LONG TERM STUDY

Native Species Replace Introduced Grass Cultivars Seeded following Wildfire

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ABSTRACT

Seeding of non-native species following wildfires to stabilize soils and prevent erosion has become a controversial practice because it risks inhibiting tree regeneration, introducing noxious weeds, and permanently replacing native species. This paper reports the fate of non-native seeded species during 31 years of postfire forest succession in northcentral Washington state, USA. In that region, catastrophic wildfires in grand fir (*Abies grandis*)/pinegrass (*Calamagrostis rubescens*) associations characteristically result in a flush of lodgepole pine (*Pinus contorta*) regeneration that creates a dense tree monoculture. In the study, seven grass cultivars were broadcast seeded to prevent erosion, limit tree regeneration, and increase forage production for wildlife and livestock. Tree regeneration, native and non-native species cover, and aboveground biomass were evaluated in 1971, 1975, 1980, 1989, and 2001. The seeded species quickly established dominant cover with levels of biomass production two to three times the level of native species. Density of tree regeneration was inversely correlated with perennial grass cover during the first 10 years. Between 1980 and 1989, the seeded grasses disappeared, long before tree canopy closure. Within 15 to 20 years native species had regained dominance, and after 30 years the last remnants of the non-native cultivars were replaced in the seeded areas by a diverse mixture of native graminoids, forbs, shrubs, and trees. In contrast, a monoculture of lodgepole pine dominated the unseeded areas. This study showed that non-native grasses seeded after wildfires do not always persist and can serve as a transition to restoring a more diverse seral community.

Key words: fire succession, grass seeding, lodgepole pine (*Pinus contorta*), pinegrass (*Calamagrostis rubescens*), wildfire restoration

During the two-week period between 23 August and 7 September 1970, wildfires burned over 47,700 ha in Chelan, Okanogan, and Kittitas counties of northcentral Washington. Concerns over soil loss through erosion and subsequent movement of sediment to streams and rivers, as well as potential flooding, led to emergency rehabilitation measures that included seeding grass on approximately 22,000 ha of the more severely burned forest and rangeland (USFS 1970). High demand for large quantities of grass seed at short notice necessitated the use of introduced grass cultivars; massive volumes of seed were not available for native species. Commercial nitrogen fertilizer was applied to aid establishment of the seeded grasses.

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The burned area included land belonging to the state of Washington, and managed by Washington State University (WSU). In the wake of the fire, WSU Extension Range Management Specialist Ben F. Roché Jr. recognized the wildfire as an opportunity to investigate rehabilitation methods for midelevation grand fir (*Abies grandis*) forests while optimizing watershed values, marketable timber, and forage for wildlife and livestock. The Colockum Creek watershed furnished water to the Columbia River as well as timber harvest funds for public schools. The area also served as summer range for about 300 Rocky Mountain elk (*Cervus elaphus* ssp. *nelsoni*), part of the migratory Colockum elk herd of about 4,000 (Ed Bracken, WA Dept. of Wildlife, pers. comm.), and for cattle, under a grazing permit to a local rancher. Roché designed a study to test the potential of the seeded grasses to 1) stabilize highly erodible soils; 2) limit the postfire regeneration of lodgepole pine (*Pinus contorta*); and 3) increase forage production for elk and cattle.

Attitudes about land management after wildfires have shifted since 1970. Critics argue that seeding does not prevent erosion and stream siltation, introduces persistent non-native species, and impairs establishment of native vegetation, including tree species. Prior to European settlement and fire suppression, frequent, low-intensity fires maintained open stands of fire-resistant seral trees in these grand fir community types (Lillybridge et al. 1995). When heavy fuel loads accumulate under decades of fire suppression, wildfires become high-intensity, stand-replacing burns. Under these conditions lodgepole pine aggressively regenerates burned sites, and if the interval between catastrophic fires is less than 200 years, other seral species, such as western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*) are eliminated and lodgepole pine forms pure stands (Lillybridge et al. 1995). In addition, changing the fire regime can modify the nitrogen cycle. Forest soils are often low in available nitrogen. Nitrogen-fixing native forbs and shrubs that colonize burned sites contribute significant amounts of nitrogen until shaded by crown closure of the tree species, which occurs sooner in dense stands of lodgepole pine.

Because land managers' responses to wildfire determine the structure of future forest stands and subsequent fire regimes (Agee 1993), they need to know the long-term effects of postfire treatments in order to tailor their recommendations according to forest type and fire regime (Keeley 2004). Critical information is scarce for several reasons, including the difficulty of designing experiments around unplanned events, the ubiquity of seeding on burned sites, and confounding influences such as postfire logging (Schoennagel and Waller 1999). In addition, long-term ecological consequences in forest environments cannot be determined in short-term studies.

Although the original objectives for postfire seeding involved rehabilitation with non-native perennial grass species for economic forestry, the long-term results are particularly relevant to restoration of native vegetation. Our observations of the changes in seeded and nonseeded plant communities during 31 years postfire in a grand fir forest association showed that the seeded non-natives failed to persist and have been replaced by a community more diverse than that on unseeded sites.

Materials and Methods

Study Site

The study area, located in the North Fork Colockum Creek drainage (47°14'45" N, 120°17'20" W) of the Wenatchee River watershed, was part of the 4600-ha Colockum Multiple Use Research Unit, a branch station of Washington State University in northcentral Washington. The 20–25% slopes drain southeast into the North Fork Colockum Creek at about 1400 m elevation. Soils are Jumpe stony loam, red variant (Dystric Xerochrepts), which are well-drained medium-textured soils that formed in volcanic ash and glacial till from basalt (Beieler 1975). Most of the study area (1 ha) was potential climax vegetation of grand fir/pinegrass (*Calamagrostis rubescens*)/lupine (*Lupinus* spp.) community type (Lillybridge et al. 1995). The exceptions were the ridgetop and a cold air drainage zone along the creek, which were both potential climax of subalpine fir (*Abies lasiocarpa*)/pinegrass association (Lillybridge et al. 1995).

Prevailing weather systems from the Pacific coast are modified by two mountain ranges, the Cascade Mountains about 50 km to the west and the Wenatchee Mountains about 10 km to the west, which create an orographic rain shadow. Thus, the temperate climate has both oceanic and continental characteristics. Two thirds of the average annual 762 mm of precipitation falls as snow between October and March, when temperatures are below freezing most nights. Summers are warm and dry, with daily maximum temperatures about 26 to 29°C in the hottest months; thunderstorms are occasionally accompanied by intense rain showers (Phillips 1975).

Prior to the fire, lodgepole pine dominated the site, but the area also contained Douglas-fir, western larch, ponderosa pine, and grand fir. The larger trees were in the range of 25 to 50 cm in diameter, with a component of sapling-sized trees that were mostly lodgepole pine. The understory was dominated by pinegrass, but included scattered shrubs. The August 1970 wildfire killed almost the entire overstory; most of the trees that survived the fire died within a year. A layer of fine ash, up to 18 cm deep, blanketed the mineral soil surface. Burn severity ranged from moderate to high on the burned area emergency rehabilitation (BAER) rating scale (USFS 2000). In addition, the site exhibited the usual variability of burned forest stands: standing and fallen trees, burned-out roots, rocks, and some patches of unburned grass (Figure 1).

Grass Seeding

Treatments included seven overstory seedings (six grass cultivars and a control), two understory seedings (one grass cultivar and a control), and three fertilization regimes (control, once, three times), for a total of 42 plots (7 × 2 × 3). Plot arrangement was planned as four randomized complete blocks, with individual plots about 30 m × 500 m in size. Unfortunately, the planned replication was never established because only one block was nearly completed when winter weather prevented further seeding. Snow began falling on 20 October 1970 and the last four plots of the first block were seeded on the crusted surface of snow 5 cm deep. Before the second block could be seeded, an additional 31 cm of snow fell; when its surface hardened into a crust the following day, the seed and fertilizer slid down slope and accumulated in small depressions. Lack of replication severely limited our statistical inferences, but the story is worth telling, both for the long observation period and for the unanticipated results.

The terms overstory and understory refer to the relative heights of the grass species, with the taller species serving as an "overstory" to the shorter one. Leaf height of the overstory grasses was about 30–40 cm, with seed stalks up to 1 m. These included 'Greenar' intermediate wheatgrass (*Agropyron intermedium,* now *Thinopyrum*

Figure 1. In October 1970, after wildfires in the Wenatchee River watershed, grass seed was broadcast into ash up to 18 cm deep. Photo by Ben Roché

intermedium), 'Primar' slender wheatgrass (*A. trachycaulum*, now *Elymus trachycaulus ssp. trachycaulus*), 'Topar' pubescent wheatgrass (*A. trichophorum*, now also *T. intermedium*), 'Manchar' smooth brome (*Bromus inermis*), 'Latar' orchardgrass (*Dactylis glomerata*), and blue wildrye (*Elymus glaucus*). The understory grass was 'Durar' hard fescue (*Festuca ovina* var. *duriuscula*, now *F. trachyphylla*). It is a small, fine-leaved bunchgrass, under 20 cm tall, but with prolific roots that compete vigorously with other plants for soil resources. A multitiered grass sward may more completely occupy the site and limit natural regeneration or invasion by non-native species.

Only blue wildrye is native to the region; the other six were cultivars developed during the 1950s and 1960s at the Soil Conservation Service Plant Materials Center in cooperation with Washington State University in Pullman, Washington. When seeded alone, Durar hard fescue was seeded at the rate of 6.7 kg/ha, and each overstory grass at 9 kg/ha. When overstory and understory species were seeded together, the rate was 4.5 kg/ha for each, giving a total of 9 kg/ha. Grass seed was broadcast in the ash between 13 and 21 October 1970 using hand-held cyclone seeders. Because of differences in seed size, these seeding rates led to large differences in the number of pure live seed per square meter (Table 1).

Table 1. Seeding rates for grass species sown in 1970 after a wildfire stabilize soils and prevent erosion; rates are expressed as kg/ha and as pure live seed (PLS)/m².

	Overstory		Understory		Total
Treatment	**kg/ha**	**PLS/m²**	**kg/ha**	**PLS/m²**	**PLS/m²**
Manchar smooth brome	9	228	-	-	228
Topar pubescent wheatgrass	9	155	-	-	155
Latar orchardgrass	9	857	-	-	857
Primar slender wheatgrass	9	294	-	-	294
Greenar intermediate wheatgrass	9	166	-	-	166
Blue wildrye	9	266	-	-	266
Durar hard fescue			6.7	722	722
Manchar smooth brome + Durar	4.5	114	4.5	485	599
Topar pubescent wheatgrass + Durar	4.5	78	4.5	485	563
Latar orchardgrass + Durar	4.5	429	4.5	485	914
Primar slender wheatgrass + Durar	4.5	147	4.5	485	632
Greenar intermediate wheatgrass + Durar	4.5	83	4.5	485	568
Blue wildrye + Durar	4.5	133	4.5	485	618

Soil samples tested in September 1970 indicated adequate levels of phosphorus (5 ppm) and potassium

(> 250 ppm), with organic matter at 2.4% and pH at 6.5. High levels of ash in the soil created problems in testing for sulfur, so in addition to supplemental nitrogen, fertilization treatments included sulfur at the time of seeding (fall 1970) and in the spring of 1972 and 1975. Fertilizer was broadcast as ammonium nitrate sulfate (30-0-0-6) at a rate of 50 kg/ha nitrogen and 7 kg/ha sulfur.

Sampling transects were established in August 1971 and resampled in 1975, 1981, 1989, and 2001. Tree regeneration was determined by counting the number of tree seedlings in a 2 m × 30 m subplot located in the center of each treatment plot. Vegetative cover was estimated for each species in 25 frames (2 dm × 5 dm) at 1-m intervals along a transect in the center of the long dimension of each plot, using coverage classes described by Daubenmire (1959). A value for percent cover for each species was calculated for each plot using the midpoint value of each cover class. Because the raw data comprised many low cover values, the species were grouped for analysis into shrubs, native forbs, graminoids, and non-native forbs. Herbaceous production was sampled by clipping ten 0.089-m² plots along the transect, separating the yield by species.

Figure 2. An experimental plot seeded with Greenar intermediate wheatgrass (*Thinopyrum intermedium*) and Durar hard fescue (*Festuca trachyphylla*): (top) in 1980 this combination of seeded grasses provided the dominant cover and precluded tree regeneration on the upper slope subalpine fir forest type; (bottom) in 1989 both grass varieties had thinned dramatically, especially Durar hard fescue. Photos by Ben Roché

Results

Postfire Grass Establishment and Succession

Seeded Grasses

The cultivar grasses established well during the first growing season in 1971, providing ground cover and producing abundant forage for several years. Given the level of grass vigor, the seeded cultivars were expected to persist until canopy closure by the tree species shaded them out. However, between 1980 and 1989 the seeded grasses thinned dramatically, especially Durar hard fescue (Figure 2 top). Within 15 to 20 years after the fire, native species had regained dominance, and after 30 years the last remnants of the seeded grasses had died out (Figure 2 bottom).

In the growing season following the fire, cover values of the seeded overstory grasses averaged 14%, with individual plots ranging up to 37% cover by the seeded cultivar. The most consistent factor during the study period was the decline in percent cover of the overstory grasses, ranging from 0.4% to 0.9% per year. Although Latar orchardgrass had the highest initial cover (25.1%), it exhibited the highest rate of decline (0.9%). The understory grass cover values in 1971 averaged 21% ground cover, ranging up to 40% cover in individual plots.

As with the overstory grasses, Durar hard fescue cover declined by 0.2% to 0.9% per year. In providing ground cover for soil protection in 1971, total cover of seeded grasses, overstory and understory combined, ranged from 6% to 57%, and averaged 29%.

Shrubs

Postfire (1971) shrub cover was very low: the highest value for cover of native shrubs on any of the plots was 5%, with the mean value at 1%. Shrubs present in 1971 included species that resprouted after the fire: Scouler's willow (*Salix scouleri*), myrtle boxleaf (*Paxistima myrsinites*), kinnikinnick (*Arctostaphylos uva-ursi*), shiny-leaf ceanothus (*Ceanothus velutinus*), common snowberry (*Symphoricarpos albus*), grouse whortleberry (*Vaccinium scoparium*), white spirea (*Spiraea betulifolia*), and wax currant (*Ribes cereum*). Shrub cover increased over time in all of the treatments, from 0.5% to 1.4% per year. Shrubs showed a steady increase over time over all the treatments: 1% cover in 1971, 3% in 1975, 5% in 1980, 15% in 1989, and 27% in 2001.

Forbs

Fireweed (*Epilobium angustifolium*) was the most abundant forb the year after the fire. Early colonizers also included common yarrow (*Achillea millefolium*), fewflower pea (*Lathyrus pauciflorus*), and silky and bigleaf lupines (*Lupinus sericeus* and *L. polyphyllus*). Other species present in low frequency included littleleaf pussytoes (*Antennaria microphylla*), silverleaf phacelia (*Phacelia hastata*), yellow penstemon (*Penstemon confertus*), bigflower agoseris (*Agoseris grandiflora*), large-flowered collomia (*Collomia grandiflora*), biscuitroot (*Lomatium* sp.), mountain tarweed (*Madia glomerata*), Douglas knotweed (*Polygonum douglasii*), tapertip hawksbeard (*Crepis acuminata*), heartleaf arnica (*Arnica cordifolia*), Scouler's woollyweed (*Hieracium scouleri*), spreadingpod rockcress (*Arabis divaricarpa*), and zigzag groundsmoke (*Gayophytum heterozygum*). After the first growing season (1971), total forb cover ranged from 0% to 12%, with an average of only 4% over all the plots. Overall forb cover across all the treatments was 4% in 1971, 6% in 1975 and 1980, 19% in 1989, and 17% in 2001.

Non-native forbs were limited to scattered individuals of only five species: prickly lettuce (*Lactuca serriola*), common dandelion (*Taraxacum officinale*), common mullein (*Verbascum thapsus*), yellow salsify (*Tragopogon dubius*), and yellow sweetclover (*Melilotus officinalis*). Their combined contribution to ground cover was less than 0.1%.

Native Grasses

Despite an intensity that consumed most of the aboveground vegetation (except trees), the fire did not kill the native rhizomatous pinegrass, which reappeared in all of the plots in 1971 (Shea 1981). This species comprised most of the native graminoid cover, but native sedges were included in this value, as well as small amounts of other native grasses: squirreltail (*Elymus elymoides*), blue wildrye, mountain brome (*Bromus marginatus*), Sandberg bluegrass (*Poa secunda*), slender hairgrass (*Deschampsia elongata*), and western needlegrass (*Achnatherum occidentale*). Durar hard fescue seeded without an overstory grass appeared highly competitive with native graminoids, decreasing their cover by 15.0%; only the combination of Primar slender wheatgrass with Durar hard fescue showed a similar decrease in native graminoid cover (15.7%). Native graminoids appeared to increase with fertilization when no overstory grass was seeded (6.7%) and decrease with fertilization and Topar pubescent wheatgrass (5.6%). As with the forbs and shrubs, native graminoid cover increased across all treatments as time elapsed after the fire, ranging from 0.5% to 1.3% per year. Cover values for native graminoids across all treatments increased from 6% in 1971, to 11% in 1975, and 13% in 1980; with the disappearance of the seeded grasses, their cover increased to 32% in 1989 and remained there in 2001.

Tree Regeneration

During the first ten years, lodgepole pine regeneration was lower on seeded plots: density of tree regeneration inversely correlated with seeded perennial grass cover (p = 0.0015). Five to ten years after the fire, there were 6,180 lodgepole pine seedlings per hectare in the untreated plot. Density of lodgepole pine seedlings on the untreated area surrounding the plots was even higher, about 10,000 trees/ha (Shea 1981). By 1989 tree density on the untreated plot had increased to 9,250 trees/ha; two-thirds of which were the lodgepole pine already established in 1975. Thirty years after the fire, these dense lodgepole pine trees were only about 5 to 7 cm in diameter (Figure 3). Tree density on seeded plots in 1980 was highly variable, ranging from 0 to 4,840 trees/ha.

In 1989 over 90% of the tree regeneration was still lodgepole pine, making it the dominant tree species, even on the seeded plots. However, six other tree species established in the burned area, primarily in seeded plots, including western larch, ponderosa pine, Douglas-fir, grand fir, subalpine fir, and Engelmann spruce

Figure 3. The unseeded area in 2001 was an almost impenetrable stand of lodgepole pine (*Pinus contorta*) 30 years after the 1970 wildfire. Photo by Robert Korfhage

(*Picea engelmannii*). The first three, considered successional species in this habitat type, were the most abundant; western larch and ponderosa pine each represented 29% of the other species, followed by Douglas-fir at 20%. The three later successional species were less frequent: grand fir at 9%, subalpine fir at 8%, and Engelmann spruce at 5%. Western larch began establishing the first year together with lodgepole pine, and by 1989 the trees ranged in size from 0.1 m to 8 m, with 48% of these over 2 m in height. Height of young trees ranged from 3 dm to 5 m in ponderosa pine and Douglas-fir, with over half of the seedlings less than 1 m tall. Individuals ranged up to 2 and 5 m, respectively, for grand fir and subalpine fir, with 85% of the grand fir and 57% of subalpine fir less than 1 m tall. Only 15% of Engelmann spruce seedlings exceeded 1 m in height. The presence of new small trees indicated that all six species were continuing to establish 15 years and more postfire. As a result of continued regeneration, plots with few tree seedlings in 1980 evolved into a more diverse, uneven-aged forest community.

Soil Protection and Fertility

On plots seeded with both overstory and understory grasses, seeded grass cover averaged 29% at the first evaluation in July 1971, and increased to 35% by 1975. Native and seeded grasses combined provided 38% ground cover in 1971. Total cover (including forbs and shrubs) was 50% in 1975. Plots seeded with only the overstory grass species averaged 16% cover of seeded grass in 1971, increasing to 22% in 1975. Total cover of all vegetation was 29% in 1971 and increased to 47% by 1975.

The best total cover (50%) in 1971 was achieved on plots seeded with only the understory grass, Durar hard fescue. This species established aggressively and achieved 45% cover during the first summer after seeding. It maintained this high level (46%) through 1975. Total cover had increased slightly by 1975, to 56%.

Figure 4. Thirty years after seeding, the non-native species had disappeared, leaving an open stand of native species. Trees on the left are lodgepole pine (*Pinus contorta*) and western larch (*Larix occidentalis*); shrubs include willow (*Salix* spp.) and kinnikinnick (*Arctostaphylos uva-ursi*); herbaceous dominants are pinegrass (*Calamagrostis rubescens*), northwestern sedge (*Carex concinnoides*), fewflowered pea (*Lathyrus pauciflorus*), and bigleaf lupine (*Lupinus polyphyllus*). Photo by Robert Korfhage

On unseeded plots, native graminoid cover was 12% in 1971; total cover (including forbs and shrubs) was 22%. By 1975, native graminoid cover on the unseeded plots had increased to 18%, with total cover of 39%.

Forage Production

Production values are observational owing to the lack of replication and because sampling occurred after moderate grazing by elk (Shea 1981). In 1975, herbage production by the seeded grasses averaged 1000 kg/ha on unfertilized plots, 1050 kg/ha on plots fertilized once, and 1900 kg/ha when fertilized a second time (Shea 1981). On the unseeded plots in 1975, pinegrass averaged 70, 530, and 400 kg/ha on the unfertilized, once fertilized, and repeat fertilized plots, respectively. However, the increase in production from the cultivars was temporary: seeded species represented 90% of the production in 1975, 69% in 1980, and only 12% in 1989, with a corresponding increase in native species (10%, 31%, and 88%). As cultivars were replaced by native species and the effects of fertilization faded, total production decreased, leveling off to an average of 500 to 600 kg/ha across all plots by 1980.

Discussion

Postfire Succession

The most noteworthy outcomes of this study were that the seeded grass cultivars were entirely replaced by native species and that instead of dense lodgepole pine regeneration, open, more diverse forest became established in seeded areas (Figure 4). The risk of crown fires is reduced when canopy closure is less than 40% (Hollenstein et al. 2001) and the likelihood of variable intensity ground fires is increased by the presence of herbaceous fuels (Schoennagel et al. 2004). Over time, lower intensity fires favor larger individuals of western larch and ponderosa pine and maintain more diversity in the undergrowth plant community (Arno and Fiedler 2005).

Cover and yield of non-native grasses peaked around 1975 (5 years after seeding), with the seeded species dominating the site (Figure 5). Native forbs, shrubs, and graminoids provided less than 20% cover on seeded plots. In contrast, unseeded plots had almost 40% cover by native species. By 1989 (19 years after seeding), however, the seeded grasses had dwindled to less

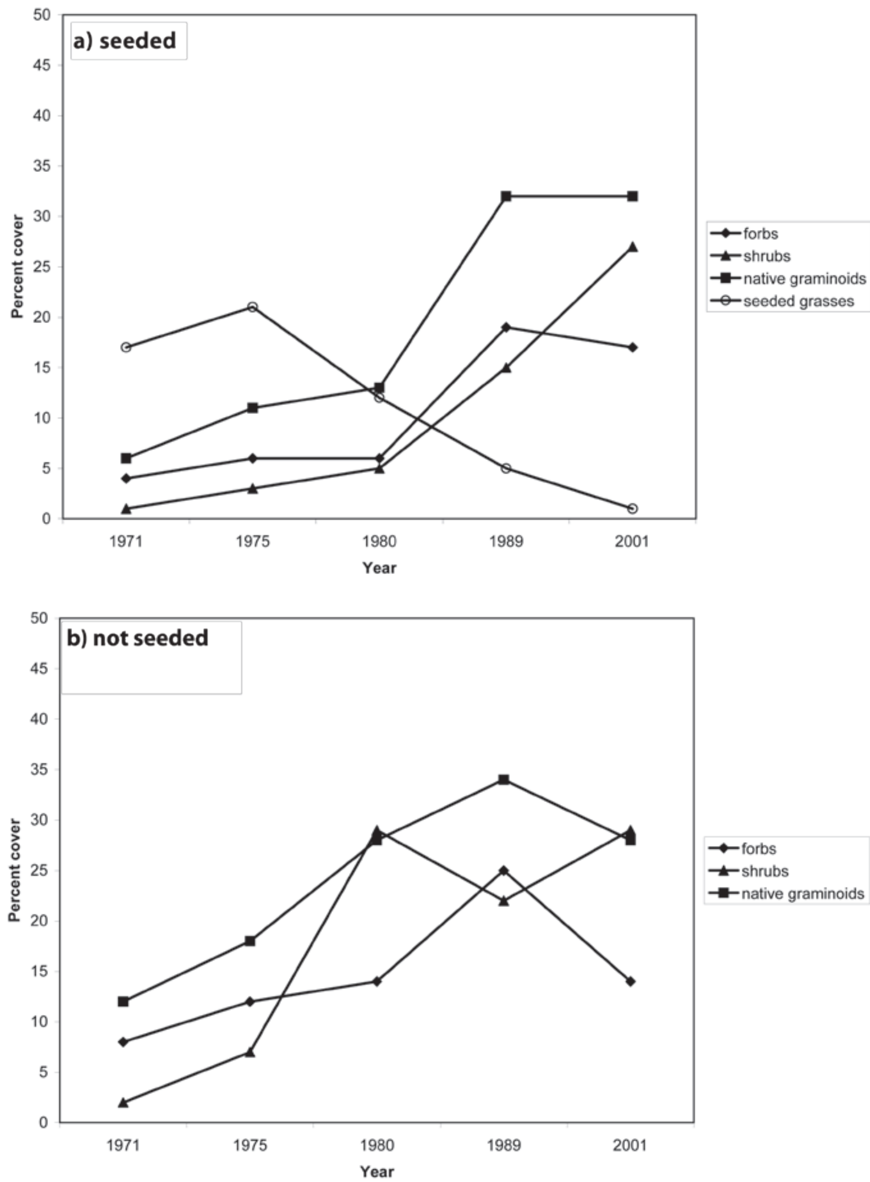

Figure 5. Cover by vegetation class from 1971 through 2001 on a) seeded and b) not seeded plots.

than 1% cover. Replacing them were native forbs (20% cover), shrubs (20% cover), and native graminoids (30% cover), primarily pinegrass and northwestern, elk, and Ross sedges (*Carex concinnoides*, *C. geyeri*, and *C. rossii*).

Cover and production of the nonnative grasses began to decline after 10 years, and their replacement by native species was complete after 30 years. This outcome was not expected: these long-lived perennial grass cultivars were selected for long-term forage production, at least until forest canopy closure. As evidence of the competitive nature of the cultivars, one of them, Manchar smooth brome, was later determined to be invasive enough that it was discontinued from the breeder seed production line by the Plant Materials Center in 2002 (Wayne Crowder, USDA NRCS, pers. comm.). We cannot determine the reasons that the seeded grasses failed to persist; we do know that they were not shaded out by tree canopy closure.

Regional observations by the Forest Ecologist suggest that the probable cause for decline of the seeded grasses is competition for moisture and nutrients by pinegrass, but other possible compounding factors include selective foraging by elk, changes in soil fertility (low nitrogen levels after depletion of fertilizer and/or the postfire flush of nutrients), a series of drought years, and competition from other native species (Terry Lillybridge, pers. comm.).

The forest community in the seeded area contained more tree species and was more open than surrounding unseeded sites, with greater diversity of shrubs, forbs, and graminoids. A long-term consequence of the seeding was a forest that will remain more open and diverse than dense even-aged lodgepole pine.

Tree Regeneration

The first five years were the critical time period for tree seedling establishment (Figure 6). Lodgepole pine seeds released from cones are not viable in appreciable numbers for longer than one year (Lotan et al. 1985). Its seedlings are poor competitors, with weak, relatively slow-developing root systems (Lotan et al. 1985). Grass competition is cited as the most detrimental to lodgepole pine seedling survival (Lotan and Critchfield 1990). In this, as well as other studies (for example, Powell et al. 1994), seeded grasses, with and without supplemental fertilization, reduced establishment of lodgepole pine seedlings. In our study, native grasses and forbs did not occupy the site quickly enough to compete with tree seedlings during the first critical years. High initial cover is more important than persistence in regulating seedling density of lodgepole pine.

Soil Protection and Fertility

Prompt establishment of ground cover by fibrous-rooted vegetation has traditionally been considered the most practical means of minimizing soil loss by wind and water erosion, especially on slopes; other methods include mulching, contour-felled logs, or contour trenches (Robichaud et al. 2000). Sites are most susceptible to erosion during the first season of precipitation immediately following wildfires. To be effective, the seeded species must establish quickly, developing more

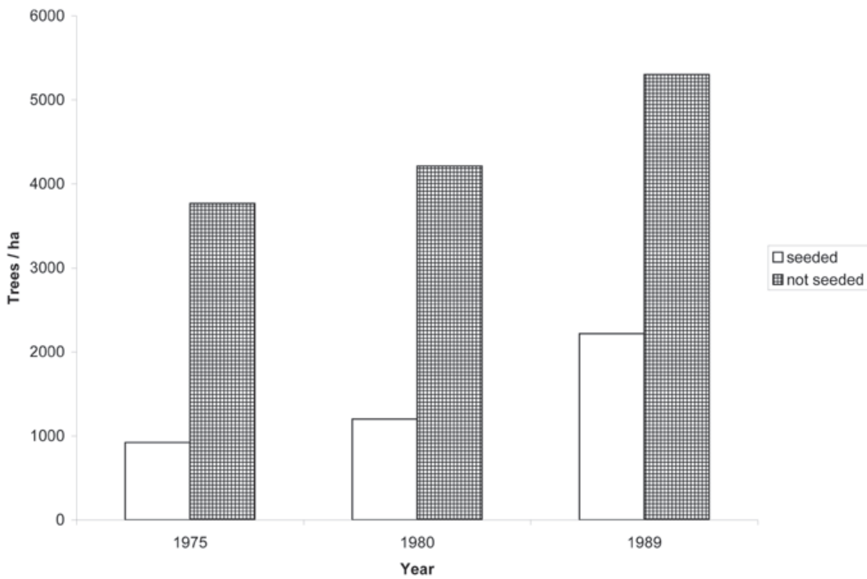

Figure 6. Tree density from 1975 to 1989 on seeded and unseeded plots.

roots and surface cover sooner than natural regeneration of native species. Seeding has a low probability of reducing the first season erosion because most of the benefits of the seeded grass occur after the initial damaging runoff events (Robichaud et al. 2000). This pattern held true at the Colockum site, where vegetative cover on seeded plots was greater than on control plots the summer following the fire, as well as five years later, but not during the first winter and spring.

Most monitoring of the effects of artificial seeding following wildfire fails to quantify reduced erosion and stream siltation, and the Colockum study is no exception. One of the difficulties in proving effectiveness in preventing erosion is that the seeding is done in response to the *risk* of catastrophic events. If torrential rains or rapid snowmelt and runoff do not occur within the first few years following the wildfire, then the seeding served the same purpose as buying an insurance policy without incurring an accident. Recent analyses recommend that BAER teams assist decisionmakers to compare alternatives by understanding that erosion is a direct consequence of storm events and that the risks can be calculated from probability of storm intensity and frequency (Robichaud et al. 2000).

Postfire seeding mixes often include legumes to increase available nitrogen in the soil after the postfire nutrient flush has been exhausted, aiding the growth of seeded grasses and native vegetation (Ratliff and McDonald 1987). At the Colockum site, fertilizer was applied because nitrogen was recognized as a limiting factor for the grass cultivars. The primary nitrogen-fixing species at the Colockum site, fewflowered peavine and lupines, were the most abundant forb species across all seeded plots in 1989 and 2001. Although they had been present in 1975 and 1980, few plants of either lupine or peavine remained in the unseeded areas that had become severely shaded by lodgepole pine. Productivity is reduced in dense lodgepole pine regeneration for two reasons: heavy shade inhibits nitrogen-fixing species such as lupine, and intraspecific competition for the available nitrogen is severe (Hendrickson and Burgess 1989).

Forage Production

Seeding of palatable grass species after the catastrophic fire ensured that ample forage was soon available for herbivores, both large and small. The grass species selected are rated valuable to highly valuable as forage for Rocky Mountain elk (Cook 2002) and cattle (Hafenrichter et al. 1968). The cultivars served as a short-term replacement until native species returned to full production. Forage production was similar to patterns noted in other lodgepole pine studies (McClure 1958, McLean and Clark 1980) and grand fir habitat types (Leege and Godbolt 1985). Forage yields by the grass cultivars increased during the first 2 to 5 years, and remained higher than native grasses for about 15 years.

Benefits to elk habitat extended well beyond the temporary increase in forage production. Decreased or delayed tree regeneration led to open, uneven-aged, mixed-species stands that produce higher quantities of forage over the life of the stand (Urness 1985). These open seral stands could be maintained by low-intensity fires or eventually form climax grand fir communities. Climax grand fir/pinegrass/lupine communities are among the most productive habitats in the North Cascades for elk forage, with a yield of 560 kg/ha total herbage (Lillybridge et al. 1995). Thus, in this habitat type, both the climax and open seral stages produce more forage for elk than dense, pure stands of lodgepole pine.

Studies have shown that fertilization of pinegrass affects all three factors important to grazing animals: yield, palatability, and nutritive value (Freyman and van Ryswyk 1969, Wikeem et al. 1993). Although elk utilization was not quantified, field notes indicate that elk were attracted to the fertilized seedings (Shea 1981). Other studies have also reported elk preference for forage in burned areas that had been fertilized (Skovlin et al. 1983, Long 1989). As seeded grasses declined, production of native forbs increased. Many of the native forbs are valuable elk forage (Cook 2002), including scarlet paintbrush (*Castilleja miniata*), bigflower agoseris, heartleaf arnica, Scouler's woollyweed, fireweed, fewflower pea, ailky and bigleaf lupines, and yellow penstemon. Diversity and persistence of forbs in the community was enhanced by reduction in lodgepole pine seedlings and the associated delay of canopy closure.

Conclusion

Our observations in the grand fir zone in northcentral Washington are that while artificial seeding of non-native species following wildfires may not meet all the goals of the BAER program (to protect soil, water, ecosystem function, and human safety), neither does it always have the detrimental effects attributed by those critical of the practice. During the key period of first runoff, seeded non-native grass cultivars in the Colockum study were probably no better than the native vegetation in preventing soil erosion. However, by the next critical risk period (high intensity rainfall from convective storms in July-August of the first growing season) and for several years thereafter, the non-native species provided greater cover than the native species. BAER reports indicate that surface runoff can be reduced by half with 30% ground cover (Robichaud et al. 2000.) Tree regeneration was lower on the seeded plots, but altering the trajectory of succession by limiting regeneration of lodgepole pine was one of the objectives.

Although artificial seeding did not prevent reestablishment of native shrubs and herbaceous species, it did appear to delay it, a conclusion reached by most short-term studies (Beyers 2004). A study conducted two years after wildfire seeding in a grand fir forest in the northern Cascade Mountains concluded that there were only detrimental effects on recovery of native species (Schoennagel and Waller 1999). Evaluation of our Colockum study two years after seeding would have yielded roughly the same conclusion. However, after 31 years we found that the non-native species did not persist and were replaced by a greater diversity of native species compared to the unseeded area. Thus, delay of a few years in establishment of shrubs and other native species was followed by a community 30 years later that comprised more native species than in the unseeded areas.

In the 1970s, land managers selected aggressive persistent perennial grasses for long-term forage production and expected them to persist indefinitely (McClure 1958, Anderson and Brooks 1975, Clark and McLean 1975). By the 1990s, policies had shifted; use of non-native species for rehabilitation seed mixtures is now under severe criticism and there is strong pressure for federal land management agencies in the western United States to seed only native species during restoration and rehabilitation, or to forego seeding and allow natural recovery of the vegetation (Richards et al. 1998, Beschta et al. 2004). Appropriately, by the time the non-native grasses had fallen from favor, they had also faded from the plant community. Restoration of forests after wildfire (i.e., guiding their composition, structure, and function to a condition within historical range of variability) is still considered desirable when historical human activities modified the fuel structure and subsequent intensity and severity of the fire (Noss et al 2006). These activities may include both passive and active techniques such as allowing natural fire or thinning small trees (Schoennagel et al. 2004). A key element of this process is restoring the native understory plants (Noss et al. 2006).

Using 30-year hindsight, would we recommend seeding of non-native grasses on this site? Yes, but primarily for limiting tree regeneration and increasing forage production, not for short-term erosion prevention. We speculate that two factors were important in the failure of seeded grasses to persist: the competitiveness of pinegrass and inadequate nitrogen levels for grass cultivars. Anecdotal reports from Wenatchee National Forest employees relate that non-native species (such as intermediate wheatgrass) have persisted in drier forest habitats with bunchgrass understories.

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