TECHNIQUES TO RESTORE ASPEN FORESTS IN THE WESTERN U.S.

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ABSTRACT: A series of case studies conducted in Colorado, Arizona, and Utah have shown that vegetative regeneration of declining aspen (*Populus tremuloides* Michx.) can be initiated through manipulations that provide three critical elements defined as the aspen regeneration triangle: 1) hormonal stimulation, 2) proper growth environment, and 3) sucker protection. Results of the studies used to formulate this treatment model are presented along with recommendations for innovative treatments to restore aspen in landscapes where it is rare or in decline. Soils and site productivity, competition from other plants, and the potential impact of browsing animals upon new regeneration should all be considered. Choosing a course of action depends upon a careful evaluation of the size, vigor, age, and successional status of candidate aspen clones. Treatments may include doing nothing, removal of existing aspen trees, removal of competing vegetation, prescribed burning, mechanical root stimulation, and browse protection.

Key words: aspen, *Populus tremuloides*, regeneration treatments, root suckers

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Aspen (*Populus tremuloides* Michx.) is widely distributed throughout western North America, occurring in a wide variety of ecosystems and climatic regimes. Aspen forests are a crucial component of many western landscapes, providing understory diversity, critical wildlife habitat, and highly desirable scenic values. Aspen is a disturbance dependent species that is well adapted to the fire regimes that existed in western landscapes prior to European settlement. One adaptation that allows aspen to establish under fire disturbance regimes is its intolerance of shade. Aspen requires full sunlight to thrive, allowing it to grow very well in areas cleared by fire. However, this trait also makes it very sensitive to competition from shade tolerant species like spruce (*Picea* sp.) and fir (*Abies* sp.) in mixed species forests. Periodic fires in the past cleared away competing conifers and allowed aspen to maintain its presence in these landscapes. Although aspen does produce abundant crops of viable seed (McDonough 1979), it reproduces primarily by root suckering throughout most of its western range. Occasional seedlings do establish, but seedlings require bare mineral soil and constant moisture to survive (McDonough 1979). These conditions rarely occur in many of the areas where aspen grows today. Therefore vegetative regeneration by root suckering is the only viable means of regenerating aspen in the western U.S. (Shepperd 2001).

ASPEN SYMPOSIUM

Vegetative regeneration of aspen requires the interruption of the auxin/cytokynin hormone balance between roots and shoots to stimulate root buds to begin growing (Schier et al. 1985). This hormonal imbalance can result from any disturbance that interrupts the flow of auxin from photosynthesizing leaves to a tree's roots. This can result from disturbances that kill the parent trees outright, such as a fire, disease, and timber harvest, or from disturbances that only temporarily defoliate the parent tree, such as a late frost, defoliating insect attack, or light herbicide application. Severing lateral roots from parent trees can also initiate suckering, as would occur when fire, burrowing animals, or other factors kill portions of a lateral root. The sucker initiating process has been referred to as interruption of apical dominance (Schier et al. 1985.).

In any case, the initiation of bud growth must also be accompanied by sufficient sunlight and warmer soil temperatures to allow the new suckers to thrive (Navratil 1991, Doucet 1989). Full sunlight to the forest floor best meets these requirements. However, young aspen suckers are susceptible to competition from other understory plants and herbivory from browsing ungulates, even if abundant suckers are present.

The interaction and co-dependency of aspen sucker initiation, growth environment, and damaging agents can be summarized into a model similar to the regeneration triangle used for other species (Shepperd 2001) (Fig. 1). In this model, successful vegetative regeneration of aspen is dependent upon three key interacting components: hormonal stimulation, growth environment, and protection of the resulting suckers. One or more of the silvical characteristics of aspen discussed above is involved in each of these factors. Just as all three sides of a triangle must be present for it to be strong, any manipulation of aspen has to satisfy all three of these requirements to successfully regenerate the species.

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CASE STUDIES USING THE ASPEN REGENERATION TRIANGLE

The three elements of the aspen regeneration triangle may not always need to be actively provided by managers when trying to regenerate aspen. One or more of the elements could already exist in any particular aspen stand that managers are attempting to regenerate. Identifying which factors are lacking is crucial. Therefore, I would like to present results from a series of case studies that were used to develop the aspen regeneration triangle model to illustrate how it can be used to analyze and select treatment alternatives to regenerate aspen.

Techniques that can be use to initiate aspen suckering and provide a favorable growth environment include harvest of aspen, mechanical root stimulation, removal of competing vegetation, and prescribed burning. Protection of existing suckers can be provided by either satiating browsing demand, constructing physical barriers to browsing animals, or controlling animal movement.

Clearfell-Coppice Harvest

Complete removal of all aspen trees from a site has been the traditional method to regenerate aspen vegetatively. Since the forest will be regenerated by root suckering and not seeding or planting, the correct silviculture term for this activity is clearfell-coppice (Ford-Robertson 1971) rather than clearcutting. This technique fully stimulates the roots to produce new suckers through the complete removal of parent trees. Allowing full sunlight to reach the forest floor provides the proper growth environment. The numbers of suckers that normally result add an element of protection from browsing animals and diseases.

Clearfell-coppice treatments require large areas of aspen in order to be applied successfully. Commercial markets for the aspen trees that are removed are usually necessary for such projects to be economically viable. Clearfelling does not work well in areas where aspen stands are small, unless cut units are fenced from browsing animals following treatment. Although clearfell-coppice harvest can introduce new age classes of aspen into landscapes, a disadvantage is that it eliminates old trees, which provide many ecologic characteristics that are desirable for aspen forests. Potential compaction of lateral roots during harvest operations can also occur (Shepperd 1993).

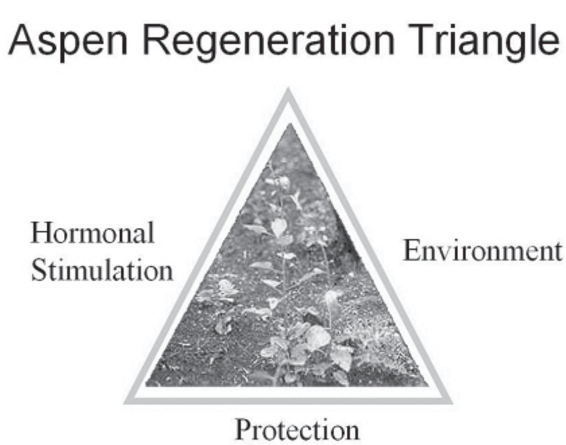

Figure 1. The aspen regeneration triangle model.

Mechanical Root Stimulation

Severing lateral roots at some distance from parent trees is one means of regenerating aspen while retaining an older tree component in the aspen forest. This technique relies on the wide-spreading root habit of aspen to establish suckers in locations where they have a more favorable growth environment than that found under dense large aspen. Severing lateral roots blocks the flow of auxin from parent trees and provides the hormonal stimulation to allow pre-existing buds to produce suckers, providing the other elements of environment and protection are in place.

This particular treatment technique was developed as an offshoot of results of a study published earlier (Shepperd 1996). This study in Central Colorado compared bulldozing and chainsaw felling of aspen and also evaluated the effects on sucker production of fencing and retaining all logging slash on site. Results from this study clearly showed that bulldozed areas produced more suckers than cut areas and that more aspen suckers established in fenced areas than in those left unfenced. However, leaving all cut or bulldozed overstory aspen on site clearly inhibited aspen sucker establishment in this study. The stimulation effect of the bulldozed treatments was attributed to the complete severing of the stems from the roots. Apparently the stumps from cut trees retained some auxin which had an inhibitory effect on subsequent suckering when the stumps were left attached to the roots.

Results from this initial study prompted the establishment of two additional studies in Arizona to investigate alternative mechanical treatments that might be used to stimulate aspen suckering. The first study was established in an aspen stand on the Coconino NF in an aspen stand that had been partially cut about 15 years previously, but had not successfully regenerated. The stand contained about 150 large aspen trees in a five-acre area. Some suckering had probably occurred following the initial harvest, but elk, which were abundant in the area, likely consumed the sprouts. Without suckers to support them, roots attached to trees that were cut probably died, leaving the remaining roots in hormonal balance with the overstory trees, thus inhibiting any further sucker initiation. If this were true, severing some remaining roots would interrupt auxin flow from parent trees and initiate new suckers. To test this hypothesis, the entire stand was fenced and a crawler tractor with a ripper attachment was used to sever lateral roots in half of the area (Fig. 2). The tractor was driven in a circle around each large aspen in the ripped area, taking care to sever roots approximately 8-10 m away from existing trees, so some roots were left to supply the trees with water and nutrients.

Five years following treatment the ripped portion of this stand had about 1200 suckers per hectare while the unripped, but fenced portion had only half that amount. Although fencing the stand clearly had an effect on suckering, the extra hormonal stimulation provided by the ripping treatment doubled the resulting suckers. In addition, the establishment of these additional suckers was accomplished without any mortality to the overstory trees.

The success of this first study prompted a second ripping study on the Coconino NF in Arizona using a different approach. In this case, we ripped along the edge of a small isolated aspen clone that was growing beside a meadow. This clone was located within an area that was fenced to exclude browsing animals for another study. The ripping treatment consisted of a single tractor

Figure 2. Severing lateral aspen roots using a tractor-mounted ripper. Coconino, NF, Arizona.
tion with standard error bars.

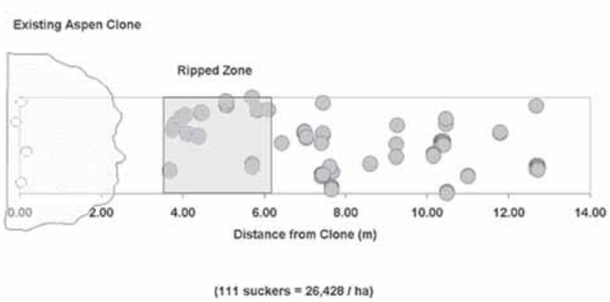

Figure 3. Map of aspen suckers in a 2 x 14 m transect extending into a meadow adjoining an edge-ripped aspen clone, one year after treatment. Coconino NF, Arizona

pass cutting to a depth of 20cm that severed the roots extending into the meadow from the existing trees. This simple treatment resulted in the establishment of the equivalent of over 26,000 stems ha^{-1} in the meadow adjoining the existing aspen clone. A map of suckers in a belt transect established from the aspen clone into the meadow (Fig. 3) shows that aspen suckers appeared up to 14m away from existing trees (Shepperd 2001). This indicated that lateral roots were capable of suckering about a tree height to a tree height and a half away from existing mature trees in this case. However, no suckers were noted between the ripped zone and existing trees (Fig. 3), indicating that no hormonal imbalance existed on the portion of roots in that zone. As in the previous study, no existing trees were killed by the ripping treatment.

The results of this study are consistent with natural suckering events that have been observed in isolated aspen clones surrounded by meadows or shrublands and indicate the potential for expanding the size of existing aspen clones or introducing new aspen age classes into a clone without sacrificing existing trees. However, since such clones are usually small, protection from browsing animals may be necessary.

Removal of Competing Vegetation

Sometimes, modifying the growth environment is all that is needed to allow suckers to thrive, providing that the hormonal stimulation already exists and that protection for the suckers will be provided. In many cases where conifer encroachment is stressing older aspen, the hormonal stimulation to regenerate already exists. Removal of the conifers may be all that is necessary to provide the proper growth environment for aspen suckers. However, protection from browsing may still be necessary to achieve successful regeneration.

Removal of competing conifers modifies the growth environment by allowing full sunlight to reach the forest floor. This will enhance any natural sucker production that is already occurring in declining clones. It also has the advantage of retaining any remaining old aspen trees for aesthetic and wildlife purposes. However, clones in advanced stages of decline may require protection of new aspen suckers in order for them to successfully establish.

The following case illustrates an extreme example of how conifer removal can help re-invigorate a declining aspen clone. This clone was located on the Kaibab NF in Arizona, south of the Grand Canyon. The clone consisted of only two live, but declining aspen trees surrounded by a dense ponderosa pine forest. No other aspen clones existed within seven kilometers of this site. The root systems of these two trees were mapped by closely examining the ground surrounding them to search for dead suckers that had not survived in the dense shade. After the root system was mapped, all conifers within this zone were removed, creating a 0.1 ha opening surrounding the two aspen trees. An elk-proof fence was constructed around the perimeter of this opening to protect new suckers. Four years later the entire fenced area contained 173 surviving aspen suckers (Fig. 4), the tallest of which exceeded 6 m, nearly 2/3rds the size of the original parent stems. Amazingly, one of the original aspen trees was still alive. In this case removal of conifers provided a favorable growth environment for suckers, which were protected from browsing by the fence. Hormonal stimulation had already occurred in the roots of the two declining trees, so no additional treatment was needed.

Protection from Browsing

In some cases protecting new suckers may be the only factor necessary to achieve successful aspen regeneration. If clones are in decline and large numbers of overstory stems have died (as evidenced by numerous snags or downed logs on the forest floor), the hormonal stimulation to sucker already exists. If few conifers are present sufficient sunlight is likely reaching the forest floor to provide a favorable environment for sucker growth. This situation can usually be recognized by the existence of dead or heavily browsed "shrubby" aspen suckers in the understory or along the periphery of the aspen clone.

In these cases protection from browsing may be all that is needed to ensure that new suckers will survive and not succumb to damage and disease. Direct protection will likely be expensive, because of the cost of constructing fences. However it may be the only way to successfully reestablish aspen in many areas in the western United States where aspen is not a large component of forested landscapes and browsing animals are present.

A critical question in planning for protection from browsing animals is how long the protection will be needed? Additional data from a study initially reported by Shepperd and Fairweather (1994) may shed some light on this question. In this case, all aspen were clearfelled in a 6.5 hectare unit in 1986 and an elk proof fence constructed around the area. In 1991 the area contained 86000 stems ha^{-1}, the tallest of which exceeded 3m in height. Several clones were present within the unit, which meant that some genetic diversity was present. The fence was removed in 1992, a year in which cattle were excluded from the area. Elk severely damaged stems in one clone in the study area (Fig. 5), breaking off all stems less than 4 cm in diameter at 1.4m (diameter breast-height, or DBH) to access foliage in the crowns. These stems were subsequently infected with *cytosproa* canker and died. Roots were apparently killed too, because no new suckers appeared in subsequent years. Approximately 500 stems ha^{-1} remained in this one clone. Only stems over 4 cm DBH survived, which were apparently too big for the elk to break.

Aspen Clone Rehabilitation

After pine removal   4 years later

Figure 4. Removing competing conifers and fencing the clone allowed new suckers to establish. Kaibab NF, Arizona

This damage occurred only in one of the four-to-five clones within this study area. Elk did not heavily browse other clones until the first clone had been depleted, approximately two years after fence removal. In this ensuing time many stems in the surviving clones grew above 4cm DBH and consequently were too large for animals to break off during browsing. The result was heavy browsing of lower branches, creating a distinct browse line in these clones, but not harming terminal leaders and thus not affecting sucker height growth. Approximately 25,000 freely-growing aspen stems ha^{-1} survived. My conclusion from this experience is that aspen stems need to be larger than 4cm DBH and 4-5m tall to survive under extreme elk browsing pressure. In most cases eight to ten years of normal growth are necessary for suckers to attain these sizes.

Prescribed Fire

Fire can be used in aspen stands to provide hormonal stimulation of sucker production by killing overstory stems and by injuring lateral roots, which effectively separates them from parent trees. Prescribed fire can also provide ideal growing conditions for suckers by removing competing vegetation and blackening the soil surface, allowing it to be warmed by the sun. However, prescribed fire may not provide protection to the new sprouts, unless large enough areas of aspen have been burned to satiate browsing animals' appetite for aspen sprouts.

Using prescribed fire in pure aspen forests is somewhat difficult because the lush understory vegetation that exists under them usually has high moisture content, is difficult to burn, and does not contain sufficient biomass to burn effectively. Because of this pure aspen forests are usually considered firebreaks by wildland fire fighters.

Figure 5. Severe elk damage to a 5-year-old aspen sucker stand, following fence removal. Coconino NF, Arizona.

The key to get effective burns in these stands is to time the fire when fuels are dry and use alternative fuels to carry the fire into the aspen. One way to do this is to burn sagebrush lands that contain small aspen clones as was done on the Gunnison NF in the late 1970's. Such fires will usually burn into the aspen far enough to stimulate new aspen suckering along the edges of clones, even if the overstory aspen are not killed outright. This can create a diverse landscape in which some clones are completely replaced by new suckers while others have some surviving overstory stems, but with new suckers beneath them and extending out from the periphery of the surviving trees. In both cases the footprint or the area occupied by aspen in these landscapes will be increased by about one and one half to two times tree height away from existing aspen stands, as occurred in the studies described above.

Another burning technique, which has been applied successfully on the Dixie NF in southern Utah, is the use of prescribed crown fire in mixed conifer/aspen forests. In these cases the conifer component carries the crown fire through the forest, killing all the aspen as well as the conifers, similar to what would happen in a wildfire. Such burns should be planned when soil moisture is high, to avoid excessive damage to aspen roots. Although risky, prescribed crown fire provides all elements of the aspen regeneration triangle and can reintroduce large areas of pure aspen into mixed species landscapes. There are many positive benefits to this approach. Crown fire will not only rejuvenate aspen and reset vegetation succession, but it can also increase understory vegetation diversity, forage production, and water yields, as well as improve habitat for many wildlife species (Bartos and Campbell 1998). However, a major disadvantage to using prescribed crown fire is safety. It can be used in areas where natural firebreaks exist to limit where the crownfire will burn, or it has to be applied in areas where mixed crown and surface fire can be tolerated across large landscapes. In either case there is a certain degree of risk that an unintended wildfire might result. However, it goes without saying that this form of fire is probably what maintained many aspen mixed conifer forests in pre-settlement times.

Combined Treatment Techniques

Combining mechanical treatment and prescribed fire to regenerate aspen can provide a means of emulating natural fire regimes with minimal risk of wildfire. It can provide maximum hormonal stimulation and optimal growth environments for aspen suckers, eliminate or reduce competing conifers, and in some cases leave an aspen overstory component on-site. As with all regeneration techniques, careful attention is needed to insure that all elements of the aspen regeneration triangle are in place for a project to be successful. The following three case studies illustrate this very well.

A small study done on the Coconino NF in Arizona combined commercial harvest, prescribed burning and fencing to successfully regenerate aspen while leaving old aspen on-site. A 10ha area adjoining the highway to the Grand Canyon contained several aspen clones that were surrounded by a dense ponderosa pine forest. The management objective for this area was to enhance the view of aspen from the highway while reducing competition from the pine and introducing new aspen to the site. First, all ponderosa pine were removed within and surrounding the aspen clones in a commercial timber sale and the entire area was fenced with an elk-proof wire fence. Logging slash was then scattered throughout the area creating light fuel loadings of 2,000-4,500 kg ha^{-1}. A

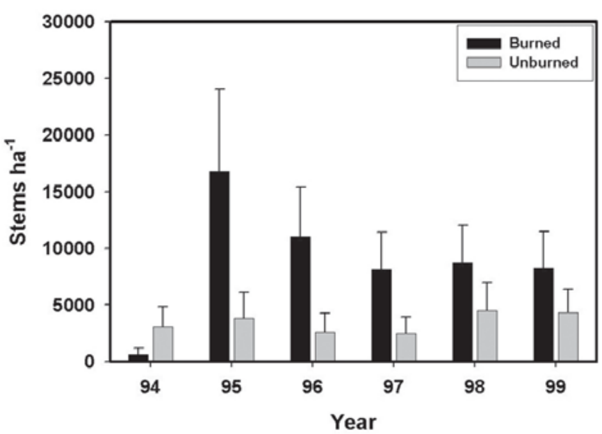

Figure 6. Sucker densities (with standard deviation bars) before (1994) and five years after a spring prescribed burn in light logging slash, Coconino NF, Arizona

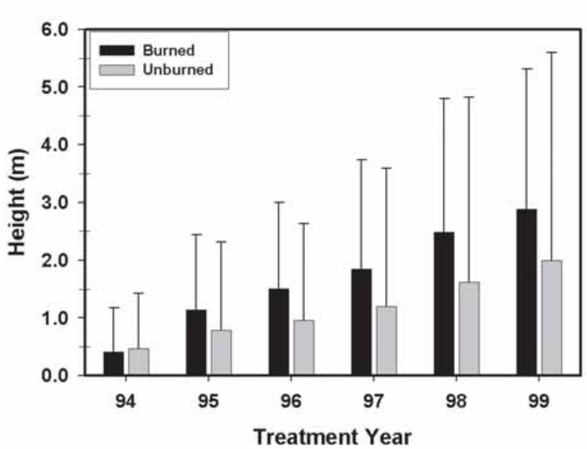

Figure 7. Average dominant sucker height (with standard deviation bars) before (1994) and five years after a spring prescribed burn in light logging slash, Coconino NF, Arizona

prescribed fire was applied to half of the area the next spring following snowmelt, when soils were wet. The fire consumed all logging slash and blackened about 30% of the forest floor. Numbers and growth rates of aspen suckers in the burned and unburned treatments were monitored for five growing seasons following treatment. The prescribed burn had a striking effect on both the numbers of suckers that were produced and survived over the five year period (Fig. 6) and on their height growth. Not only did the burning treatment produce more suckers, but they also grew at a faster rate (Fig. 7), reaching nearly 3m in height in the burned area after five years. Part of this effect was undoubtedly due to nutrients introduced into the soil by the fire, but the solar warming of the soil during the first growing season following the fire (Fig. 8) likely contributed as well. Average soil temperatures below 5 cm depth were significantly higher under blackened soil throughout the first growing season and were well above the 15ºC crucial to initiate aspen suckering.

However, burning heavy logging slash in harvested areas can be detrimental to aspen suckering, especially when conditions are dry. A study completed on the Uncompahgre Plateau in western Colorado illustrates this clearly. A 10ha block of commercial aspen forest was logged in deep snow during the winter, which left accumulations of logging debris scattered throughout the unit. A prescribed burn was applied to the unit the following summer under dry soil conditions, but only concentrations of large woody debris were able to carry the fire and burn. Half of the entire unit was fenced following the burn to exclude both cattle and elk.

The intense heat penetration into the soil from the burn apparently killed the aspen roots beneath. Four years later, significantly fewer aspen suckers were present in

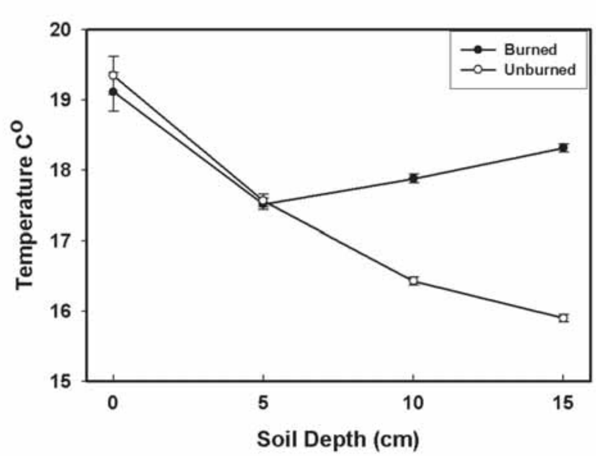

Figure 8. Average soil temperatures during the first growing season after treatments for burned and unburned aspen sites, Coconino NF, Arizona, with standard error bars.

burned areas within this study site than in areas that did not burn (Fig. 9). Furthermore, almost no aspen survived outside of the fence after four years, illustrating the effect of repeated and prolonged browsing on aspen sucker populations (Fig. 9). This experience emphasizes the need to pay attention to all elements of the aspen regeneration triangle.

However, aspen roots can be protected if soil conditions are wet when burning heavy slash in harvested areas. A study in the San Juan NF illustrates how this can occur. A mixed aspen/conifer forest was completely harvested during the winter and all of the logging slash scattered on the site in this particular area. The following spring, a prescribed burn was conducted in this area immediately after snowmelt. This burn reduced both fine and rotten fuels but did not consume heavy logs which reduced heat penetration into the soil (Fig. 10). The burn killed existing fir and conifer seedlings but apparently did not adversely harm aspen roots as more suckers appeared in the burned treatment the first year after the burn than appeared in the non-burned treatment (Fig. 11). The lack of a fence in this study was clearly evident, as cattle and elk browsing reduced sucker numbers during the 5 years after treatment until very few remained on the site in 2002 (Fig. 11). The impact of animal browsing on sucker height growth is striking (Fig. 12) when these data are compared to sucker height growth in the burned and fenced study in Arizona described earlier (Fig. 7). None of the suckers

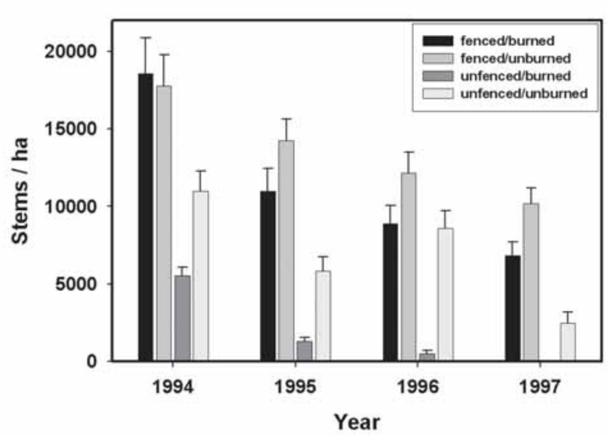

Figure 9. Average aspen sucker densities (with standard error bars) by burn and fence treatments, for the first four years following treatment. Uncompahgre NF, Colorado.

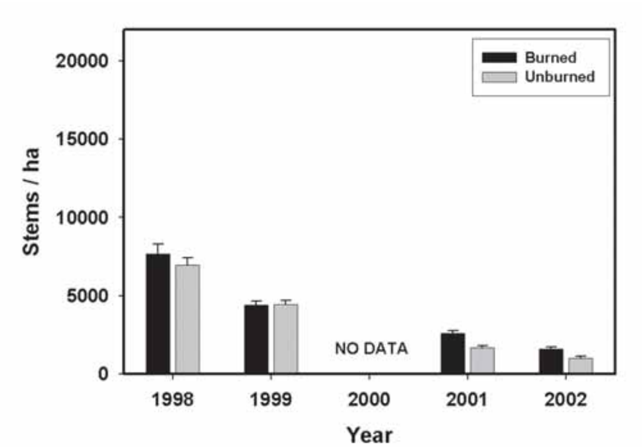

Figure 11. Average sucker densities (with standard error bars) by burning treatment for the first five years following treatment of a mixed aspen/conifer harvest area, San Juan NF, Colorado.

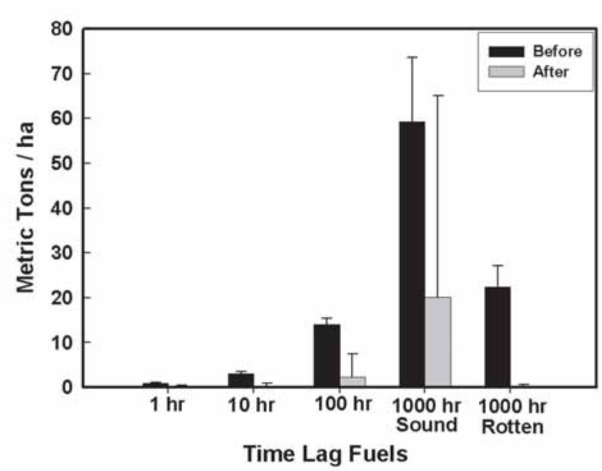

Figure 10. Effect of prescriped burn on fuels in mixed aspen/conifer harvest area, San Juan NF, Colorado. Average fuel loadings by Time Lag class and sound or rotten condition with standard error bars.

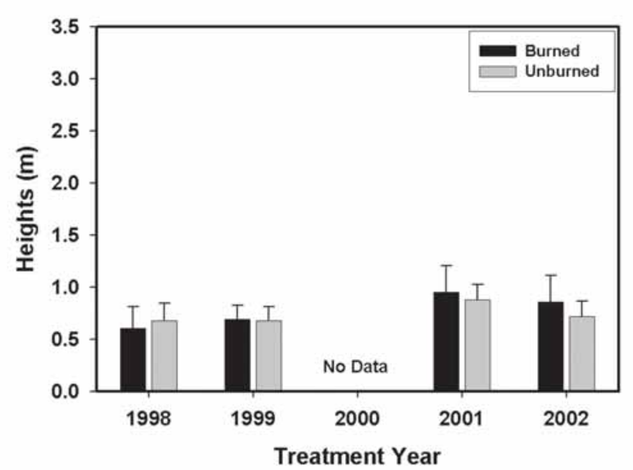

Figure 12. Average dominant sucker heights (with standard error bars) by burning treatment for the first five years following treatment of a mixed aspen/conifer harvest area, San Juan NF, Colorado.

in the San Juan study had grown above reach of browsing animals at the end of the five-year monitoring period.

DISCUSSION AND MANAGEMENT RECOMENDATIONS

A number of silviculture techniques can be used to regenerate aspen, but to be successful they must provide all three essential elements illustrated by the aspen regeneration triangle model (Fig. 1) (Shepperd 2001). Briefly, these factors are:

1. Hormonal Stimulation - Because western aspen regenerate almost exclusively by vegetative root suckering the production of auxin by photosynthesis must be interrupted to allow root buds to grow into new aspen suckers. This occurs naturally when trees die or are defoliated by insects, disease, or climatic events. Or alternately, cutting or burning trees or severing lateral roots connected to live trees can interrupt auxin flows and initiate suckering.
2. Environment - Optimal conditions for sucker establishment would include full sunlight to the forest floor and soil temperatures at or above 15° C in the root zone. While suckers can establish under partially shaded conditions, the best growth and highest sucker densities occur under full sunlight and warm soil temperatures.
3. Protection of new suckers - New suckers must survive damage from browsing animals, insects, diseases, and climatic events to achieve good form and grow to mature trees.

How these factors are considered in making decisions to treat aspen depends upon the condition of the aspen in a landscape and the management objectives for it. Complete clearfell coppice is the best option where aspen is to be managed for commercial fiber production. Management of multi-aged cohorts in commercial aspen forests is not recommended. Damage to residual trees during logging will result in reduced quality of future wood through rot, defect, or disease. Protection of new suckers is still necessary to guarantee successful aspen regeneration, even when clearfelling. Removal of harvested stems results in optimal growth environment for new suckers. Fencing or other means to control animals may still be needed to insure good sucker survival and growth if sufficient acreage has not been cut to satiate browsing demand.

Complete removal of the aspen overstory is not necessary where the management objective is to introduce new age classes into an aspen forest while retaining age and structural diversity. Previous research has indicated that not all aspen roots in a clone are connected and that new suckers develop independent root systems as they age (Shepperd and Smith 1993). Therefore, it is not necessary to harvest all stems to initiate a sucker response, providing other conditions exist for successful sucker growth. The aspen regeneration triangle can be used to evaluate existing conditions and identify a course of action by considering the following questions:

1. Is the aspen stand in decline as evidenced by abundant dead trees, downed logs, or holes in the overstory canopy? If not, the stand may be adequately stocked and in hormonal balance and therefore not attempting to regenerate.
2. Are aspen suckers or saplings present in the stand? If so, the stand may be naturally regenerating and not in need of management intervention.
3. If the stand is in decline and no successful suckers are present, are scattered browsed or clipped sprouts in the understory? If present, fencing the stand will probably allow them to release and grow. If no suckers are evident, competing trees, or dense understory vegetation may be preventing an adequate environment for sucker growth. Removing competing vegetation may initiate suckering without cutting any aspen. Another possibility in declining clones with no suckers may be that the area is a root rot epicenter, which cannot be remedied by management action

Where the goal is to retain the existing aspen overstory managers should first remove competing vegetation and protect the area from browsing. If suckers still don't appear, only then should overstory aspen be cut to stimulate suckering. It is not necessary to cut an entire clone at one time to initiate suckering, but sufficient openings should be created to allow full sunlight to reach the ground for most of each day. Removing conifers from within mixed aspen/conifer stands will often stimulate sprouting as well. A single pass of a ripper along the edges of clones surrounded by meadows can cut lateral roots and stimulate suckering for about 1.5 tree heights away from the existing aspen trees. This will effectively enlarge the clone while retaining existing stems. Edge-ripping can also be used to enlarge clones surrounded by conifer forest, except that conifers should first be removed a sufficient distance away from the aspen to insure that sunlight will reach lateral roots extending away from existing aspen trees. Ripping roots in the interior of aspen clones should be done only in open-canopied stands and only after fencing and conifer removal have proved unsuccessful.

In conclusion, the order of approaching regeneration, enhancement and expansion of aspen clones should be first to protect existing sprouts, then modify the growth environment to enhance their growth, and finally stimulate new suckering by initiating a hormonal growth response as outlined in the case studies reported above.

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