural Experiment Station for funding this research. Technical assistance from Morgan Christensen, the Cedar Mountain site manager, was superb. Working as part of the Cedar Mountain Initiative has been an enjoyable experience, and I appreciate those involved with this group.

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Seth Ray Ohms

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CHAPTER I

INTRODUCTION

Quaking aspen (*Populus tremuloides* Michx.) is highly valued for its amenities in the Rocky Mountains and Intermountain West, perhaps more than any other tree (Knight 2001). Due to their ability to provide habitat for many species of plants (Mueggler 1985a, 1988, Chong et al. 2001), mammals (DeByle 1985b), birds (DeByle 1985b, Struempf et al. 2001) and insects (Chong et al. 2001), aspen systems are second only to riparian zones in total biodiversity on western landscapes (Bartos and Campbell 1998b, Kay 1997, 2001a). Benefits from aspen dominated lands include: forage production for livestock, wildlife habitat, watershed protection, water yield, timber products, landscape diversity, recreational opportunities, and esthetics (DeByle and Winokur 1985, Mueggler 1989, Bartos and Campbell 1998a, 1998b). In the Intermountain West, aspen stands have deteriorated and are declining on the landscape (Kay 1997, Bartos 2001). Bartos (2001) indicated the decrease of aspen in eight western states to be at least 60% of the historically aspen dominated 9.6 million acres. This decline ranges from 49% in Colorado to 96% in Arizona (Bartos 2001). Lands in Utah that were once dominated by aspen have declined by 1.5 million acres. This represents a 51% decline; the greatest decrease in total acreage of any western state (Bartos and Campbell 1998b).

Cedar Mountain Initiative

This study was conducted as part of the Cedar Mountain Initiative (CMI), and was intended to provide a deeper understanding of the regeneration of deteriorating aspen clones. In 1999, the Utah Legislature charged the Utah Agriculture Experiment Station

(UAES) with the task of determining effective management practices of Utah's mountain rangelands to optimize long-term health of the land with benefits for ranchers, local communities, sportsmen, and other Utah residents. This, in part, was a continuation of work Utah State University researchers have been conducting at the UAES Miners Peak study site on Cedar Mountain (Fig. 1) in Southern Utah for the past 20 years. Their research has largely focused on the compatibility of livestock grazing involving both sheep and cattle. The CMI has expanded previous studies. A multidisciplinary team of researchers was assembled to investigate innovation adoption among ranchers, wildlife/livestock interactions, domestic livestock grazing, and aspen regeneration on mountain rangelands.

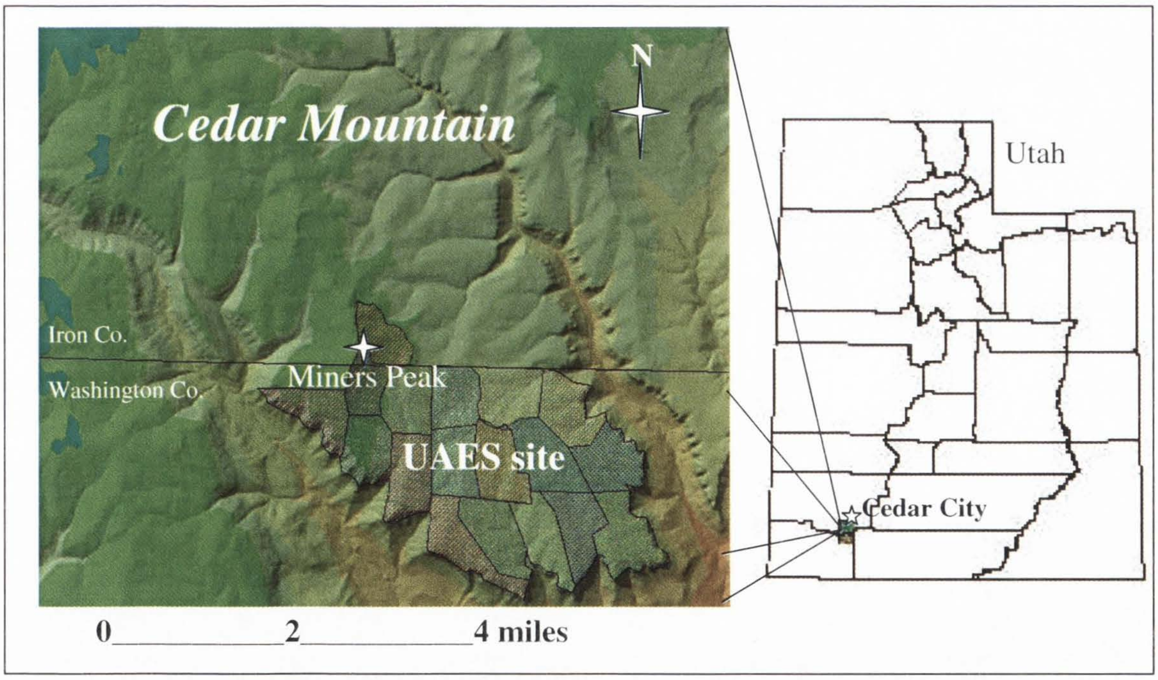

Fig. 1. The UAES site at Miners Peak on Cedar Mountain located in Southern Utah.

Purpose of this study

In an effort to gain deeper understanding of the current decline in an aspen-dominated system of Southern Utah, this study focused on determining the inherit ability of non-regenerating, deteriorating aspen clones to successfully regenerate when disturbed. The study also addressed the likelihood of sucker, and consequently, clone survival under ungulate use. The following chapter (II) contains a review of relevant literature developed in silvicultural and rangeland disciplines providing an overview of aspen biology and aspen systems; it also includes an examination of causative agents of aspen decline. A synopsis of aspen decline on Cedar Mountain is presented in Chapter III. Chapter IV is a description of the quantitative approach used for this study. It offers research objectives, site description, methods used in field data collection, and statistical analysis methods. The results and discussion are presented in Chapter V. The conclusion of the thesis (Chapter VI) addresses recommendations and identifies the application of this study to rangeland management.

CHAPTER II

LITERATURE REVIEW

Some postulate that the present aspen clones of the Intermountain West became established many thousands of years ago, perhaps during Pliocene or Miocene times (Barnes 1975, Schier 1981, Harper et al. 1985). Aspen seed, produced annually in copious amounts, has no dormancy, and thus remains viable for only a short period of time (Schier 1981, McDonough 1985). In controlled environments, seeds have been shown to remain viable as long as 48 weeks (McDonough 1985). However, the harsh environment of the Intermountain West severely limits viability (Schier 1981). Occasionally, natural conditions are conducive to seed survival and subsequent germination, however seedling survival is rare, due to critical temperature and moisture requirements for the seedling (McDonough 1985). Some suggest that possible warming and drying of the climate of the Western U.S. since prehistoric times may be such that the establishment of new clones by means of sexual reproduction seldom occurs (Barnes 1966, McDonough 1985, Mitton and Grant 1996).

Aspen clones reproduce almost entirely through asexual regeneration in the Intermountain West (Schier et al. 1985, Bartos and Campbell 1998a, Bartos 2001). This process requires disturbance of hormone ratios in the ramet (tree) to induce suckering (adventitious shoot production) (Schier et al. 1985). Suckering is regulated by the relationship between auxin (a sucker-suppressing hormone) and cytokinin (a sucker-promoting hormone) (Bancroft 1989). Auxin, which promotes apical dominance, is produced at growth points in the crown of the ramet (Schier 1972), and is translocated

toward the root system, where cytokinin is produced. The continual translocation of auxin suppresses sucker genesis (Schier et al. 1985). Regeneration usually occurs when the normal flow of auxin to the root system declines, or is entirely eliminated, allowing for cytokinin-induced suckering (Schier 1981). Disturbance is essential for successful regeneration of the clone, and may be as extensive as the removal of the ramet, yet in some cases, may be as subtle as seasonal variations in auxin production (Schier et al. 1985, Bartos and Campbell 1998a, Shepperd 2001). Vigorous clones are capable of producing from 70,000 (Bartos et al. 1991) to more than 370,000 stems per hectare (ha) (Ferguson 2001). All the ramets of an individual clone originate from the same root system, and are therefore genetically identical (Barnes 1966). Though some clones may be hundreds or thousands of years old (Cartwright et al. 1994), no one knows how long a clone may persist by means of asexual regeneration (Schier 1981).

Aspen systems

Aspen in the Intermountain West exist as either aspen/conifer or aspen-dominated systems (Mueggler 1985a, 1989, Bartos 2001, Shepperd et al. 2001). The aspen/conifer system, at times referred to as "seral aspen" (Mueggler 1985a, 1988), accounts for approximately two-thirds of all aspen (Mueggler 1989). On the landscape, aspen/conifer systems occur where environmental factors such as precipitation and temperature are conducive to conifer establishment. Once established in the aspen understory, conifers shade out young regenerating suckers (Mueggler 1985a). Eventually only a few aspen trees remain as a component of the new coniferous forest (Mueggler 1988, Shepperd et al. 2001). Historically, short fire return intervals allowed for fire to remove juvenile

conifers from the aspen understory and stimulate regeneration by removal of the ramets (Baker 1925, Bartos and Campbell 1998a). However, active fire suppression, resulting in prolonged fire intervals (DeByle et al. 1987), has allowed for successional replacement of many hectares of aspen by conifers (Bartos et al. 1983, Jones and DeByle 1985a). In locations where the aspen/conifer system borders on open meadows, aspen will often colonize the open patch through regenerating suckers from lateral roots extending in excess of 30 meters from the parent stand (Peterson and Peterson 1992). This increase of aspen is likely a temporary phenomenon in forests where open patch space is limited (Mueggler 1988). As open patches are eliminated, and conifer encroachment continues, the eventual decline of aspen due to conifer encroachment occurs (Bartos et al. 1983, Shepperd et al. 2001). This process has led to decline not only in aspen (Mueggler 1988), but also in open patches within the aspen/conifer system (Manier and Laven 2002). Because of its dominance on the landscape, this system has received much attention with respect to aspen decline.

The aspen-dominated system accounts for the remaining one-third of aspen populations (Mueggler 1989). This type is also referred to as "stable aspen" (Mueggler 1985a, 1989), "pure aspen" (Shepperd et al. 2001), or "climax aspen" (Mueggler 1985a). This aspen type usually occurs in systems where a conifer seed source is limited, or where environmental conditions (e.g., temperature and moisture), are not suitable for conifer establishment and subsequent type conversion (Mueggler 1985a). The aspen-dominated system is characterized as having an extremely productive understory (Mueggler 1988, Bartos and Campbell 1998b) capable of producing 1125 to 2250 kg/ha of biomass, and in some areas as much as 4500 kg/ha (Mueggler 1985b). Historically,

years of accumulated biomass followed by unusually dry intervals likely led to sufficient conditions to carry fire (Brown and Simmerman 1986, DeByle et al. 1987), allowing for the needed disturbance to regenerate the clone. However, normal moisture regimes allow the understory vegetation to remain green in dry months. Thus, the aspen-dominated system is referred to as an "asbestos type" (DeByle et al. 1987), largely incapable of carrying fire (Fechner and Barrows 1976, Brown and Simmerman 1986). Decline of this system has not been as extensively documented as has the aspen/conifer system. This perhaps is simply due to its relative rarity on the landscape.

Decline and mortality

Aspen-dominated systems are declining, at least partly due to the results of improper management since European settlement (Schier and Campbell 1980, Kay 1997, 2001b, Bartos and Campbell 1998a, Bartos 2001). Only recently has attention has been brought to these systems (Mueggler 1989, Campbell and Bartos 2001). This increase of interest is largely due to the decline of the desirable values associated with this aspen type.

As stated previously, aspen regeneration is largely regulated by the auxin/cytokinin ratio. When a disturbance occurs in the aspen-dominated system, leading to severe crown dieback, reduction in the flow of auxin that leads to cytokinin-induced suckering is expected (Schier et al. 1985). Throughout the Intermountain West such disturbances are occurring, yet in some locations aspen is failing to adequately regenerate (Mueggler and Bartos 1977, Mueggler 1989). The reasons for decline, and in some cases elimination of entire clones of the aspen-dominated system, are not completely clear.

The primary cause for decline in the aspen/conifer system as mentioned previously is the lengthened fire interval, resulting in less frequent and more intense fires. Due to the limited role of fire in the aspen-dominated system, decline has been attributed to the following: climate change, old age, genetic variability, insects, pathogens, and excessive herbivory (DeByle and Winokur 1985, Mueggler 1989, Hogg and Schwarz 1999).

Climate

The warming and drying of the climate since prehistoric times has probably limited aspen to those locations where it is currently found (Jones 1985, Peterson and Peterson 1992). These aspen clones have persisted on these sites for centuries, if not millennia, surviving climatic variations (Campbell and Bartos 2001). Recent warming trends may lead to greater stress on these clones (Hogg 2001, Romme et al. 1995), and a reduction in ability to regenerate. However, studies utilizing long-term exclosures have indicated no apparent correlation between climate change and aspen's ability to regenerate (Baker et al. 1997, Kay and Bartos 2000, Kay 2001b).

Old age

It is thought that once an aspen clone reaches a certain age, which could be tens of thousands of years, it will decline and eventually die (Schier 1975, Hinds 1985). This seems unlikely since new regeneration produces new root systems and a subsequent turning over of the old to the new (Schier and Campbell 1978, Schier 1982, Shepperd 1991). Yet, if a clone has been inoculated by a virus (Hinds 1985), that virus could pass from the old to the new tissues, and an accumulation of viruses over thousands of years may lead to clone elimination (Schier 1975).

Ramet age may influence clone regenerative abilities of the clone (Schier 1975). Hinds and Wengert (1977) demonstrated that Intermountain West aspen clones whose ramets are between 80 and 120 years of age, have reduced vigor and are more susceptible to insect and pathogen infestations. Schier (1975) demonstrated that overmature ramets maintain apical dominance over the shrinking root system. If the hormone ratio remains undisturbed, these clones may fail to regenerate. However, if the hormone ratio changes, successful regeneration of these clones can be expected (Schier 1975, Mueggler 1989).

Genotype

The ability to produce suckers and the amount of suckers produced by a clone is largely a function of genotype (Schier 1975, Schier and Campbell 1980, Jones and DeByle 1985b). Some clones respond to the slightest alteration of the auxin/cytokinin ratio (e.g., frost or dormancy) with profuse suckering (Schier 1976). These clones often exhibit multi-age stand demographics, and are capable of self-perpetuation on a site indefinitely (Mueggler 1989). Other clones require more substantial disturbances (e.g., entire top removal) to initiate suckering (Schier 1975, Schier et al. 1985). If no substantial action is taken to encourage regeneration of these clones, they become overmature, increasingly decadent and may fail to regenerate (Schier 1975). Fire suppression has perpetuated decline in some clones that evolved under that major disturbance (Mueggler 1989). Without significant disturbance, these clones might be eliminated from the landscape.

In areas where ungulates are present, some clones are more preferred than others as forage (Lindroth 2001). This difference in palatability is also a genotypic characteristic (Lindroth 2001). The continual selective browsing of regenerating ramets might lead to the eventual elimination of more palatable clones. Also, some clones are genetically more susceptible than are others to insect and pathogen infestations (Harniss and Nelson 1984, Jones and DeByle 1985b).

Pathogens and insects

Insects (Jones et al. 1985, Schmitt 1997) and fungal pathogens (Hinds 1985, Johnson et al. 1995) have been known to cause extensive damage to aspen clones (Harniss and Nelson 1984, Hogg and Schwarz 1999). However, infestations usually occur only after the clone has been weakened by other influences, such as bark wounding or drought (Harniss and Nelson 1984, Hinds 1985). Therefore, infestations are usually not the primary cause of decline. In many instances, the infestation of insects and (or) pathogens causes severe defoliation and dieback, which in turn modifies the auxin/cytokinin ratio, and the clone regenerates successfully (Schier 1975, Bartos and Mueggler 1979, Harniss and Nelson 1984). When infestations are gradual, dieback usually is a more prolonged process. As only a few ramets die, other adjacent living ramets maintain apical dominance, inhibiting regeneration. The root system becomes weaker and smaller as more ramets slowly die (Shepperd and Engelby 1983). It is thought that slow, prolonged infestations do not allow for regeneration, and result in decline and eventual elimination of entire clones (Schier 1975).

Herbivory

The introduction of livestock and early improper grazing practices, allowed for overuse of the understory forage in aspen stands (Mueggler 1985a, 1985b, 1988, Holechek et al. 1998). With reduced understory production and less build-up of biomass due to overgrazing, the aspen-dominated system seldom burns (Jones and DeByle 1985a, Brown and Simmerman 1986). Overgrazing not only affected understory grasses and forbs, but also aspen regeneration (Sampson 1919, Smith et al. 1972, DeByle 1985a). Repeated herbivory of aspen suckers by livestock leads to reduced vigor, and subsequent decline (Mueggler and Bartos 1977, Kay 2001b). Large wild ungulates such as deer (*Odocoileus hemionus* Merriam) and elk (*Cervus elaphus* L.) also utilize aspen suckers as forage, and in many cases their highly concentrated use has led to clone decline and, in some cases, complete elimination (Krebill 1972, Smith et al. 1972, DeByle 1985a, Bartos et al. 1994, Kay 1997, Kay and Bartos 2000, Rolf 2001). It seems likely that the effects of browsing by ungulates may be amplified if the clone is concurrently experiencing poor regeneration due to gradual insect or pathogen infestations, over-mature stand demographics, or its regeneration genetics.

Although in some situations the agent of decline may be immediately apparent, decline is likely due to the cumulative or interacting effects of many factors (LaRoe et al. 1995).

CHAPTER III

CEDAR MOUNTAIN ASPEN

Aspen clones on Cedar Mountain (Fig. 1) are similar to those described by Mueggler (1988) as *Populus tremuloides/Bromus carinatus* and *Populus tremuloides/Symphoricarpos oreophilus*/Tall Forb. However, Cedar Mountain clones differ in the respect that conifers only rarely occur. The few conifers that do occur were likely established under highly unusual and temporary climatic conditions (Mueggler 1985a). Also contributing to the rarity of conifers is the apparent lack of a continuous seed source. Though conifers may eventually invade this system (Mueggler 1988), the process would likely take hundreds, if not thousands of years (Mueggler 1985a, 1988).

Since European settlement in the mid 1800s, there is no documented occurrence of wildfire on the mountain. The presence of dated pre-twentieth-century inscriptions on aspen tree trunks supports this claim. Lightning strikes have been known to smolder for days, never spreading from the original strike location before dying out.

Landowners and resource managers have expressed strong concern about the aspen clone mortality that is occurring on Cedar Mountain. The deterioration of aspen clones was first noticed in the early 1990s (personal communication, Dr. J.E. Bowns, Southern Utah University, Cedar City). A few clones were identified by their tendency to form leaves later in the spring than other nearby clones. Beginning in 1990, a clone identified as "Lister 1" was photographed periodically by Dr. Bowns (Fig. 2). Leaf onset of this clone continued to occur later each year, and leaf area decreased (Fig. 3, Fig. 4), until the ramets died completely (Fig. 5).

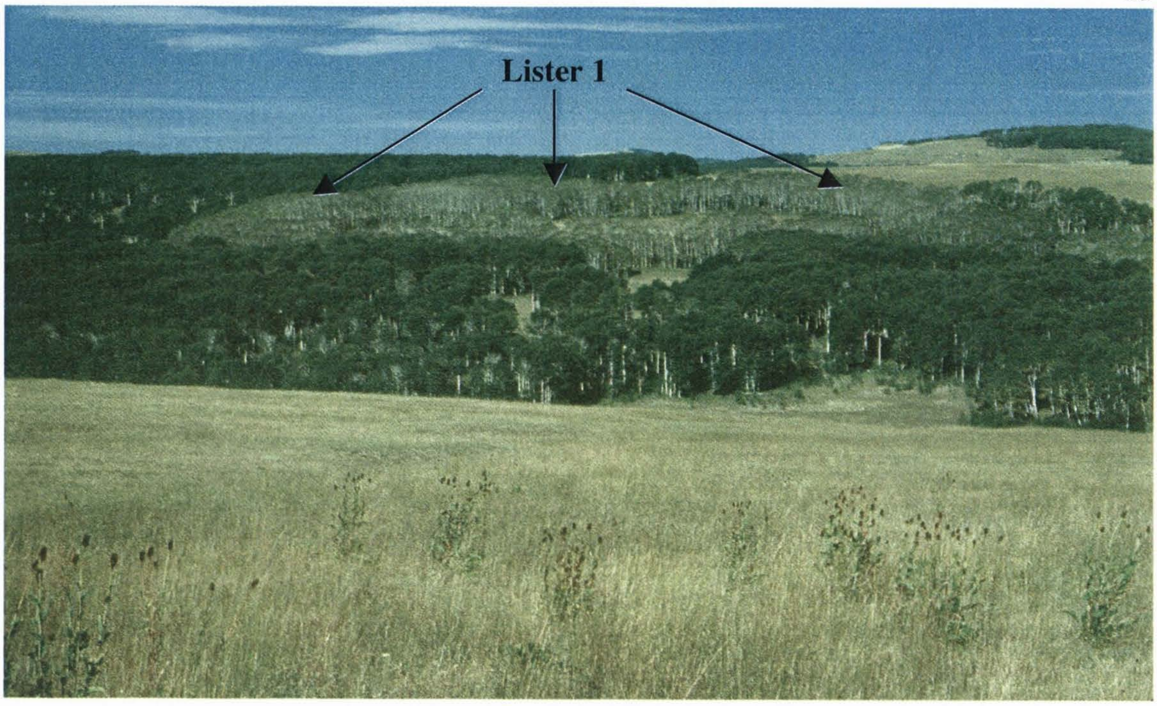

Fig. 2. Clone "Lister 1" as it appeared in summer 1990. The ramets are still living but leaf area has decreased. (Photo by James Bowns)

Fig. 3. Lister 1 as it appeared in summer 1992. Many of the ramets show signs of mortality. (Photo by James Bowns)

Fig. 4. Lister 1 as it appeared in summer 1998. Very few ramets remain alive. (Photo by James Bowns)

Fig. 5. Lister 1 as it appeared in summer 2002. Few living ramets remain, and no regeneration is present. (Photo by author)

In 1996, during an on-site examination of the Lister clone, no regeneration was found in the understory (personal communication, Dr. J.E. Bowns). Other clones undergoing similar processes have recently been identified in the area (Fig. 6).

Local landowners and land managers fear that these clones may be incapable of stand replacing regeneration and will soon be lost. Old age of the ramets, or a predisposition to fungal attack perhaps has weakened these clones, leaving them vulnerable to boring insects that girdle the ramet (e.g., *Agrilus liragus* Barter and Brown). Schier and Smith (1979) indicated that the continual draining of nutrient reserves caused by girdling contributes to dieback in the root system, poor regeneration, and subsequent ramet mortality.

Fig. 6. Webster 1 (center) and Webster 2 (foreground-right) as they appeared in summer 2002. (Photo by author)

Many clones in the vicinity of these rapidly declining clones (in some places closely adjacent), with apparently similar insect/pathogen relationships, are successfully regenerating (Fig. 7). The reason(s) for the decline of some clones, while not others, is uncertain. Differing grazing practices between landowners and an increase in the local elk population are possible explanations, as are different site characteristics. Schier (1975) and Schier and Campbell (1980) grew root cuttings of decadent and healthy clones from Northern Utah and found the ability of decadent clones to regenerate was not significantly different from that of healthy clones. In their studies, decadent clones were described as having low ramet and suckering densities. The deteriorating clones of Cedar Mountain reflect similar low density in ramets, but suckers are not present. The main purpose of this study was to evaluate the regenerative ability of these clones.

Fig. 7. Clone in foreground exhibits successful regeneration, while the clone in the upper-right (Smith 1) is deteriorating with no regeneration. (Photo by author)

CHAPTER IV

METHODS

Research objectives

The primary objectives of this research were:

1. Determine if decadent, non-regenerating mature aspen stands could be regenerated through clearcutting.

    Ho: Disturbance is not sufficient to induce suckering in decadent, non-regenerating clones.

    Ha: Disturbance will sufficiently induce suckering to produce regeneration in decadent, non-regenerating clones.

2. Determine the effect of ungulate use on regeneration of aspen ramets.

    Ho: Ungulate use does not impact regeneration of decadent aspen clones.

    Ha: Aspen regeneration is suppressed by ungulate herbivory.

Other objectives considered include development of a protocol for determining clone decadence and subsequent regeneration abilities. Due to the variety of decadence represented in study clones, it was hoped that variation among clonal attributes could be modeled to explain any regeneration that occurred. Also, a comparison of the variation of historic photos with current clonal conditions was employed to assess the timing and amount of decline.

Study area

Clones used in the study are located near the boundary of Iron and Washington Counties Utah, on land in the vicinity of Miners Peak on Cedar Mountain (Fig. 1). The site is located on the top of the Straight Cliffs, known as the Kolob Terrace of the Markagunt Plateau. Physical features of the site include: mean elevation of 2700 meters, slopes from 0 to 28%, and mean annual precipitation of 74.5-77 cm mainly as winter snowfall and as much as one-third from summer monsoons. The soils are predominantly Argic Pachic Cryborrolls, fine montmorillonitic faim clay loam (Bowns and Bagley 1986). The vegetation consists of interspersed mountain meadows and woodlands of quaking aspen, with patches of Gambel oak (*Quercus gambelii* Nutt.), and mountain snowberry (*Symphoricarpos oreophilus* Gray). Characteristic herbaceous species include Letterman needlegrass (*Stipa lettermanii* Vasey), mountain brome (*Bromus carinatus* Hook & Arn), Kentucky bluegrass (*Poa pratensis* L.), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinn.), tarweed (*Madia glomerata* Hook.), dandelion (*Taraxacum officionale* Webber ex Wiggers), Louisiana wormwood (*Artemisia ludovisiana* Nutt), and coneflower (*Rudbeckia occidentalis* Nutt.). Due to historical heavy continuous grazing by sheep, the area is thought to have converted from a tall forb community to the current graminoid-dominated situation (Bowns and Bagley 1986). Plant nomenclature follows Welsh et al. (1993).

Clone selection and sampling

During the summer of 2001, 10 different clones that exhibited various levels of decline on a continuum from relatively healthy to extremely deteriorated, were selected

for study. Criteria for clone selection were (1) some level of canopy deterioration (i.e., crown dieback), (2) absence of regeneration, and (3) an identifiable clone boundary. Characteristics used to identify individual clones included bark color, timing of leaf onset and leaf drop, leaf shape, branching habit, and other morphological characteristics (Barnes 1966, Shepperd 1982).

Attributes of the 10 clones were sampled using 5 randomly located 2 x 30 m belt transects (Kay and Bartos 2000, Kay 2001b). The belt transects were randomly identified by the researcher, standing on the outside of the clone, throwing a survey pin over his back into the clone. The pin became the centerline of the transect, with 1 meter to either side. The directional layout of each transect was identified by the direction that the point of the survey pin indicated. The attributes sampled in each clone were: tree and sucker density, basal area, height, age, mortality, percent crown dieback, and presence of boring insects and deleterious pathogens (sample survey sheet can be found in Appendix A).

All ramets, living and dead that occurred in the transect were counted. In an effort to maintain the proper sample area for each transect, every other ramet that intersected the outer perimeter of the transect was eliminated from the count. Percent mortality and ramet density were obtained from the counts.

Diameter at breast height (DBH) (1.37 m) in centimeters was measured on each ramet in the transect. Basal area (BA) (m^2/ha) was determined for each ramet using the following formula: BA (m^2) = 0.0000785398 x DBH^2, where DBH is in cm. Combined

BA of the ramets in the transect (60 m^2) was multiplied by 166.67 to yield BA/ha. The BA totals of all 5 transects were then averaged to identify BA/ha of the clone.

A clinometer was used to obtain the height (m) of the ramets in each transect. Height was measured at a distance of 20.1 m horizontally for each ramet. To correct for height of the observer 1.7 m were added to the total height of each ramet.

An increment borer was used to obtain cores for aging from the 2 largest ramets at breast height in each transect. The largest ramets were selected based on the assumption that size is a function of age, thus the largest ramets were considered to be the oldest. Rot frequently prevented obtainment of complete cores from which reliable ring counts could be made. The intact cores were used to represent the oldest possible age for each clone. Increment cores were placed in paper straws and refrigerated for storage. The cores were then glued into a shallow grove cut into a 2.5 x 2.5 cm wooden mounting strip, and sanded with increasingly finer grain sandpaper until the annul rings became apparent (Asherin and Mata 2001). Dye was not needed as a dissecting binocular scope sufficiently aided in counting the annual rings. Where the center pith was not obtained due to off-center boring, concentric half circles representing the dimensions of a 10-year-old sapling in cross section were used (Campbell 1981). Four years were added to the total number of annual increments on the cores to correct for core collection at breast height (Campbell 1981).

The presence of insects and pathogens was determined for each ramet in the transect by the presence of their various symptoms. Identification of symptoms was

based on consultation with John Guyon, Forest Service pathologist, and an expert on aspen diseases in the Intermountain West (Guyon 1993).

Crown dieback of each ramet in the transect was assessed visually. Five classes were used to characterize the percentage of dead branches in the crown. The classes were as follows:

- None 0-5% (Score = 0)
- Light 6-30% (Score = 1)
- Moderate 31-70% (Score = 2)
- Heavy 71-99% (Score = 3)
- Dead 100% (Score = 4).

Similar rating classes have been used in quantifying aspen dieback in Canada (Hogg and Schwarz 1999).

The results of the 5 belt transects were averaged to obtain tree and sucker density (ha), percent dieback, percent mortality, basal area (m^2/ ha), height (m), age, and percent insect and pathogen occurrence for each of the 10 study clones.

Treatments

One 500 m^2 clearcut plot and one uncut control plot of equal area were randomly located in each clone (Fig. 8). Viable areas in each clone where living ramets existed were identified. These areas included (1) portions of extremely deteriorated clones, and (2) the whole of more healthy clones. In clones where high mortality had occurred, only small pockets of living ramets were found. These viable areas were assigned numbers

written on pieces of paper, placed in a hat, mixed and then 1 was drawn. Clones where mortality was low were identified on a topographical map of the area. Gridlines were placed over the clones and line intersections numbered. The numbers were written on pieces of paper, placed in a hat, mixed and then 1 was drawn. The randomly selected locations were identified on the ground. Wooden stakes were driven in the 4 corners of both the treatment and control plots for identification. The first stake represented the southwest corner for each plot in each clone. A compass, identifying magnetic north, was used to place the second stake 22.36 m due north of the first, the third due east 22.36 m from the second, and the final stake 22.36 m south of the third, or 22.36 m east of the first.

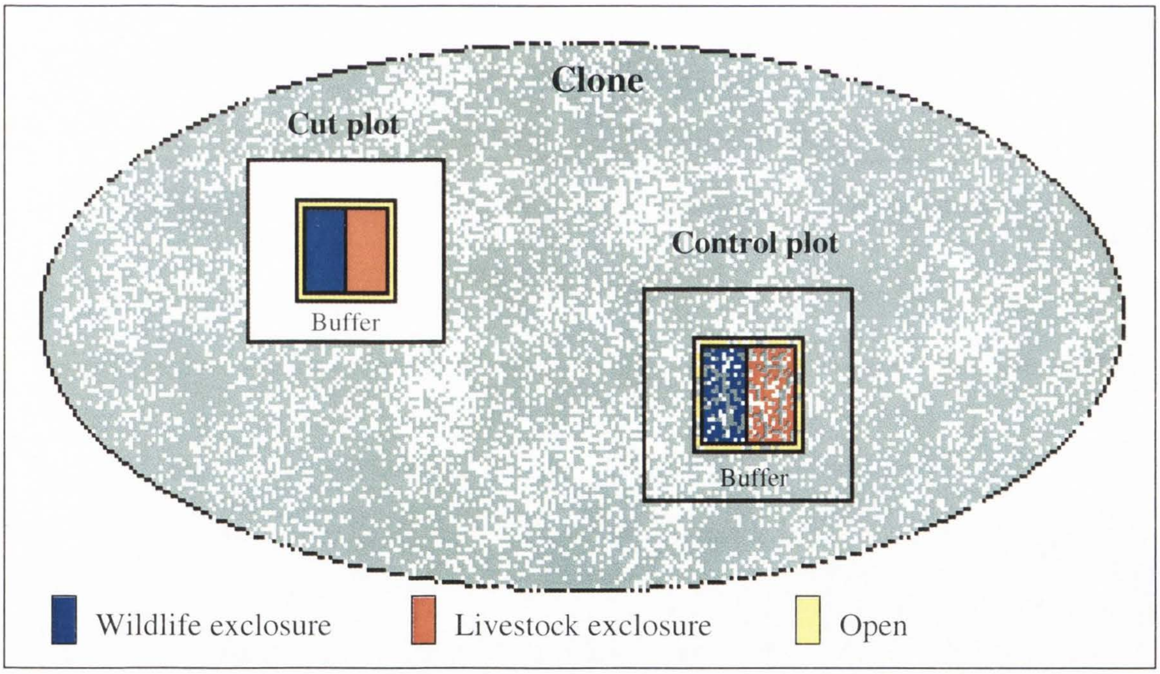

Fig. 8. Layout of treatment plots and exclosures in an aspen clone. The area between the open portions to the plot boundary comprises a 5 m buffer.

Density, BA, and mortality of the ramets in the plots were measured. In August 2001, the selected 500 m^2 plots were clearcut. In the late fall of 2001 and the early spring of 2002, when the trees were dormant, slash was scattered and cut logs were removed from the clearcut plots.

Within the clearcut area, a 10 x 10 m nested wildlife/livestock exclosure was constructed (Fig. 8). Exclosure construction took place before leaf flush in the spring of 2002. The exclosure of the clearcut plot was randomly aligned for each clone. A wooden stake, on which a pointer-end had been designated, was spun in the air to identify directional alignment. The direction indicated by the stake upon landing on the ground was used to identify setup; as the wildlife exclosure preceded the livestock exclosure. For example, if the stake pointed north, the wildlife exclosure was constructed on the south side of the livestock exclosure. The nested exclosure was the result of the side-by-side alignment of a 5 x 10 m, 2.1 m tall wildlife exclosure, and a 5 x 10 m, 1.2 m livestock exclosure. The exclosures were constructed of 2.1 m tall black plastic netting and 1.2 m livestock panels. A 5 m buffer was maintained on the interior perimeter of the plot to eliminate possible edge effect caused by uncut ramets near the outside edge of the clearcut (Fig. 8). For control, a second nested wildlife/livestock exclosure of the same design was constructed in the paired uncut control plot (Fig. 8).

Regeneration in the treatment plots was monitored weekly throughout the 2002 growing season. Regeneration data included density (stems/ha) and growth rate. These data were collected in mid-September 2002, and were measured by counting the number, height (cm), and basal diameter (DGL) (mm) of suckers in both the 5 x 10 m wildlife, and 5 x 10 m livestock exclosures, as well as in 50 m^2 of the unprotected portion of each

plot. In an effort to maintain the 5 m buffer, the 50 m^2 area was located on the immediate exterior of the nested exclosure and surrounded the exclosure (Fig. 8).

Utilization by ungulates was determined for each ramet at the time of data collection. Six classes were used to characterize the intensity of utilization, ordered from low to high intensity. The classes were as follows:

0 = Non-browsed.

1 = Stem browsed but regrowth exceeding the browse point.

2 = Leaves stripped from <50% of the stem and apical bud intact.

3 = Leaves stripped from ≥50% of the stem and apical bud intact.

4 = Apical bud removed and leaves stripped from <50% of the remaining stem.

5 = Apical bud removed and leaves stripped from ≥50% of the remaining stem.

(A sample data sheet can be found in Appendix B)

Suckering capacity was measured on root segments from each clone that were collected and propagated in a controlled greenhouse environment following methods described by Schier (1978) and Campbell (1984).

In early August 2002, 30, 1 to 2.5 cm in diameter lateral root segments, were collected from 30 different locations in the 10 clones. Lateral roots were found by excavating soil from around the base of established ramets. During collection, roots were kept cool in moistened cloth sacks to prevent excessive drying. The roots were washed with tap water, secondary roots were removed, and roots were then cut to 10 cm lengths for planting. The root segments were planted in trays 1 to 2 cm deep using moistened

vermiculite as a growing medium. Trays were placed in the Southern Utah University greenhouse in Cedar City on a misting bench, where temperatures ranged between 25 and 15° Celsius. After 6 weeks of sucker production, the number of suckers per segment and height (cm) of all suckers greater than 5 mm were measured. (A sample data sheet can be found in Appendix C.)

Historic photographs of the area that included entire clones or portions of the clones selected for study were obtained with permission from Dr. James Bowns of Southern Utah University (Appendix D). Repeat photographs taken in September and August of 2002 were compared with the earlier photographs to identify the timing and rate of aspen decline on Cedar Mountain.

Statistical analyses

Regeneration data collected were analyzed using PROC GENMOD in SAS version 8.2 (1999) (code can be found in Appendix E). The Generalized Linear Model worked best due to the repeated measure of basal area for each clone. Analysis of variance was used to identify relationships between regeneration and clone basal area. The negative binomial distribution was utilized because preliminary analysis using the Poisson distribution indicated significant overdispersion.

Height of the regeneration was assessed using PROC MIXED (SAS v8.2 1999) (code can be found in Appendix E). A test for normality of residuals from PROC MIXED for regeneration height had a p-value of 0.57, indicating the normality assumptions were satisfied. Analysis of variance was used to identify differences in height based on the treatment and exclosure effects.

Greenhouse data were analyzed using the multi-response permutation procedure (MRPP) as implemented in a macro for MS Excel 2000 (King 2002), which is based on Euclidean distance for one-factor designs (Mielke and Berry 2001). This analysis involved the division of the clones into 2 classes; those with < 50% mortality, and those with ≥ 50% mortality. The MRPP macro was also used on the field regeneration data. Comparison of greenhouse regeneration and field regeneration was done utilizing the MRPP test results.

CHAPTER V

RESULTS AND DISCUSSION

A number of growth and regeneration related attributes for each study clone are presented in Table 1. The previously described criteria used in clone selection (canopy deterioration and absence of regeneration) successfully produced the desired gradient in clone conditions, from extremely deteriorated to relatively healthy.

Regeneration

Regeneration data collected fall of 2002 are presented in Table 2. The data indicate that in response to the clearcut disturbance, regeneration did occur at various levels in the study clones. Thus, the null hypothesis of regeneration failure is rejected. The amount of regeneration differed significantly between the cut and control plots (Table 3), with the clearcut treatment significantly stimulating regeneration. Interestingly, the control plots experienced some regeneration, though measurably less than the cut plots. The presence of regeneration in the control plots and the lack of regeneration in the remainder of the clone indicates unstimulated regeneration success must be short lived and is likely restricted by external factors such as browsing. In the clones where mortality exceeded 50%, though significant, the effect of the treatment was reduced.

Regeneration prediction model

The differing levels of regeneration, including the gradient of clonal decadence, facilitated model development for predicting regeneration. The effect of basal area

Table 1. Attributes of the study clones. Clones are arranged by increasing mortality from left to right.

Attributes	Lister 3	Webster 3	Lister 2	Smith 2	Webster 2	Smith 1	Webster 1	Meeks 1	Clark 1	Lister 1
Total ramets/ha	667	1,067	700	400	1,100	467	1,000	800	1,000	833
Living ramets/ha	567	767	500	233	633	233	333	233	233	100
% Mortality	11.7	27.7	29.5	36.7	49.8	50.0	67.4	77.9	80.5	86.0
% Dieback	16.7	15.8	8.3	37.5	10.2	48.3	32.3	43.8	52.1	33.3
Height (m)	22.7	16.3	19.0	15.5	16.9	18.0	16.8	14.9	16.9	15.0
DBH (cm)	44.1	29.4	29.8	44.4	25.3	41.1	26.7	33.4	27.4	33.0
Basal Area living m^2/ha	82.8	59.0	43.4	29.0	33.1	30.8	27.5	24.5	12.8	3.5
% Infection of living ramets	78.3	72.0	68.7	50.0	58.3	100.0	100.0	100.0	100.0	100.0
Age	130	138	139	126	127	125	145	140	129	119

Table 2. Regeneration attributes by treatment plot and exclosure level for the study clones (suckers/50 m²).

Clones

Lister 3 (11.7% mortality)					Webster 3 (27.7% mortality)				
Plot	Exclosure	Suckers	Height (cm)	DGL (mm)	Plot	Exclosure	Suckers	Height (cm)	DGL (mm)
Cut	*Wildlife*	239	52	7	*Cut*	*Wildlife*	230	39	4
	Livestock	511	58	7		*Livestock*	217	28	4
	Open	232	4	4		*Open*	130	2	1
Control	*Wildlife*	8	26	3	*Control*	*Wildlife*	27	10	3
	Livestock	3	26	3		*Livestock*	10	16	3
	Open	4	23	5		*Open*	9	30	4
Lister 2 (29.5% mortality)					**Smith 2 (36.7% mortality)**				
Plot	Exclosure	Suckers	Height (cm)	DGL (mm)	Plot	Exclosure	Suckers	Height (cm)	DGL (mm)
Cut	*Wildlife*	87	50	6	*Cut*	*Wildlife*	27	37	5
	Livestock	172	47	6		*Livestock*	32	41	5
	Open	88	10	5		*Open*	24	1	2
Control	*Wildlife*	22	44	5	*Control*	*Wildlife*	4	28	4
	Livestock	9	20	4		*Livestock*	14	23	4
	Open	23	17	3		*Open*	0	0	0
Webster 2 (49.8% mortality)					**Smith 1 (50.0% mortality)**				
Plot	Exclosure	Suckers	Height (cm)	DGL (mm)	Plot	Exclosure	Suckers	Height (cm)	DGL (mm)
Cut	*Wildlife*	47	53	7	*Cut*	*Wildlife*	30	61	7
	Livestock	4	49	7		*Livestock*	20	34	5
	Open	25	5	3		*Open*	3	3	2
Control	*Wildlife*	21	31	5	*Control*	*Wildlife*	9	29	5
	Livestock	16	31	5		*Livestock*	31	25	4
	Open	3	8	4		*Open*	2	7	5
Webster 1 (67.4% mortality)					**Meeks 1 (77.9% mortality)**				
Plot	Exclosure	Suckers	Height (cm)	DGL (mm)	Plot	Exclosure	Suckers	Height (cm)	DGL (mm)
Cut	*Wildlife*	4	19	4	*Cut*	*Wildlife*	0	0	0
	Livestock	0	0	0		*Livestock*	0	0	0
	Open	0	0	0		*Open*	0	0	0
Control	*Wildlife*	0	0	0	*Control*	*Wildlife*	0	0	0
	Livestock	0	0	0		*Livestock*	7	12	3
	Open	3	18	4		*Open*	2	8	7
Clark 1 (80.5% mortality)					**Lister 1 (86.0% mortality)**				
Plot	Exclosure	Suckers	Height (cm)	DGL (mm)	Plot	Exclosure	Suckers	Height (cm)	DGL (mm)
Cut	*Wildlife*	2	52	6	*Cut*	*Wildlife*	0	0	0
	Livestock	11	22	4		*Livestock*	0	0	0
	Open	0	0	0		*Open*	0	0	0
Control	*Wildlife*	0	0	0	*Control*	*Wildlife*	0	0	0
	Livestock	0	0	0		*Livestock*	3	9	3
	Open	0	0	0		*Open*	0	0	0

Table 3. Differences of least squares means and chi-square significance levels for the treatment plot and exclosure effects as well as their respective interactions on regeneration.

Effect	Plot	Exclosure	Plot	Exclosure	Parameter Estimate	Standard Error	Chi-Square	Pr > ChiSq
Plot	Control		Cut		-1.3038	0.2681	23.66	<.0001
Exclosure		Protected		Open	0.8337	0.2758	9.14	0.0025
Plot*Exclosure	Control	Protected	Control	Open	1.0973	0.4844	5.13	0.0235
Plot*Exclosure	Control	Protected	Cut	Protected	-1.0402	0.3533	8.67	0.0032
Plot*Exclosure	Control	Protected	Cut	Open	-0.4701	0.4194	1.26	0.2623
Plot*Exclosure	Control	Open	Cut	Protected	-2.1375	0.3464	38.07	<.0001
Plot*Exclosure	Control	Open	Cut	Open	-1.5674	0.3745	17.51	<.0001
Plot*Exclosure	Cut	Protected	Cut	Open	0.5701	0.1972	8.36	0.0038

on regeneration was found to be significant (Table 4). A Michigan study utilized stand basal area to identify 3 broad classes of regeneration (Graham et al. 1963). The classes were (1) stands <11.5 m^2/ha basal area, regenerating 12,844 suckers/ha, (2) stands between 11.5 and 23 m^2/ha basal area, regenerating 17,290 suckers/ha, and (3) stands >23 m^2/ha basal area, regenerating 24,453 suckers/ha. The basal area classes used in that study did not successfully predict the regeneration that occurred in this study. Possibly the reason lies in the clonal approach of this study as compared to the multi-clone stand approach of Graham et al. (1963).

The model, with basal area as the predictor, demonstrates the ability of less decadent clones to regenerate in greater amounts than the more decadent clones (Fig. 9). In essence, clonal decadence can be identified as the amount of living basal area. Associated error is large, particularly as basal area increases (Fig. 9). This error is likely due to the sample size of only 10 clones. With the addition of more clones, the error would become smaller and result in a better-fit model (i.e., closer to the mean value). A categorical prediction table, based on this model, is presented in Appendix F.

Table 4. Empirical standard error estimates, significance values, and parameter estimates used in regeneration prediction. The significant relationships of basal area, treatment plots, and exclosures on regeneration are identified.

Parameter	Plot	Exclosure	Estimate	Standard Error	Z	Pr > |Z|
Intercept			0.1936	0.4824	0.40	0.6882
Plot	Control		-1.5674	0.3745	-4.18	<.0001
Plot	Cut		0.0000	0.0000	.	.
Basal Area			0.0723	0.0095	7.59	<.0001
Exclosure		Protected	0.5701	0.1972	2.89	0.0038
Exclosure		Open	0.0000	0.0000	.	.
Plot *Exclosure	Control	Protected	0.5272	0.4927	1.07	0.2846
Plot *Exclosure	Control	Open	0.0000	0.0000	.	.
Plot *Exclosure	Cut	Protected	0.0000	0.0000	.	.
Plot *Exclosure	Cut	Open	0.0000	0.0000	.	.

Predicted regeneration per 50m² = e^ (0.1936 - 1.5674 (if control × 1, if cut × 0) + (0.0723 × BA) + 0.5701 (if protected × 1, if open × 0) + 0.5272 (if control protected × 1, all others × 0))

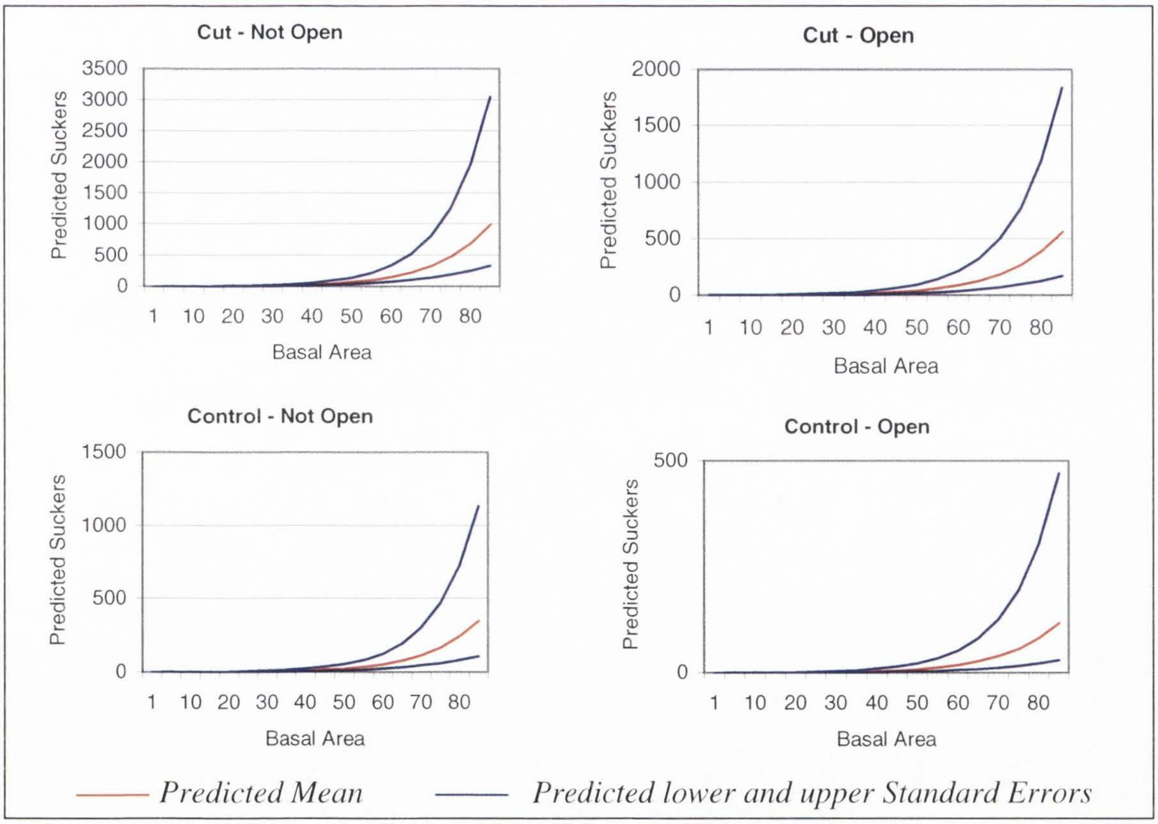

Fig. 9. Regeneration means (suckers / 50 m²) and standard error generated from the predictive model. The significant effect of basal area efficiently predicts an increase in mean regeneration.

Greenhouse regeneration

The MRPP was used to identify differences in regeneration between clones of < 50% mortality, and clones ≥ 50% mortality for the field regeneration data. The results indicate a significant difference (p=0.0317) in amount of regeneration between the 2 classes. However, the propagation of lateral roots in a controlled greenhouse environment indicates no significant difference (p=0.3333) in regeneration between the 2 classes (Fig. 10). These greenhouse findings concur with those of Schier (1975), and Campbell (1984), who found that both decadent and healthy clones are equally capable of successful regeneration. The reason for discrepancy between field and greenhouse data results may be due to differences in the abundance of living belowground lateral root biomass. Shepperd et al. (2001) found that the amount of regeneration in regenerating

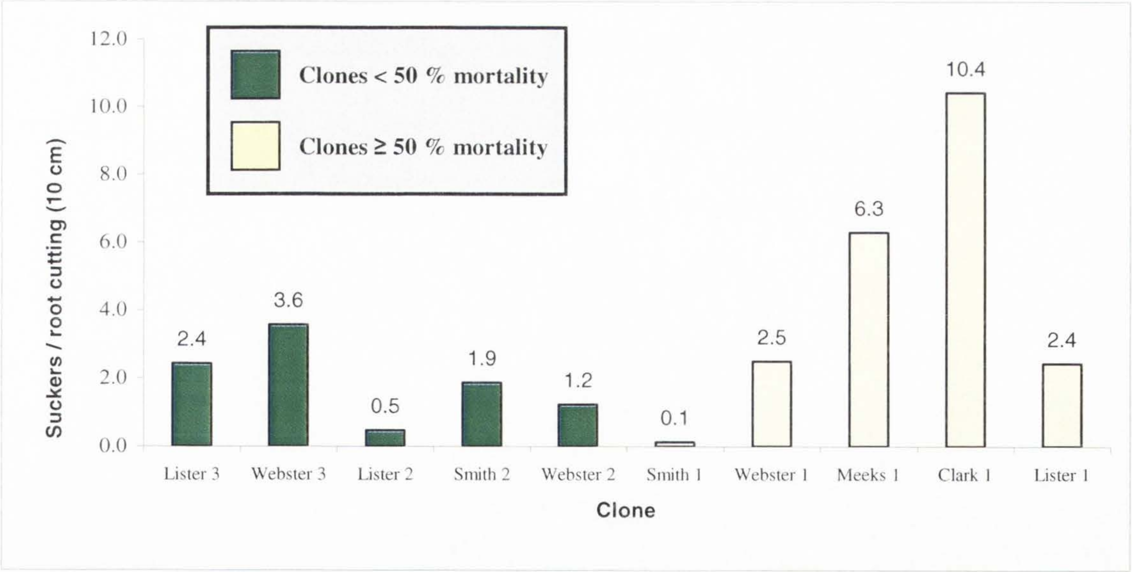

Fig. 10. Root sucker production in greenhouse trials. Clones are ordered from left to right, lowest to highest mortality. MRPP p=0.3333 indicates no significant difference between the 2 classes.

versus non-regenerating clones was attributed, in large part, to the abundance of belowground biomass. Thus, ramet mortality occurring in Cedar Mountain clones subsequently has led to root mortality. The lack of regeneration in the most decadent clones can be attributed to the rarity of living lateral roots (Shepperd et al. 2001), not an inherent inability to regenerate (Mueggler 1989). During the collection of lateral roots, particularly in the more decadent clones, many dead roots were found and (or) sustained damage from pocket gophers was observed.

Exclosures

In the fall of 2002 the lack of use by wildlife in the livestock exclosure became apparent, as none of the suckers in that exclosure were browsed. The reason for the non-use may be due to the small size of the exclosure. Initially, it was thought that if the suckers in the unprotected open areas were heavily utilized, the wildlife would then use the regeneration in the livestock exclosure. Due to the non-use, the exclosure data were analyzed as (1) protected from browsing (protected), and (2) not protected (open) (Table 3), and utilization was considered to be the combined effect of both wildlife and livestock.

The effect of exclosure on regeneration alone was significant (Table 3). Though the exclosure did not stimulate more regeneration, it did protect suckers from browsing pressures (Table 2). This indicates that due to browsing, significant sucker mortality occurred in the unprotected open portion of the plots. The effect of browsing is further substantiated since the regeneration in the unprotected open portion of the cut plots, and the protected portion of the controls, was not significantly different (Table 3). In essence,

this means that the browsing of treatment-stimulated regeneration was after one year's time, only as effective as a non-treated, protected plot. The regeneration prediction model (Fig. 9, Appendix F) illustrates this point.

If the treatment of a healthy clone was to yield an overabundance of regeneration, these findings indicate that browsing could be used as a management tool to decrease the amount of suckers in order to attain management objectives. Due to the reduced number of suckers, the draw of nutrients from the parental root system should then allow the remaining suckers to grow more vigorously (Smith et al. 1972, Jones and Shepperd 1985).

The differences seen in Table 3 between the unprotected portion of the control and both the protected and unprotected portions of the cut are, in large part, effects of the treatment. The categorical prediction table (Appendix F) illustrates the predicted regeneration for these treatment-exclosure effects. The difference in regeneration between the unprotected portions of both plots is noteworthy, as it identifies the result of browsing across the treatments.

Sucker height

In order to assess regeneration vigor, sucker height from ground level to the apical bud (or browse point) was measured (Table 2). Basal diameter, or diameter at ground level "DGL" was also measured (Table 2). Initial analysis indicated the 2 measurements were correlated, both yielding the same significant relationships. Due to the importance of sucker height from a browsing management standpoint, only the height

data were used as an assessment of regeneration vigor, though the DGL data would yield similar results.

Regenerating suckers must quickly grow beyond the reach of browsing ungulates if they are to survive (Smith et al. 1972, DeByle 1985a). This need is also critical for land managers in deciding the amount of rest needed before grazing practices can be resumed in an area where aspen have been treated (Sampson 1919).

The analysis of height measurements indicated that the treatment alone did not affect vigor (Table 5). However, this includes all height data and does not take into account the significant effect of the exclosures (Table 5). The comparison of the total ungulate-excluded (protected) area of both the control and cut plots (Table 5) indicates that the regeneration with a clearcut is indeed significantly taller. Average sucker height of the protected regeneration was 38.9 and 20.7 cm for the cut and control plots, respectively. The 47% difference in height is significant (Table 5). This is not to conclude that the exclosure encouraged sucker growth, but that the unprotected suckers were significantly browsed. The exclosure effect in the cut plot resulted in a significant difference in sucker height (Table 5), which is likely due to browsing ungulates. In the control plot, however, regenerating sucker height was not different due to the exclosure (Table 5). The reason for the inconsistency between treatment plots is the result of shorter (Table 5) and fewer regenerating suckers (Table 3) in the control plots than in the cut plots. Table 5 indicates no difference for height in the open portion for both treatment plots. This further substantiates the significant effect of ungulate browsing.

Table 5. Differences of least squares means including significance values for the effects of treatment plots, exclosures, and their interactions on sucker height.

Effect	Plot	Exclosure	Plot	Exclosure	Parameter Estimate	Standard Error	t Value	Adjustment	Adj P
Plot	Control		Cut		-3.5000	3.1718	-1.10	Tukey-Kramer	0.2984
Exclosure		Protected		Open	17.5000	3.1718	5.52	Tukey-Kramer	<.0001
Plot *Exclosure	Control	Protected	Control	Open	5.4000	4.4856	1.20	Tukey-Kramer	0.6282
Plot *Exclosure	Control	Protected	Cut	Protected	-15.6000	3.6624	-4.26	Tukey-Kramer	0.0007
Plot *Exclosure	Control	Protected	Cut	Open	14.0000	4.4856	3.12	Tukey-Kramer	0.0173
Plot *Exclosure	Control	Open	Cut	Protected	-21.0000	4.4856	-4.68	Tukey-Kramer	0.0002
Plot *Exclosure	Control	Open	Cut	Open	8.6000	5.1795	1.66	Tukey-Kramer	0.3583
Plot *Exclosure	Cut	Protected	Cut	Open	29.6000	4.4856	6.60	Tukey-Kramer	<.0001

The effect of the exclosure across treatments was also significant (Table 5) with taller suckers found in the exclosures.

Utilization

As indicated from the height and regeneration data, ungulate browsing significantly decreased sucker growth and survival. During collection of the regeneration data (fall 2002) numerous browsed suckers that had died were observed. Figure 11 identifies the amount of regeneration occurring in the treatment plots and exclosures of the study clones. The effect of herbivory on regeneration as previously indicated (Table 3) was significant. Browsing of the suckers, as measured by height, was also significant (Table 5). Average sucker height of the control plots across the protected and unprotected open portions was 20.7 and 16.0 cm, respectively, and for the cut plots was 38.9 and 4.7 cm, respectively. A height difference of 88% in the cut plots indicates the percent of the sucker utilized as browse in the open area. In the control plots, utilization, as measured from height, was only 23%. Perhaps the presence of suckers in the control

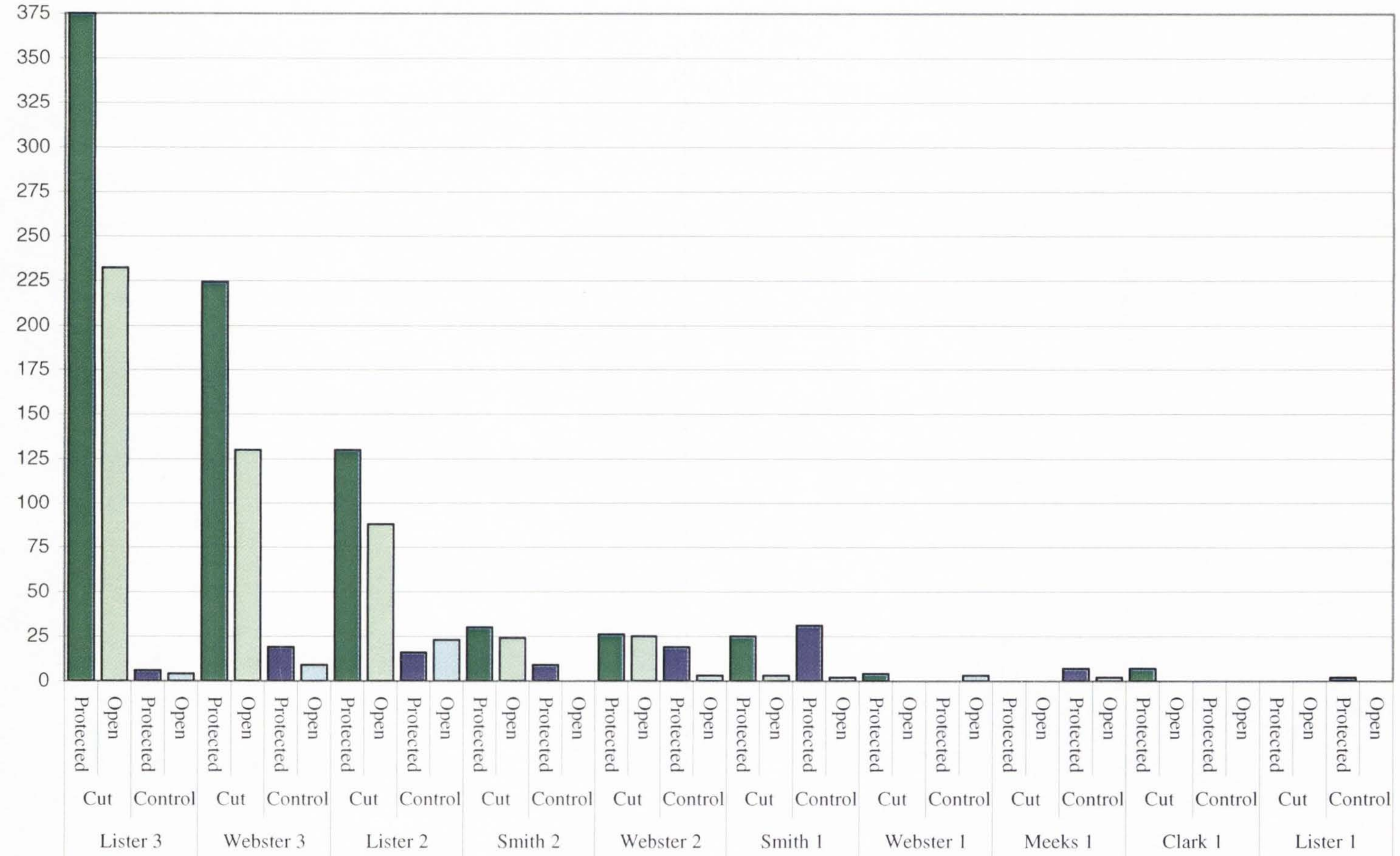

Fig. 11. Regenerating suckers per 50 m² (y-axis) by treatment plot and exclosure level.

plots that were less impacted from browsing is due to sucker scarceness, leading to greater difficulty for the ungulates to find and intensely browse them. In contrast, regeneration in the cut plots was greater and thus more easily found. Subsequently, the regeneration in the cut plots was more intensely browsed.

Browsing intensity classes ranging from 0 to 5 in magnitude, were used to quantify actual browsing pressure from ungulates (Table 6). The data were collected in the open, unprotected portion of the treatment plots, and represent the combined effect of wild and domestic ungulates. For broad representation purposes, utilization data of like intensity classes were combined and identified to 3 distinct levels of browsing, (1) None (class – 0), (2) Light – Moderate (classes 1 – 2 – 3), and (3) Heavy (classes 4 – 5). Percentage of suckers browsed at each intensity level is identified (Fig. 12). As indicated previously (Table 5), sucker height of the open areas is not significantly different across treatments due to browsing. Therefore, the utilization levels presented in Figure 12 are the averages of all the study clones, regardless of treatment. The data indicate, overwhelmingly, that regenerating suckers were heavily browsed; thus, the null hypothesis of non-impact by ungulates is rejected.

Important to note, is that an extreme drought coincided with this study. During the middle of the growing season abundant grasses and forbs that are usually green and growing vigorously had already senesced, attaining low stature. The effect of drought on vegetation at the study site is presented (Fig. 13). Precipitation during 1984 was 101% of normal (76 cm), whereas, in 2002 it was only about 43% of normal (32 cm). Precipitation data are the average of 2 SNOTEL (SNOwpack TELemetry) site data

Table 6. Percentage of suckers browsed in each intensity class by clone and treatment plot.

		Browsing intensity					
Clone	**Treatment**	**Class - 0**	**Class - 1**	**Class - 2**	**Class - 3**	**Class - 4**	**Class - 5**
Lister 1	Control*	-	-	-	-	-	-
	Cut*	-	-	-	-	-	-
Clark 1	Control*	-	-	-	-	-	-
	Cut*	-	-	-	-	-	-
Meeks 1	Control	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	Cut*	-	-	-	-	-	-
Webster 1	Control	33.33%	0.00%	0.00%	0.00%	0.00%	66.67%
	Cut*	-	-	-	-	-	-
Smith 1	Control	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	Cut	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
Smith 2	Control*	-	-	-	-	-	-
	Cut	8.33%	16.67%	0.00%	0.00%	12.50%	62.50%
Webster 2	Control	0.00%	0.00%	0.00%	0.00%	66.67%	33.33%
	Cut	56.00%	4.00%	0.00%	0.00%	4.00%	36.00%
Lister 2	Control	0.00%	0.00%	8.70%	21.74%	0.00%	69.57%
	Cut	15.91%	6.82%	0.00%	0.00%	0.00%	77.27%
Webster 3	Control	0.00%	0.00%	0.00%	11.11%	0.00%	88.89%
	Cut	20.00%	2.31%	0.77%	0.00%	19.23%	57.69%
Lister 3	Control	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	Cut	15.95%	8.62%	0.43%	0.00%	1.29%	73.71%
Average	**Control**	**4.76%**	**0.00%**	**1.24%**	**4.69%**	**9.52%**	**79.78%**
	Cut	**19.37%**	**23.07%**	**0.20%**	**0.00%**	**6.17%**	**51.20%**
	Total	**12.06%**	**11.53%**	**0.72%**	**2.35%**	**7.85%**	**65.49%**

* No regenerating suckers were found in this open area.

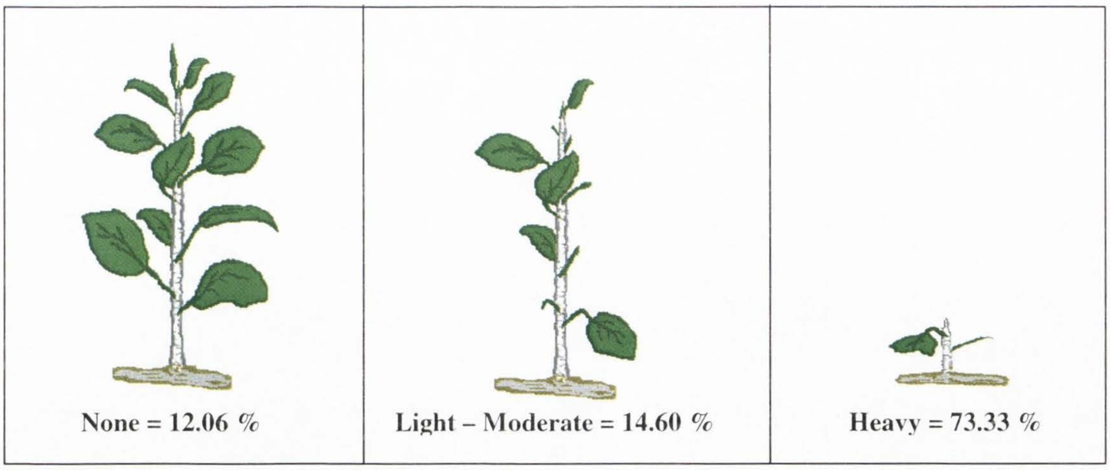

Fig. 12. Browsing intensity levels across the study clones.

reports (National Water & Climate Center), one located at Webster Flat, north and east of the study site, and the other at Kolob-Crystal, west of the site. It is plausible that regenerating suckers were utilized at a higher intensity level due to the drought. As surrounding herbaceous vegetation became dry and less palatable, ungulates may have used the regenerating aspen suckers more intensely. The treatment plots, due to their relatively small size, became islands of green vegetation, surrounded by a sea of dry yellow, and brown herbage. This island effect perhaps led to ungulate preference for the vegetation of the treatment plots. It may be that during a normal precipitation year (e.g., 1984) browsing intensity levels would be lower than those observed during this study. Grasshoppers (*Melanoplus spp.* Stål) and crickets (*Anabrus simplex* Haldeman) were also observed foraging on the aspen regeneration. Clones where insect foraging was observed were Smith 2, Lister 1, Clark 1, and Meeks 1. Similar to the ungulates, their defoliating effects may be greater during drought.

Fig. 13. Photographic comparison of July vegetation from a normal precipitation year (1984) left, and the drought of 2002 (right). Photographs are along an established transect used in previous studies at the UAES Miners Peak site. The transect is found ca. 30 m south of study clone Webster 2. (1984 photo by James Bowns, 2002 photo by author)

Repeat photography

Photographic data, obtained from Dr. James Bowns, yielded invaluable information regarding the general timing of aspen decline on Cedar Mountain. A broad representation of aspen decline from 1983 to 2002 is presented (Fig. 14, Fig. 15) (zoomed-in comparisons of these photographs are presented in Appendix G). The photographs were taken atop Miners Peak (Fig. 1) in a north, northwestern direction. In 1983, the study clones appeared to be in good health (i.e., no visible crown deterioration). Focusing on Lister 1, the clone that was originally identified by Dr. Bowns as undergoing rapid decline, it is evident that by 1990 deterioration in the form of canopy dieback was already extensive (Fig. 2). By 1998 most of the ramets appeared to be dead (Fig. 4). Since decline must have initiated sometime during the middle to late 1980's, the rate of decline from an apparently healthy condition to near complete mortality ranges from 8 to 12 years for this clone. Repeat photographs of Webster 1 and Webster 2 indicate other clones are declining at a similar rate (Figs. 16, Fig. 17).

The combined area of the 10 study clones, as identified using aerial photographs in a Geographic Information System is approximately 60 hectares (Fig. 18). If current processes continue, it is possible these clones will be eliminated. It is important to note that the study clones represent only a sample of the clones that are in decline on Cedar Mountain. Thus, aspen loss is much greater than only the area of the study clones.

A presentation of repeat photographs including study clones, is found in Appendix G.1 through G.17. Also presented are photographs of other declining clones of Cedar Mountain that were not included as study clones. These photographs illustrate

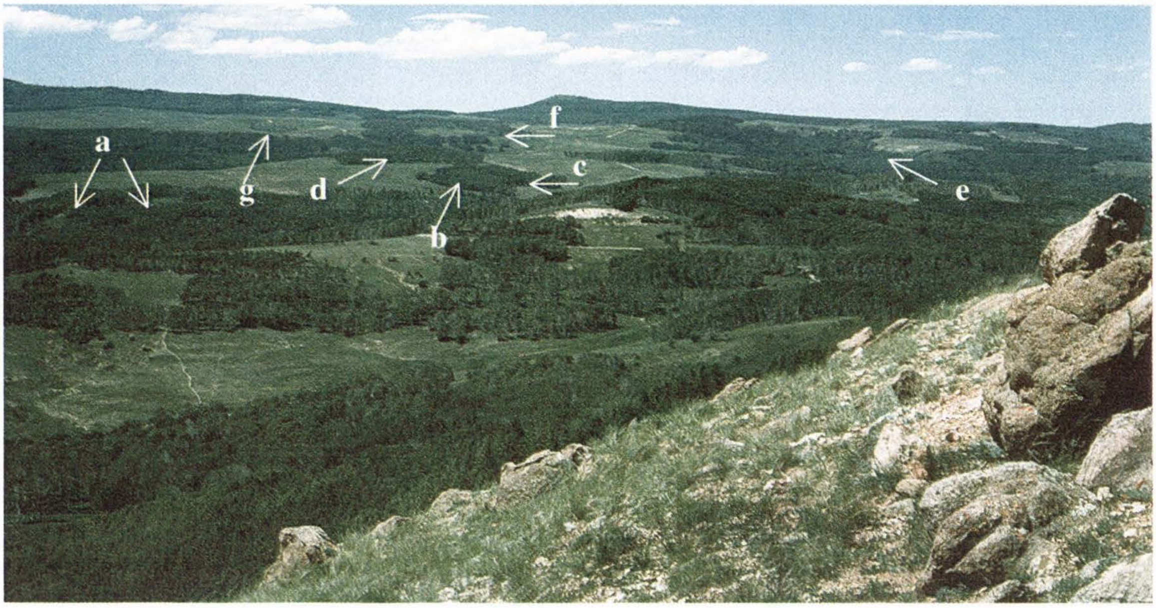

Fig. 14. View of study area (August 1983). Study clones are (a) Lister 1, (b) Lister 2, (c) Lister 3, (d) Meeks 1, (e) Clark 1, (f) Smith 1, and (g) Smith 2. See figure 18 for detailed clone boundaries. (Photo by James Bowns)

Fig. 15. View of study area (August 2002). Clone identification is the same as in figure 14. Deteriorating clones are also present in the foreground, and to the right of Clark 1 (e). (Photo by author)

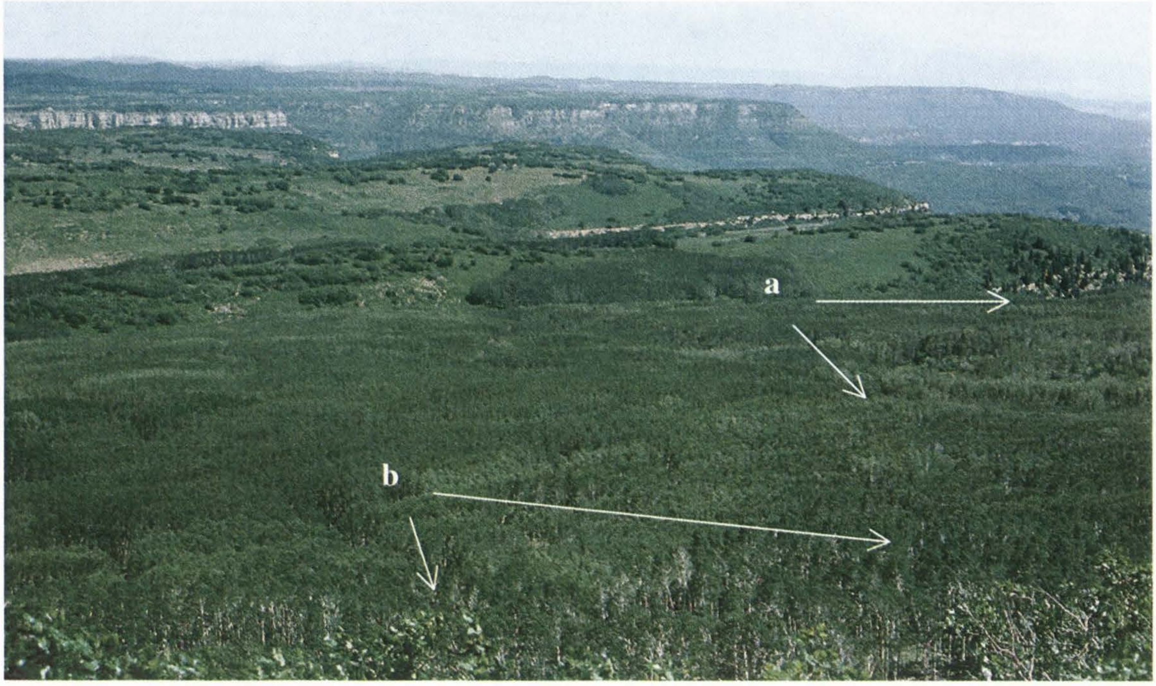

Fig. 16. View of clones Webster 1 (a) and Webster 2 (b) as they appeared in summer 1983. (Photo by James Bowns)

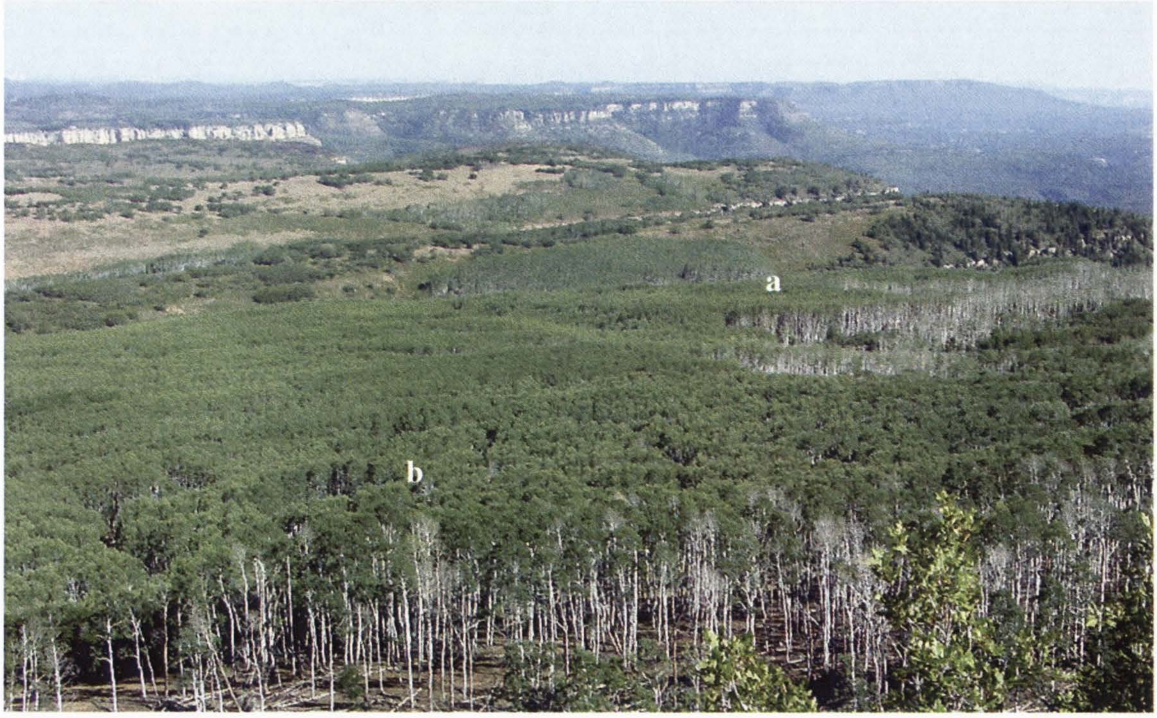

Fig. 17. Declining clones, Webster 1 and 2, during summer 2002. Clone identification is the same as in figure 18. (Photo by author)

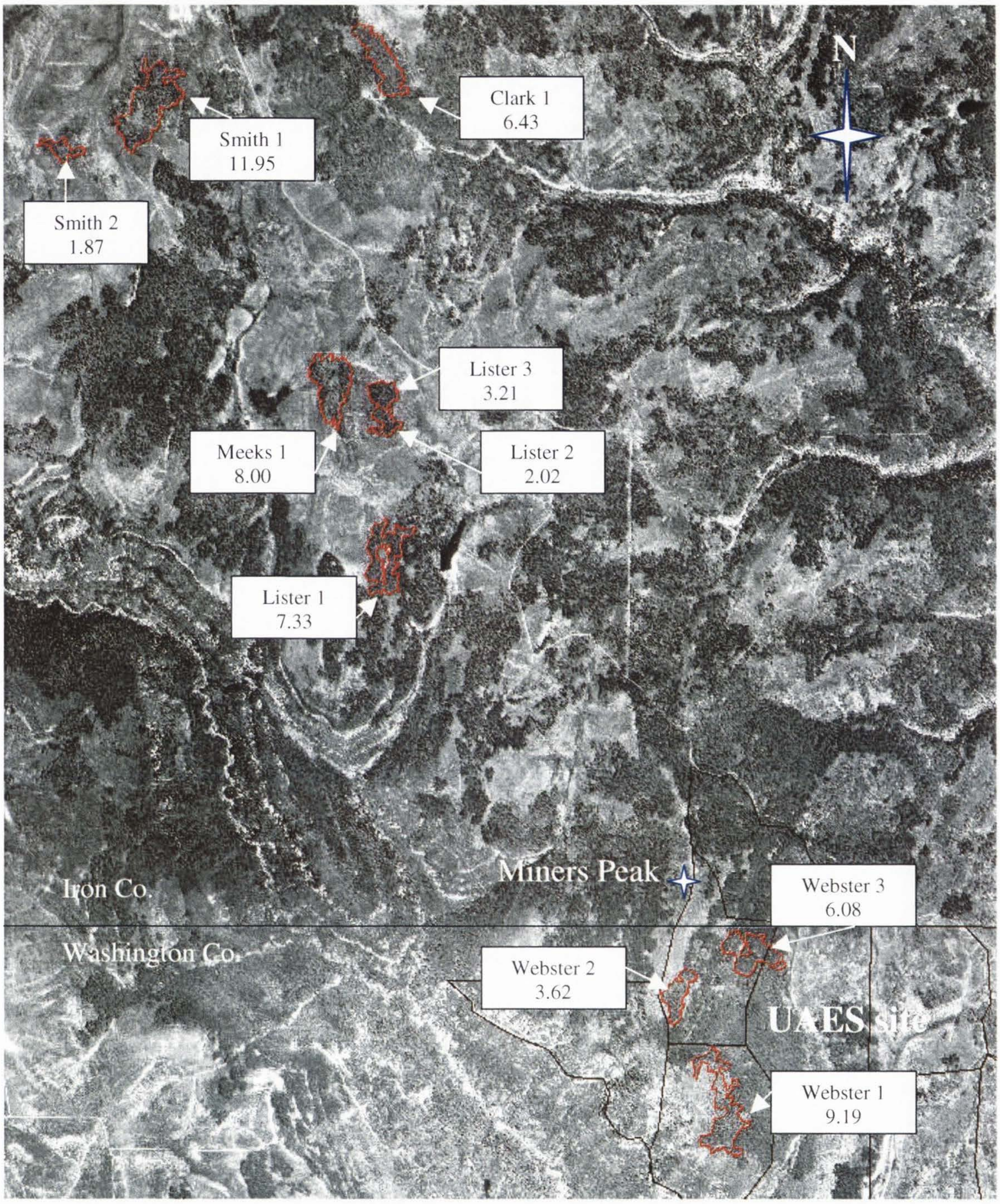

Fig. 18. Aerial digital orthophoto quad of the study site in 1993. GPS data points for each clone are red and outline clonal boundaries. Area measurements are in hectares. (Photo by U.S. Geological Survey)

decline that has occurred in the respective study clones as well as other clones across the mountain.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

The abundant resources associated with aspen-dominated communities are largely reliant on the sustained dominance of aspen (Bartos and Campbell 1998b). If declining clones are not disturbed and regenerated, these valuable resources will decline, or be eliminated (Kay 1997, Bartos and Campbell 1998a). This study has demonstrated that the declining clones on Cedar Mountain, thought by some to be incapable of regeneration, are in fact capable of regenerating to varying degrees, depending on the extent of clonal decadence. Furthermore, survival of regenerating suckers appears to be heavily influenced by browsing ungulates, both wild and domestic.

If nothing is done to stimulate and (or) protect regeneration of the deteriorating aspen clones of Cedar Mountain, decline will continue and clone elimination will occur. This loss not only represents the elimination of the genet (Bartos and Campbell 1998b), but a decrease or elimination of valuable associated resources (Kay 1997). Campbell and Bartos (2001) provide recommendations for the proper management of aspen systems, suggesting to "take action now, make actions large, and take action often." If landowners and land managers are to preserve the declining Cedar Mountain aspen, these recommendations should be implemented immediately.

Management recommendations

The following dichotomous key presents various management scenarios for Cedar Mountain aspen based on the results of this research (Table 7). The key uses clone basal

Table 7. Management recommendation key developed for determining proper restoration practices for Cedar Mountain aspen.

Key to Management Recommendations

Step 1 - a) Clone basal area ≥ 40 m^2/ha .... go to step 2.
b) Clone basal area < 40 m^2/ha .... go to step 3.

Step 2 - a) Regenerating suckers absent .... see **MR-1**.
b) Regenerating suckers present .... go to step 6.

Step 3 - a) Clone basal area ≥ 25 m^2/ha .... go to step 4.
b) Clone basal area < 25 m^2/ha .... go to step 5.

Step 4 - a) Regenerating suckers absent .... see **MR-2**.
b) Regenerating suckers present .... go to step 6.

Step 5 - a) Regenerating suckers absent .... see **MR-3**.
b) Regenerating suckers present .... go to step 6.

Step 6 - a) Suckers suppressed by browsing .... see **MR-4**.
b) Suckers not suppressed by browsing .... see **MR-5**.

Management Recommendations

MR-1. Conduct disturbance treatment. Some short-term management or possibly none.

MR-2. Conduct disturbance treatment. Moderate short-term management.

MR-3. Conduct disturbance treatment. Intense short-term management.

MR-4. Long-term management.

MR-5. No management needed

area and regeneration condition prior to treatment to determine management recommendations.

Recommendation – 1 (MR-1)

The first bifurcation divides clones by the total amount of living basal area. For clones where basal area is ≥ 40 m^2/ha and regeneration does not occur a disturbance treatment is recommended. Though clones may exhibit low mortality and low crown dieback, the lack of suckers is indication that the clone may be experiencing regenerative problems and further deterioration can be expected to occur rapidly. Some short-term management might be needed in order to ensure the survival of the regenerating suckers upon treatment. However, if the treated area is relatively large and regeneration is extensive, there may be no need for further management.

Recently on Cedar Mountain, a landowner clearcut a large stand of aspen. After 2 years regenerating suckers had attained heights of 1.2 to 1.8 m (Fig. 19). Livestock and wildlife use was not limited and browsing occurred. Perhaps the large area of the cut allowed ungulates to disperse, minimizing the possible harmful effects of browsing. At the same time, another smaller cut was made in a nearby area in close proximity to a sheep bed ground. After 2 years, the suckers were only 0.3 to 0.9 m tall, and signs of extensive browsing were present. In clones such as the first, intervention may not be necessary, however, in clones like the latter where browsing pressure is high or the treatment is small in area, some short-term intervention is suggested (Smith et al. 1972).

The most control the land manager or landowner has on regeneration, after the treatment is made, is regulating the ungulate pressure and particularly livestock. Short-

term management might include livestock grazing rotation where the aspen are not browsed for part of the grazing season, thus allowing regrowth to occur. Temporary fencing (wire or electric) might be employed to exclude livestock and wildlife (if tall enough). Herding could also be used to keep livestock from utilizing the regeneration too heavily. The duration of these management practices would be dependent upon the amount of time needed for the suckers to exceed the reach of browsing ungulates. At 1.2 to 1.5 m high, sheep and deer will no longer be able to browse the apical leaders (Smith et al. 1972). The regeneration will outdistance cattle by 1.8 to 2.1 m (Sampson 1919). For elk, which have been known to bend juvenile suckers over in order to browse on them, 2.4 to 3.0 m of height might be needed (DeByle 1985a, 1985b). Short-term management commitment would likely range from 2 to 5 years depending on these

Fig. 19. Aspen regeneration 2 years after clearcut under ungulate use. (Photo by author)

factors (Smith et al. 1972).

Recommendation – 2 (MR-2)

This study has demonstrated that clones that exhibited low basal area prior to treatment will not produce numerous suckers. The management recommendation key indicates the management of these clones should be of greater intensity than the first scenario just described, though, due to the disturbance-induced sucker height duration may be the same. Short-term exclusion of livestock may be necessary to ensure that the regenerating suckers survive (Sampson 1919, Smith et al. 1972). Herding or rotational grazing might be effective practices for this scenario, but efforts should be taken to limit sucker utilization by ungulates.

Recommendation – 3 (MR-3)

Once treated, to ensure the survival of the few suckers that regenerate in clones with very low basal area (<25 m^2/ha), management actions should be of greater intensity than MR-1 and MR-2, though duration the same. Ungulate exclusion may be the best management practice for sucker and subsequently clone survival. If the few suckers are browsed too intensely, even for a short duration, the clone might not be capable of recuperation as quickly as its more healthy counterparts and it may completely die.

Recommendation – 4 (MR-4)

If regenerating suckers are present in the clone, no disturbance treatment is recommended. Regenerating suckers can, if not suppressed, successfully restock the clone. If suckers show signs of suppression from browsing ungulates (e.g., leaf stripping,

leader damage, and (or) hedged appearance) intervention may be required to protect the suckers from ungulates. Due to low stature of the suckers and poor regeneration amount as compared to suckers of disturbance induced regeneration, intense management practices (e.g., fencing) would need to be long-term, in order to allow sufficient time for the regeneration to exceed the reach of browsing ungulates (Shepperd et al. 2001). Management duration may range from 5 to 10 years. If the landowner or land manager decides to treat the clone, management would then follow MR–1, 2, or 3 depending on clone basal area (Table 7).

Recommendation – 5 (MR-5)

If regenerating suckers occur in the clone and no evidence of suppression from ungulates is apparent, intervention is likely not required, as unsuppressed suckers will in time successfully restock the clone.

Reasons for decline

Decline in aspen systems is likely due to the cumulative or interacting effects of many factors (LaRoe et al. 1995). This is probably true for the aspen involved in this study. Though this study did not directly investigate the causative factors for the aspen decline occurring on Cedar Mountain, some factors can be addressed. The following hypothesis was developed in an effort to identify why these clones have declined so dramatically. It is based on results from this study, general knowledge of aspen systems, and experience working on the site with landowners and land managers.

This study has indicated that declining Cedar Mountain aspen, as with other aspen, rely on disturbance in order to induce suckering (Schier et al. 1985, Bancroft

1989). In the absence of disturbance, regeneration is generally inhibited, due to mature ramets maintaining apical dominance over the root system (Schier 1975). Once ramets become overmature and begin to die, roots die as well (Shepperd and Engelby 1983, Shepperd et al. 2001). Remaining, scattered ramets are then capable of continually maintaining apical dominance over the weakened root system (Schier 1975). As the clones become weaker and weaker, they are more susceptible to insects and pathogen infestations (Hinds 1985), and regeneration decreases (Bartos 2001). The study clones appear to be at this stage, as the percentage of living ramets infected with pathogens, or infested with insects range from 50 to 100% (Table 1), and regeneration capability of the control plots was poor (Table 2).

Genotype difference among clones determines if a clone will regenerate due to slight disturbance (e.g., an insect or pathogen infestation) or if a more intrusive disturbance is needed (e.g., clearcut or fire) (Schier 1975, 1976, Schier and Campbell 1980, Shepperd et al. 2001). The declining clones on Cedar Mountain appear to be the latter type (Table 3). These clones may only recruit nominal amounts of regeneration due to small-scale disturbances, whereas other clones in the same area dramatically regenerate under similar circumstances (Fig. 20).

Increment cores from the study clones indicate that these clones experienced regeneration events between 1857 and 1883 (Table 1), which coincides with modern settlement of the area. Though the role of fire is currently latent in this system, pre-settlement conditions such as unusually dry weather patterns may have provided adequate conditions for fire to disturb and regenerate these clones. Kay (1997) suggests that such a fire would have likely resulted from the intentional ignition by aboriginal people. The

Homestead Act brought modern settlers to the site in the late 1860s (Jones and Jones 1972). As with most other places in the West, fire suppression efforts began at settlement time. Due to early overgrazing the area, once dominated by tall forbs, is now grassland (Bowns and Bagley 1986). This vegetation conversion, along with present grazing practices, suggests a drastic decrease in the fuels needed to carry fire (Brown and Simmerman 1986). During June of 2002, in the midst of an extreme drought, a wildfire sparked by lightning burned near the study site. Fire suppression efforts were successful in containing the fire before it reached the study clones. Due to the unusually dry and windy conditions at that time, it is likely the fire if not suppressed could have reached the study clones. However, it is unlikely that the study clones would have been significantly impacted, considering that even in the extreme drought situation the understory plants at that time were green. Thus, fire events remain extremely rare on the Cedar Mountain.

Fig. 20. Disease or insect induced regeneration (foreground). The mature ramets of this clone are similar in appearance to those in other clones where regeneration does not occur. (Photo by author)

Some, including local landowners, have suggested that livestock (mostly sheep) are responsible for the decline. During a recent fieldtrip for landowners regarding aspen decline, a landowner suggested that aspen regeneration found on his land might have occurred during the middle 1960s, at a time when his sheep were not grazing in the area. However, a photograph of the same area indicates regeneration had not occurred by 1972 (Fig. 21). But, the repeat photograph for the site indicates that by 2002 regeneration had occurred (Fig. 22). The landowner said sheep had been using the site from the late 1960s until present. This suggests for this area that the effect of sheep browsing alone is likely not responsible for the decline. Furthermore, vigorously regenerating clones are known to occur in the same pastures as decadent clones (Fig. 7). This observation supports the idea that genotype may play a significant role in determining clonal regeneration abilities (Jones and DeByle 1985b), or that selection preference by livestock and wildlife alike is occurring (Lindroth 2001). Because both healthy and deteriorating clones occur in close proximity to one another (at times bordering), site characteristics do not appear to have any controlling effect on these aspen clones.

As stated, regeneration in the deteriorating clones is scarce. If the regeneration were allowed to grow uninhibited, the result would be a multi-aged stand, due to the perpetual recruitment of a relatively few new suckers each year. The lack of juvenile and middle-aged ramets suggests that the few regenerating suckers occurring annually are suppressed (Fig. 12). Figure 23 shows a ramet that has been browsed repeatedly for numerous years. This photograph was taken in a moderately declining clone that bordered with Lister 1.

Fig. 21. Leigh pasture, fall 1972. No regeneration in the 2 clones in the center. (Photo by James Bowns)

Fig. 22. Leigh pasture, summer 2002. The clones have experienced successful regeneration. (Photo by author)

In summary, the lack of substantial disturbance (in genets that require it) has led to clones with few, scattered, overmature ramets with weakened root systems. Subsequently, vigor lessens and defenses against insect and (or) pathogen infestations are weakened. Remaining ovematurе ramets that slowly die maintain apical dominance and inhibit stand-replacing regeneration. As vigor continues to decrease, regenerative ability, due to rarity of living roots, declines as well. The few suckers that may regenerate remain suppressed by ungulate browsing, until finally nutrient reserves are exhausted and the clone is eliminated.

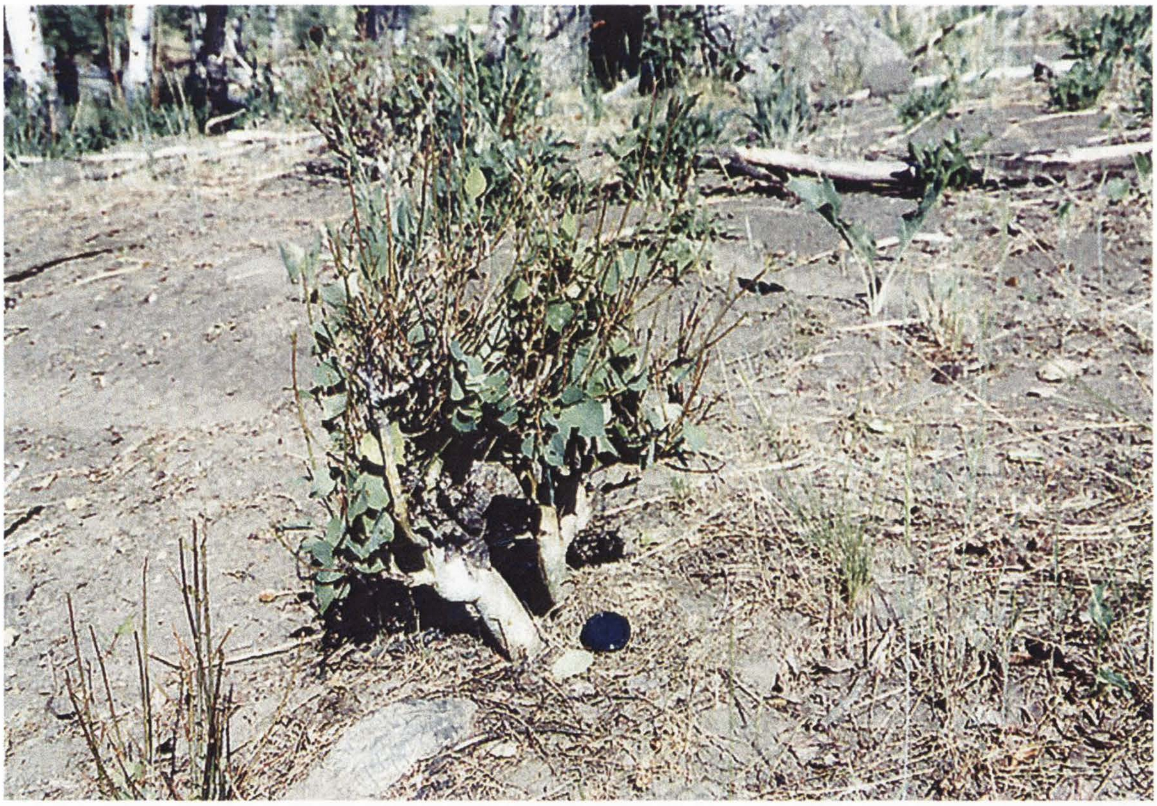

Fig. 23. Hedged appearance of sucker indicates repeat browsing (2002). (Photo by author)

Future studies

This study has identified that decline of some clones on Cedar Mountain can be reversed through management practices. If decline continues to worsen, and vigorously regenerating clones begin to experience mortality, more study should be undertaken to better determine the agents of the decline. Such a study might focus on the effects of fungal, bacterial and (or) viral pathogens on aspen physiologic processes.

Regeneration prediction

This study has demonstrated the ability to predict regeneration based on living basal area. As stated during the discussion of the prediction model, the associated error is large due to the small sample size. An expanded study including numerous clones from various locations throughout the Intermountain West should lead to a stronger predictive model, with much greater extent in application.

Palatability

This study has indicated that the possibility exists that ungulate preference might be a factor in clone decline. If ungulates selectively browse some clones while not others, those clones selected would be in jeopardy of declining as regeneration is suppressed. A study could attempt to identify secondary metabolites produced by aspen clones that increase or diminish palatability. Also, an attempt to identify genetic variability among clones would be appropriate. Once these factors are understood, methods should be developed that can be used to determine those clones in greatest risk of preferential browsing from ungulates.

Seedling establishment

Due to severe deterioration that has already occurred in many aspen clones on Cedar Mountain, including some of the study clones, efforts should be made to determine the optimal methods for establishing aspen via outplanting from nursery stock. Some landowners, whose clones are deteriorating, have expressed interest in restocking their clones in such a way. During this study, an attempt was made by the Utah State University Extension Service to restock some of these clones with seedlings, however, none survived. Failure was likely due to the fragile nature of the seedlings combined with the deleterious effects of frost, drought, insects, and ungulates. A new study might address proper timing for outplanting, as well as water needs of the seedlings. Such a study, if successful, would enable landowners and land managers to develop new beneficial resources that would accompany the revitalized or newly established aspen stand. These resources include increases in biodiversity and watershed capabilities, both of which are currently demanding the attention of land managers, government entities, and researchers alike across the arid and semiarid Intermountain West.

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APPENDICES

Appendix A. Clone survey sheet

30m

25m

20m

15m

10m

5m

2m

Belt transect

Clone# ________ Transect# ________ Date: ________

Tree #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
DBH (cm)																					
Height (ft)																					
Age																					
Basal Area																					

Insects & Pathogens

Borers																				
Marssonina																				
Hypoxylon																				
SB Cenangium																				
Cytospora																				
Ganoderma																				
Ceratocystis																				
Rough bark																				
Heart rot																				
Other:																				

Crown Dieback

Score																				

Dead=4 (100%) Light=1 (6-30%)

Heavy=3 (71-99%) None=0 (0-5%)

Moderate=2 (31-70%)

Mortality		Basal Area (m. sqd.)		Density (Stems/Ha.)		Dieback
	Live		Live		Live	
	Total		Total		Total	

Appendix B. Regeneration tally form

Regeneration Tally Form

Date	Clone	Exclosure		
		Study		Control
		Open	Livestock	Wildlife

Diameter of the sucker measured at ground level. **DGL**	*Measured at the highest bud or the browse point.* **Height**

Herbivory

0 = *Non-browsed.*
1 = *Stem browsed but regrowth exceeding the browse point.*
2 = *Leaves striped from < 50% of the stem & apical bud intact.* 4 = *Apical bud removed & leaves striped from < 50% of the remaining stem.*
3 = *Leaves striped from ≥ 50% of the stem & apical bud intact.* 5 = *Apical bud removed & leaves striped from ≥ 50% of the remaining stem.*

Sucker #	DGL	Height (cm)	Herbivory	Sucker #	DGL	Height (cm)	Herbivory
1				28			
2				29			
3				30			
4				31			
5				32			
6				33			
7				34			
8				35			
9				36			
10				37			
11				38			
12				39			
13				40			
14				41			
15				42			
16				43			
17				44			
18				45			
19				46			
20				47			
21				48			
22				49			
23				50			
24				51			
25				52			
26				53			
27				54			

Appendix C. Greenhouse data sheet

Root Cutting Regeneration Tally Form

Date	Clone	*Measured from the point of genesis to the highest bud.*	**Height (cm)**
		Total suckers / root segment (>5mm).	**#Suckers**
Notes			

Root#	#Suckers	Height
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

Ave Suckers/Cutting ______

Ave Sucker Height ______ cm

Appendix D. Copyright permission letter

2/26/03
Seth Ohms
Dept. of Forest, Range, and Wildlife Sciences
Utah State University
Logan, Utah 84321-5230
(435) 797-3095

Dear : Dr. James Bowns

I am in the process of preparing my thesis in the Department of Forest, Range and Wildlife Sciences at Utah State University. I hope to complete in the Spring of 2003.

I am requesting your permission to include the attached material as shown. I will include acknowledgments and/or appropriate citations to your work as shown and copyright and reprint rights information in a special appendix. The bibliographical citation will appear at the end of the manuscript as shown. Please advise me of any changes you require.

Please indicate your approval of this request by signing in the space provided, attaching any other form or instruction necessary to confirm permission. If you charge a reprint fee for use of your material, please indicate that as well. If you have any questions, please call me at the number above.

I hope you will be able to reply immediately. If you are not the copyright holder, please forward my request to the appropriate person or institution.

Thank you for your cooperation,

Seth Ohms

I hereby give permission to Seth Ohms to reprint the following material in his thesis.

Photographs including figures 2, 3, 4, 15, 16, 18, 22, G.1, G.3, G.5, G.7, G.9, and G.11.

Citation : Bowns, J.E. Cedar Mountain photograph collection. So. Ut. Univ., Cedar City, Ut.

Fee ______ none ______

Signed____________________

Appendix E. SAS code

SAS code for regeneration with basal area as covariate.

```
data seth.aspen60;
  set seth.aspen60;
  excl="Open";
  if (exclo>0) then excl="NotOpen";

run;

proc genmod data=seth.aspen60;
  class clone treat excl;
  model regen=treat ba excl treat*excl/dist=negbin link=log lrci;
  repeated subject=clone/type=exch;
  lsmeans treat excl treat*excl/pdiff;
  output out=predtba p=pred resdev=resdev reschi=reschi l=lower
u=upper;
run;

proc univariate data=predtba normal plot;
  var resdev reschi;
run;
```

SAS code for vigor assessment using sucker height.

```
data seth.aspen60;
  set seth.aspen60;
  excl="Open";
  if (exclo>0) then excl="NotOpen";
run;

proc mixed data=seth.aspen60 CL covtest;
  class clone treat excl;
  model regenht=treat excl treat*excl ba/outp=pred;
  random clone clone*treat;
  lsmeans treat excl treat*excl/pdiff adjust=tukey;
run;

proc univariate data=pred normal plot;
  var resid;
run;
```

Appendix F. Categorical prediction table

Table F.1. Regeneration prediction table (suckers / ha). Predictions for regeneration are based on four different treatments, utilizing clone basal area as the predictor.

Basal area (m^2/ha)	**Cut Protected**	**Cut Open**	**Not cut Protected**	**Not cut Open**
1 - 5	216 - 1248	103 - 844	72 - 468	24 - 157
5 - 10	304 - 1682	144 - 1148	101 - 635	34 - 218
10 - 15	465 - 2287	218 - 1572	154 - 869	50 - 307
15 - 20	706 - 3141	328 - 2173	232 - 1201	73 - 436
20 - 25	1058 - 4374	489 - 3033	346 - 1681	106 - 628
25 - 30	1567 - 6189	723 - 4283	509 - 2386	152 - 914
30 - 35	2282 - 8909	1055 - 6123	739 - 3437	215 - 1347
35 - 40	3268 - 13044	1521 - 8862	1058 - 5024	301 - 2006
40 - 45	4601 - 19391	2165 - 12983	1492 - 7441	416 - 3014
45 - 50	6379 - 29192	3046 - 19232	2076 - 11149	571 - 4562
50 - 55	8733 - 44383	4239 - 28769	2856 - 16863	777 - 6949
55 - 60	11839 - 67990	5840 - 43397	3891 - 25700	1052 - 10641
60 - 65	15930 - 104749	7980 - 65922	5263 - 39406	1416 - 16363
65 - 70	21311 - 162080	10828 - 100715	7074 - 60710	1898 - 25251
70 - 75	28388 - 251618	14608 - 154601	9464 - 93882	2535 - 39078
75 - 80	37690 - 391613	19615 - 238236	12615 - 145611	3376 - 60621
80 - 85	49913 - 610714	26236 - 368280	16764 - 226381	4486 - 94227

Appendix G. Photographs

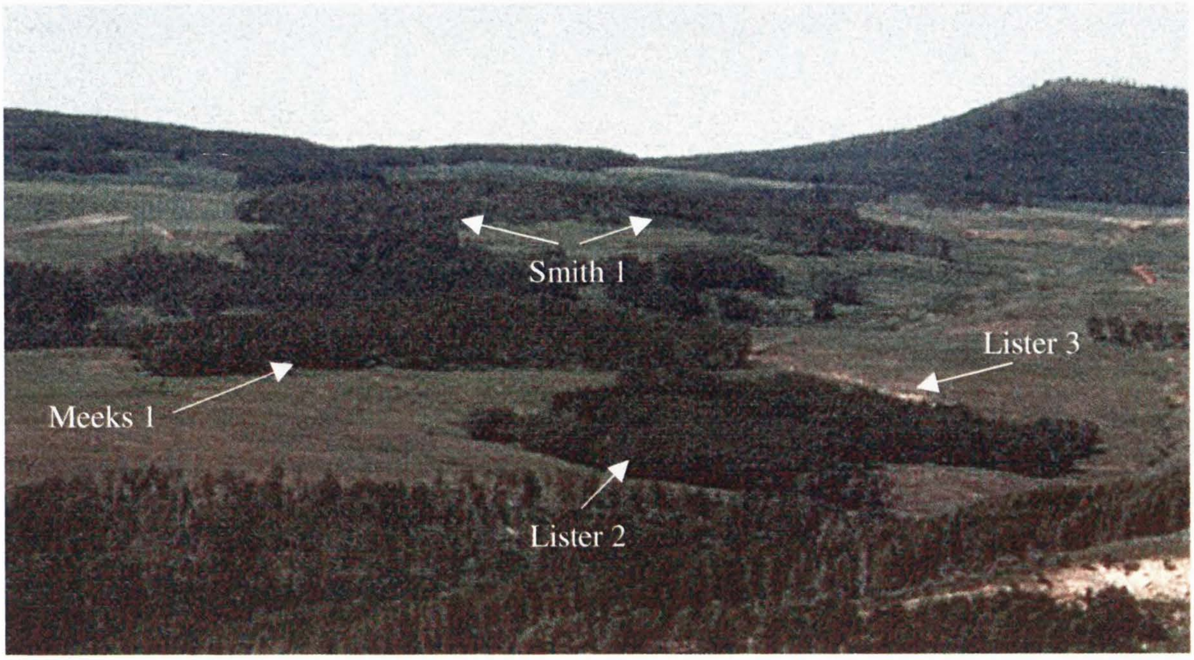

Fig. G.1. Lister 2 and 3, Meeks 1, Smith1 zoomed in, August 1983. All the clones appear healthy, no canopy deterioration. (Photo by James Bowns)

Fig. G.2. Lister 2 and 3, Meeks 1, Smith1 zoomed in, August 2002. Canopy deterioration at various levels apparent in all clones. (Photo by author)

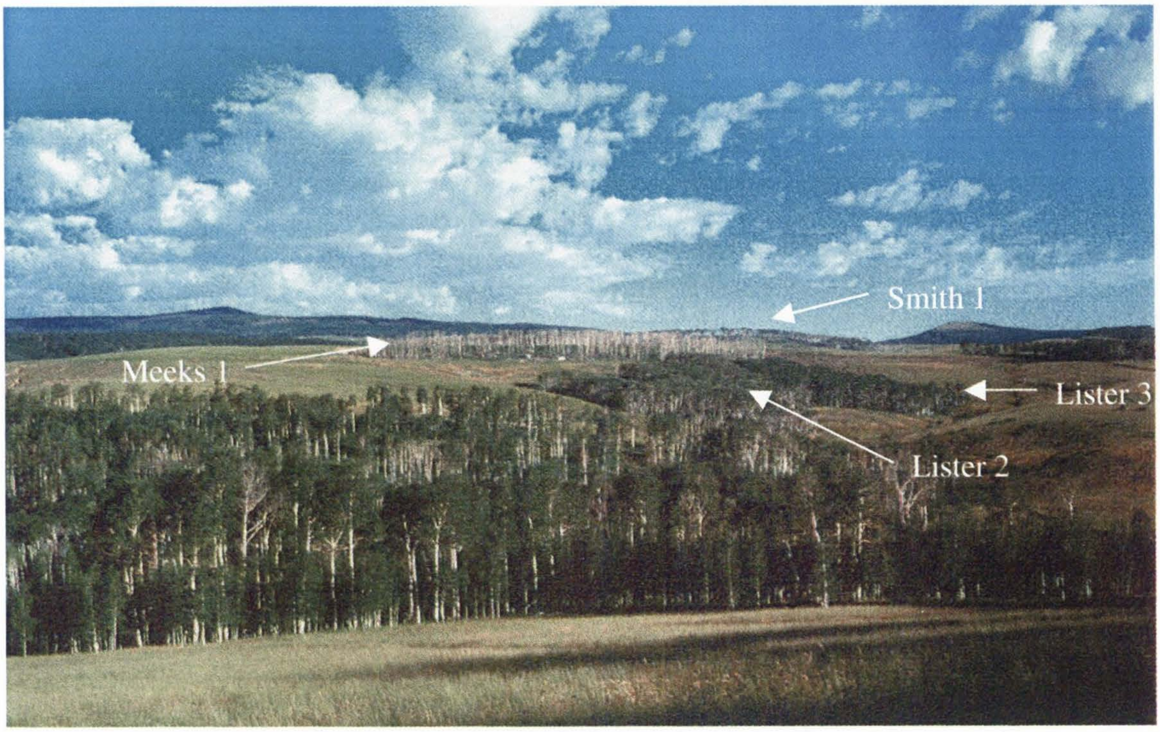

Fig. G.3. Lister 2 and 3, Meeks 1, Smith1, August 1998. (Photo by James Bowns)

Fig. G.4. Lister 2 and 3, Meeks 1, Smith1, August 2002. Differentiation among clones more apparent due to canopy dieback. Clone center-left has deteriorated as well (Fig. G.16). (Photo by author)

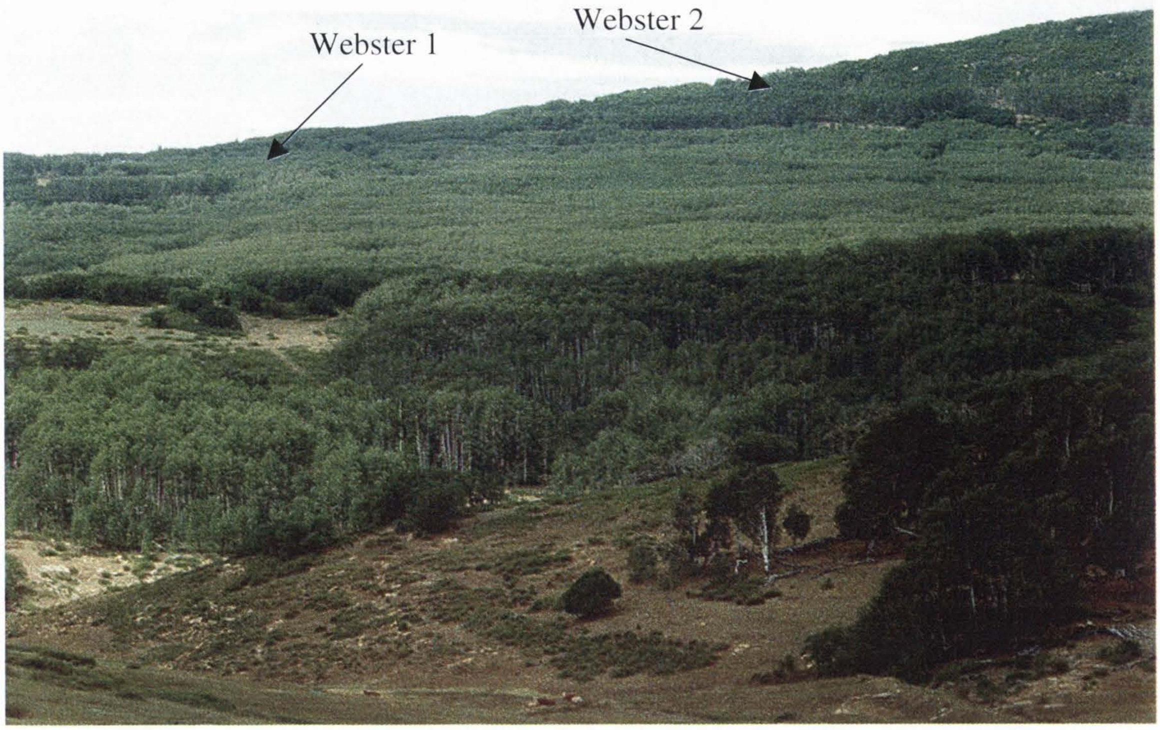

Fig. G.5. Webster 1 and 2, summer 1989. (Photo by James Bowns)

Fig. G.6. Webster 1 and 2, summer 2002. (Photo by author)

Fig. G.7. Webster 1 and 2 from Miners Peak, summer 1983. (Photo by James Bowns)

Fig. G.8. Webster 1 and 2 from Miners Peak, summer 2002. (Photo by author)

Fig. G.9. Webster 3 (September 1987). Clone boundary is indicated by anomalous leaf discoloration. (Photo by James Bowns)

Fig. G.10. Webster 3 (September 2002). Visible tree boles indicate dieback has occurred. (Photo by author)

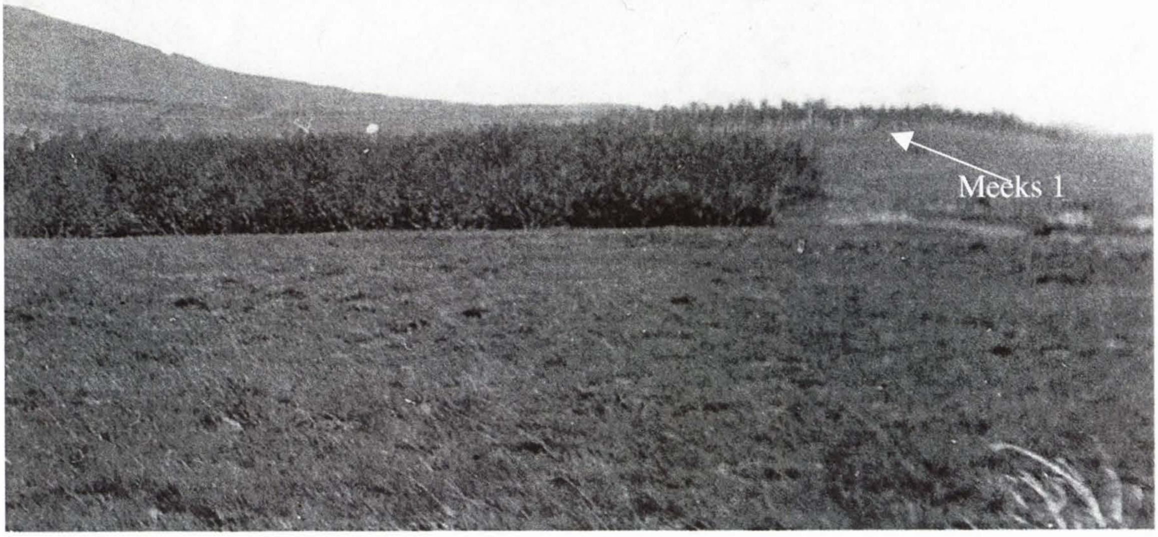

Fig. G.11. Meeks 1 1917. White tree trunks indicate the stand is mature, and no regeneration on the clone exterior. (Photo provided by James Bowns)

Fig. G.12. Meeks 1 2002. All but far right fringe of clone is dead. (Photo by author)

Fig. G.13. Clark 1, summer 2002, looking southwest. Nearly all of the clone is dead, only small patches of living ramets remain. (Photo by author)

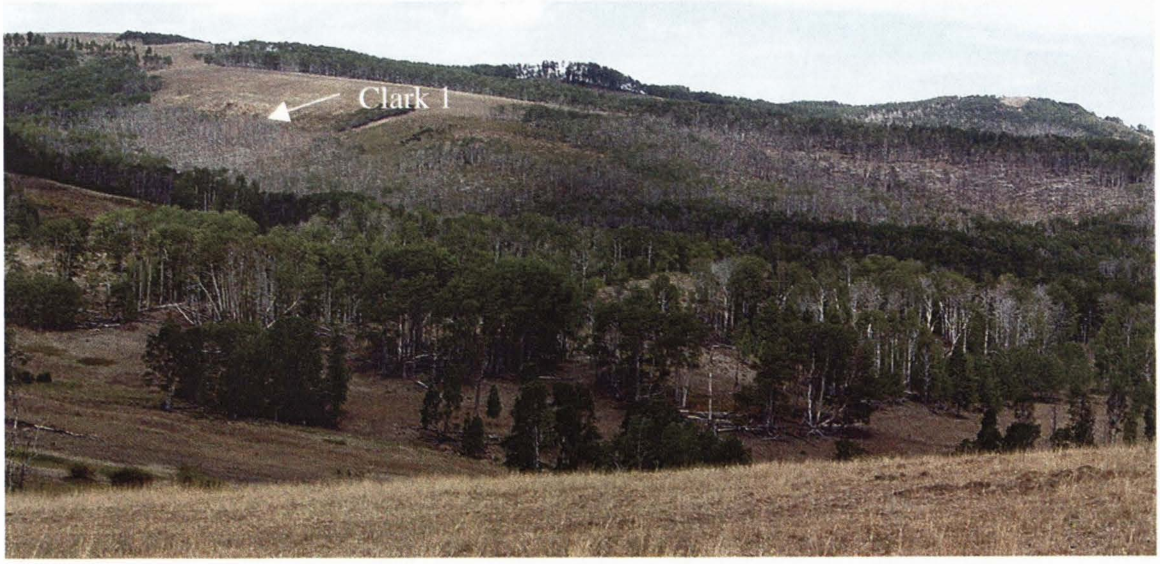

Fig. G.14. Clark 1 and nearby clones, summer 2002, looking northeast. This area known as the Jackson pasture has experienced wide spread aspen mortality. (Photo by author)

Fig. G.15. Lister 2, 3, and Meeks 1, summer 2002. Clone differentiation easily identifiable due to differing levels of dieback. (Photo by author)

Fig. G.16. Rapidly declining clone, late-summer 2002. In 2001 the clone exhibited normal leaf coloration and appearance. Though the ramets are dying, regeneration has begun to restock the stand. (Photo by author)

Fig. G.17. Smith 1, summer 2002. Numerous dead ramets in the understory indicate the extensive mortality. (Photo by author)