LOW ELEVATION RIPARIAN FOREST RESTORATION ON A FORMER GRAVEL MINE, NORTH CASCADES NATIONAL PARK: NATIVE PLANT GERMINATION, GROWTH AND SURVIVAL IN RESPONSE TO SOIL AMENDMENT AND MULCHES

by

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Abstract

Low Elevation Riparian Forest Restoration on a Former Gravel Mine, North Cascades National Park USA: Native Plant Germination, Growth and Survival in Response to Soil Amendment and Mulches

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Glacial outwash deposits along Pacific Northwest watercourses have yielded easily extractable aggregate materials such as gravel, sand and cobble for construction for over a hundred years. Discontinued mines throughout the Cascades may be subject to volunteer colonization by seral native plant species overtime however, highly altered topography, lack of organic soils, risk of erosion and threat of invasive plant establishment precludes reliance on a passive approach to restoration. Techniques supporting native plant establishment and survival on former gravel mines and other disturbed sites lacking significant organic soils have involved accelerating the development of biologically active soils through the use of amendments and mulches.

The Goodell Creek Gravel Mine Restoration project is a 1.7 ha portion of a 15 ha acre site on the eastern bank of Goodell Creek, a tributary of the Skagit River, in the North Cascades National Park Complex near Newhalem, Washington. Gravel mining ceased approximately 20 years ago at Goodell and has since been used as a construction staging and aggregate storage area. The restoration site occupies the riparian terrace zone immediately adjacent to the creek. The seedlings of three native tree species and a native seed mix comprising 19 shrub, forb and grass species subjected to straw, woodchips, or no mulch laid over an incorporated partially digested sawdust/paper mill sludge soil amendment or no amendment in a 2 X 3 factorial design. The six treatment combinations were evaluated for their effect on the survival and growth of three native tree species, black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*) and Douglas fir (*Pseudotsuga menzeisii*) and the initial germination and survival of the native seed mix. First and third growth season response data indicate *Alnus rubra* and *Pseduotsuga menzeisii* displayed increased growth with amendment while *Populus balsamifera* showed no significant growth difference between treatments. Conversely tree mortality was increased with amendment especially in conjunction with woodchip mulch. Seed mix germination response varied from species to species but as a whole germinated more successfully and experience greater survival with either straw or no mulch and no amendment treatments.

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Down from the mountain hollers, up from the piedmont, down the tidewater coast, out of the piney woods, I thank my ancestors, my family, who are too numerous to mention and who's inspiration and support would require an epic poem to relate fully and honestly.

DEDICATION

This work is dedicated to the memories of both of my grandfathers, Thomas A. Pond and Howard E. Kiser and my step-father, Robert E. Hart, all of whom died over the time it took me to complete Masters work. From their roots in the land I found inspiration, from their hands unafraid of dirt I learned to dirty my own with pride.

CHAPTER 1

INTRODUCTION AND STUDY OBJECTIVES

Ecosystems tend to respond to natural disturbances in variable but predictable successional pathways according to the availability of pioneer organisms, their ability to reach disturbed substrates and the amenability of the substrate to the colonizing species. Anthropogenic and natural disturbances in ecosystems also create disturbed substrates that offer opportunities for successional processes (Walker, 2003a). However the severity, frequency, extent and distribution of disturbances often subvert the ability of ecosystems to initiate autogenic repair processes (Bradshaw, 1980; Whisenant, 1999) due to:

- complete loss of nutrient capital – removal of organic soils
- interrupting accumulation of allogenic inputs – continued removal of organic and other nutrient inputs or isolation from source of inputs
- precluding colonization – mortality of colonizers or isolation from source of colonizers
- extreme edaphic conditions – excessive drought, cold, saturation, pH, salinity, etc.

In the context of continued and/or extreme disturbance damaged ecosystems can fray and unravel in a downward feedback spiral of degradation leading to loss of ecosystem functions from which they are slow to recover.

Restoration of disturbed ecosystems entails two primary tasks: (1) cessation of disturbance and (2) re-initiation of autogenic ecosystem processes. Often the source of the disturbance has long since ceased and the degraded system has languished barren of any development due to isolation , remained vulnerable to frequent natural disturbance due to limited allogenic inputs and/or slow development under harsh conditions or in an arrested stage of early succession due to frequent natural disturbance or biological invasion. In order to 'bootstrap' such degraded systems, allogenic inputs in the form of organic matter, organisms, structural elements, water, nutrients, site preparation, etc. are applied to ameliorate site conditions to the point at which the subsidies substantially shift the ecosystem from self-reinforcing degradation loops and arrested development and toward autogenic self-repair (Whisenant, 1999). The implicit assumption in ecological restoration is that the general direction of successional processes can be anticipated and therefore directed using certain restoration techniques. Much of the available practical restoration knowledge exists in the form of long term trial-and-error experience held by restoration practitioners. While such cultural knowledge is absolutely vital there remains a need for basic research into the consequences of specific restoration techniques so that the art of restoration can be strengthened and sustained by the science of restoration.

It is in this spirit that this research project was undertaken to investigate the ability of certain allogenic organic inputs, mulch and amendment, to promote the development of native vegetation at an anthropogenically degraded site, an abandoned aggregate mine in the low elevation riparian forest of the North Cascades. Glacial outwash deposits along Pacific Northwest watercourses have yielded easily extractable aggregate materials such as gravel, sand and cobble for construction for over a hundred years. Extraction can occur within the active creek bed but usually forested riparian terraces offer the most easily extractable materials. Abandoned mines throughout the

Cascades may be subject to volunteer colonization by pioneer native plant species overtime. However, highly altered topography, lack of organic soils, erosion and invasive plant establishment precludes autogenic successional processes. ‘Bootstrapping’ techniques supporting native plant establishment and survival on former gravel mines and other disturbed sites lacking significant organic soils have involved accelerating the development of biologically active soils through the application of organic amendments and mulches prior to or concurrent with installation of live plants, seeds and/or other propagules .

The Goodell Creek Gravel Mine Restoration project occupies a 0.27 ha portion of a 7.5 ha acre site on the eastern bank of Goodell Creek, a tributary of the Skagit River, in the North Cascades National Park Complex near Newhalem, Washington. Gravel mining ceased approximately 20 years ago and it has since been used as a construction staging and aggregate storage area. The restoration site lies in a low elevation (150-200 m) riparian terrace zone immediately adjacent to the creek and in the 35 years since cessation of mining operations experienced spotty establishment of native riparian vegetation along with some invasive species. Seedlings of three native riparian tree species and native seed mix comprised of 19 shrub, forb and grass species were subjected to a 2 x 3 factorial experiment testing the ability of mulches and amendment to support growth, germination and survival. Wheat straw, red alder woodchips, or no mulch were laid over either an incorporated partially-digested sawdust/paper mill sludge soil amendment or no amendment yielding six treatment combinations. The three native tree species, black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*) and Douglas-fir (*Pseudotsuga menzeisii*) were monitored for growth and survival response while the 19 species native understory seed mix (Table 2) was monitored for both initial germination and long term survival response to the treatments.

The working hypotheses or *explicit* assumptions driving this experiment are based on testing the ability of organic mulches and amendments to boost and accelerate vegetative development so that primary production, nutrient cycling and water retention occur in a mutually reinforcing manner with no further inputs. Therefore the experimental application of mulches and amendment to a mineral substrate lacking vegetative development is intended to have two primary effects: (1) ensure survival and growth of installed seedlings and (2) promote seed germination and survival of germinants.

- *Hypothesis 1:* Soil amendment will increase growth of installed bare root tree seedlings.

Increasing the organic matter (OM) content of soils improves moisture retention and provides a substrate for soil organisms to proliferate and mineralize nutrients. Plant growth responds to higher available water and nutrients with increased biomass (Brown, 2003; Bulmer, 2000; Jackson et al., 2000; Kelting, 1998; Querejeta, 1998).

- *Hypothesis 2:* Soil amendment will increase the survival of bare root tree seedlings.

A primary cause of mortality in the first growing season for bare root transplants in many ecosystems is lack of available moisture. OM raises the water retention capacity of soils therefore incorporating an organic amendment into the rooting zone will enhance survival (Bulmer, 2000; Cogliastro, 2001; Kost et al., 1997; Kramer et al., 2000b).

- *Hypothesis 3:* Application of mulch over amended soils will enhance the growth and survival of bare root tree seedlings.

Organic mulch serves as a semi permeable barrier that slows the evaporation of soil moisture through physical impedance and surface cooling, suppresses competitors and promotes percolation of precipitation through disruption of physical soil crusting (MacDonald, 1990; McDonald, 1994; Teasdale & Mohler, 2000; Watson, 1988). Mulch will enhance the increased soil moisture retention with amendment especially during periods of seasonal drought.

- *Hypothesis 4:* Application of mulch will increase seed mix germination

Organic mulch creates a matrix of hospitable microsites at the soil surface that trap and retain seed and provide consistently moist and moderated temperature conditions for germination (Chambers, 2000; Facelli, 1991; Teasdale & Mohler, 2000). Mulch will therefore increase seed germination.

- *Hypothesis 5:* Application of mulch over amendment will enhance germinant survival

Application of mulch alone may increase germination however the ultimate goal is to secure the survival of germinants to maturity. As noted in Hypotheses 1 and 2 soil amendment improves moisture and nutrient conditions in the soil that enhance both plant growth and survival. Utilizing mulch over amended soils should increase seed germination and germinant survival (Beukes, 2003; Paschke et al., 2000).

CHAPTER 2

LITERATURE REVIEW

2.1 Mine Restoration

The need to restore metal, coal, aggregate and other former mine sites began to be acknowledged in the 1880's during the industrial revolution with the revegetation or reclamation of colliery spoils, clay wastes, chalk pits and other mine sites in the United Kingdom. In North America such awareness lagged behind though the earliest recorded intentional revegetation of a gravel mine occurred in 1887 in Ontario, Canada (Larson, 1996). With a limited land base and centuries of mining scarring the countryside and taking land out of useful production a concerted effort arose in the UK during the 1940's to approach land reclamation systematically utilizing scientific methodologies (Bradshaw, 1980). By the 1950's in both North America and the UK considerable focus was put into two technical aspects of revegetation; soil revitalization and plant selection.

Soil revitalization initially (and commonly still is) was constructed on an agricultural production model that focused on subsidizing mineral soils with standard agricultural N-P-K fertilizers to establish vegetative cover for site stabilization. Customized soil treatments in the form of lime, sulfates, carbonates and other chemical amendments were also utilized when extremes in pH and/or metal toxicity precluded establishment of vegetative cover (Bradshaw, 1980). This approach often yielded the desired results of site stabilization but was not construed as ecosystem restoration. In the 1970's with the rise of environmentalism, whole systems thinking and subsequent enactment of environmental legislation efforts were refocused to move disturbed lands such as mines beyond basic revegetation towards restoration of native ecosystems. With this new holistic view of the land the soil was recognized as a complex, dynamic biological system that required nurturing of its nutrient cycling processes via the soil food web. Mining operational practices changed in light of this recognition of soil vitality and top soils began to be carefully stockpiled and retained for reapplication after closure of mining operations. As well, the view of nutrient subsidies moved toward organic sources to support and perpetuate nutrient cycling and accumulation in the form of compost, biosolids, crop residues, incinerator ash, saw dust, manures, etc. that retain moisture and support soil organisms that release macro- and micro-nutrients gradually through decomposition.

The selection of plant species for revegetation of former mines followed a connected, parallel evolution of technique. Early revegetation efforts utilized whatever species that seemed to tolerate the poor soil conditions. Sometimes these were native species adapted to extremes of alkalinity, acidity and/or aridity and were early colonizers of abandoned mine sites (Bradshaw, 1980). Many times though, especially in North America, nonnative grasses, forbs and shrubs were introduced for their ability to rapidly establish and therefore stabilize the soil. Moving beyond site stabilization further efforts were exerted into turning former mines into productive landscapes for farming, ranching and forestry which implemented agricultural techniques (chemical fertilizers, tilling, irrigation, chemical pest control, etc.) for maximizing production through intensive monoculture. With the advent of ecologically based land revegetation plant selection derived from a desire to create self sufficient, functional plant communities based on both unique site conditions and undisturbed reference native plant communities. Naturally, ecologically based soil improvement and plant selection techniques evolved in concert with the recognition that the basis of ecosystem restoration in severely disturbed landscapes lies in soil-plant interactions. For example, reserving topsoils retain not only organic matter and soil organisms but also the seeds and other plant propagules of the pre-mining plant community.

2.1.1 Gravel Mine Restoration

As of 2003 the US extracted 1.13 billion metric tons of gravel and sand for the construction industry producing $5.8 billion in revenue while disturbing tens of thousands of hectares of land. The Pacific Northwest has consistently been the top producer of sand and gravel in the US providing 22% of the nation's total output (Bolen, 2004). Because often the richest and most easily extractable deposits of aggregates are in riparian zones, mining impacts are widespread in protected areas including national parks, national forests and other state and federal owned public lands. Of 387 National Park Service units 134 have abandoned mines (ore, coal, sand and gravel, etc.) with more than 3,200 sites and over 10,000 individual mine openings, waste piles, pits and other disturbances (NPS, 2003).

While gravel or aggregate mining generally lacks the heavy metal toxicity and/or extremes of pH associated with coal and metalliferous ore extraction the spatial and physical extent of the disturbance is similar. Whole scale removal of vegetation and associated biologically active topsoils occurs before aggregates are extracted. During mining operations adjacent land is impacted by facilities and road construction, dust and noise. After mining operations cease the original topography and soil profile are radically altered, the surface a bare mineral substrate with no organic soil development. The cumulative effects of these disturbances result in a bereft landscape slow to develop self- sufficient ecosystem processes. Without intervention, disused aggregate mines remain vulnerable to continued disturbance from erosion, noxious weed invasion, illegal dumping and illicit recreational use. As with other forms of mining the restoration challenge remains the same, reestablishing autogenic ecosystem processes (Whisenant, 1999).

2.2 Amelioration of Disturbed Soils

Ecosystem restoration has as its foundation an applied, adaptive whole system approach which develops techniques based in reestablishing ecosystem processes that promote autogenic soil-plant-animal interactions. For exposed mineral soils such as in abandoned mines, roadbeds, and eroded surfaces there are several primary obstacles to autogenic repair;

- Poor moisture retention
- Low nutrient capital, cycling and retention
- Lack of appropriate surface conditions for seed rain retention and germination
- Highly variable and extreme soil surface temperatures
- High risk for wind and water erosion
- Soil compaction

These obstacles primarily can be attributed to the lack of biologically active organic soils, vegetative cover and root development. Therefore amelioration of these conditions requires the replacement the organic capital lost with the removal of the original vegetation and topsoil (Whisenant, 1999). There is a continuum of strategies used to increase the organic capital in disturbed mineral soils depending on severity of disturbance. Under low disturbance, planting fast-growing species to increase primary production maybe a successful strategy while with increased disturbance intensity application of organic materials in a wide variety of forms may be essential to create conditions necessary for vegetative survival and growth. Experimental applications of organic materials to anthropogenically disturbed soils has occurred in a variety of ecosystems; the subarctic (Houle & Babeux, 1994), heathlands (Bradshaw, 1980), boreal forests, deserts (Hien et al., 1997), scrub-shrub (Badia & Marti, 2000; Messina & Duncan, 1993), steppe (Cotts et al., 1991), temperate forests (Kost et al., 1997; Kramer et al., 2000a, b; McDonald, 1994), grasslands (Glendening, 1942) and many others. In each case the amendments were chosen to test their ability to create specific soil conditions that promote the development of vegetative cover and/or soil biotic processes. While there are a vast and varying multitude of organic materials used in restoration they can be divided into two very general categories: mulches and amendments.

2.2.1 Use of Mulch on Disturbed Soils

Mulches are surface-applied materials, organic or inorganic, that serve to improve soil surface and sub-surface conditions. The primary functions of mulch are to:

- Stabilize the soil surface against wind and water erosion
- Slow transpiration of soil moisture
- Alter soil surface temperatures to favor survival and growth of intended species
- Provide microsites for seed rain retention, germination and survival
- Suppress weedy competitors of intended species
- Increase biotic activity of soil via temperature and moisture moderation (and hence nutrient cycling)
- If organic, act as carbon and nutrient source for soil food web in short to long term depending on the form

Mulches, in terms of supporting vegetative establishment, can be utilized in two basic ways; (1) to create soil surface conditions favorable to seed retention, germination and survival and (2) to promote subsurface soil conditions favorable to installed plant survival and growth. Mulches intended for the purpose of vegetative establishment from seed do so by creating a surface matrix that stays in place yet allows seed rain to reach the soil surface, physically retains the seed rain and/or sown seed by resisting wind and/or water movement, and protects soil surface microsites that maintain the light, moisture and temperature conditions required for germination while not inhibiting physical emergence (Chambers, 2000; Facelli, 1991; Teasdale & Mohler, 2000). Experimental applications of mulch at restoration sites using seed for vegetative introduction have found overall that mulches which retain surface moisture yet allow emergence tend to result in greater germination and survival (Beukes, 2003; Chambers, 2000, 1990; McGinnies, 1987; Paschke et al., 2000; Petersen, 2004; Windsor & Clements, 2001). The ability of various mulches to satisfy these requirements depends on their physical characteristics. Moderate surface area to mass ratios and structural ability to form and maintain an open knit matrix such as with straw, hay, or manufactured wood shaving mats such as excelsior tend to perform better with seed than heavier, low surface area to mass ratio mulches like woodchips or high surface area to mass ratios like leaf or sheet mulches both of which tend to form overlapping layers that block physical emergence and light (Teasdale & Mohler, 2000). Seeds also have temperature requirements for germination that can be met through selection of mulch with appropriate insulation and reflective qualities. Guariglia & Thompson (1985) found that surface applied sawdust increased soil temperatures resulting in earlier and greater emergence of Douglas-fir (*P. menziesii*) seedlings while a waste paper fiber hydromulch incurred the coolest soil temperatures and resulted in the lowest emergence.

Mulch alone may not be sufficient to promote seed emergence and survival especially in arid ecosystems. Beukes (2003) found that in the succulent Karoo of South Africa, straw mulch in combination with a gypsum amendment (for improved water infiltration) resulted in the highest emergence and survival of sown seeds over mulch or gypsum treatments alone. Paschke et al. (2000) reported that excelsior (mats made of shaved aspen) and a commercially available granular organic fertilizer, Biosol® produced the highest percent plant cover of seeded species at an arid road-cut revegetation at Mesa Verde National Park in southwest Colorado. Creating surface irregularities such as pits before mulch application has also proved to be a successful strategy to promote seed germination and survival in mine restorations in New South Wales, Australia (Windsor & Clements, 2001). Similarly de-compaction and/or breaking physical soil surface crusts in conjunction with mulch have yielded greater germination and survival. Hien (1997) attempted to improve germination of *Cassia tora* in the Sahel using straw and tillage combinations and found that straw or tillage alone resulted in high seedling mortality while tillage prior to seeding followed by straw application disrupted physical soil crust formation and allowed for higher average germination and survival rates.

Mulch applied to increase the survival and growth of installed plants functions primarily to conserve soil moisture and promote favorable soil temperatures. The moisture conservation function of mulch derives from the ability to physically impede the evaporation of soil moisture, cool soil temperatures and create a zone of high humidity near the soil surface to limit evaporative losses and to physically suppress competitors in the rooting zone of the installed plant. The appropriate physical characteristics of mulch used in this manner have less to do with surface area to mass ratio as it does with the application rate (or thickness), permeability of the material to precipitation and physical resistance to competitor establishment from seed rain, seed bank and/or vegetative propagation (MacDonald, 1990; McDonald, 1994; Teasdale & Mohler, 2000; Watson, 1988). Manipulation of soil temperatures can be accomplished through choosing materials with specific thermal conductivities and/or colors (Cochran, 1969). Heavier, denser materials adsorb heat and release it slowly moderating soil surface temperature fluctuations while thinner, lightweight materials allow for greater soil temperature fluctuations. Lighter colored materials reflect light (increased albedo) and cool surface temperatures while darker ones adsorb heat and raise soil surface temperatures (radiative heat). The temperature of the soil especially near the surface is strongly influenced by the soil moisture content. Higher soil moisture contents moderate temperature fluctuations in conjunction with albedo and radiative heat balance. One can create specific desired soil temperature conditions by choosing a mulch that combines desirable characteristics, for example creating higher soil temperatures during the day to kill competitors, then a thinner material in a dark color such as black plastic sheeting would be appropriate (of course this also kills soils biota). Given the choice of mulches as diverse as wood chips, polypropylene sheets, cardboard, plywood, paving stones, old carpet, ground tires, burlap sacks, plastic sheeting, et cetera, a material can be chosen based on it's specific ability to retain moisture, exclude competitors and achieve desirable soil temperatures.

Installed plants have shown consistent success in survival and growth with black polypropylene/ethylene landscape cloth. Parfitt & Stott (1984) grew willow (*Salix alba*) and poplar (*Populus tacamahaca x trichocarpa*) stakes in polyethylene mulched plots which out-performed stakes grown in straw, bare soil and partial grass cover in terms of root biomass, shoot number and total shoot length. McDonald (1994) experimentally applied 10' x 10' and 2' x 2' polypropylene squares as mulch around 2-0 bare root Douglas-fir seedlings installed in a grass/forb dominated system and discovered that while both size squares suppressed competitors, that the 10' x 10' square kept competitors outside of the Douglas-fir root zone which allowed them to accrue greater stem diameter and root mass than the 2' x 2' square which allowed competitors to root into the trees' rooting zone. MacDonald (1990) in a review of silvicultural mulching practices in California and Oregon also reports that porous black sheets of durable woven synthetics effectively increase soil moisture, raise soil temperatures, suppress competitors and benefit tree growth over less durable material like polyethylene sheets, kraft paper, cardboard, newspaper, straw and woodchips in their particular climate.

Wood chips have been commonly used in horticulture and restoration to suppress competitors, improve soil moisture and increase soil biotic activity. Watson (1988) applied a wood chip/leaf mulch under established 20+ year old trees encroached by grass and increased root biomass by 195% over controls. Houle & Babeux (1994) increased survival but not the growth of *Salix planifolia* cuttings using *Alnus* wood chips in the Canadian subarctic compared with plastic sheet mulches which decreased survival and growth. Kraus (1998) applied wood chips, ground tire and gravel mulches to landscape plantings of desert willow, *Chilopsis linearis*, in Texas and found that all the mulches retained greater soil moisture and increased root and shoot biomass over plants in bare soil however in the second year of grow the wood chip mulched trees displayed significantly lower biomass than the other mulches. Kraus speculates that wood chips suppressed nitrogen mineralization as they began to decompose and incorporate into the soil, a commonly reported problem with wood chips but usually when woodchips are incorporated at the outset as an amendment (Cogliastro, 2001). Hallsby (1995) utilized freshly chipped post-clear cut slash as an experimental treatment with Norway spruce (*Picea abies*) and reported the highest height increase among all treatments which he attributed to decreased grass competition and greater soil moisture.

Straw applied as mulch for live material has displayed variable performance. Parfitt & Stott (1984) compared the response of poplar and willow stakes to polyethylene sheeting or straw and found that while straw retained over 100% more soil moisture than the control that it cooled soil temperatures due to high reflectance well below either the control or the polyethylene. This resulted in poor stake growth response compared to either the polyethylene which produced the greatest growth response or control (bare soil) treatments. Since straw is less recalcitrant to decomposition than woodchips, the benefits it may provide in soil moisture retention and erosion control will be short term. However this may be offset by the contribution of the decomposing straw to soil OM and hence improved aggregation, moisture retention and nutrient cycling through greater soil biotic activity. Holland (1987) compared using straw as mulch versus straw as incorporated amendment in an agroecological experiment. They found that straw applied as mulch resulted in greater soil fungal biomass, higher N immobilization and increased soil OM accumulation while incorporated straw incurred higher bacterial biomass, loss of soil OM through more complete decomposition (loss as CO_2), higher N mineralization and drier soils. Zink & Allen (1998) found similar results in their test of the ability of oat straw to promote soil biota when applied as mulch. They concluded that microbial activity, especially fungal activity, was substantially improved in coastal sage scrub habitat while N immobilization increased which favored the native flora over ruderal invasives. *Artemisia californica* survival and plant volume doubled with straw mulch application over the controls.

2.2.2 Use of Amendments in Disturbed Soils

Amendments as soil subsidies are distinguished from mulches in that they are applied to primarily improve subsoil conditions in the following temporary ways:

- Increase soil moisture retention
- Foster formation of stable aggregates
- Provide a substrate for soil biota therefore promoting nutrient cycling
- Lower bulk density for greater root penetration, drainage and aeration
- Increase long-term nutrient availability through the addition of organic matter boosting plant survival and growth

Amendments can be surface applied or incorporated. The intention behind incorporation is to promote a more rapid accumulation of OM in the plant rooting zone (and hence the benefits of greater soil OM) through greater surface area contact between the amendment and the mineral soil. Surface application of amendments more closely mimic the accumulation of surface OM in natural systems which encourages a decompositional gradient with the greatest biotic activity concentrated around the OM – mineral soil interface. As a result of surface application the OM that accumulates in the mineral soil tends to be soluble organic acids and humates. With incorporation amendment forms a matrix of mineral soil particles suspended in OM in various states of decomposition.

The ability of an amendment to increase soil moisture, fuel the soil food web, nutrient cycling and ultimately plant survival and growth depends substantially on the form of amendment, especially how decomposed it already is or how rapidly it will decompose and whether or not it is incorporated or surface applied. Undecomposed OM such as straw, woodchips or sawdust when incorporated tends to encourage bacterial decomposition and initially immobilize N (Hallsby, 1995; Holland, 1987; Orton, 2002). Undecomposed OM such as straw decays rapidly when incorporated and may result in net N mineralization and loss of soil OM after a brief period of immobilization. Wood chips and sawdust which have higher C:N ratios tend to incur a longer period of N immobilization which can be beneficial in the restoration of systems naturally low in available N favoring natives over nitrophilic exotics exploiting artificial nutrient enrichment (Averett, 2004; Blumenthal, 2003; Hallsby, 1995). Incorporation of undecomposed OM also can have the deleterious effect of sharply lowering available soil moisture due to lower bulk density, excess aeration, wicking and the unavailability of water held by OM to plant roots (Averett, 2004; Blumenthal, 2003; Hallsby, 1995; Walker & Powell, 2001; Walker, 2003b). In contrast surface application of amendments combines the benefits of mulching and amending. Surface applied undecomposed amendments have been shown to favor fungal decomposition and increase N immobilization while allowing for net increases in soil OM which has the overall effect of higher plant survival and growth over unsubsidized soils (Holland, 1987; Zink & Allen, 1998).

More decomposed amendments such as biosolids, aged sawdust, municipal compost, aged manure, digested paper pulp etc. which contain more highly decomposed and partially decomposed materials along with the biomass of the decomposers themselves often offer a more readily available substrate for soil biota, higher nutrient availability and are far more chemically reactive than less decayed OM (Brown, 2003; Bulmer, 2000; Jackson et al., 2000; Kost et al., 1997; Querejeta, 1998). The partially decayed fraction of composted amendments supplies the available nutrients and substrate for soil biota while the more highly decayed fraction (fulvates and humates) that is less available to soil biota improves cation exchange, nutrient storage, soil aggregation, and soil moisture retention (Ashman, 2002; Brady, 2000). When employing composted amendments for the purpose of restoring depleted mineral soils it is common practice to mix low C:N ratio composted OM with high C:N ratio uncomposted OM to achieve a certain C:N ratio that balances N immobilization and mineralization and short term C availability with long term C availability (Brown, 2003; Henry, 1999). The salutary benefits of amendment though are temporary and the expectation is that energy and nutrient capture via primary production will perpetuate autogenic ecosystem processes.

The effects of soil amendments on seed germination and germinant survival have been studied less directly than the effects of mulch. Amendment often has been an additional treatment applied in conjunction with mulch to achieve other experimental goals, not to directly assess seed response. Paschke et al. (2000) did directly assess the response of seeded (and installed) desert sagebrush species in SW Colorado to an organic humate based ‘fertilizer’ amendment with and without excelsior mulch and found that the fertilizer amendment alone produced a significantly greater seed germination (measured as mean percent plant cover) than all other treatments second only to the fertilizer amendment + excelsior mulch treatment which produced the highest mean percent cover. Orton (2002) achieved a 2063% increase (399 T/ha) in seeded blue wildrye (*Elymus glaucus*) biomass over unamended controls with incorporated municipal biosolids at a mid elevation forest road revegetation project in Umpqua National Forest in south central Oregon after one growing season. Brown (2003) assessed several surface applied high and low nitrogen amendment combinations on the revegetation of mine tailings in central Idaho and found that they uniformly increased seeded plant biomass over control plots with the best yields achieved from lower application rates of high N biosolids combined with fly ash. They also determined that seed germination rates were highest when the seed is broadcast 24-48 hours after amendment application.

CHAPTER 3

MATERIALS AND METHODS

Since this project encompassed experimental research and ecological restoration goals the methods to accomplish both required certain compromises. The ability to strictly control site conditions for the experiment gave way to adjusting the experimental design to accommodate for the heterogeneous topography, shade and substrate of the site. Species choices as well as the experimental treatments had to coincide with the overall restoration goals of the site as guided by the National Park Service. The balance of the site not within the experimental plots was restored using the same plant materials and mulches as the experiment. The restoration of the entire site was heavily influenced by the experimental design since the experimental plots occupy the majority of the site. If the site had been simply restored without the experimental strictures the restoration would have been designed and installed differently in many aspects.

3.1 Site Assessment

In May 2001, a team of North Cascades National Park Service staff and two UW graduate student researchers conducted a visual assessment of the Goodell Creek Gravel Mine restoration site. The section of the gravel mine set aside for the project consisted of a 1.7 ha roughly circular area immediately adjacent to the east bank of Goodell creek lying approximately 5 m above the creek bed in a riparian terrace zone. The site has been considerably altered first by aggregate extraction from the 1920s through the early 1970s, during which time levee construction was initiated to protect the mine from catastrophic flooding and then abandoned before completion. The mining activity probably decreased markedly after the formation of North Cascades National Park in 1969 and had ceased all together by the late 1970s. Since cessation of mining operations the site remained in continuous use as a road maintenance materials stockpile area and a dump for rockslide material and landscape waste for Washington State Department of Transportation (WADOT), Seattle City Light (SCL) and the NPS. Inevitably illicit waste dumping occurred as the site access is open. An unpaved road leading to a locally popular fishing and swimming hole on the creek bisected the site forming an area of compaction. The site also bore signs of off-road/all-terrain vehicle and dirt bike use in addition to illicit fire pits and scattered ‘party’ garbage.

The site at the time of the assessment supported several native trees typical of western Cascades riparian zones such as *Populus balsamifera*, *Pseudotsuga menziesii*, *Betula papyrifera*, *Tsuga heterophylla*, *Acer macrophyllum* and *Alnus rubra* that had established small volunteer stands within and bordering the site totaling no more than 0.17 ha of the total site area with woodland strawberry, *Fragaria vesca*, common throughout. Some non-indigenous herbaceous species primarily *Tanacetum vulgare* and *Verbascum thapsus* were scattered over the site in addition to a landscape waste pile covered with a wide variety of common non-indigenous weeds and ornamental woody species. Despite the promising existence of volunteer native vegetation the majority of the site was largely without vegetative cover with a well drained mineral substrate lacking any significant accumulation of organic matter.

The surrounding matrix of the project site consisted of the balance of the former gravel mine to the east and north, a volunteer forest on the abandoned levee to the south and east and relatively intact mature forest stand to the north and west. The gravel mine continues to be utilized as a fill site for material from highway rockslides and a storage area for construction aggregates. The road into the mine allows public access to the project site and the trail through the site back to the creek. The gravel mine also supports a fascinating but troublesome diversity of non-indigenous vegetation brought in from the roadside rockslide debris which has the potential to spread into surrounding areas, especially the project site.

3.2 Project site experimental design

The purpose of the experiment was to evaluate the effects of straw, woodchip or no mulch in combination with either a partially digested paper pulp/sawdust amendment or no amendment had on native tree seedling growth and survival and on native seed mix germination and survival. The assumption was that soil moisture would be the key factor influencing growth and survival in the first growing season. The position, substrate, aspect and topography of the project site introduced potential variability in soil moisture across the site that might confound possible differences in the moisture retention effects of the treatments. The potentially most influential variable on the project site was the existence of two abandoned aggregate piles, one sand, the other drain-rock size (pea) gravel. Each pile covered approximately half of the entire site with the sand closest to the creek edge. The concern was that the sand and gravel would have differences in drainage strong enough to impact the soil moisture content of the overlaying topsoil and amendments. Therefore the site was blocked for this potential effect. As seen in the site schematic figure 1 the site was blocked in halves for the substrate and then the amendment treatment was applied to a randomly chosen half of each block. The combination of two amendment treatments (either amendment or none) and three mulch treatments (woodchips, straw or no mulch) resulted in a 2 x3 factorial design yielding 6 treatment combinations (table 1).

Table 1: Experimental treatment combinations – 2x3 factorial
These abbreviations will be used later in the text

	AMENDED	UNAMENDED
STRAW	**STA**	**STN**
WOODCHIPS	**WCA**	**WCN**
NO MULCH	**NOA**	**NON**

Six replicates of each treatment combination were then randomly assigned within each of the amendment and no amendment blocks for a total of 36 plots divided among 4 blocks, 9 plots per block (figure 1). The plots were circular covering an area of 20 m^2 (5 m in diameter) with a large stone marking the center (figure 2).

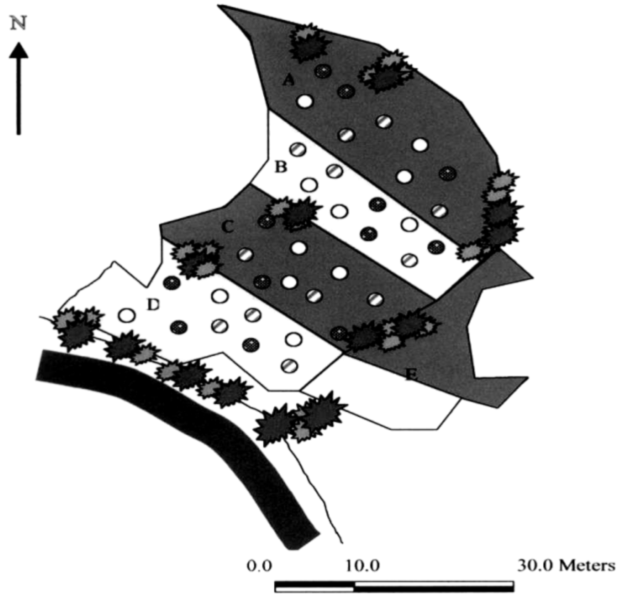


Figure 1: Goodell Creek experimental project site schematic
Blocks A & B = gravel, C & D = sand; Blocks A & C = amendment, B & D = no amendment
Thick black line = Goodell Creek; shaded blocks = amendment

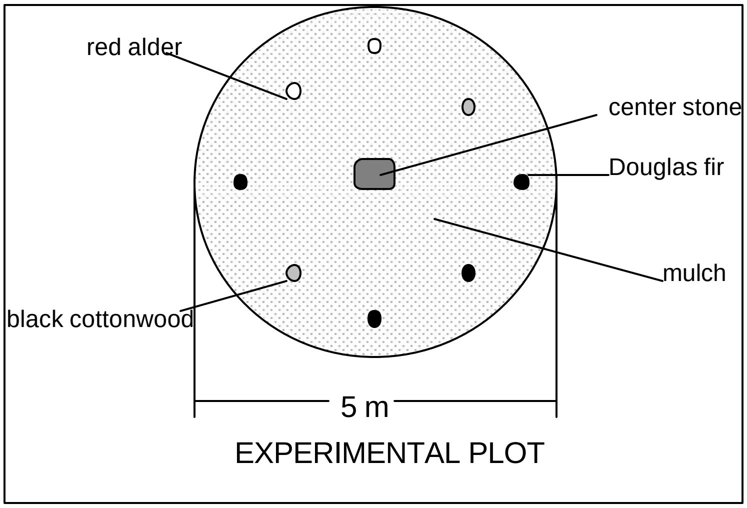


Figure 2: Experimental plot schematic

Three native tree species typical of North Cascades riparian terraces, red alder (*Alnus rubra* Bong.), black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* [T. & G.] Brayshaw) and Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco var. *menziesii*) (Hitchcock, 1973) were planted in November 2001 as 40-60 cm tall seedlings locally salvaged (within 2 km of the site) by NPS staff and held temporarily (less than a month) in moist sawdust beds until planting. Eight trees in total, four Douglas-fir, two red alder and two black cottonwood, were installed in a circular formation 2 m from the center stone allowing for at least a 1 m buffer between the trees and the next plot at the cardinal compass points for ease of tracking and identification. After tree installation a native seed mix consisting of 19 species (table 2) was broadcast evenly throughout the plot after having been mixed with several handfuls of moist sterile sand. The seed had been locally gathered May through September 2001 within 2 km of the project site by NPS staff, cleaned and held in dry room temperature conditions before sowing. The mulch treatments were then applied to an approximate depth of 3 cm to allow for seedling emergence.

Table 2: Native seed mix applied to experimental plots.
Note: Seed counts over 100 are estimated by weight and/or volume

Species	Family	Common Name	Seed/plot
Acer circinatum	Aceraceae	Vine maple	42
Acer macrophyllum	Aceraceae	Big-leaf maple	7
Alnus rubra	Betulaceae	Red alder	16
Anaphalis margaritacea	Asteraceae	Pearly everlasting	7000
Arctostaphylos uva-ursi	Ericaceae	Kinnikkinnick	6
Aruncus sylvester	Rosaceae	Goat's beard	500
Cornus nuttalii	Cornaceae	Pacific dogwood	1
Elymus glaucus	Poaceae	Blue wild rye	850
Epilobium angustifolium	Onagraceae	Fireweed	6000
Geum macrophyllum	Rosaceae	Large-leaved avens	70
Holodiscus discolor	Rosaceae	Oceanspray	2300
Physocarpus capitatus	Rosaceae	Pacific ninebark	70
Rosa gymnocarpa	Rosaceae	Baldhip ose	3
Rubus parviflorus	Rosaceae	Thimbleberry	42
Rubus ursinus	Rosaceae	Trailing blackberry	270
Spiraea douglasii	Rosaceae	Hardhack	800
Symphoricarpos albus	Caprifoliaceae	Snowberry	4
Vaccinium parviflorum	Ericaceae	Red huckleberry	400

No weed control, watering or any other standard practice restoration maintenance was performed on the site during the course of the experiment. This was done in order to mimic the level of maintenance expected in backcountry conditions to determine the efficacy of soil amendment and mulches in supporting native plant establishment with only seasonal precipitation and minimal maintenance.

3.3 Project site preparation

The project site was prepared during the first two weeks of October 2001 by North Cascades National Park facilities personnel. The site was first cleared of garbage and nonnative plants were excavated out and disposed of by deep burial (6+ feet) and then the sand and gravel piles were graded to a 5-10 % slope with a southerly aspect. Over the graded substrate, sandy loam topsoil that had been stockpiled on the site for 30+ years was applied over the entire site to an approximate depth of 15 cm. The site was then blocked for the substrates and divided into sub-blocks for the amendment treatment that ran parallel to the site slope.

3.3.1 Amendment procurement and application

The amendment consisted of a secondarily digested paper pulp sludge stabilized with fly ash from the Kimberly-Clark paper mill in Everett WA. The high available N content of the paper pulp sludge necessitated raising the C:N ratio before application with sawdust procured from a local Skagit valley sawmill (Smukler, 2003). The intent was to raise the OM content of the soil and therefore the soil moisture holding capacity without increasing N mineralization which would have either resulted in N leaching from the well drained soil or supporting ruderal nonnative plant species present on the site. The cool temperate forests of the western Cascades are generally low in available N and therefore higher C:N ratios in soil amendments should favor native species. The amendment was spread by a front end loader in blocks A and C and then tilled into the topsoil to a maximum depth of 6” using a tractor with a tiller attachment. This resulted in 6” of amended soil over semi-compacted subsoil. Unamended plots were not tilled.

3.3.2 Mulch procurement & application

The wheat straw used for mulch in the experiment was obtained from a supplier in Douglas county WA who sells it as ‘weed-free’ straw. Washington state at this time does not have a weed-free certification process established as do other states therefore the claims could not be completely confirmed. There was concern that the straw could have been contaminated with chloropyralids (a common herbicide used to keep straw free of broadleaf weeds) however there was no sign of this after application (indicated by the lack of wide spread sudden plant tissue browning and followed by death). The woodchips were obtained from chipped red alder that were cleared from a bridge widening project approximately 2 km west of the project site. After application it was discovered that the woodchips had been processed and stored in a nearby pasture and then transported to the site contaminated with typical nonnative pasture species such as clovers (*Trifolium repens* L. , *T. aureum* Pollich. , *T. hybridum* L.), quackgrass (*Elymus [Agropyron] repens* [L.] Gould), ox-eye daisy (*Leucanthemum vulgare* Lam.), sweet clover (*Melilotus alba* Medikus) and others (Hitchcock, 1973). The mulch was applied to a depth of 3 cm in each plot after tree installation and seed broadcasting. The light application was required to allow for seed germination.

3.4 Data collection and analysis

3.4.1 Tree growth

Initial tree height and diameter measurements were taken at the end of the growing season after full leaf abscission of the deciduous trees in November 2001. Each tree was measured shortly after planting. Height measurements were taken to the nearest millimeter from the soil level to the end of the terminal bud of the main stem (or the longest main stem if there were multiple leaders) using a standard meter stick in 1 mm increments. Stem diameter was taken using digital calipers to the nearest tenth millimeter approximately 4 cm above the soil level in order to be above root crown swelling but between any branch nodes. The height and diameter measurements were repeated in November 2002 in the same manner and height only again in September 2004. Preliminary data analysis showed a strong correlation between stem diameter and height so only height was measured in 2004. The difference between the 2002 and 2004 growth measurements and the initial measurements, change in height (?HT) and change in diameter (?DI) were log+1 transformed and analyzed with univariate full factorial analysis of variance (ANOVA) utilizing SPSS 11.5 (SPSS, 2003) to compare block effects, mulches, amendment and mulches plus amendment for significant differences. Multiple means differences were compared for significance using Tukey's HSD.

3.4.2 Tree mortality

The number of dead vs. live trees per species for each experimental plot was counted in September 2002 and again in September 2004. Counts were converted to percent mortality for each species per experimental plot and then statistically analyzed using ANOVA as per (Lumley, 2002).

3.4.3 Native seed germination - ¼ m^2 subplots

June through September 2002 and once again in August 2003, two ¼ m^2 subplots were surveyed for identifiable germinants in each of the 36 - 20 m^2

experimental plots. The subplots were assigned to permanent positions 0.5 m away from the base of each the north and south tree at a position between the center rock and the tree. Germinants were counted in each subplot once a month and identified to the most specific taxon possible. *A. rubra, P. balsamifera,* and *Elymus glaucus* Buckl. were chosen for statistical analysis since these three species comprised over 80% of all germinants counted. All nonnative germinants were counted and grouped together under 'nonnatives' for analysis. The average germinants per experimental plot were log+1 transformed if necessary to normalize the distribution of the data and analyzed using univariate full factorial ANOVA.

3.4.4 Native germinant survival - whole plot

In September 2002, 2003 and 2004 each experimental plot was surveyed for identifiable surviving native plant germinants greater than 2 cm in height. The 2 cm cut-off was chosen to separate recent, often unidentifiable germinants (usually *A. rubra* and *P. balsamifera* seedlings) with an overall poor rate of survival from seedlings who were clearly identifiable and potentially developed enough to survive to maturity. Each plot was divided into quarters and each quarter was visually surveyed for viable, identifiable germinants. In the case of *E. glaucus* a percent cover was assigned since bunches began to merge with maturity and it was difficult to tell individual plants apart. *A. rubra, P. balsamifera,* and *E. glaucus* were chosen again for statistical analysis along with *Anaphalis margaritacea* (L.) B. & H. and five native shrub species, *Holodiscus discolor* [Pursh.] Maxim, *Physocarpus capitatus* [Pursh] Kuntze, *Rosa gymnocarpa* Nutt. , *Rubus parviflora* Nutt. and *Rubus ursinus* var. *macropetalus* [Dougl.] Brown, (Hitchcock, 1973) that were grouped together under the designation ‘native shrubs’. As with the other collected data the counts and percent cover were log+1 transformed if the data if necessary to normalize the distribution of the data and analyzed using ANOVA.

3.4.5 Seed rain and litterfall

Seed rain and litterfall were collected in 26 cm x 26 cm x 6 cm black plastic trays secured to the soil surface with a galvanized spike. 12 trays were installed at the beginning of March 2002, three in each block at the top, middle and bottom of the slope. The contents were collected in November 2002 and dried at 70°C for seven days, sorted by species and weighed. Seed was identified by species and counted.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Tree growth response – first (2002) and third (2004) years

Change in height and diameter were measured one year and three years after installation on all three species, *P. menziesii, A. rubra* and *P. balsamifera.* In both years change in growth was calculated by subtracting the initial installed height from the measured height (ie. first season measurements were not subtracted from third season measurements to calculate year three results). Since height and diameter are strongly correlated growth indicators and since height was easier and more precise to measure change in height was selected to be used in statistical analyses.

4.1.1 Douglas-fir – Pseudotsuga menziesii (PSME)

4.1.1.1 Block effects

PSME displayed significantly differential growth for the block effect substrate in 2002 favoring sand over gravel ($p< 0.0001$) with 1.79 cm versus 0.52 cm change in height but not so for shade ($p<0.932$). By 2004 there were no measurable block effects (substrate $p<0.694$, shade $p<0.265$). The initial differences may have been due to post installation settling.

4.1.1.2 Amendment

There was no significant difference in gained height for PSME (figure 3) between amended and unamended plots in 2002 ($p<0.838$). By 2004 PSME height was significantly greater (figure 4) with amendment ($p<0.018$). However the significantly higher mortality in amended plots (see section 4.2 below) may have skewed these results in favor of fewer survivors with greater growth response. This also may be reflected in the greater variability in growth response with the amended plots.

4.1.1.3 Mulch

PSME did show a slight but significantly greater change in height when grown with straw over no mulch ($p<0.035$) in 2002 (figure 5) though it was not statistically different from woodchips. PSME change in height did not differ significantly (figure 6) among the mulches in 2004 ($p<0.739$) though woodchips showed a slight advantage based on means.

4.1.1.4 Mulch and amendment

The first year change in growth showed no significant mulch x amendment treatment interaction for PSME height (figure 7) in 2002 ($p<0.248$). Correspondingly there were no significant differences between any of the individual treatments in either year (2002 $p<0.248$, 2004 $p<0.265$) however the trend of the means reaffirmed the mulch results with straw treatments (STN and STA) showing the greatest change in height followed by woodchips (WCA and WCN) then no mulch (NOA and NON). This was still true in 2004 (figure 8) with no significant mulch x amendment interaction ($p<.073$) for change in height with the trend favoring amended plots and no observable trend among the mulches.

4.1.2 Black cottonwood – Populus balsamifera (POBA)

4.1.2.1 Block effects

Comparisons of potential block effects showed no difference in 2002 (substrate p<0.248, shade p<0.818) or in 2004 (substrate p<0.777, shade p<0.297) therefore any differences in response between plots is assumed to be due to the mulch and amendment treatments.

4.1.2.2 Amendment

In 2002 the mean change in height for POBA was greater for the amended plots (figure 3) however the difference between the treatments was not statistically significant (p<0.073). By 2004 POBA still showed increased growth with amendment (figure 4) however this difference was even less significant (p<0.952). It was observed that of the three tree species POBA had the greatest incidence of tip die-back. Instead of recording negative heights, tip die-back was recorded as ‘0’ increase in height. As well 50% mortality of POBA in the amended plots in 2004 may be affecting the results. Again the higher variability of the amended plot data may reflect this or some other variation in the treatment or site conditions which result in higher mortality while increasing growth.

4.1.2.3 Mulch

There was no significant difference in the change in height for POBA (figure 5) according to mulch in 2002 (p<0.940) with no discernable trend in the means that favor mulch or no mulch. By 2004 this was still the case (p<0.561) with the trend favoring no mulch (figure 6).

4.1.2.4 Mulch and amendment

No significant mulch x amendment interaction was found in the model for change in height in 2002 (p<0.150) or 2004 (p<0.301) (figures 7 & 8) as might be expected given the non-significant effects of both mulch and amendment separately. Trend wise patterns in the means for change in height show a slight growth advantage for amendment in 2002 but by the end of 2004 there is no discernable trend in towards amendment or mulch.

4.1.3 Red alder – Alnus rubra (ALRU)

4.1.3.1 Block effects

Differences between blocked environmental variables were significant in the case of shade in 2002 with a slightly significant increased change in height (p<0.049) for the shadier blocks. In the third year this difference disappeared (p<0.477).

4.1.3.2 Amendment

There was a pronounced difference between amended and unamended plots for mean change in height in both 2002 and 2004 for ALRU (figures 3 & 4). Amendment resulted in three-fold increase in mean height (p<0.001) in 2002 and in the 2004 (p<0.0001). ALRU displayed the strongest growth response of the three tree species with some individual ALRU trees gaining 10x their initial height at installation in three years. Like with the other species, the variation in ALRU height increase was greater with amendment, nearly twice the variation of the unamended plots which may indicate more variability in conditions due to uneven application and/or formulation of the amendment.

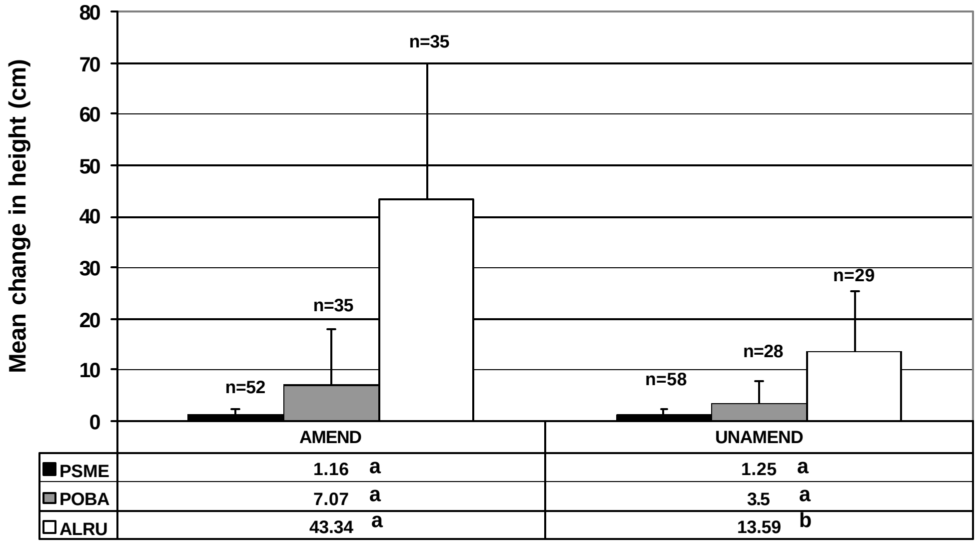
4.1.3.3 Mulch

ALRU growth was significantly greater with straw in 2002 ($p<0.01$) followed by woodchips then no mulch (figure 5). By 2004 there was no significant difference amongst the mulch treatments ($p<0.185$) though trend still favored straw followed by no mulch and then woodchips (figure 6). It must be noted that WCA plots experienced 92% mortality by 2004 and therefore comparisons of the mulches are essentially skewed in the third year.

4.1.3.4 Mulch and amendment

There was a significant mulch x amendment interaction in both 2002 ($p<0.006$) and 2004 ($p<0.0001$). In 2002 STA and WCA treatments outperformed the other treatments (figure 7) while in 2004 STA and NOA favored ALRU growth (figure 8). This result, as previously mentioned, may be an artifact of the 92% mortality of ALRU in WCA plots by the third year. The WCA treatment was left completely out of the 2004 growth analysis for mulch x treatment comparisons since only one individual out of 24 had survived.

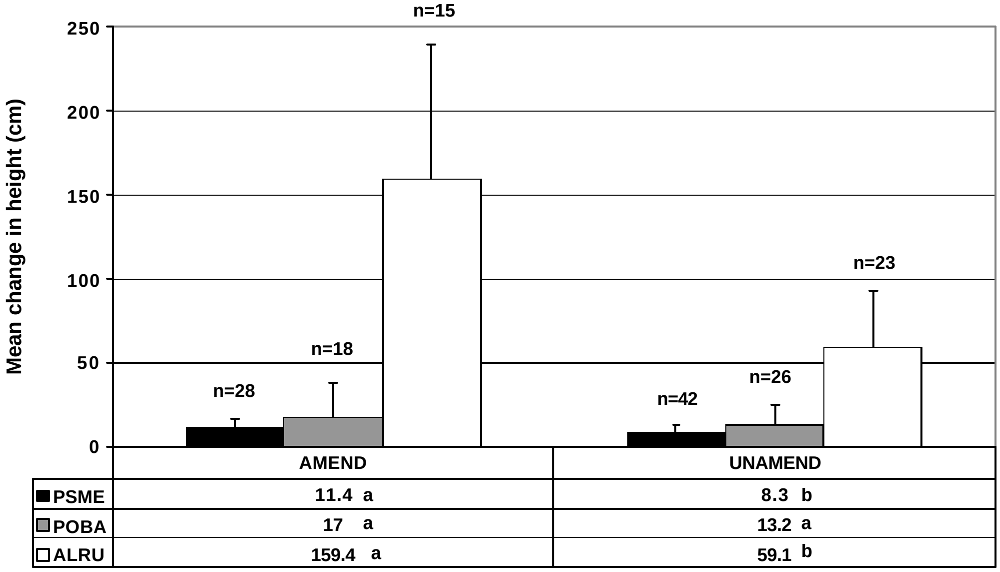
Tree Seedling Transplants 2002
mean change in height - amendment



	AMEND	UNAMEND
■ PSME	1.16 a	1.25 a
▨ POBA	7.07 a	3.5 a
□ ALRU	43.34 a	13.59 b

Figure 3: First growing season height response of tree transplants to amendment Different letters indicate significance at $p<0.05$ level; error bars indicate SD

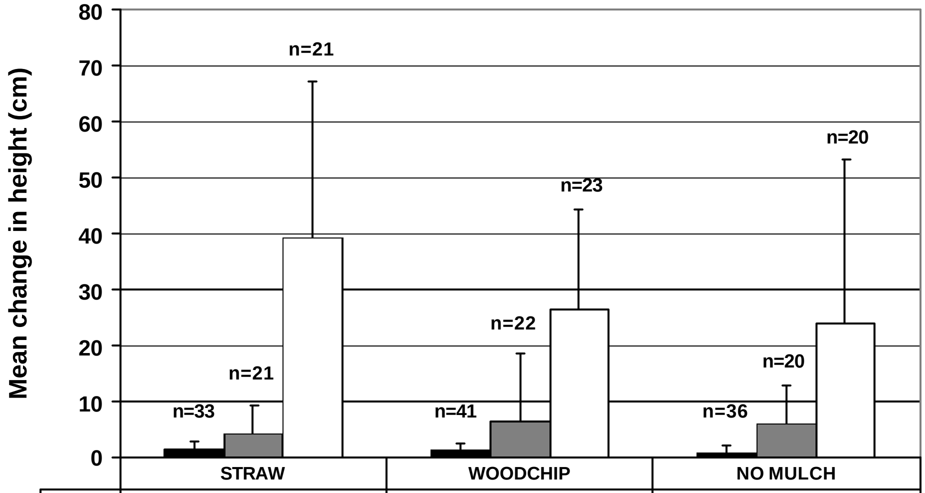
Tree seedling transplants 2004
mean change in height - amendment



	AMEND	UNAMEND
■ PSME	11.4 a	8.3 b
▨ POBA	17 a	13.2 a
□ ALRU	159.4 a	59.1 b

Figure 4: Third growing season height response of tree transplants to amendment Different letters indicate significance at $p<0.05$ level; error bars indicate SD

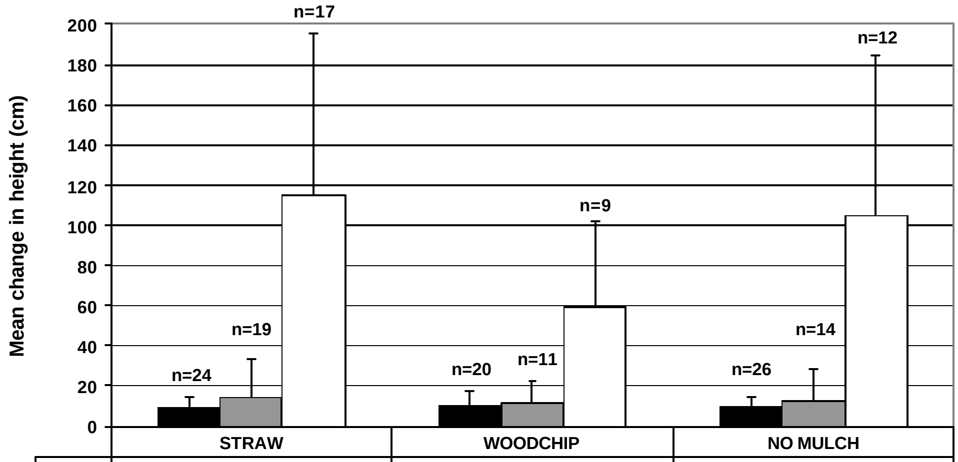
Tree Seedling Transplants 2002
mean change in height - mulch



	STRAW	WOODCHIP	NO MULCH
■ PSME	1.53 a	1.27 ab	0.83 b
▨ POBA	4.1 a	6.41 a	5.91 a
☐ ALRU	39.21 a	26.42 ab	24.01 b

Figure 5: First growing season height response of tree transplants to mulch
Different letters indicate significance at $p<0.05$ level; error bars indicate SD

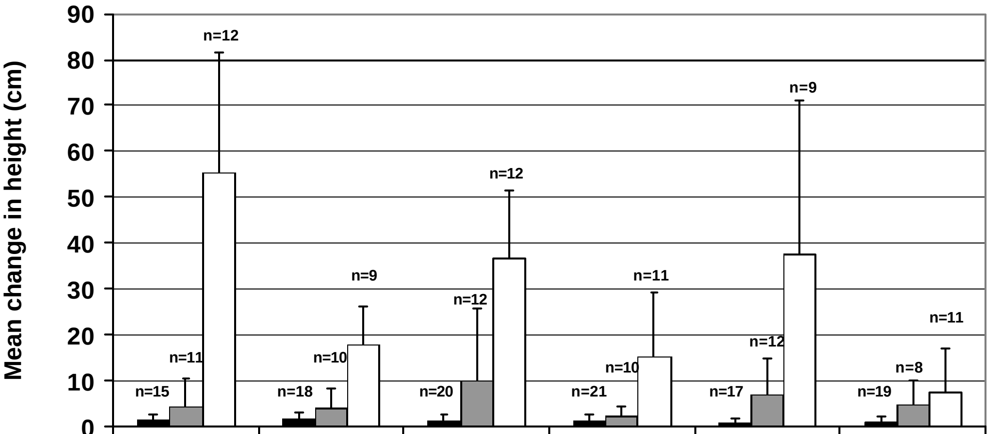
Tree seedling transplants 2004
mean change in height - mulch



	STRAW	WOODCHIP	NO MULCH
■ PSME	8.9 a	10.2 a	9.7 a
▨ POBA	14.3 a	11.7 a	12.7 a
☐ ALRU	115.2 a	59.5 a	104.7 a

Figure 6: Third growing season height response of tree transplants to mulch
Different letters indicate significance at $p<0.05$ level; error bars indicate SD

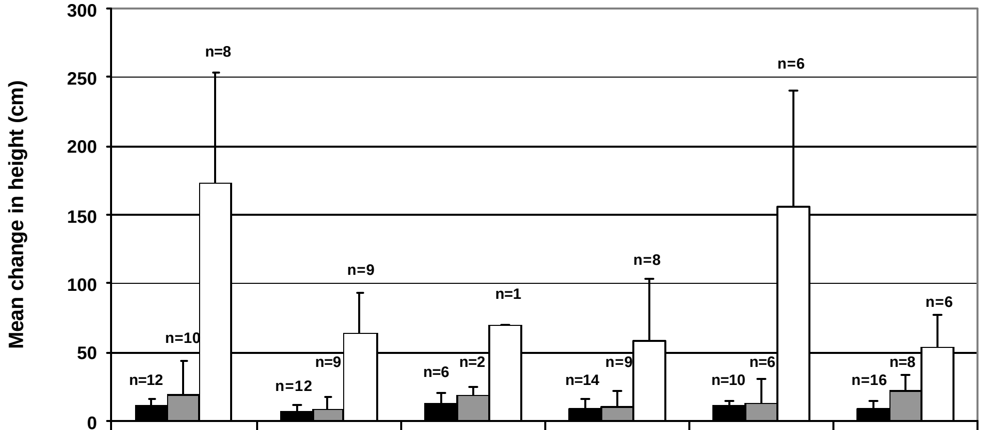
Tree Seedling Transplants 2002
mean change in height - treatments



	STA	STN	WCA	WCN	NOA	NON
■ PSME	1.49 a	1.57 a	1.26 a	1.28 a	0.75 a	0.91 a
▨ POBA	4.25 a	3.94 a	9.94 a	2.17 a	6.78 a	4.61 a
☐ ALRU	55.32 a	17.72 abc	36.7 ab	15.21 bc	37.53 abc	7.49 c

Figure 7: First growing season height response of tree transplants to mulch x amendment Different letters indicate significance at p<0.05 level; error bars indicate SD

Tree seedling transplants 2004
mean change in height - treatments



	STA	STN	WCA	WCN	NOA	NON
■ PSME	11.4 a	6.4 a	12.5 a	9.2 a	10.9 a	9 a
▨ POBA	19.5 a	8.5 a	18.2 a	10.3 a	12.4 a	21.8 a
☐ ALRU	173.1 a	63.8 b	69.4 *	58.3 b	156.1 a	53.4 b

Figure 8: Third growing season height response of tree transplants to mulch x amendment Different letters indicate significance at p<0.05 level; error bars indicate SD

4.2 Tree mortality – first (2002) and third (2004) seasons

As with change in height, there is a high level of variability in the mortality data overall which may obscure some significant differences. This is especially true for 2004 data.

4.2.1 Douglas-fir – Pseudotsuga menziesii (PSME)

4.2.1.1 Block effects

Neither shade (2002 $p<0.152$, 2004 $p<0.270$) nor substrate (2002 $p<0.152$, 2004 $p<0.584$) appeared to be contributing factors influencing PSME mortality in the first or third growing seasons and therefore any difference in mortality among plots is attributed to the mulch and/or amendment treatments.

4.2.1.2 Amendment

In 2002 there was no significant difference in mortality for PSME between amended and unamended plots ($p<0.286$) with slightly greater mortality in amended plots (figure 9). By 2004 amended plots had significantly higher mortality ($p<0.049$) (figure 10) though as seen previously had significantly greater gain in height.

4.2.1.3 Mulch

There were no significant differences in PSME mortality (figures 11 & 12) between the mulch treatments (2002 $p<0.207$, 2004 $p<593$) though for both growing seasons woodchips incurred the highest mortality rate especially in conjunction with amendment (see section 4.2.1.4 below).

4.2.1.4 Mulch and amendment

Neither the first nor the third year mulch x amendment treatment mortality was statistically significant (2002 $p<0.495$, 2004 $p<0.225$) though as noted previously WCA had the highest mortality rate of all treatments (figures 13 & 14).

4.2.2 Black cottonwood – Populus balsamifera (POBA)

4.2.2.1 Block effects

Neither shade (2002 $p<0.560$, 2004 $p<0.689$) nor substrate (2002 $p<0.560$, 2004 0.275) were significantly different in terms of mortality for POBA. These block effects aside, any difference in mortality is assumed to be due to the main effects of mulch and amendment.

4.2.2.2 Amendment

There was overall very low mortality for POBA in 2002 and comparisons of treatments yielded no significant differences. In the case of amendment, amended plots had no mortality in 2002 with a non-significant 8% mortality in unamended plots ($p<0.074$). However by 2004 amended plots had incurred significantly greater mortality ($p<0.039$) with 50% of amended POBA dead (figures 9 & 10).

4.2.2.3 Mulch

After the first growing season mortality between the mulch treatments was very low and equal (2002 $p<1.0$) (figure 11). By the end of the third growing season woodchips was clearly correlated with greater mortality as it is with PSME and ALRU though this was not statistically significant (2004 p<0.074) (figure 12). Looking at variability it is interesting to note that both woodchips and no mulch displayed greater variability in mortality than straw in 2004 while straw had the lowest mean mortality.

4.2.2.4 Mulch and amendment

First year mulch x amendment interaction was not significant (2002 p<0.700) reflecting the overall low mortality regardless of treatment (figure 13). In the third year mulch x amendment interaction was significant (2004 p<0.017) with WCA causing a mean 83% mortality that was significantly greater (p<0.03) that both STA and STN treatments which both showed 17% mortality (figure 14).

4.2.3 Red alder – Alnus rubra (ALRU)

4.2.3.1 Block effects

ALRU demonstrated no difference in mortality for substrate in either year (2002 p<0.701, 2004 p<0.704) while shade had significantly greater mortality in the third growing season (2002 p<0.244, 2004 p<0.018).

4.2.3.2 Amendment

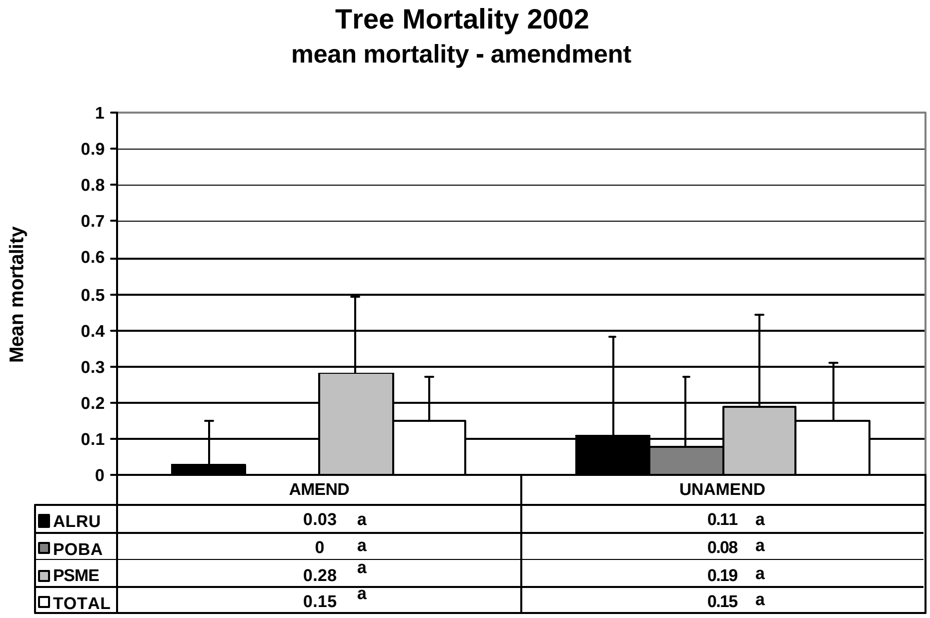
There was no significant difference in mortality between the amended and unamended plots after the first or third growing season (2002 p<0.244, 2004 p<0.123) although in the third growing season mortality was markedly higher with amended plots as it was for POBA and PSME (figures 9 & 10).

4.2.3.3 Mulch

As with POBA and PSME, woodchips had the highest mortality of the three mulch treatments in the third year (63%) although this difference was not significant (2004 $p<0.160$) (figure 12). In the first year overall mortality was low (7%) and there were no significant differences between the treatments (2002 $p<0.350$) with no mulch having a slightly elevated mortality (13%) (figure 11).

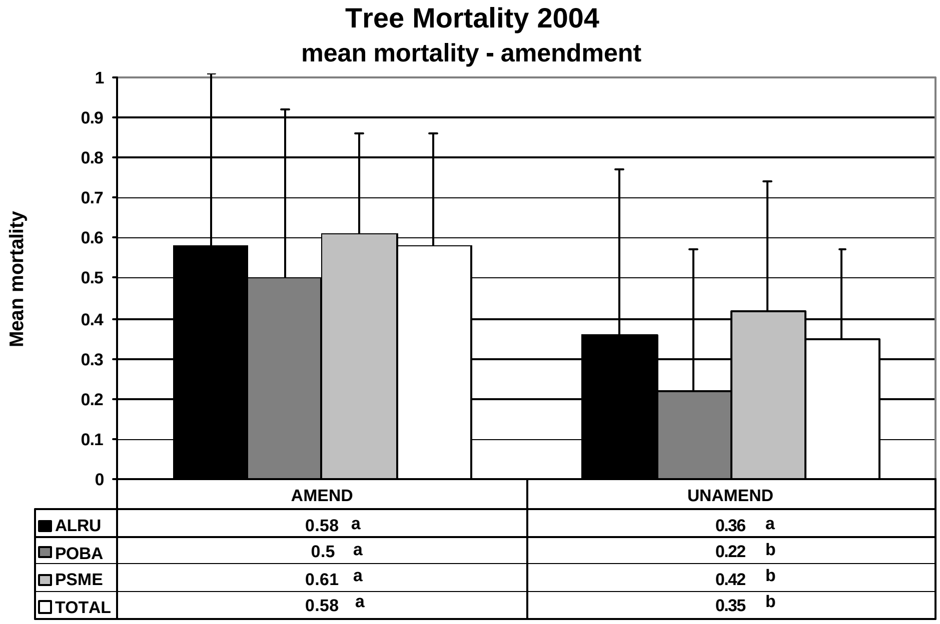
4.2.3.4 Mulch and amendment

There were no statistically significant mulch x amendment interactions (figures 13 & 14) in either the first or third growing season (2002 $p<0.507$, 2004 $p<0.083$) however WCA while having 0% mortality in the first growing season had 92% mortality by the third season. Both POBA and PSME also displayed a similar trend with no/low mortality (POBA 0%, PSME 17%) in 2002 and then their highest mortalities (POBA 83%, PSME 75%) by 2004.



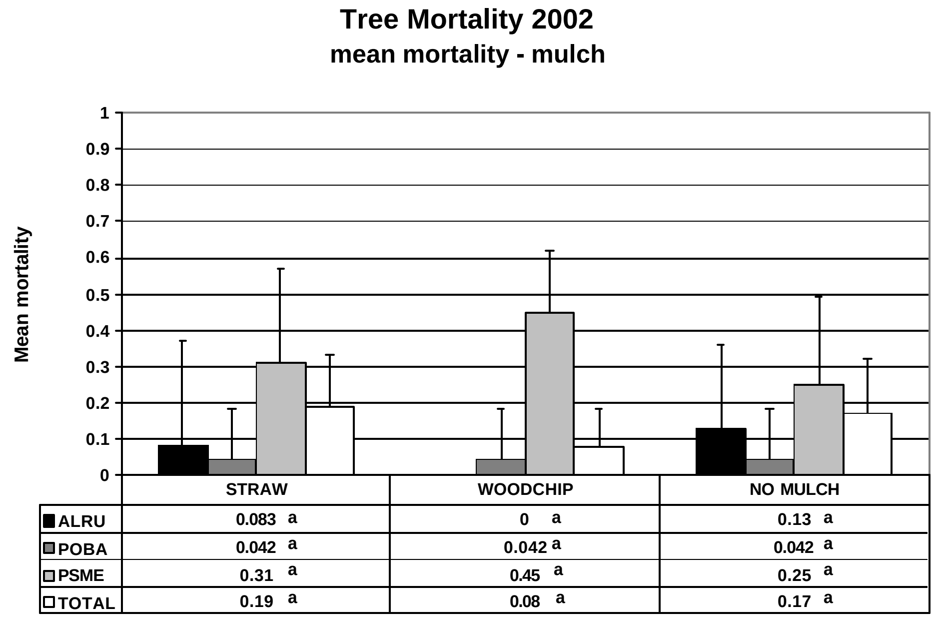
	AMEND	UNAMEND
■ ALRU	0.03 a	0.11 a
▩ POBA	0 a	0.08 a
▨ PSME	0.28 a	0.19 a
□ TOTAL	0.15 a	0.15 a

Figure 9: First growing season mean mortality by amendment
Y-axis values 0=no mortality, 1=100% mortality; n=18 for each treatment
Different letters indicate significance at p<0.05 level



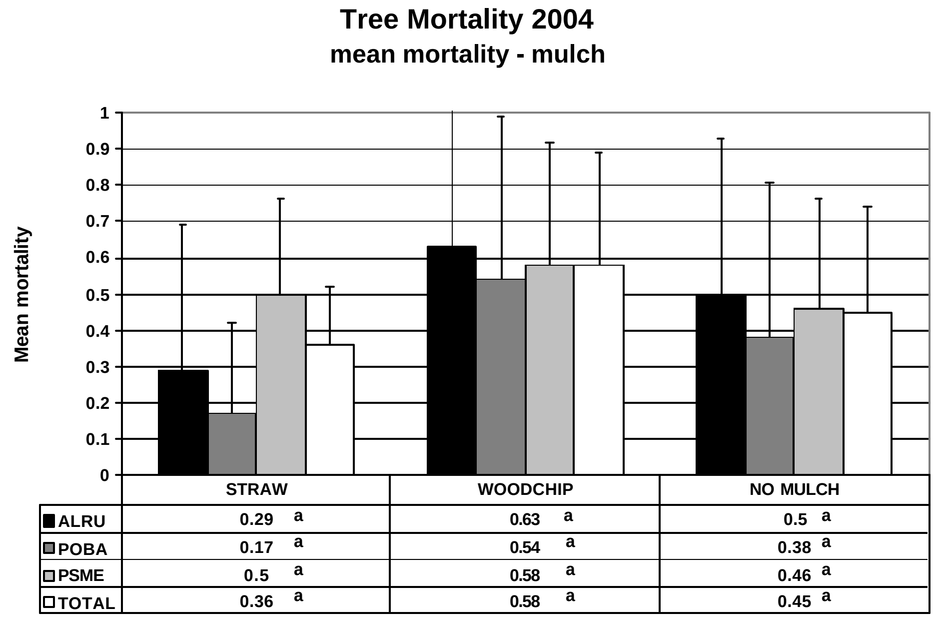
	AMEND	UNAMEND
■ ALRU	0.58 a	0.36 a
▩ POBA	0.5 a	0.22 b
▨ PSME	0.61 a	0.42 b
□ TOTAL	0.58 a	0.35 b

Figure 10: Third growing season mean mortality by amendment
Y-axis values 0=no mortality, 1=100% mortality; n=18 for each treatment
Different letters indicate significance at p<0.05 level


Tree Mortality 2002
mean mortality - mulch

	STRAW	WOODCHIP	NO MULCH
■ ALRU	0.083 a	0 a	0.13 a
▩ POBA	0.042 a	0.042 a	0.042 a
▨ PSME	0.31 a	0.45 a	0.25 a
□ TOTAL	0.19 a	0.08 a	0.17 a

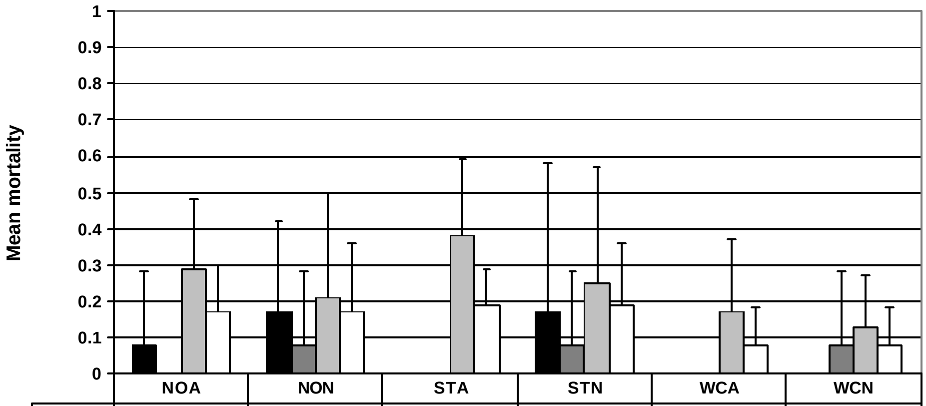
Figure 11: First growing season mean mortality by mulch
Y-axis values 0=no mortality, 1=100% mortality; n=12 for each treatment
Different letters indicate significance at p<0.05 level


Tree Mortality 2004
mean mortality - mulch

	STRAW	WOODCHIP	NO MULCH
■ ALRU	0.29 a	0.63 a	0.5 a
▩ POBA	0.17 a	0.54 a	0.38 a
▨ PSME	0.5 a	0.58 a	0.46 a
□ TOTAL	0.36 a	0.58 a	0.45 a

Figure 12: Third growing season mean mortality by mulch
Y-axis values 0=no mortality, 1=100% mortality; n=12 for each treatment
Different letters indicate significance at p<0.05 level

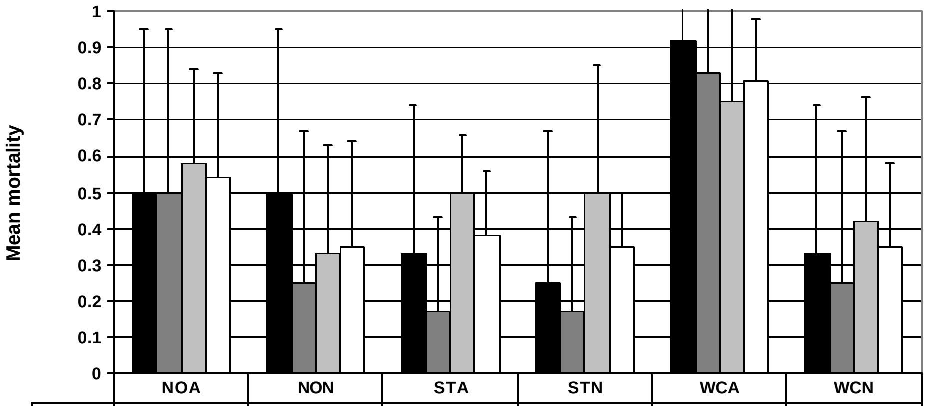
Tree Mortality 2002
mean mortality - treatment



	NOA	NON	STA	STN	WCA	WCN
■ ALRU	0.08 a	0.17 a	0 a	0.17 a	0 a	0 a
▨ POBA	0 a	0.08 a	0 a	0.08 a	0 a	0.08 a
▨ PSME	0.29 a	0.21 a	0.38 a	0.25 a	0.17 a	0.13 a
☐ TOTAL	0.17 a	0.17 a	0.19 a	0.19 a	0.08 a	0.08 a

Figure 13: First growing season mean mortality by treatment
Y-axis values 0=no mortality, 1=100% mortality; n=6 for each treatment
Different letters indicate significance at p<0.05 level

Tree Mortality 2004
mean mortality - treatment



	NOA	NON	STA	STN	WCA	WCN
■ ALRU	0.5 a	0.5 a	0.33 a	0.25 a	0.92 a	0.33 a
▨ POBA	0.5 ab	0.25 ab	0.17 b	0.17 b	0.83 a	0.25 ab
▨ PSME	0.58 a	0.33 a	0.5 a	0.5 a	0.75 a	0.42 a
☐ TOTAL	0.54 ab	0.35 b	0.38 ab	0.35 b	0.81 ab	0.35 b

Figure 14: Third growing season mean mortality by treatment
Y-axis values 0=no mortality, 1=100% mortality; n=6 for each treatment
Different letters indicate significance at p<0.05 level

4.3 Native seed mix germination

The seed mix of 19 locally collected native tree, shrub, forb and grass species showed very low germination overall with germination rates for individual species ranging from 0 to 21% with an average germination rate of 2% (averages exclude *Alnus rubra* due to heavy recruitment from seed rain). The number of seed spread per species per plot ranged widely from 1/plot (*Cornus nuttalli*) to a roughly estimated 7000/plot (*Anaphalis margaritacea*) (see appendix A). Seed rain/litterfall traps installed on site from March-November 2002 captured both *A. rubra* and *Populus balsamifera* seed with an estimated 207 *A. rubra* seed falling in each plot on average and an indeterminate but profuse amount of *P. balsamifera* seed falling into each plot (*P. balsamifera* seed is miniscule and lost amidst its 'cotton') (appendix E, figure 41).

The overwhelming majority of native germinants in 2002 were *A. rubra* (1472 germinants, 65%) and *Elymus glaucus* (400 germinants, 18%) out of a total of 2202 native germinants. In 2003 surviving germinants were still dominated by *A. rubra* (602 germinants, 55%) with the addition of *P. balsamifera* (218 germinants, 20%) and *A. margaritacea* (118 germinants, 11%) out of a total of 1085 native germinants. Since *A. rubra*, *P. balsamifera*, and *E. glaucus* were well represented in the first year germination subplot counts they were chosen for statistical analysis of treatment effects. Additionally all nonnative germinants were counted and grouped together for analysis as 'nonnatives'. Two established subplots per individual treatment plot were assessed for identifiable germinants from June through September 2002 and once again in August 2003 in order to determine the effects the treatments had on initial germination of the native seed mix. Germinant survival was tracked on a whole plot basis and is covered in the next section.

The subplot count data was also highly variable which may be due to the patchy distribution of germination in the whole plots combined with using permanent subplots. The established subplots may or may not have captured enough area to reflect a true measure of the mean for the whole plot.

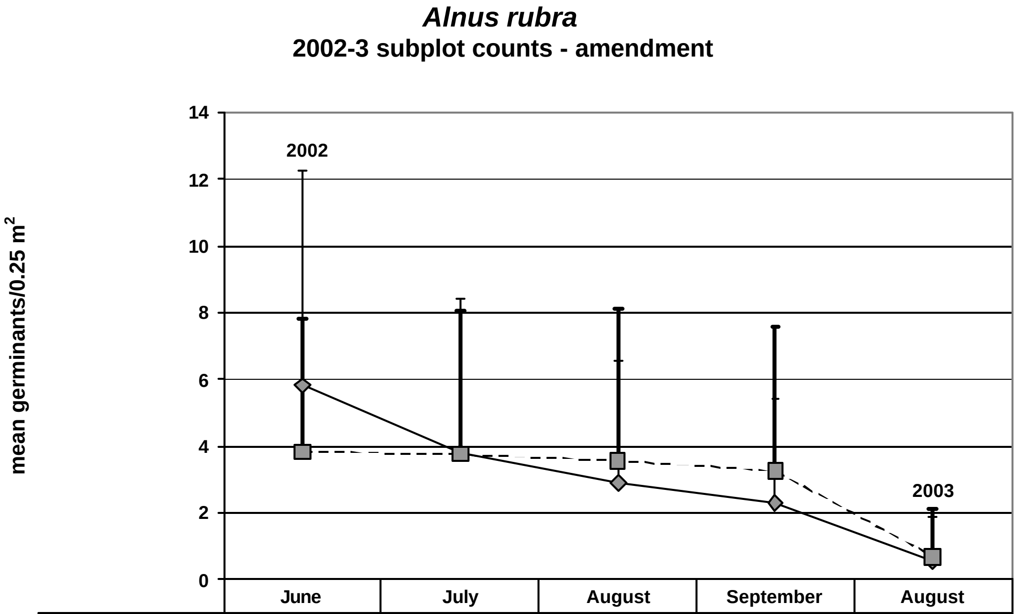
4.3.1 Alnus rubra (ALRU) germination

4.3.1.1 Block effects

June 2002 germinant counts revealed a substrate block effect favoring sand ($p<0.006$) and a significant interaction between mulch and substrate ($p<0.003$) and mulch and amendment ($p<0.038$). Individual block differences were also significant with block A (amended+shade) producing the majority of June 2002 ALRU germinants ($p<0.022$). By July 2002 these block effects had disappeared and then reappeared slightly in August 2002 with a nonsignificant ANOVA ($p<0.062$). The block effect substrate was also significant in August 2002 ($p<0.044$) but this time favoring gravel. In September 2002 there were no discernable block effects and by August 2003 there were still no significant block effects.

4.3.1.2 Amendment

There was no significant difference between amended and unamended plots in terms of ALRU seed germination during the subplot monitoring period though trend-wise amended plots (figure 15) saw a steady decline in seedling numbers over the summer while unamended plots remained steady and surpassed in average numbers of germinants by July 2002. By August 2003 however the unamended lots had lost germinants over the previous winter and held only slightly more ALRU germinants on average.

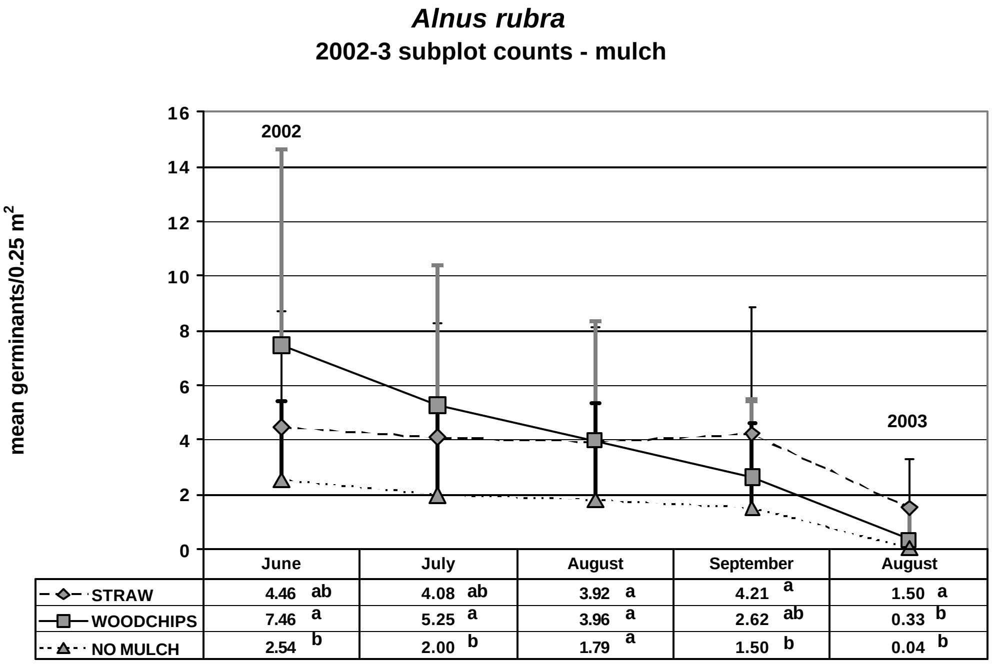


	June	July	August	September	August
—◆— AMENDED	5.81 a	3.81 a	2.89 a	2.31 a	0.56 a
- -■- - UNAMENDED	3.83 a	3.75 a	3.56 a	3.25 a	0.69 a

Figure 15: *Alnus rubra* 0.25 m^2 subplot germination by amendment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=18 for each treatment

4.3.1.3 Mulch

For the first two months woodchips supported significantly more ALRU germinants (figure 16) than no mulch but not significantly more than straw (June 2002 $p<0.037$, July 2002 $p<0.035$). As with amendment, woodchips displayed a steady decline in germinant numbers over the monitoring period and by September 2002 straw, which supported consistent germinant numbers over the summer, surpassed woodchips significantly (p<0.018). A year later in August 2003 straw still supported a highly significant (but low number) of germinants (p<0.0001).

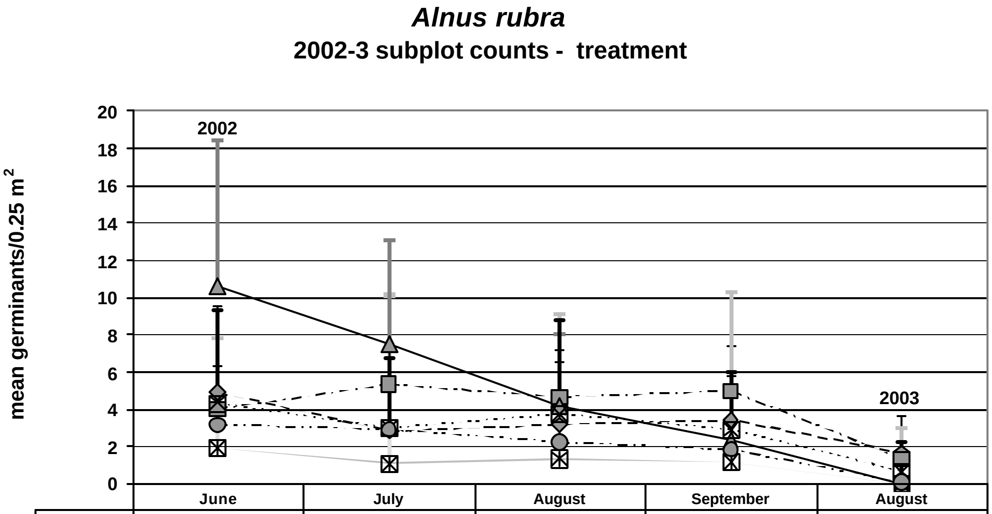


	June	July	August	September	August
STRAW	4.46 ab	4.08 ab	3.92 a	4.21 a	1.50 a
WOODCHIPS	7.46 a	5.25 a	3.96 a	2.62 ab	0.33 b
NO MULCH	2.54 b	2.00 b	1.79 a	1.50 b	0.04 b

Figure 16: *Alnus rubra* 0.25 m^2 subplot germination by mulch
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=12 for each treatment

4.3.1.4 Mulch and amendment

Mulch x amendment interactions were found to be significant in June (p<0.038) and July (p<0.029) 2002 (figure 17) with WCA dominating the ALRU germinant counts. By August 2002 this was no longer the case and as seen with the separate analyses of mulch and amendment WCA declined steadily to 0 ALRU germinants by August 2003 with STA supporting the greatest number of surviving germinants (p<0.0001).



	June	July	August	September	August
STA	4.92 ab	2.83 ab	3.17 a	3.42 a	1.67 a
STN	4.00 ab	5.33 ab	4.67 a	5.00 a	1.33 ab
WCA	10.58 a	7.50 a	4.17 a	2.33 a	0.00 c
WCN	4.33 ab	3.00 ab	3.75 a	2.92 a	0.67 abc
NOA	1.92 b	1.08 b	1.33 a	1.17 a	0.00 c
NON	3.17 ab	2.92 ab	2.25 a	1.83 a	0.08 bc

Figure 17: *Alnus rubra* 0.25 m^2 subplot germination by treatment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=6 for each treatment

4.3.2 Populus balsamifera (POBA) germination

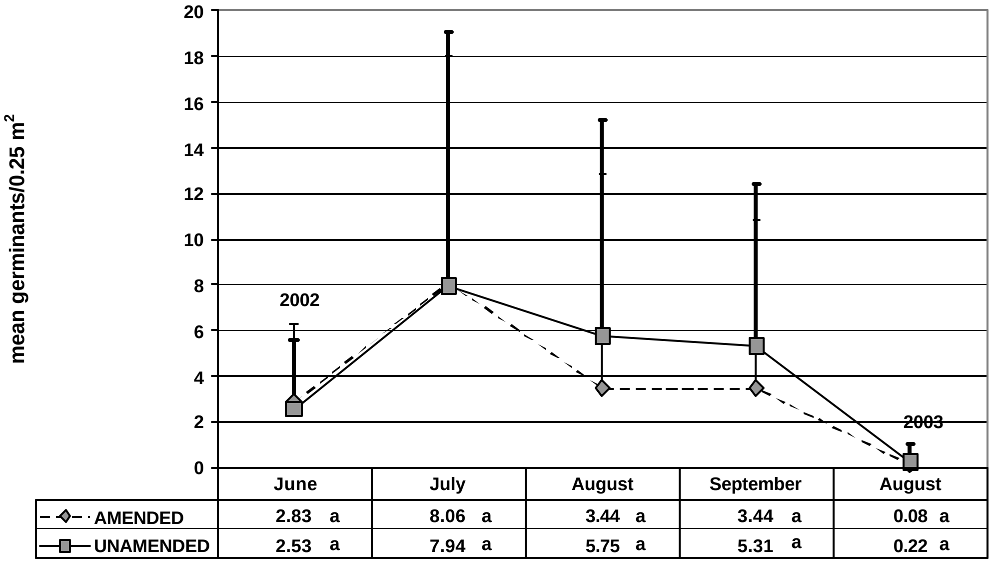
4.3.2.1 Block effects

Gravel ($p<0.008$) and shade ($p<0.03$) significantly favored POBA germination when the total number of POBA seedling spiked in July 2002. There was also a significant interaction between mulch and substrate ($p<0.003$) and mulch and shade ($p<0.001$) in July 2002 favoring woodchips, gravel and shade. In August and September 2002 the substrate block effect was no longer significant however the effect of shade increased in significance (August 2002 $p<0.003$, September 2002 $p<0.005$). A year later in August 2003 there was no significant difference between any of the various block effects, most likely due to the poor overall germinant survival.

4.3.2.2 Amendment

POBA did not respond significantly to either amended or unamended plots throughout the monitoring period though from August 2002 onwards greater average numbers of germinants were found in unamended plots (figure 18).

Populus balsamifera
2002-3 subplot counts - amendment

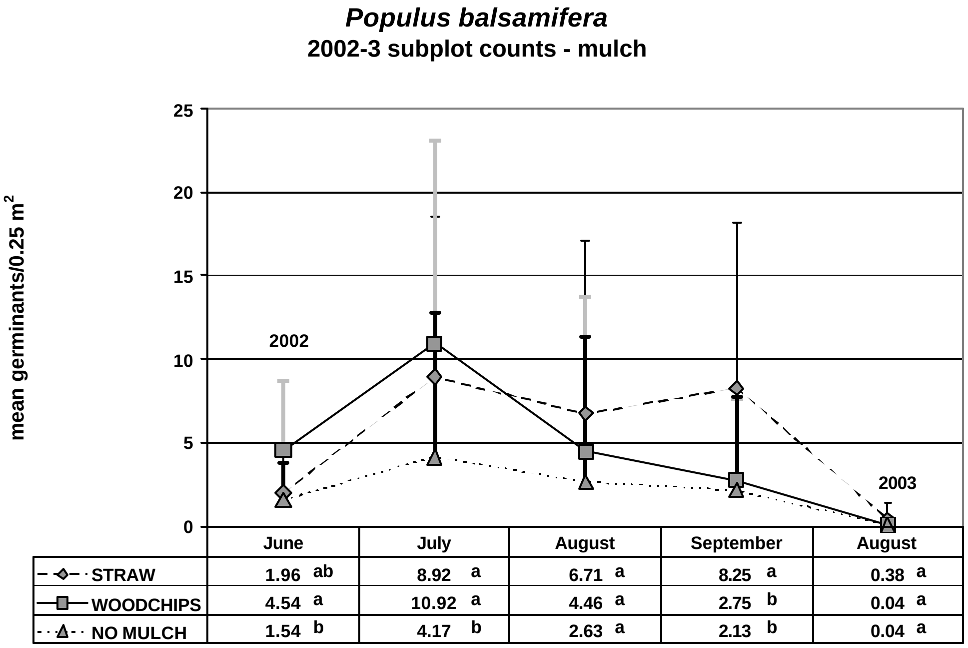


	June	July	August	September	August
AMENDED	2.83 a	8.06 a	3.44 a	3.44 a	0.08 a
UNAMENDED	2.53 a	7.94 a	5.75 a	5.31 a	0.22 a

Figure 18: *Populus balsamifera* 0.25 m^2 subplot germination by amendment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=18 for each treatment

4.3.2.3 Mulch

As with ALRU, POBA germination was initially greater with woodchips than no mulch (figure 19) but not significantly different than straw (June 2002 $p<0.002$, July 2002 $p<0.009$). By August 2002 the mean number of germinants in straw had surpassed woodchips and was significantly greater in September 2002 ($p<0.006$) and remained higher (though no significantly) in August 2003. Also like ALRU woodchips saw a decline in POBA germinants over the first summer while the straw held steady but then lost germinants over the intervening winter. By August 2003 straw still had more surviving germinants though this was not statistically significant.

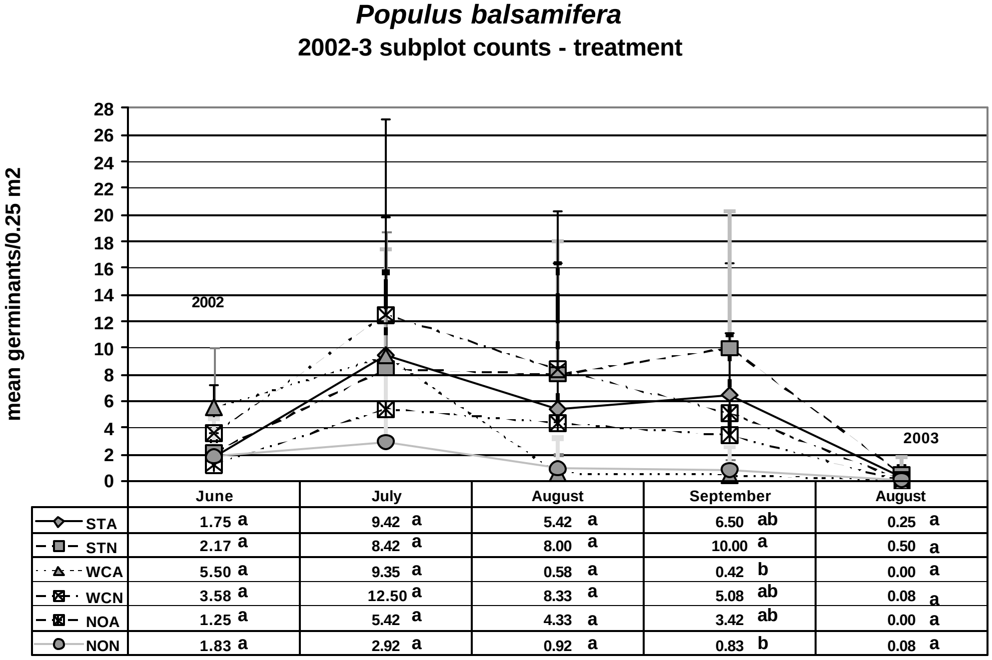


	June		July		August		September		August	
◇ STRAW	1.96	ab	8.92	a	6.71	a	8.25	a	0.38	a
□ WOODCHIPS	4.54	a	10.92	a	4.46	a	2.75	b	0.04	a
△ NO MULCH	1.54	b	4.17	b	2.63	a	2.13	b	0.04	a

Figure 19: *Populus balsamifera* 0.25 m^2 subplot germination by mulch
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=12 for each treatment

4.3.2.4 Mulch and amendment

Only once in September 2002 were there any significant differences between the six treatment combinations ($p<0.004$) with STN supporting more POBA germinants than the other treatments (figure 20). STN still supported the greatest mean number of germinants by August 2003 but not significantly so. In no month was there any significant mulch x amendment interaction for POBA.



	June	July	August	September	August
STA	1.75 a	9.42 a	5.42 a	6.50 ab	0.25 a
STN	2.17 a	8.42 a	8.00 a	10.00 a	0.50 a
WCA	5.50 a	9.35 a	0.58 a	0.42 b	0.00 a
WCN	3.58 a	12.50 a	8.33 a	5.08 ab	0.08 a
NOA	1.25 a	5.42 a	4.33 a	3.42 ab	0.00 a
NON	1.83 a	2.92 a	0.92 a	0.83 b	0.08 a

Figure 20: *Populus balsamifera* 0.25 m^2 subplot germination by treatment
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=6 for each treatment

4.3.3 Elymus glaucus (ELGL) germination

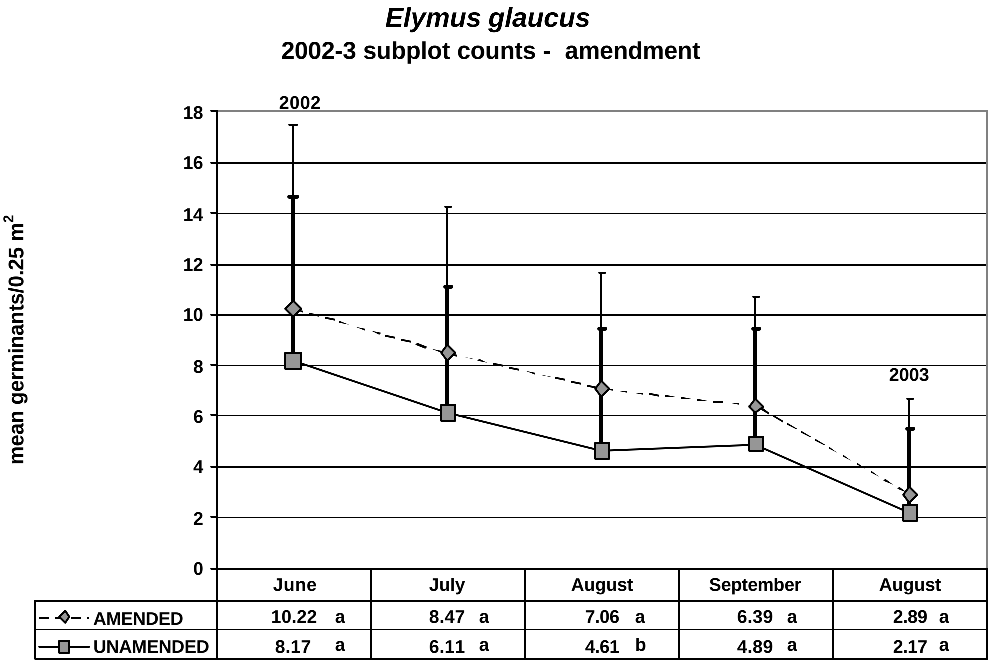
4.3.3.1 Block effects

There was a significant block effect favoring shade in both June (p<0.04) and July (p<0.029) 2002 for ELGL. This was no longer the case for the duration of the monitoring period though trend-wise shade supported greater mean numbers of ELGL germinants. In August and September 2002 and in August 2003 a substrate block effect for gravel was significant (August 2002 p<0.006, September 2002 p<0.0001, August 2003 p<0.001) thought this may be more of an artifact of the dominance of individual block A (shade+gravel+amendment) throughout the monitoring period (June 2002 p<0.02, July 2002 p<0.008, August 2002 p<0.001, September 2002 p<0.001, August

(2003 p<0.002). This is also supported by the numerous significant interactions between shade, amendment and substrate over the monitoring period.

4.3.3.2 Amendment

Unlike ALRU and POBA, ELGL mean germinant counts were consistently higher in amended plots over the monitoring period though only significantly so in September 2002 (p<0.006) (figure 21). This in part is due to the significant interactions between amendment, shade and substrate.

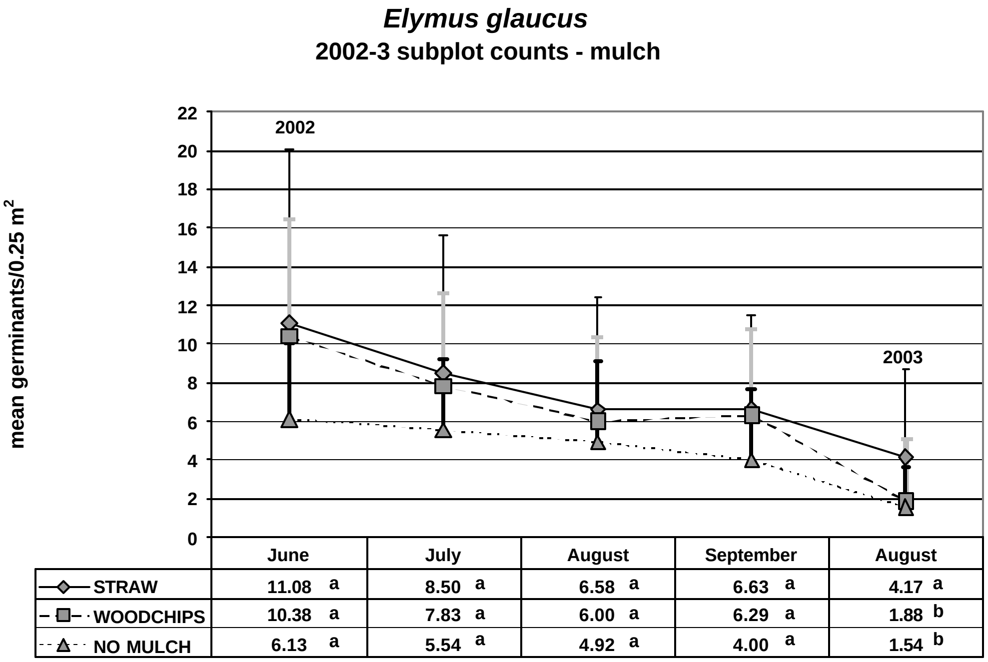


	June	July	August	September	August
AMENDED	10.22 a	8.47 a	7.06 a	6.39 a	2.89 a
UNAMENDED	8.17 a	6.11 a	4.61 b	4.89 a	2.17 a

Figure 21: ***Elymus glaucus*** **0.25 m^2 subplot germination by amendment**
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=18 for each treatment

4.3.3.3 Mulch

Straw and woodchips followed a close parallel track in mean numbers of ELGL germinants over no mulch until August 2003 when mean numbers of germinants in woodchips dropped out and straw rose to significance ($p<0.025$) (figure 22). Unlike POBA and ALRU, ELGL steadily lost germinants over the first summer with both the woodchips and straw.

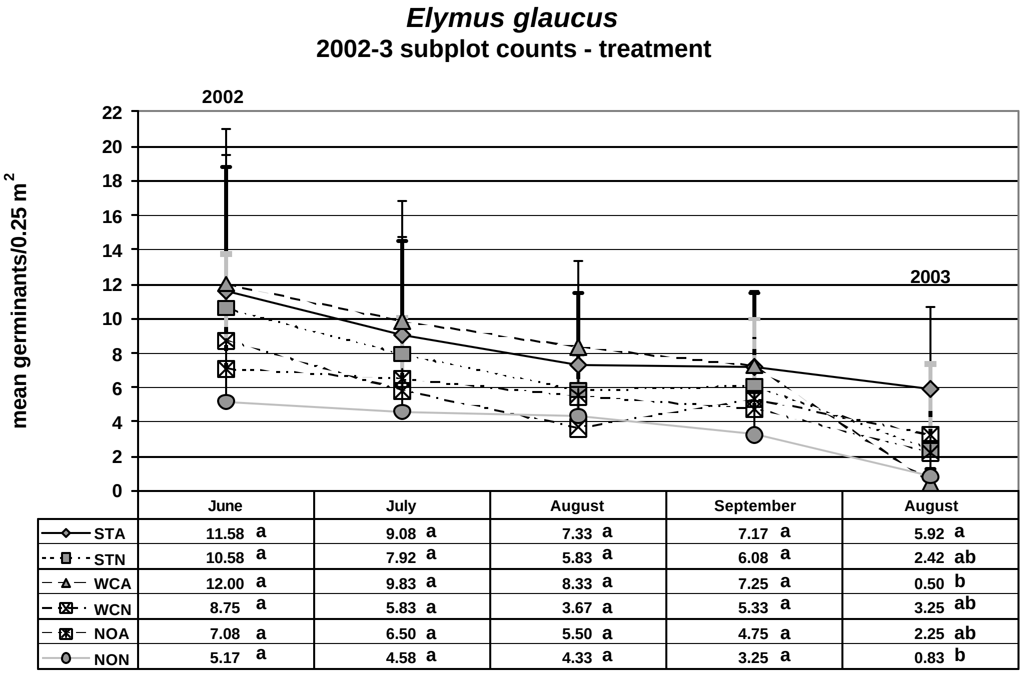


	June	July	August	September	August
STRAW	11.08 a	8.50 a	6.58 a	6.63 a	4.17 a
WOODCHIPS	10.38 a	7.83 a	6.00 a	6.29 a	1.88 b
NO MULCH	6.13 a	5.54 a	4.92 a	4.00 a	1.54 b

Figure 22: *Elymus glaucus* 0.25 m^2 subplot germination by mulch
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=12 for each treatment

4.3.3.4 Mulch and Amendment

The trend noted above is echoed here in the significant mulch x amendment interaction in August 2003 ($p<0.004$) with WCA and STA following a parallel track of the highest mean germinants until August 2003 where WCA supports the lowest mean number of ELGL germinants and STA the highest ($p<0.002$) (figure 23).



	June	July	August	September	August
STA	11.58 a	9.08 a	7.33 a	7.17 a	5.92 a
STN	10.58 a	7.92 a	5.83 a	6.08 a	2.42 ab
WCA	12.00 a	9.83 a	8.33 a	7.25 a	0.50 b
WCN	8.75 a	5.83 a	3.67 a	5.33 a	3.25 ab
NOA	7.08 a	6.50 a	5.50 a	4.75 a	2.25 ab
NON	5.17 a	4.58 a	4.33 a	3.25 a	0.83 b

Figure 23: *Elymus glaucus* 0.25 m^2 subplot germination by treatment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=6 for each treatment

4.3.4 Nonnative germinant survival

4.3.4.1 Block effects

The only significant block effect during the summer 2002 sampling period was in June favoring sun over shade ($p<0.045$). For the duration of the summer there were no other discernable block effects on nonnative germinants.

4.3.4.2 Amendment

Nonnative germinants did not show a significant preference for either amended or unamended plots though as seen in Figure 24 amended plots consistently supported more nonnative germinants over the sampling period.

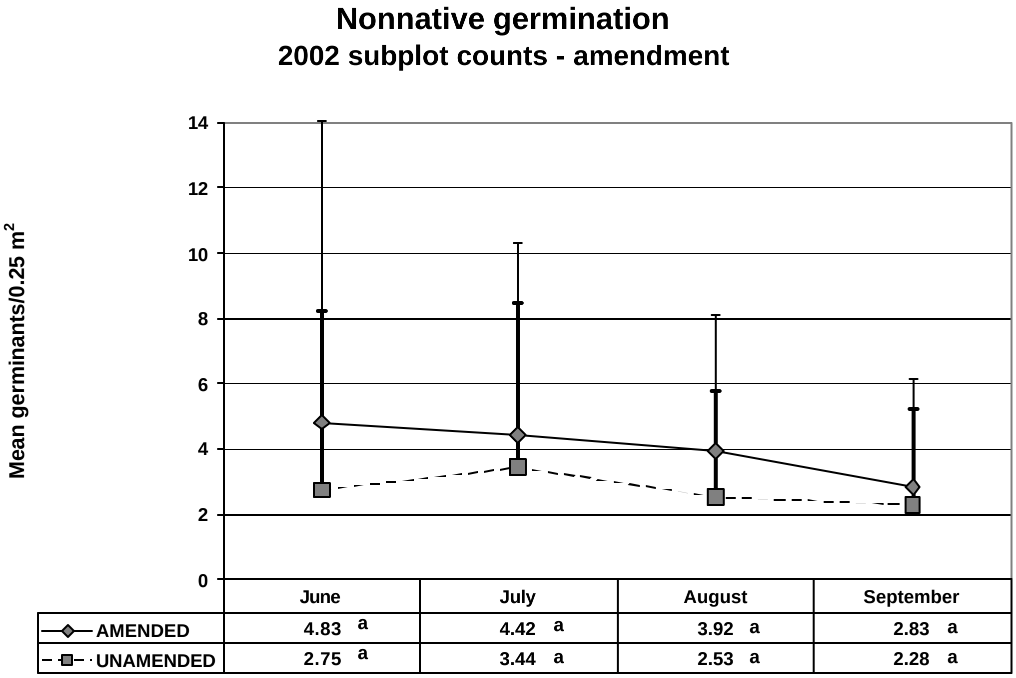
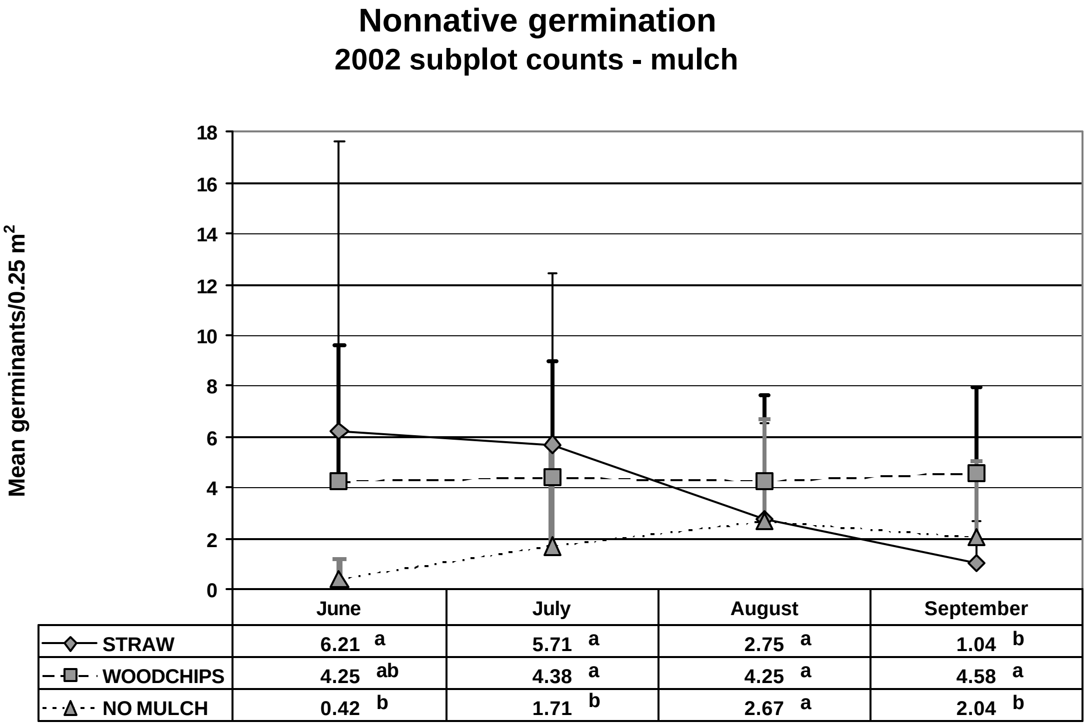


Figure 24: Nonnative 0.25 m^2 subplot germination by amendment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=18 for each treatment

4.3.4.3 Mulch

Nonnative germinants displayed a dynamic and significant response to mulches (figure 25). Straw clearly supported more nonnative germinants in the first month, June ($p<0.004$) over woodchips and no mulch. By July straw and woodchips were statistically indistinguishable with both significantly holding more nonnative germinants than no mulch ($p<0.001$). In August there were no significant differences between the mulches in nonnative germinants ($p<0.078$) as their mean numbers converged. By the end of the summer in September straw dropped to supporting the fewest germinants with woodchips ($p<0.0001$) consistently holding more or less the same numbers since June (figure 25). These results most likely are due to the difference in the species of nonnatives present in each mulch. Straw only had wheat (*Triticum aestivum* L.) germinants which died out by summer's end while woodchips had several species, mostly clover (*Trifolium* spp.) which persisted until the winter.

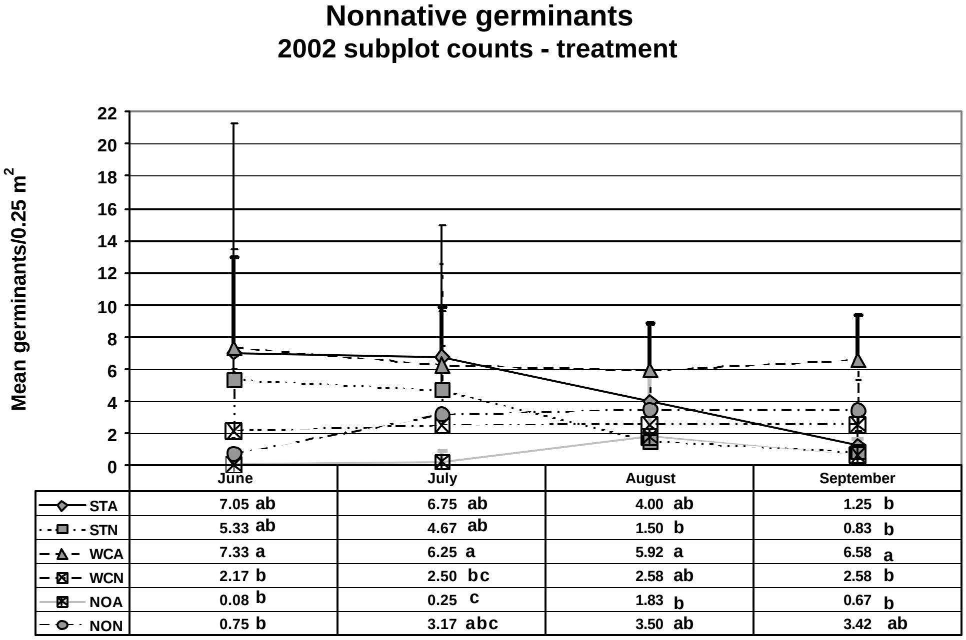


	June	July	August	September
STRAW	6.21 a	5.71 a	2.75 a	1.04 b
WOODCHIPS	4.25 ab	4.38 a	4.25 a	4.58 a
NO MULCH	0.42 b	1.71 b	2.67 a	2.04 b

Figure 25: Nonnative 0.25 m^2 subplot germination by mulch
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=12 for each treatment

4.3.4.4 Mulch and amendment

Mulch x amendment interaction was significant in every month of the sampling period (June $p<0.018$, July $p<0.001$, August $p<0.013$, September $p<0.0001$). WCA maintained the highest mean number of nonnative germinants (in contrast with WCA supporting the fewest number of native germinants, see previous sections) throughout the sampling period (June $p<0.002$, July $p<0.0001$, August $p<0.007$, September $p<0.0001$). In contrast STA and STN both dropped in mean germinant numbers well below WCA by September (figure 26). Another interesting trend was that STA and WCA remained consistently higher in mean germinants above their unamended counterparts STN and WCN while following nearly parallel tracks (both STA and STN drop as the summer passes, both WCA and WCN remain steady). The unmulched plots did tend to parallel one another however it was NON that supported more mean germinants than NOA. Again these results reflect the differences between the wheat in the straw senescing over the summer while the clover in the woodchips persists.



	June		July		August		September	
STA	7.05	ab	6.75	ab	4.00	ab	1.25	b
STN	5.33	ab	4.67	ab	1.50	b	0.83	b
WCA	7.33	a	6.25	a	5.92	a	6.58	a
WCN	2.17	b	2.50	bc	2.58	ab	2.58	b
NOA	0.08	b	0.25	c	1.83	b	0.67	b
NON	0.75	b	3.17	abc	3.50	ab	3.42	ab

Figure 26: Nonnative 0.25 m^2 subplot germination by treatment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=6 for each treatment

4.4 Native Seed Mix Survival

Given the prevalence of a few species and the overall poor germination of the seed mix, the dominant four individual native species *A. rubra*, *P. balsamifera*, *A. margaritacea* and *E. glaucus* were chosen for statistical analysis in addition to five native shrub species *Holodiscus discolor, Physocarpus capitatus, Rosa gymnocarpa, Rubus parviflora* and *Rubus ursinus* var. *macropetalus* that were grouped together for analysis under the designation 'shrubs'. Analysis was performed using the 2003 and 2004 whole plot germinant counts for two reasons, (1) the greater seedling identification accuracy incurred by a year's worth of identification experience and more mature seedlings and (2) counting germinants surviving beyond the first year should better reflect the potential ability of each treatment to secure survival to maturity rather than the ability of the treatments to support germination. Only identifiable seedlings greater than 2 cm in height were counted so as to ensure correct identification and to restrict the count to germinants from the seed mix and the first year seed rain. *E. glaucus* was quantified in the germinant survival count as percent cover due to the indistinguishable merging of clumps in many plots. As well greater percent cover by fewer individuals is assumed to be more indicative of the efficacy of the treatments than sparse cover by many individuals.

4.4.1 Alnus rubra (ALRU) germinant survival

4.4.1.1 Block effects

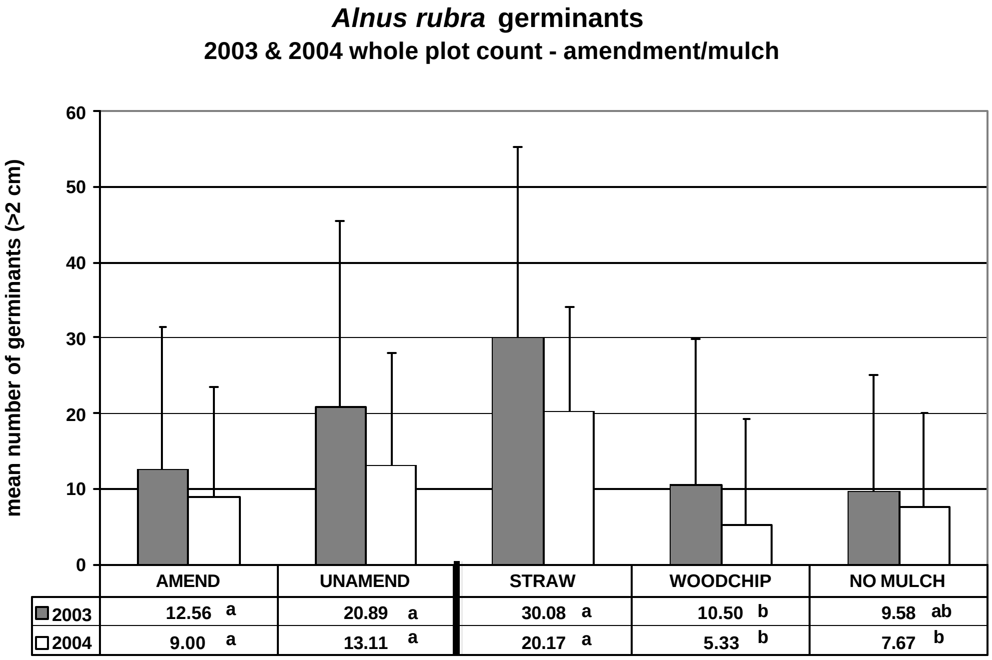
There was no meaningful block effects for shade (p<0.570) or substrate (p<0.668) blocks in surviving ALRU germinants in 2003 or 2004 (shade p<0.444, substrate p<0.356).

4.4.1.2 Amendment

Amendment did not produce significantly more surviving ALRU germinants (figure 27) than no amendment (p<0.255) in 2003 or 2004 (p<0.193) with a trend favoring no amendment in both years. The unamended plots also displayed more variability in germinant survival than amended plots.

4.4.1.3 Mulch

The mean number of extant ALRU germinants found in the straw treatments significantly exceeded both the woodchip mulch and no mulch by at least a factor of three (figure 27) in both 2003 (p<0.008) and 2004 (p<0.001) with no significant difference between the woodchip and no mulch treatments. Variability in the data was high across all three treatments.

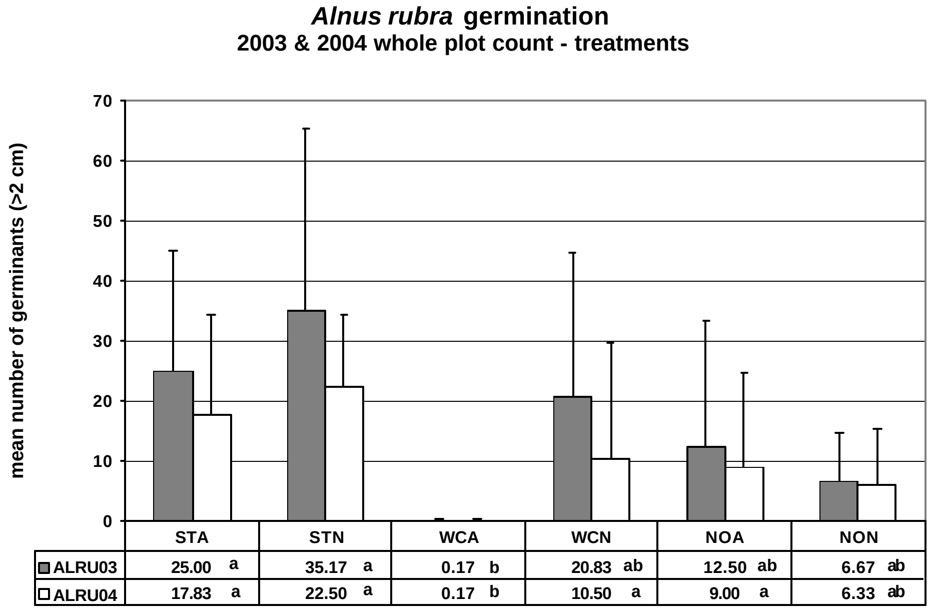


	AMEND	UNAMEND	STRAW	WOODCHIP	NO MULCH
■ 2003	12.56 a	20.89 a	30.08 a	10.50 b	9.58 ab
□ 2004	9.00 a	13.11 a	20.17 a	5.33 b	7.67 b

Figure 27: *Alnus rubra* whole plot survival by amendment and mulch
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=18 for amendment, n=12 for mulch

4.4.1.4 *Mulch and amendment*

There was no significant interaction between the mulch and amendment treatments (figure 28) in 2003 ($p<0.063$) or 2004 ($p<0.345$) however some of the individual treatment combinations did differ substantially according to mulch (as discussed above) with STA and STN promoting ALRU seedling survival significantly more than WCA in both 2003 ($p<0.005$) and 2004 ($p<0.003$). Again there was much variability in germinant survival across all treatments.



	STA	STN	WCA	WCN	NOA	NON
■ ALRU03	25.00 a	35.17 a	0.17 b	20.83 ab	12.50 ab	6.67 ab
□ ALRU04	17.83 a	22.50 a	0.17 b	10.50 a	9.00 a	6.33 ab

Figure 28: ***Alnus rubra*** **whole plot survival by treatment**
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=6 for each treatment

4.4.2 *Populus balsamifera (POBA) germinant survival*

4.4.2.1 *Block effects*

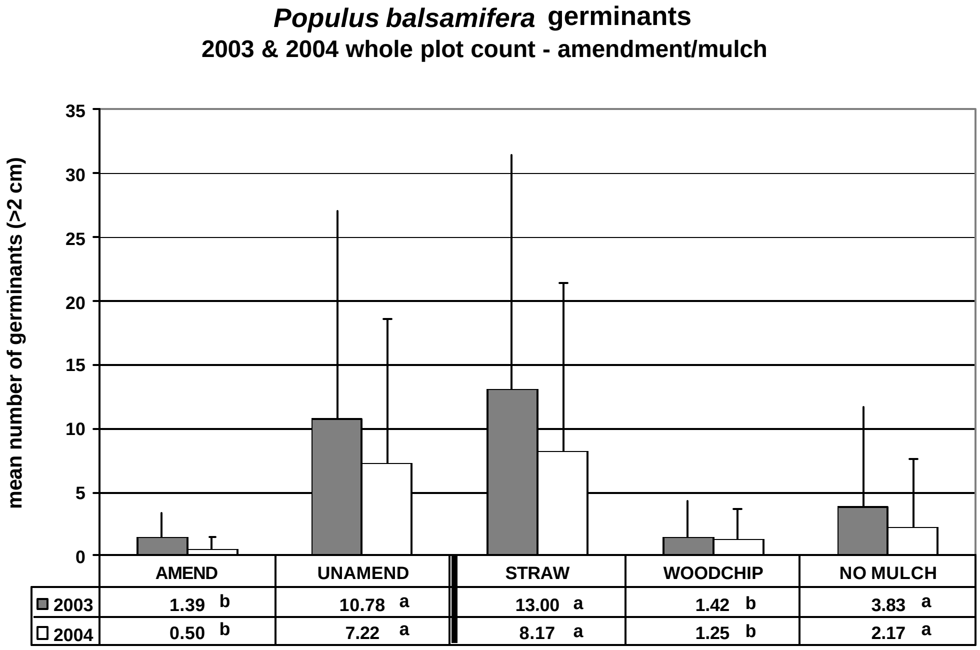
As with ALRU germination POBA did not show any discernable preference for possible block effects of shade and substrate in 2003 (shade $p<0.747$, substrate $p<0.611$) or 2004 (shade $p<0.977$, substrate $p<0.266$).

4.4.2.2 Amendment

POBA survived in significantly greater numbers (2003 p<0.018, 2004 p<0.002) in unamended plots (figure 29) following the trend with ALRU. There was considerably greater variability in the data associated with the unamended treatment possibly indicating greater heterogeneity in the distribution of 'safe sites' for germinants.

4.4.2.3 Mulch

POBA also followed ALRU in greater germinant survival in straw over woodchips or no mulch (figure 29) for both 2003 (p<0.011) and 2004 (p<0.035) though straw and no mulch were not statistically different from one another in either year. Straw also had much higher variability in the data echoing the higher variability found with the unamended plots which also had the greatest number of surviving germinants.

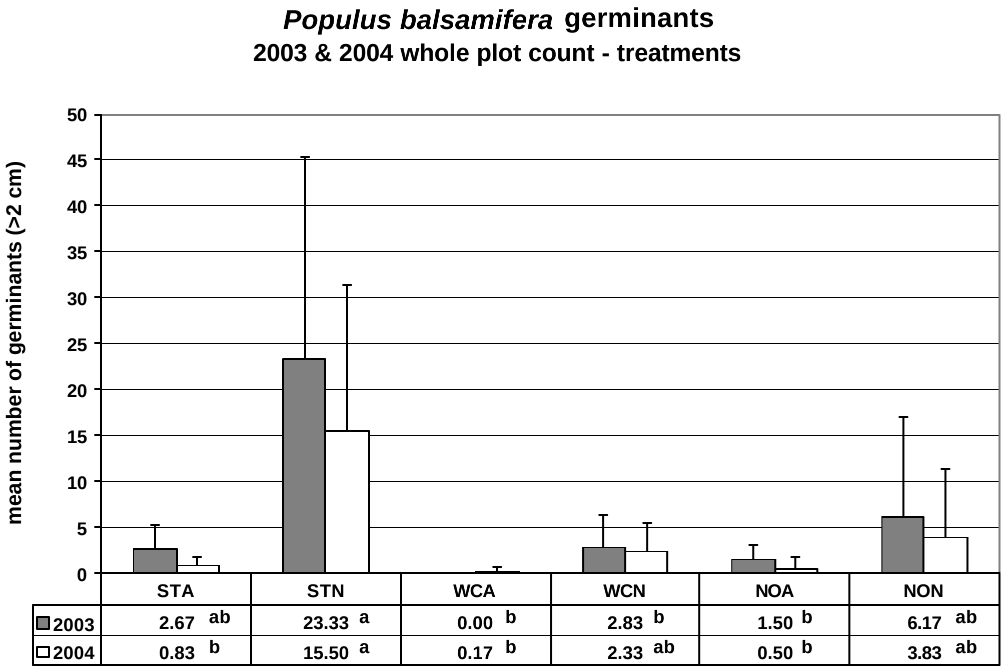


	AMEND	UNAMEND	STRAW	WOODCHIP	NO MULCH
■ 2003	1.39 b	10.78 a	13.00 a	1.42 b	3.83 a
□ 2004	0.50 b	7.22 a	8.17 a	1.25 b	2.17 a

Figure 29: ***Populus balsamifera*** **whole plot survival by amendment and mulch**
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=18 for amendment, n=12 for mulch

4.4.2.4 Mulch and amendment

There was no significant interaction between the mulch and amendment in 2003 (p<0.311) or 2004 (p<0.230) however in comparing the each treatment combination STN was clearly the best for POBA germinant survival followed by a distant second with NON (figure 30). Both of these treatments also displayed high variability in germinant survival from plot to plot. As noted throughout the study WCA proved to be the most detrimental treatment.



	STA	STN	WCA	WCN	NOA	NON
■ 2003	2.67 ab	23.33 a	0.00 b	2.83 b	1.50 b	6.17 ab
□ 2004	0.83 b	15.50 a	0.17 b	2.33 ab	0.50 b	3.83 ab

Figure 30: *Populus balsamifera* whole plot survival by treatment
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=6 for each treatment

4.4.3 Anaphalis margaritacea (ANMA) germinant survival

4.4.3.1 Block effects

Neither of the presumed block effects influenced the level of survival for ANMA germinants in 2003 (shade p<0.824, substrate p<0.224) or 2004 (shade

$p<0.384$, substrate $p<0.384$). This was also the case for individual blocks in 2003 ($p<0.224$) and 2004 ($p<0.171$) though block B supported several times the number of ANMA germinants than the other blocks. Lack of significant difference between the blocks may be attributable to the concentration on the majority of ANMA seedlings in a few plots and therefore skewing the distribution of data even when log+1 transformed.

4.4.3.2 Amendment

Looking at figure 31 ANMA obviously achieved greater survival in unamended plots in both 2003 ($p<0.018$) and 2004 ($p<0.015$) though as noted previously the preponderance of ANMA seedlings were found in a single block, B (no amend+gravel+sun). The far greater variability in the data for the unamended treatment may be due to this lopsided distribution of the germinants.

4.4.3.3 Mulch

ANMA displayed a strong, significant affinity for no mulch over either straw or woodchips in both 2003 ($p<0.0001$) and 2004 ($p<0.0001$) (figure 31) with associated high variability in the data as seen with the other treatment with the greatest number of surviving germinants.

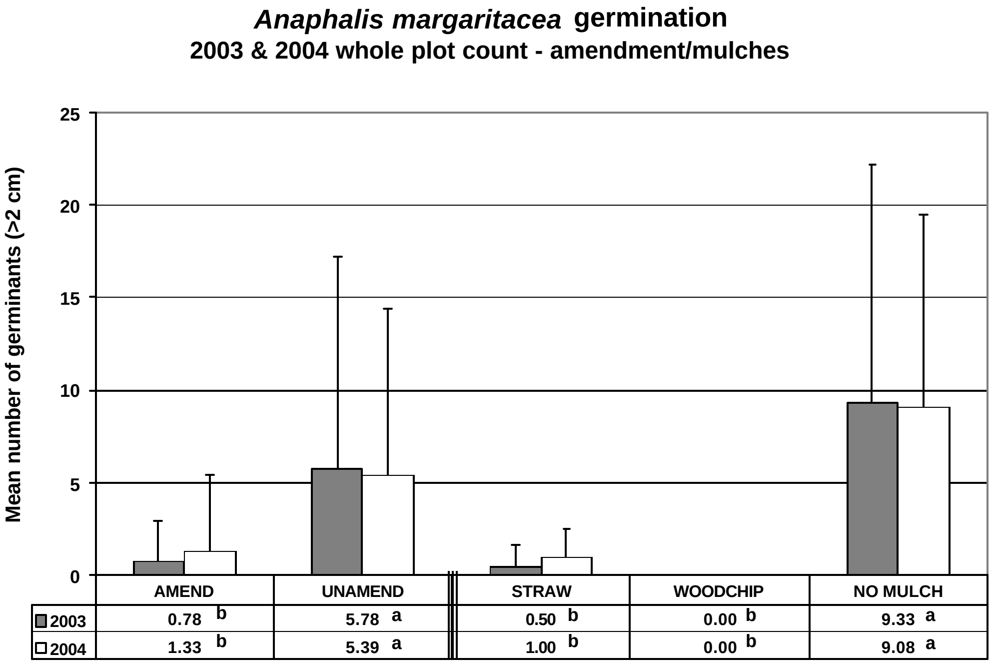
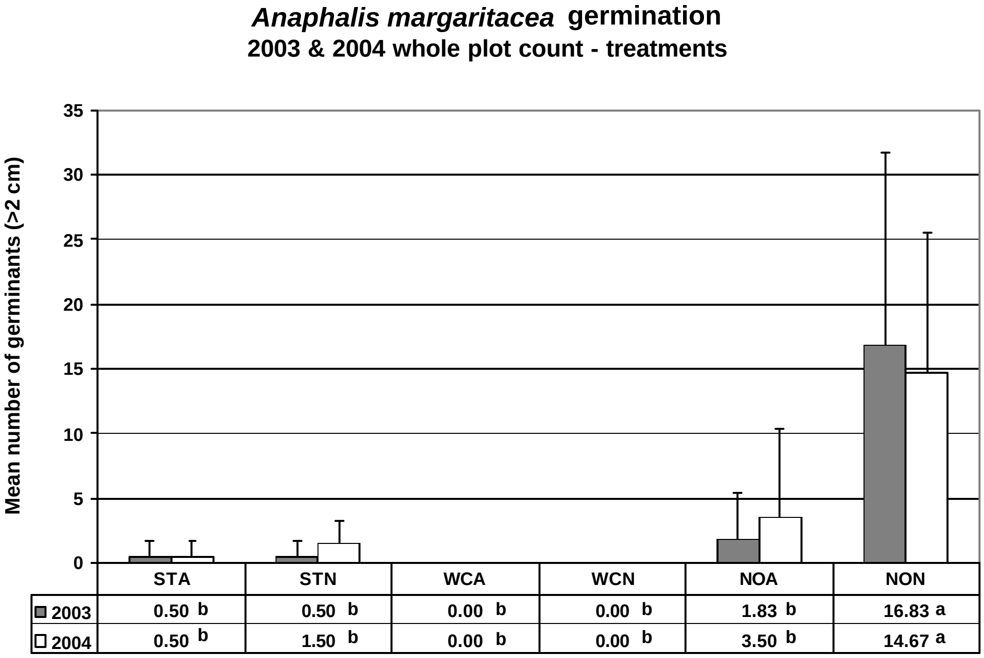


Figure 31: ***Anaphalis margaritacea*** **whole plot survival by amendment and mulch**
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=18 for amendment, n=12 for mulch

4.4.3.4 Mulch and amendment

There was a significant mulch x amendment interaction in 2003 (p<0.005) and nearly so in 2004 (p<0.054) with NON being supporting the bulk of surviving ANMA germinants (2003 p<0.0001, 2004 p<0.0001) far and above all other treatment combinations (figure 32). However this is an artifact of the concentration of the majority of ANMA germinants in three plots (plots 13, 15, & 16) in one block, B (no amend+gravel+sun). Reanalyzing the data for a mulch x amendment x shade interaction proved to be significant in 2003 (p<0.025) and 2004 (P<0.004) while mulch x amendment x substrate was not significant in either year. This would seem to confirm that ANMA is responding positively to the combination of more light and no soil treatments. Again with the greater number of surviving germinants there was an associated higher variability with NON.



	STA	STN	WCA	WCN	NOA	NON
■ 2003	0.50 b	0.50 b	0.00 b	0.00 b	1.83 b	16.83 a
□ 2004	0.50 b	1.50 b	0.00 b	0.00 b	3.50 b	14.67 a

Figure 32: *Anaphalis margaritacea* whole plot survival by treatment
Error bars indicate SD; Different letters indicate significance at p<0.05 level; n=6 for each treatment

4.4.4 Elymus glaucus (ELGL) germinant survival

4.4.4.1 Block effects

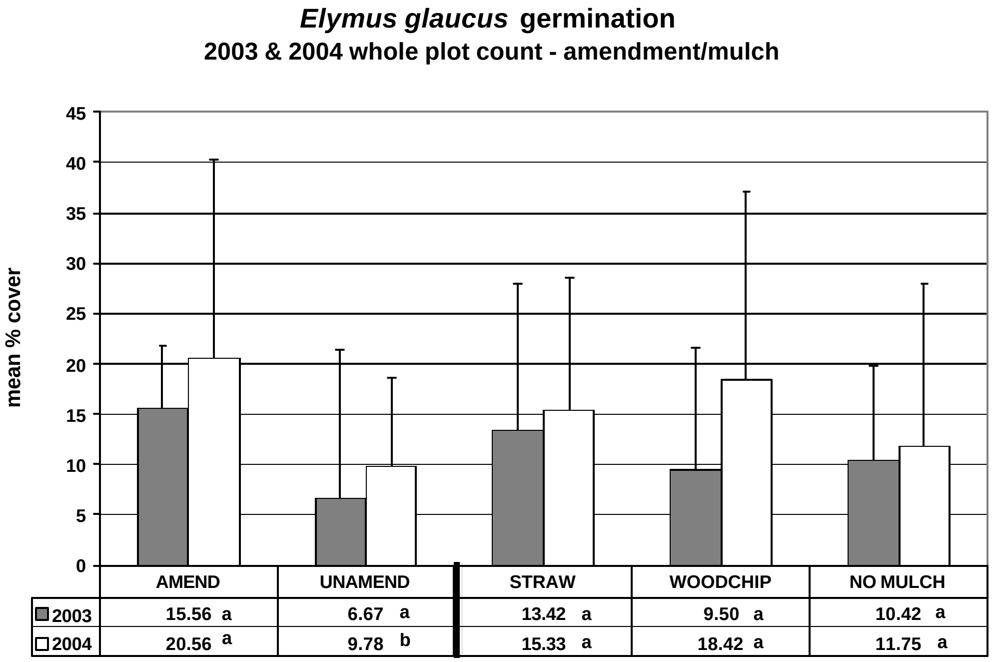
ELGL did not respond preferentially to block effects of shade or substrate in either 2003 (shade p<0.963, substrate p<0.140) or 2004 (shade p<0.748, substrate p<0.505).

4.4.4.2 Amendment

The difference in ELGL mean percent cover between amended and unamended in 2003 (p<0.102) was substantial in favor of amendment however not statistically significant (figure 33). However by 2004 there was a significant difference ($p<0.021$) with amendment still supporting over twice the mean percent cover of the unamended plots and much greater variability.

4.4.4.3 Mulch

None of the mulch treatments differed significantly in their ability to promote ELGL cover in 2003 ($p<0.523$) nor 2004 ($p<0.306$). Comparing plot means (figure 33) there is a distinct preference for straw in 2003 that echoes the other seeded species however in 2004 this had shifted in favor of woodchips.

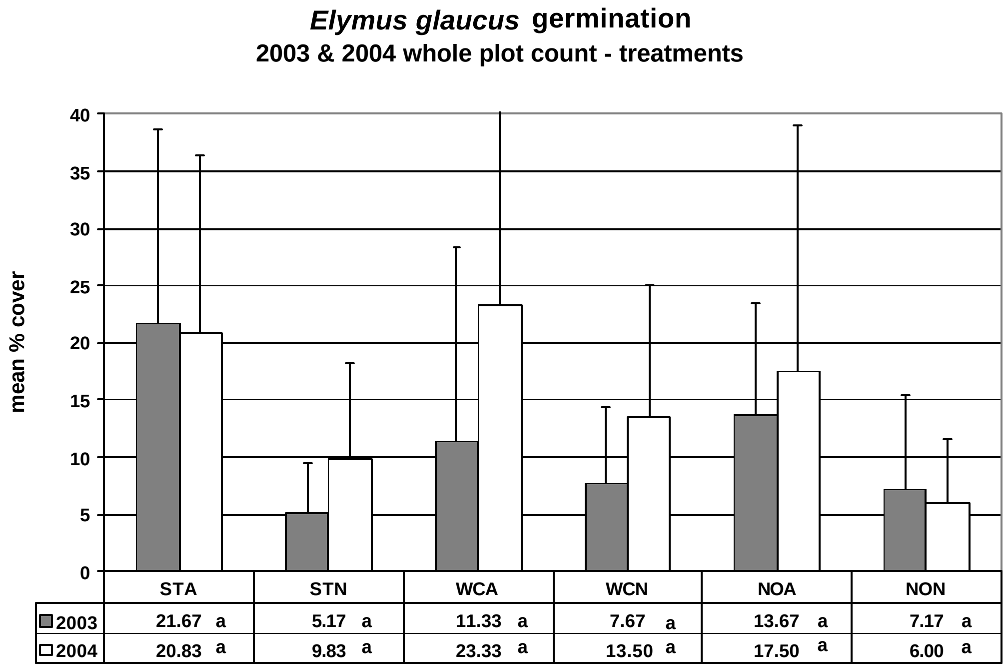


	AMEND	UNAMEND	STRAW	WOODCHIP	NO MULCH
■ 2003	15.56 a	6.67 a	13.42 a	9.50 a	10.42 a
□ 2004	20.56 a	9.78 b	15.33 a	18.42 a	11.75 a

Figure 33: ***Elymus glaucus*** **whole plot survival by amendment and mulch**
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=18 for amendment, n=12 for mulch

4.4.4.4 Mulch and amendment

As previously discussed neither mulch type nor amendment incurred a difference in mean percent cover for ELGL so therefore there is a lack of significant interaction between mulch and amendment treatments in 2003 ($p<0.117$) and 2004 ($p<0.893$). This situation is also reflected in the comparison of the individual treatments (2003 $p<0.146$, 2004 $p<0.159$). However, Figure 34 demonstrates the tendency for ELGL to achieve greater cover with the amended treatments especially STA. It is also of note that variability in the data is greater with the amended treatments than the unamended treatments.



	STA	STN	WCA	WCN	NOA	NON
▩2003	21.67 a	5.17 a	11.33 a	7.67 a	13.67 a	7.17 a
☐2004	20.83 a	9.83 a	23.33 a	13.50 a	17.50 a	6.00 a

Figure 34: ***Elymus glaucus*** **whole plot survival by treatment**
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=6 for each treatment

4.4.5 Native shrub germinant survival

Since each woody shrub species in the seed mix individually had low germination rates and since these five species are commonly found together in low elevation riparian zone in the North Cascades along the edges of clearings, *Holodiscus discolor* (HODI), *Physocarpus capitatus* (PHCA), *Rosa gymnocarpa* (ROGY), *Rubus parviflora* (RUPA) and *Rubus ursinus* (RUUR) have been grouped together for analysis under the rubric of native shrubs as indicated above in section 4.4.

4.4.5.1 Block effects

Mean native shrub germinant survival did not differ significantly according to block effects in either 2003 (shade $p<0.298$, substrate $p<0.555$) or 2004 (shade $p<0.411$, substrate $p<0.751$).

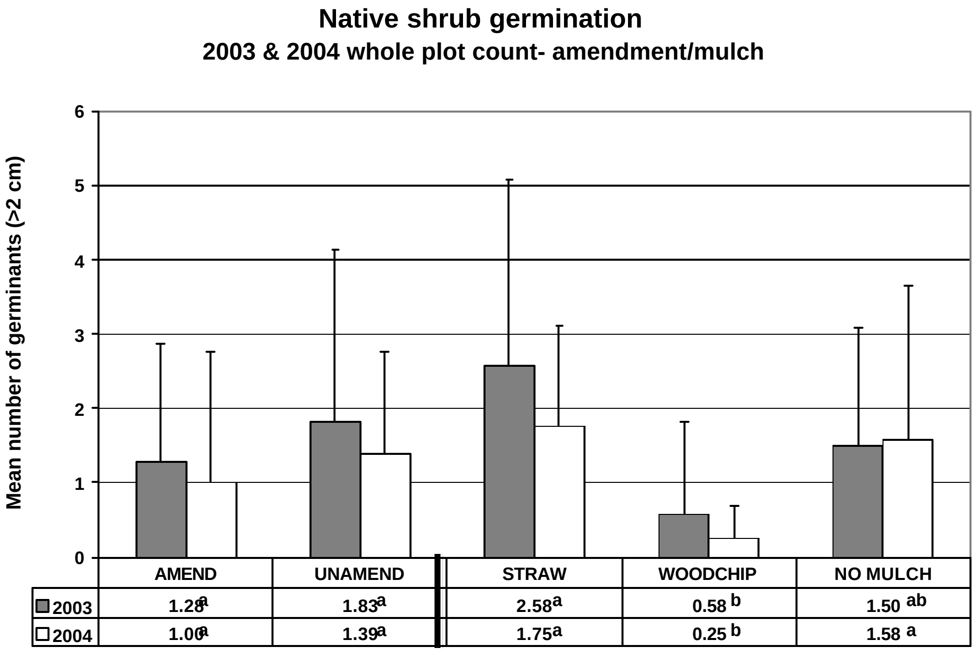
4.4.5.2 Amendment

Native shrubs showed no significant difference in survival for either amendment or no amendment (figure 35) in 2003 ($p<0.383$) and 2004 ($p<0.156$). Based on the comparison of means a slight but ultimately not very meaningful difference can be detected favoring no amendment for native shrub germinant survival.

4.4.5.3 Mulch

As it was with ALRU and POBA germinant survival, mulch significantly influenced native shrub germinant survival (figure 35) in 2003 ($p<0.012$) and in 2004 ($p<0.006$) with straw supporting significantly more shrub germinants than woodchips.

Straw also had higher mean germinants than no mulch but not significantly so. Straw also had the greatest variability in the data. In 2004 woodchips had significantly less surviving germinants than either straw or no mulch. The significance of these results is tempered by the fact that the highest mean number of germinants was less than 6.

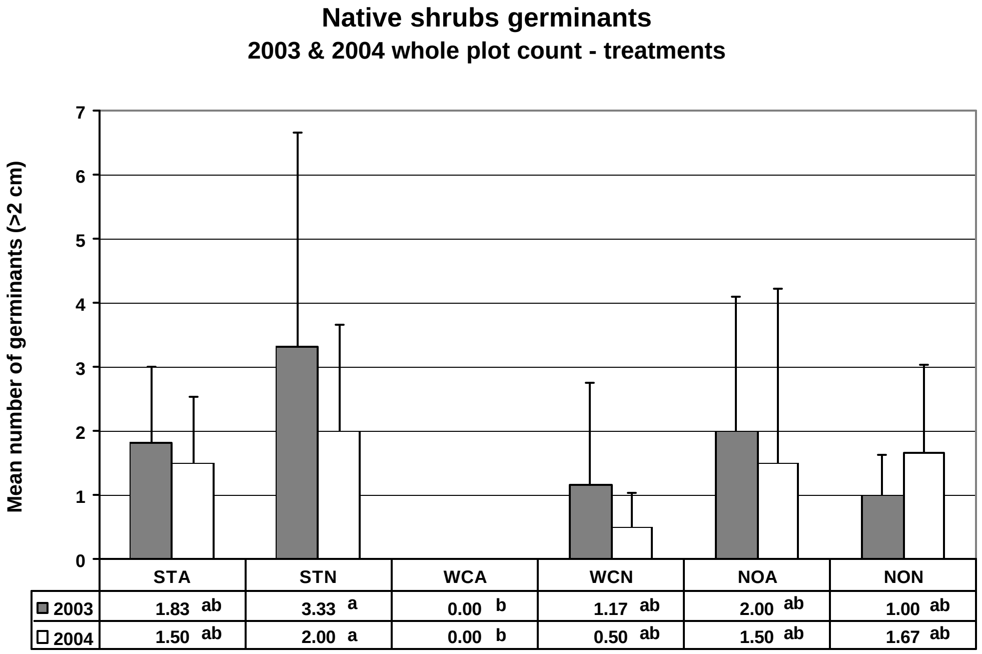


	AMEND	UNAMEND	STRAW	WOODCHIP	NO MULCH
■ 2003	1.28 a	1.83 a	2.58 a	0.58 b	1.50 ab
□ 2004	1.00 a	1.39 a	1.75 a	0.25 b	1.58 a

Figure 35: Native shrub whole plot survival by amendment and mulch
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=18 for amendment, n=12 for mulch

4.4.5.4 Mulch and amendment

Overall there was no mulch x amendment interaction (figure 36) in 2003 ($p<0.287$) or 2004 ($p<0.893$). On the basis of individual treatments one difference was significant, STN supported more surviving germinants than all the other treatments especially WCA which had no surviving native shrub germinants in both 2003 ($p<0.019$) and 2004 ($p<0.029$) reflecting the previously noted preference for straw and a trend towards no amendment with ALRU and POBA. As seen through out the germinant survival data, the treatment with the greatest number of survivors also had the greatest variability in the data.



	STA	STN	WCA	WCN	NOA	NON
■ 2003	1.83 ab	3.33 a	0.00 b	1.17 ab	2.00 ab	1.00 ab
□ 2004	1.50 ab	2.00 a	0.00 b	0.50 ab	1.50 ab	1.67 ab

Figure 36: Native shrub whole plot survival by treatment
Error bars indicate SD; Different letters indicate significance at $p<0.05$ level; n=6 for each treatment

CHAPTER 5

DISCUSSION

5.1 Tree growth response

The three tree species chosen for this experiment *Alnus rubra* (ALRU), *Populus balsamifera* (POBA) and *Pseudotsuga menziesii* (PSME) are all early seral pioneer species in riparian zones throughout the North Cascades adapted to successful germination and survival on droughty alluvial mineral substrates lacking organic soil development. While colonization occurs rapidly on these sandy to gravelly substrates growth is often slow, especially in more open sites exposed to wide temperature fluctuations and wind desiccation. The experimental premise was that improving soil moisture retention by way of organic amendment would increase growth and survival of transplanted tree seedlings and ultimately accelerate vegetative development.

Straw and woodchip mulches were also evaluated in this experiment and although mulches are commonly employed for soil moisture retention the primary experimental goal for using these mulches was to test their ability to enhance germination of the native seed mix (see sections 5.3 and 5.4 below). In order to allow for seedling emergence a light (2-3 cm) application was used rather than a thicker application more typically utilized for soil moisture retention with transplants. Although others have demonstrated that even a light mulch application can yield significant reductions in evaporative losses of soil moisture (Greenly, 1995; Russell, 1939) it was anticipated that the secondary paper pulp/sawdust amendment incorporated into the root zone would have a more significant impact on soils moisture retention than the scant woodchip or straw application. Smukler (2003) found that the mulch indeed had negligible impact on soil moisture in his assessment of the soils in this experiment (appendix D, figure 40).

Each tree species exhibited a unique change in height response to the amendment and mulch treatments over the three years of monitoring. It should be noted that height may be a poor measure of growth response since transplants tend to put most of their first year growth into root establishment. PSME did not respond significantly after the first growing season to the amendment however it did show a small but significant increase in height with both straw and woodchips over no mulch. By the end of the third growing season the change in height was significantly greater in amended soils but there was no significant difference between the mulch treatments. There is some doubt that the first season differences in response to mulches and substrates were truly growth responses to those factors. In March 2002, three months after the PSME seedlings had been installed, it was discovered that they had not been bare rooted prior to planting (the planting was not supervised by the researcher due to illness) but planted with the soil from the locations they were salvaged. The intent was to assess the response of bare root transplants to the soil treatments and the rich humic soil surrounding the PSME roots would have certainly skewed the results, therefore the PSME transplants were excavated, bare rooted, replanted and re-measured. Differential settling of the transplants or re-transplant shock or may have been the cause behind the observed first year response. The fact that the first year response differences between mulches and substrate did not persist into the third season would seem to indicate that this may be the case. The growth response by PSME to amendment in the third season was independent of interaction with mulch or block effects therefore it can be assumed the significantly greater mean change in height with amendment is due to the amendment.

POBA completely lacked any significant response to any of the treatments or block effects in either the first or third growing season. Trend-wise POBA had increased mean change in height with amendment in both 2002 and 2004 however large variability in the data combined with the tendency for POBA to experience tip die-back (senescence of the leader down to a lateral shoot) may have obscured the significance of this response. In cases of tip die-back, change in height was recorded as ‘0’. Perhaps if negative growths had been measured a significant difference would have been found between amended and unamended plots.

ALRU proved to be the fastest grower of the three trees acquiring more than 25 cm in height in the first year and 100 cm in the third year on average. ALRU growth proved to be significantly improved by amendment in both 2002 and 2004 showing a 319% and 270% increase in mean change in height with amendment over no amendment. Mulch also proved to be a significant influence on ALRU growth. In 2002 straw mulched plots supported greater mean changes in height than woodchips (not significant) or no mulch (significant) while in 2004 there was no significant difference between the mulch treatments. This was the case even though straw again incurred higher mean changes in height, nearly twice that of woodchips and half again as much as no mulch. As might be expected there was a strong interaction between mulch and amendment. In 2002 the amendment treatment combinations STA, WCA and NOA, displayed greater mean changes in height over the unamended treatments STN, WCN, and NON though the only significant difference was between STA, the best performing treatment, and WCN and NON, the poorest performers. By 2004 the strong trend for amendment was somewhat confounded by a 92% mortality of ALRU trees in the WCA treatment which left only one ALRU alive out of 24 that were in that treatment. Given this the WCA treatment was left out of the statistical analysis of the mulch x amendment treatments. Even without the WCA treatment in the analysis, STA still incurred strongest growth response with NOA in a close second, both of which still significantly exceeded the unamended treatments by nearly 300%. Clearly the amendment provided a favorable edaphic environment for ALRU to grow.

Overall the amendment did improve the growth of transplanted bare root trees even with confounding influences of mortality, tip die-back and re-planting detracting from the strength of that response. Straw and woodchip mulch gave mixed results, which was expected given the light application though it would seem straw provided an extra ‘boost’ to ALRU either in measurable growth or a ‘boost’ in statistical average due to reduced mortality (see following section).

Variability in the growth response data was large with the amended treatments for all three tree species. This may reflect poor mixing of the sawdust and sludge prior to application and/or uneven distribution and incorporation of the amendment. Uneven distribution and incorporation was observed and attempts were made to redistribute the amendment manually after deep pockets of the amendment were discovered especially in block C.

5.2 Tree mortality

In 2002, one year after installation, there was very low mean mortality for all three tree species, 24% for PSME, 7% for ALRU and 4% for POBA with no significant differences in mortality between any of the treatments or block effects. Two years later in 2004 however mean mortality jumped to 51% for PSME, 47% for ALRU and 36% for POBA. Surprisingly, it was amendment that significantly increased mortality for POBA and PSME as well as raising ALRU mortality 160% over no amendment though not significantly. Given the observed positive growth effect of amendment this would seem to be contradictory. Mulch alone did not significantly affect mortality for any of the three species or trees as a whole however there was a very significant difference among the mulch x amendment treatment combinations (though mulch x amendment *interaction* was not statistically significant). WCA proved to significantly foster the highest mortalities for all three species, 92% for ALRU, 83% for POBA and 75% for PSME for an all tree mean of 81%. This exceeds the next highest mortality for all trees NOA at 54%, implying that adding woodchips to amendment *increased* mortality by 27%. In contrast WCN at 35% mortality for all trees had 46% *less* mortality than WCA which seemingly implies that amendment has the stronger effect on mortality in the synergistic effect of woodchips and amendment. Amendment also raised the mortality when combined with straw or no mulch. With straw the effect was slight, from 35% to 38%, only a 3% rise and hardly significant while there was a more appreciable jump from 35% mortality with NON to 54% with NOA, a 19% increase. From these results straw would appear to have an ameliorating effect on the mortality inducing properties of amendment or simply lack some mortality inducing property (such as allelopathic compounds) that woodchips may have.

The potential explanation for the observed mortality response may lie among several factors which may or may not be interacting to produce the observed effects none of which were directly measured. The amendment was formulated as a balanced soil amendment (Henry, 1999) utilizing fresh sawdust with a high C:N ratio mixed with low C:N ratio digested secondary paper pulp sludge resulting in a final 125: 1 C:N ratio for the amendment (Smukler, 2003). This was done in order to immobilize nitrogen for long term gradual N mineralization that favors native plants adapted to low N soils over ruderal nonnatives that respond adventitiously to high available N (Blumenthal, 2003; Henry, 1999). Using high C:N amendments to immobilize nitrogen can also have the negative effect of reducing growth and establishment of the desired plant community (Averett, 2004). Smukler (2003) found that this was not the case with these experimental soils; the amended plots had consistently higher available N than the unamended plots. As well, *A. rubra* which fixes its own nitrogen commensally with *Frankia* spp. would have been unaffected by excessively low available N and yet experienced 92% mortality with the WCA treatment and 58% mortality with just the amendment alone.

The amendment also drastically changed the physical and structural quality of the soil. The resulting admixture of undecomposed sawdust and pulp sludge created a very ‘fluffy’ textured medium where the sawdust constituted the bulk of the volume. Incorporating this amendment had the effect of strongly lowering the bulk density of the soil in the rooting zone where the sawdust excessively diluted the mineral soil. While the amended plots retained a significantly higher *volumetric* soil moisture content than the unamended soils throughout the May-November 2002 monitoring period (Smukler 2003) it is possible that the *soil water potential* (water accessible for uptake by plant roots) was severely lower in amended plots due to the combined effect of sawdust absorbing soil moisture (like a sponge) and a greater tendency for lower bulk density soils to transpire moisture through wicking and excessive aeration. Similar effects were observed (Chow, 2002; Walker and Powell, 2001; Walker, 2003b) by using paper pulp, straw and compost. During extended dry periods like the summer of 2003 (appendix A, figure 37) the amended soils may have been a much more stressful environment in terms of soil water potential than the unamended mineral soils where the bulk density higher. A higher bulk density while inhibiting root penetration can also have the effect of trapping moisture and slowing transpiration. As well, 15 cm below the surface in the rooting zone moisture may condensate around and under larger mineral particles such as cobble and gravel. The explanation based on moisture does not necessarily sync with the synergistic raising of mortality with woodchips since they should have had a more ameliorative effect on soil moisture. However there is the possibility that the denser woodchips may have intercepted, absorbed and then transpired the scant precipitation during the summer of 2003 rather than allowing it to percolate into the root zone. This leaves in question though why the straw amendment would seem to have had a mortality lowering, tempering effect in combination with amendment. It may be that the straw as a lighter sparser thatch (that was almost completely decomposed by summer 2004) did allow for more precipitation to access the soil; on the other hand evaporation would have also increased. Straw is also lighter colored and thus has higher albedo which would have the effect of cooling the soil surface while the much darker, lower albedo woodchips would have had higher surface temperatures. Soil surface temperature monitoring over the summer of 2002 did reveal that woodchip mulch incurred higher (1.5 to 2°C) temperatures than straw but definitely much lower temperatures than no mulch (appendix D, table 4). Straw being lighter colored has a greater albedo and tends to reflect light and decrease radiative heat.

Soil pH and electrical conductivity (EC) were measured (Smukler, 2003) in the spring-fall of 2002. While pH and most ECs proved to be within normal bounds, the WCA treatment had an electrical conductivity of 0.9 dS/m, nearly twice that of the other amended treatments. EC does not typically begin to affect plant growth and survival negatively until levels of salinity reach 4 dS/m or greater however 0.9 dS/M does fall with in the range of increasing impacts to salt-sensitive species (Ashman, 2002; Brady, 2000). Other potential explanations behind the increased mortality with amendment may be:

- A proliferation of soil pathogens or root nematodes in response to the fresh input of a carbon substrate
- Amendment suppressed formation of mycorrhizal associations necessary for accessing moisture and nutrients
- Allelopathic compounds in the coniferous sawdust and/or the red alder woodchip mulch (unlikely, seeds did germinate)
- Other undetected chemical factors such as nutrient depletion particularly micronutrients

Overall, lack of sufficient soil water potential would seem to be the most plausible 'story' with four potential moisture reducing and/or water stress inducing factors. (1) The Goodell Creek gravel mine is an open riparian terrace with a south-southeasterly aspect that gets very warm during the summer months with daily highs into the +30°C range. The extended dry period between May and September 2003 (appendix B, figure 37) which was the driest summer in the past three years at Goodell may have desiccated the sawdust-laden, highly porous amended soils well into the root zone causing water stress. The amendment once dry would have had to re-hydrate considerably before moisture would have been available to plant roots. (2) If, as the EC would seem to indicate, that there were higher levels of soluble salts in the matrix of the woodchips plus amendment treatment then the higher osmotic potential of the soil environment would have further induced water stress on the transplants. (3) Woodchips may have exacerbated both the drying of the soil by raising surface temperatures while at the same time have been an interceptive barrier to negligible rain over the summer of 2003. This would have had the effect of allowing the low bulk density, highly porous amendment to wick soluble salts-laden moisture up to the near surface but then preventing the dilution and flushing of that salt accumulation. (4) The last compounding factor unique to the woodchip plus amendment treatment was the proliferation of nonnatives, especially clovers (*Trifolium repens, T. praetense, T. hybridum, T. agraricum*) in WCA plots. In many WCA plots clover cover reached 100% in 2002 and by September 2002 *Trifolium spp.* (mostly *T. repens*) had an average 44% cover on WCA plots. This would have resulted in significant competition with the bare root tree transplants for water and nutrients in their first growing season. However overall tree mortality was low at the end of summer 2002 so any effects on mortality due to competition most likely occurred in 2003. It is interesting to note that the clovers, typically perennials in our mild winter climate did not survive after the summer of 2003, another indicator perhaps of the harsh site conditions and high level of competition for resources.

The overall high variability observed with the mortality data may reflect substantial variation in conditions across the site regardless of treatment exacerbated by the selective pressures of an especially dry summer in 2003.

5.3 Native seed germination

Each plant species requires idiosyncratic, sometimes complex but always necessary conditions for successful germination of its seed. In the general sense all seeds need to find those necessary conditions on or immediately below the soil surface where they are deposited. The physical conditions of soil surface, the seed bed, are far more variable in temperature, moisture, light, disturbance, etc. than those in the root zone. In this exposed state seed must find microsites which are consistent in the required conditions for a period of time sufficient to allow the seed to break dormancy, imbibe moisture, germinate, access light and put roots into the more stable moisture environment deeper in the soil profile (Harper, 1965). Plant seeds often have adapted physical attributes and/or biochemical traits that increase the likelihood they reach and secure themselves into microsites or safe sites typical of their ecosystem after dispersal (Baskin, 1998). In riparian zones the quiescent spaces between pieces of gravel, cobble and woody debris or the upwind areas behind large boulders and logs provide those opportune microsites for seed to germinate. However riparian zones are dynamic systems with often variably harsh edaphic conditions and periodic disturbance (Naiman & Decamps, 1997). If seed does not get dislodged and washed or blown away, the germinants may wither during the summer in hot, well-drained gravelly/sandy/cobble substrate and/or be subject to gramivores. Therefore in order to ensure germination and germinant survival on mineral soils in riparian zone restorations a stable seed bed must be provided (Goodwin, 1997).

Mulches, straw and woodchips were applied experimentally for the explicit purpose of assessing their capacity to stabilize the seed bed and provide microsites for germination. The assumption was that the mulches or lack of mulch had a primary effect on seed germination and that the incorporated amendment would have a co-dominant role in germinant survival with mulch over the summer and in successive seasons. Therefore germination was assessed monthly over the first growing season and germinant survival was assessed at the end of three successive seasons. Woodchips initially promoted the highest mean number of germinants for both POBA and ALRU early in the summer but by August the number of germinants in woodchips was sharply declining while the numbers in straw remained steady and exceeded woodchips. With both species no mulch supported the least number of germinants throughout the sampling period. In the final subplot counts of August 2003 straw retained more ALRU and POBA germinants than woodchips or no mulch however it was only significant for ALRU. This divergent trend in germinant loss over the first growing season may point toward important differences between the physical properties of woodchips and straw and their effects on soil temperature. As noted previously with tree mortality woodchips displayed higher surface temperatures than straw likely due to lower albedo. The slow establishing small germinants of woody species like ALRU and POBA would have been vulnerable to high surface temperatures over the course of summer with woodchips while the reflective straw would have cooled the soil surface and promoted germinant survival, as observed. Conversely straw would have been poorer protection against surface freezing during the winter and may explain the observed loss of germinants over the winter with straw. The fact that straw still marginally held the greater number of survivors by the second summer may indicate that high summer temperatures may be a more significant source of germinant mortality than winter freezing.

ELGL germinant numbers were virtually identical for straw and woodchips over the course of summer 2002 with straw consistently slightly above woodchips and both exceeding no mulch by up to 180%. By the August 2003 ELGL woodchips germinant numbers significantly dropped below straw to the level of no mulch. The similarity of ELGL response to woodchips and straw may illustrate an important difference between fast-growing species such ELGL and slow-growing species such as POBA and ALRU. ELGL matures in one season with roots penetrating deeper and quicker into the soil profile than most Pacific Northwest woody species. It would make sense then that after the first two months mulch would be much less an influence on ELGL growth and survival than the amended or unamended substrate into which it has rooted. The observed loss of ELGL germinants over the summer with both mulches may be more due to a general trend of senescence over the summer than any treatment effect. However the clearly greater ELGL survival with straw after one year may be attributable to the same soil cooling and hence moisture retaining properties as observed with ALRU and POBA germinants and tree mortality

Nonnative germinant response to straw and woodchips was the reverse of the native response. Straw initially contained the most nonnative germinants in the early summer and by September had the fewest while wood chips maintained virtually the same mean number of nonnative germinants the whole summer long. This pattern is almost completely explained by the fact that the predominant nonnative species in the straw was summer wheat, *T. aestivum*, which is an annual grass that senesces over the summer while the predominant nonnative in the woodchips was white clover, *Trifolium repens*, a perennial in mild climates.

The effect of amendment on seed germination varied between the tree seeds, ALRU and POBA and the perennial grass, ELGL. ALRU germination at the beginning of the first growing season in June 2002 was favored by amended plots but then quickly fell below the unamended plots in July and continued to decline over the summer. Unamended plots supported steady numbers ALRU germinants over the first growing season. By the end of the second growing season there was no significant difference between ALRU germinant numbers in amended and unamended plots. POBA germinant numbers in June were low but then spiked in July with indistinguishable mean germinant numbers between the amended and unamended plots. In August germinant numbers in the amended plots fell substantially (but not significantly) below unamended plots and remained at that point until September. By the end of the second growing season the number of POBA germinant survivors was small (<1 germinant/m^2) though unamended plots still supported a higher mean number. For the small tree germinants with their incipient root systems right at the surface would have suffered the same depredations as the tree transplants due to the inhospitable soil water and temperatures incurred by the amendment. Early in the season the amendment may have been moister and encouraged germination but as the amended soil surface dried out over the summer germinants would have declined, as observed. The unamended soils while a difficult substrate to establish on may have provided marginally better soil water potential for the small germinants (which are adapted to germination on miner substrates) over the summer. The intervening winter followed by the droughty summer of 2003 may have evened out the numbers of survivors between the treatments.

ELGL germination and first season survival was consistently greater with amendment, even until the end of the second growing season a year later. This again makes sense in terms of ELGL rapidly establishing roots into the soil profile. ELGL may be more efficient at accessing soil water with a greater density (and hence surface area) of roots penetrating deeply into the low bulk density amendment than the tree transplants which may make ELGL more tolerant of droughty conditions. Nonnative germinants followed an identical pattern with amended plots supported higher mean numbers of nonnative germinants over the first growing season and to the end of the second growing season and most likely for the same reasons.

Looking at the germination response to the combination of mulch and amendment the trend with ALRU and POBA is for woodchip treatments to promote a strong early flush of germinants greater than the other treatments, WCA for ALRU and WCN for POBA, and then precipitously lose those germinants over the summer while the straw treatments hold more or less steady numbers with STN >STA in for both

ALRU and POBA July-September. No mulch with or without amendment never surpassed either of the mulch treatments in numbers of POBA or ALRU germinants though by the end of the second growing season NON still supported a few germinants (0.32/m^2) while the NOA treatment had none. The combined treatment effect affirms the observed trends seen separately with mulch and amendment where both amendment and woodchips started with high germinant numbers but then lost them over the summer while straw and unamended soils had lower germinant numbers that persisted over the summer.

The amended treatments tended to produce higher numbers of ELGL germinants with WCA and STA closely paralleled above all other treatments and steadily dropping germinant numbers over the first growing season. By the end of the second growing season WCA had the fewest germinants of all the treatment combinations, even below the no mulch treatments while STA supported the most ELGL germinants. Again as previously discussed the amendment (or lack there of) would be more of an influence on survival with this rapidly establishing species.

With the nonnative germinants the pattern driven by the wheat/straw and woodchip/clover relationship was evident with the numbers of germinants WCA holding steady and high over the course of the season and straw losing a substantial portion of its germinants by the end of the first summer. The overwhelming presence of clover in the WCA plots may have also have been a contributing factor in poor tree germinant survival with WCA due to competition for water and nutrients.

5.4 Native seed germinant survival

By the end of the second growing season in 2003 the surviving numbers of germinants in the 0.25 m^2 subplots had dropped to the point that most had ‘0’ germinants of any species. It was at this point germinants were counted on a whole plot (20 m^2) basis in order to assess the efficacy of the treatments in supporting the survival of germinants toward potential maturity. Counting on a whole plot basis also allowed other species which had not been prominent in the subplot counts such as *Anaphalis margaritacea* (ANMA) and five grouped together shrub species (see section 4.4) to be included for analysis.

Both POBA and ALRU survived in greater numbers with straw and no amendment (STN) over the summer 2003 and 2004 counts. This preference was strong in the case of POBA with STN supporting a mean 23 germinants/plot over the second most number of germinants, 6, in the NON treatment. STA was near second for ALRU after STN, 35 vs. 25 mean germinants with WCN at 21 mean germinants a close third. For both POBA and ALRU WCA supported by far the fewest germinants, virtually none, in both years. The collective five species of native shrubs counted on a whole plot basis responded to the treatment combinations much like ALRU and POBA germinant survivors. While overall germinant numbers were low, STN promoted the highest germinant survival of the treatments while WCA supported 0 germinants in both 2003 and 2004. While the difference between STN and WCA was significant, the difference between STN and the other treatments was close with STA, NON and NOA at 1.5, 1.67 and 1.5 germinants/plot to 2 germinants/plot with STN in 2004. The reasons for the observed results with these woody species are most likely the same as those observed for the subplot germinant results, slow-growing small germinants with shallow root systems experiencing desiccation due to the poor soil water potential incurred by physical properties of the woodchips and amendment.

ANMA germination and survival was distinctly favored by no mulch and no amendment, NON, with 15 mean germinants per plot by 2004 over 0 germinants with either woodchips treatment, WCN and WCA, and virtually none in straw treatments STA and STN, 0.5 and 1.5 mean germinants/plot. NOA also supported very few ANMA germinants by the end of the 2004 growing season at 3.5 mean germniants/plot. This preference for unamended substrates without mulch makes sense for ANMA which is a frequent and successful colonizer of disturbed gravelly substrates throughout the Pacific Northwest which. ANMA may require large diurnal variations in temperature to initiate germination and therefore germinate poorly with mulches and amendment which would moderate diurnal temperature variation.

ELGL, which was quantified as a percent cover rather than by counting individuals, reflected the overall improved survival in an amended substrate as found with the subplot germinant counts. Straw plus amendment, STA, produced the most substantial ELGL cover at 22% in 2003 while WCA was half that at 11%. In 2004 WCA caught up with and surpassed STA slightly, 23% to 21%. Analyzing amendment and mulch separately the influence of the amendment is clearly stronger and more significant with mean ELGL amended plot %cover in 2004 at 21% compared to 10% for unamended plots. For mulches the differences were more muted in 2004, 15% for straw, 18% for woodchips and 12% for no mulch. As seen with ELGL subplot germination and previously explained ELGL establishes rapidly, most likely roots deepr in the low bulk density amendment and is more efficient at obtaining soil water from deeper in the soil profile.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

Did this research project answer the original question; *can allogenic organic inputs such as mulch and amendment promote the development of native vegetation at an anthropogenically degraded site*? The most honest answer is: it depends. It is a popular sentiment in the community of restoration practitioners that adding any form of organic material to depleted and disturbed soils is a 'good thing'. The results of this experimental application of incorporated digested paper pulp/sawdust amendment and either woodchips or straw demonstrate that the response to these treatments depends on the species in question, the life form chosen for installation, site conditions upon installation and the conditions over the study period. Seeds and transplants differ in their site preparation requirements to ensure greater survival and growth. With seeds the requirements for successful germination are driven by the properties of the soil surface or seed bed, while continued persistence and hopefully growth towards maturity of those germinants depends more on the subsurface soil conditions of the root zone for faster maturing plants, slower maturing plants must survive conditions for several seasons until roots are well established in the subsoil. With bare root transplants the subsurface soil conditions are paramount and must be able to nurture the seedlings through the transplant shock phase. In both cases survival and growth in the first few growing seasons relies heavily on consistently available soil moisture through the growing season. Revisiting the experimental hypotheses, it must be emphasized that the results are particular to the specific materials employed and the manner in which they were applied. This does not mean that some meaningful generalizations can not be made but they come with caveats.

6.2 Hypotheses

***Hypothesis 1:* Soil amendment will increase growth of installed bare root tree seedlings**

All three tree species, *A. rubra. P. balsamifera* and *Pseudotsuga menziesii* achieved increased height in response to the incorporated digested paper pulp/sawdust amendment over no amendment by the end of the third growing season, though only in the case of ALRU and PSME was this statistically significant. While this hypothesis can be accepted these results must be interpreted in the light of the higher mortality of trees in the amended soils which most likely selected for more robust individuals and somewhat skewed a 'pure' response to the amendment. The high variability in the amended data possibly indicates some heterogeneity in the available resources due to application or formulation which would result in the observed trends.

***Hypothesis 2:* Soil amendment will increase the survival of bare root tree seedlings**

This amendment significantly raised the mortality of all three tree species over no amendment by the end of the third growing season. The mean percent mortality of all three species was strikingly uniform in response to the amendment therefore hypothesis 2 can be rejected without major qualifications. Other studies have found that amendments *can* increase survival of bare root transplants in disturbed sites (Bulmer, 2000; Hallsby, 1995; Jackson et al., 2000; Kelting, 1998; Kramer et al., 2000b;

Querejeta, 1998). However in those studies amendment was either surface applied (not incorporated) and the transplants planted into the mineral soil beneath the application and/or the amendment was a highly decomposed humic material not bulk volumes of fresh OM.

Hypothesis 3: **Application of mulch over amended soils will enhance the growth and survival of bare root tree seedlings**

As predicted the thin application of mulch did not induce profound differences in height or mortality for the three tree species. Trend-wise ALRU and POBA had slightly greater mean heights and lower mean mortality with straw. PSME showed no appreciable differential response to the mulch treatments. Hypothesis 3 can be rejected but only with the caveat that the mulch was applied primarily to encourage seed germination.

Hypothesis 4: **Application of mulch will increase seed mix germination**

The results were variable according to species but in general mulch did increase germination with woodchips fostering a large flush of germination early in the growing season but then failing to promote their survival through the summer dry season. Straw on the other hand initially germinated fewer seeds than woodchips (but no more than no mulch) but supported the survival of most of those germinants through the dry season. Since both mulches consistently increased germination over no mulch (though this was not always statistically significant) Hypothesis 4 can be accepted.

Hypothesis 5: Application of mulch over amendment will enhance germinant survival

The premise was that the mulch would increase germination success and the amended soil would provide a moist, low bulk density substrate into which the germinants could establish their root systems. It was also assumed the amendment would boost germination due to greater moisture holding capacity creating a more humid soil surface environment. In the first season germinant survival the tendency was for unamended soils to carry greater numbers of germinants through to the end of the summer for POBA and ALRU. For the native forest edge grass blue wildrye (ELGL) amended soils produced more germinants and supported them through the summer. In neither case were these trends statistically significant. When mulch and amendment are considered together, ALRU and POBA experienced the greatest germinant survival after three years with straw and no amendment and the lowest with woodchips and amendment. For ELGL it was straw plus amendment and wood chips with amendment that promoted the greatest survival after three years. The common native pioneer forb of gravelly substrates, pearly everlasting (ANMA), almost exclusively germinated and survived on no mulch and no amendment plots while the five species group of native shrub species shared with ALRU and POBA the preference for straw with no amendment though this was not statistically significant. In light of these varied species specific results Hypothesis 5 can be neither be rejected nor accepted.

6.3 Conclusions and recommendations

The most salient lesson to be taken from this experiment is that soil restoration techniques must be chosen based on the autecology and physiology of the plants to be introduced. Generalist soil improvement techniques based on silvicultural and agricultural practices do not always translate successfully to restoration practice with out first considering the ecological viability and consequences of those techniques. In the case of this study response to amendment and mulch application varied according to species and in what form that species was introduced. Transplants and seed can have divergent requirements for first season establishment therefore soil preparation should focus on providing optimal conditions for one or the other either spatially or temporally (or both).

On gravelly/sandy substrates in low elevation North Cascades riparian zones it may be sufficient to apply a 2-4 cm layer of straw with no amendment to ensure germination and survival of direct seeded (or recruited from seed rain) woody riparian species. For pioneer herbaceous species such as *A. margaritacea* no mulch may be the best option while for grasses amendment and mulch may produce the best results. The most ecologically sensible approach may be to group species with similar establishment strategies spatially and/or temporally and prepare the site accordingly, rather than employing a ‘one size fits all’ strategy.

On the other hand bare root transplants may be preferred in order to accelerate primary production, stabilize soils and shade out nonnatives. In this situation *surface* application (which would avoid altering the soil water potential of the native soil) of a balanced soil amendment after installation may be enough to enhance growth and establishment. In situations where there maybe extended droughty conditions 5-10 cm of straw or similarly light colored fast decomposing mulch would balance the need to trap soil moisture during establishment while applying a more persistent mulch such as woodchips which might disrupt germination from seed rain and infiltration from precipitation. Neither of these strategies necessarily preclude following successful plant establishment from seed by transplant installation or visa versa, seeding other species after transplants have become established in order to increase diversity and habitat functions. Ultimately the choice of species, installation form and site preparation technique for repairing severely degraded systems should be based on re-establishing the primary ecosystem processes that stabilize soils, enhance water and nutrient retention and boost primary productivity.

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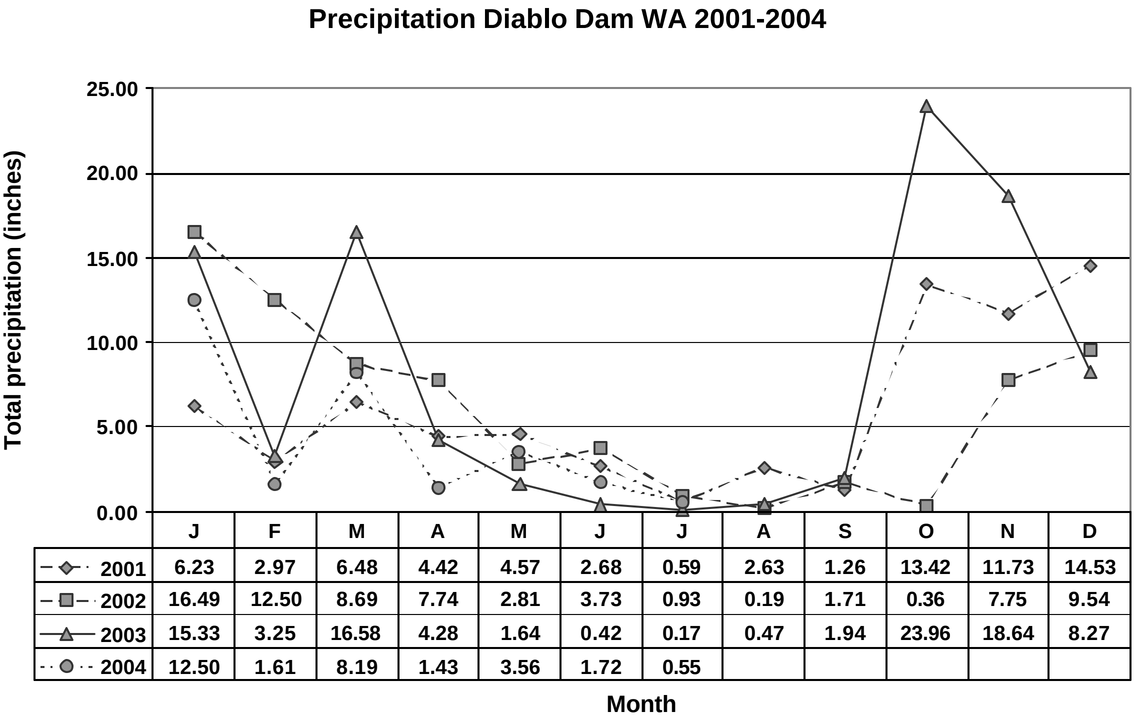
APPENDIX A: NATIVE SEED MIX STATISTICS

Table 3:Goodell Creek Germinants - Native Seed Mix

(a) Seed amounts >200 estimated by weight; (b) *Elymus glaucus* measurements switched to % cover in 2003; (c) *Alnus rubra* germinants dominated by heavy recruitment from seed rain

			Mean Germinants/ plot		**Germination rate/plot (%)**		**Total Germinants**	
Species	**Common Name**	**#Seed /plot(a)**	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**
Acer circinatum	Vine maple	42	0	0	0.00	0.00	0	0
Acer macrophyllum	Big-leaf maple	7	1.47	0.67	21.00	9.60	53	24
Alnus rubra (c)	Red alder	16	39.92	16.72	249.5	104.5	1437	602
Anaphalis margaritacea	Pearly everlasting	7000	1.56	3.28	0.02	0.05	56	118
Arctostaphylos uva-ursi	Kinnikkinnick	6	0	0	0.00	0.00	0	0
Aruncus sylvester	Goat's beard	500	1.22	0.31	0.24	0.06	44	11
Cornus nuttalii	Pacific dogwood	1	0	0	0.00	0.00	0	0
Elymus glaucus (b)	Blue wild rye	850	11	n/a	1.30	n/a	400	n/a
Epilobium angustifolium	Fireweed	6000	0	0	0.00	0.00	0	0
Geum macrophyllum	Large-leaved avens	70	1.72	0.58	2.50	0.83	62	21
Holodiscus discolor	Oceanspray	2300	0.22	0.25	0.01	0.01	8	9
Physocarpus capitatus	Pacific ninebark	70	0.56	0.39	0.80	0.56	20	14
Rosa gymnocarpa	Baldhip ose	3	0.25	0.25	8.33	8.33	9	9
Rubus parviflorus	Thimbleberry	42	0.33	0.19	0.79	0.45	12	7
Rubus ursinus	Trailing blackberry	270	0.39	0.64	0.14	0.24	14	23
Spiraea douglasii	Hardhack	800	0	0.25	0.00	0.03	0	9
Symphoricarpos albus	Snowberry	4	0.03	0	0.75	0.00	1	0
Vaccinium parviflorum	Red huckleberry	400	0	0	0.00	0.00	0	0

APPENDIX B: LOCAL PRECIPITATION 2001-2004



	J	F	M	A	M	J	J	A	S	O	N	D
2001	6.23	2.97	6.48	4.42	4.57	2.68	0.59	2.63	1.26	13.42	11.73	14.53
2002	16.49	12.50	8.69	7.74	2.81	3.73	0.93	0.19	1.71	0.36	7.75	9.54
2003	15.33	3.25	16.58	4.28	1.64	0.42	0.17	0.47	1.94	23.96	18.64	8.27
2004	12.50	1.61	8.19	1.43	3.56	1.72	0.55					

Figure 37: Goodell Creek restoration project monthly precipitation Jan 2001- July 2004 (inches)

APPENDIX C: HISTORICAL AERIAL PHOTOGRAPHS

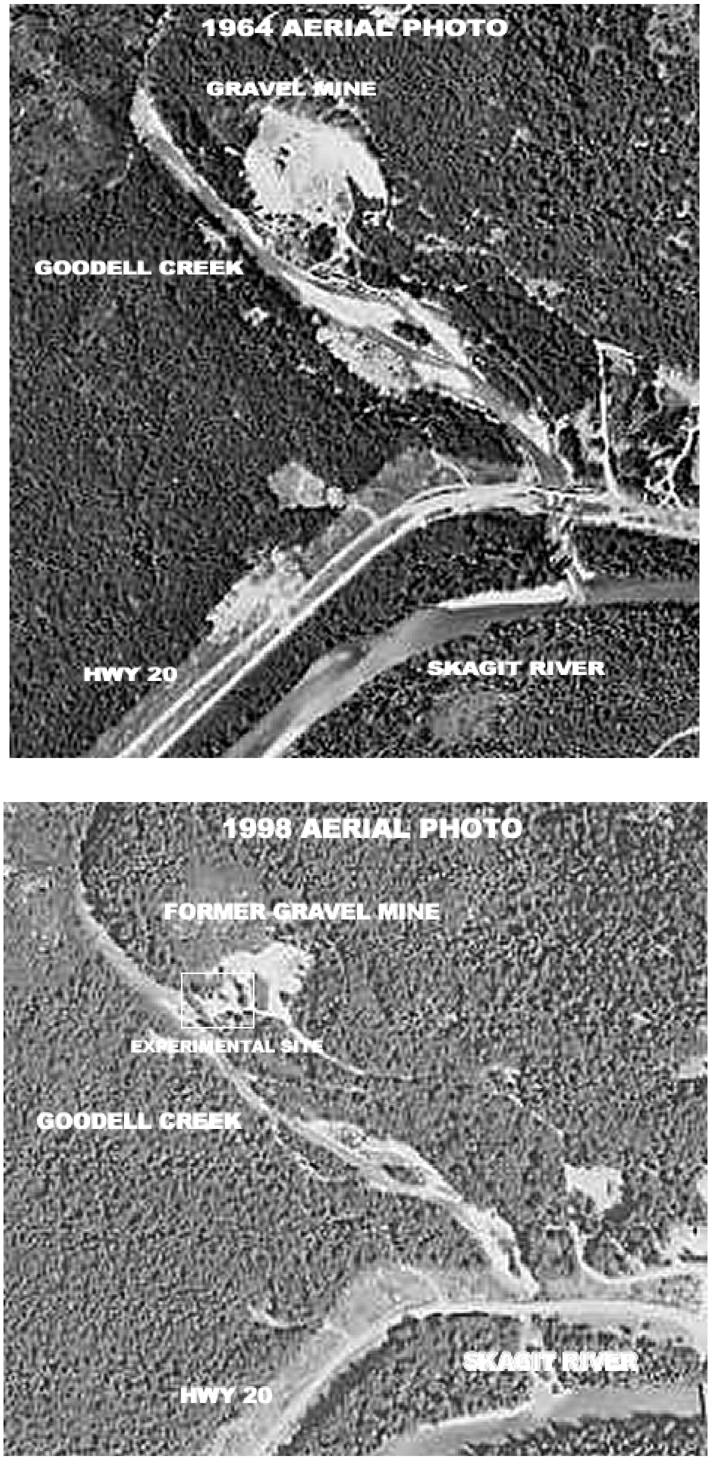
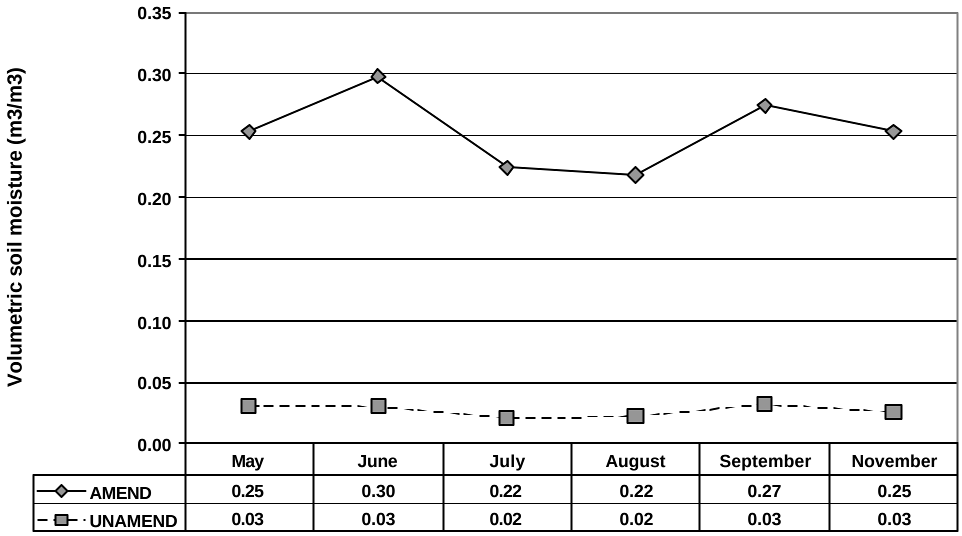


Figure 38: Goodell Creek gravel mine – 1964 & 1998 aerial surveys

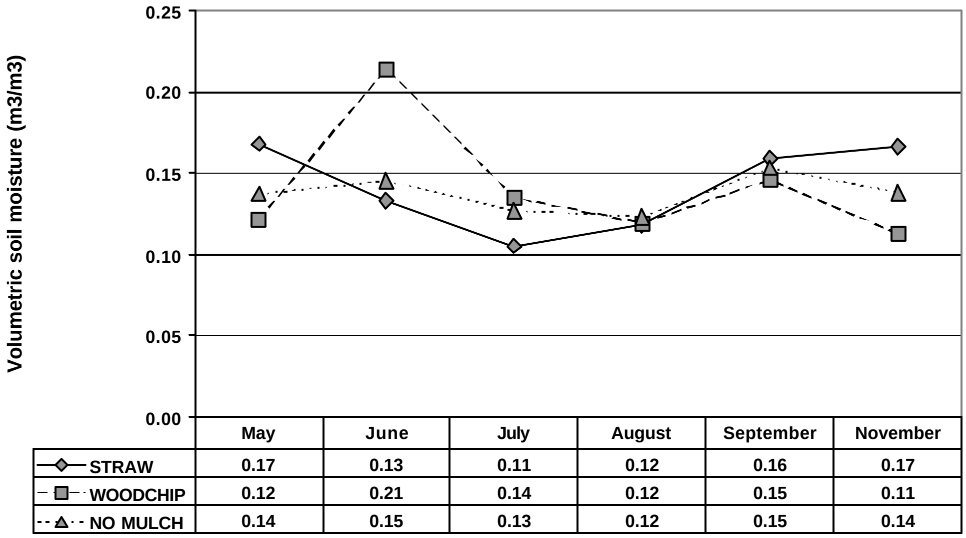
APPENDIX D: SOIL PHYSICAL & CHEMICAL PARAMETERS



Soil moisture 0-15 cm
amendment 2002

	May	June	July	August	September	November
AMEND	0.25	0.30	0.22	0.22	0.27	0.25
UNAMEND	0.03	0.03	0.02	0.02	0.03	0.03

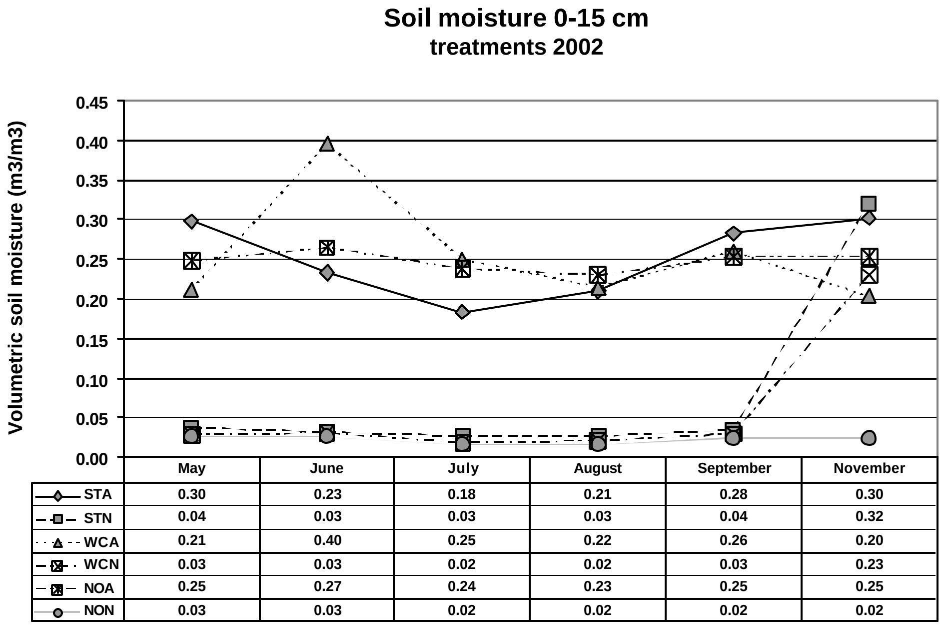
Figure 39: Goodell Creek volumetric soil moisture amendment treatments (m^3/m^3) 0-15 cm depth 2002



Soil moisture 0-15 cm
mulches 2002

	May	June	July	August	September	November
STRAW	0.17	0.13	0.11	0.12	0.16	0.17
WOODCHIP	0.12	0.21	0.14	0.12	0.15	0.11
NO MULCH	0.14	0.15	0.13	0.12	0.15	0.14

Figure 40: Goodell Creek volumetric soil moisture mulch treatments (m^3/m^3) 0-15 cm depth 2002



Soil moisture 0-15 cm
treatments 2002

	May	June	July	August	September	November
STA	0.30	0.23	0.18	0.21	0.28	0.30
STN	0.04	0.03	0.03	0.03	0.04	0.32
WCA	0.21	0.40	0.25	0.22	0.26	0.20
WCN	0.03	0.03	0.02	0.02	0.03	0.23
NOA	0.25	0.27	0.24	0.23	0.25	0.25
NON	0.03	0.03	0.02	0.02	0.02	0.02

Figure 41: Goodell Creek volumetric soil moisture mulch x amendment treatments (m^3/m^3) 0-15 cm depth 2002

Table 4: Goodell Creek restoration experiment soil chemical & physical parameters 2002

Temp=temperature; BD=bulk density; NH4=available ammonium; NO3=available nitrate; EC=electrical conductivity; Fines=soil mineral fraction<2 mm

All parameters assessed at the 0-15 cm depth

month	*Jun*	*Aug*	*Nov*	*Apr*	*Apr*	*Nov*	*Nov*	*Nov*	*Nov*	*Nov*
parameter	Temp	Temp	BD	NH4	NO3	NH4	NO3	pH	EC	Fines
units	(C°)	(C°)	(g/cm3)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)		(dS/m)	(%<2mm)
Amend	15.8	26.4	.93	5.11	1.44	5.44	.85	6.36	.64	60
No amend	19.5	30.9	1.74	3.48	.975	4.93	.67	6.17	.27	52
Straw	16.9	24.8	1.43	3.75	1.33	4.6	.91	6.28	.46	54
Woodchips	17.1	26.9	1.22	4.98	1.22	5.12	.90	6.27	.57	59
No mulch	18.9	34.3	1.37	4.16	1.08	5.85	.48	6.23	.34	54
STA	14.8	23	.88	4.65	1.54	3.88	.97	6.41	.56	58
STN	19	26.5	1.97	2.85	1.13	5.32	.85	6.15	.36	51
WCA	16.2	25.4	.91	6.16	1.83	5.15	1.07	6.38	.90	62
WCN	18.7	30.2	1.61	3.85	.69	4.79	.77	6.16	.23	58
NOA	16.3	30.8	1.01	4.52	.95	7.3	.52	6.29	.46	59
NON	21.2	37	1.65	3.71	1.19	4.68	.32	6.18	.23	43

APPENDIX E: PROJECT SITE SEED RAIN & LITTERFALL 2002

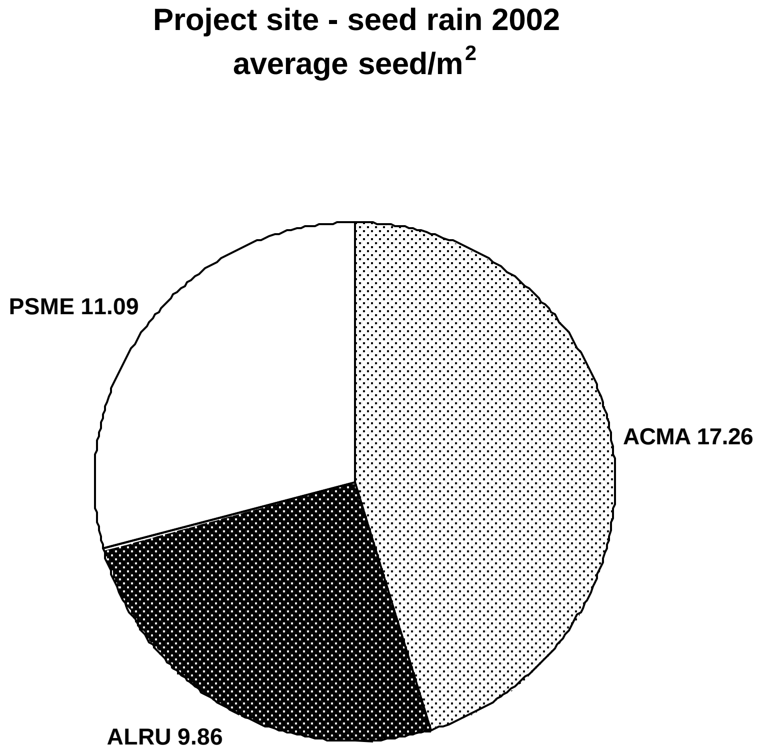


Figure 42: Goodell Creek restoration project site mean seed rain March-November 2002

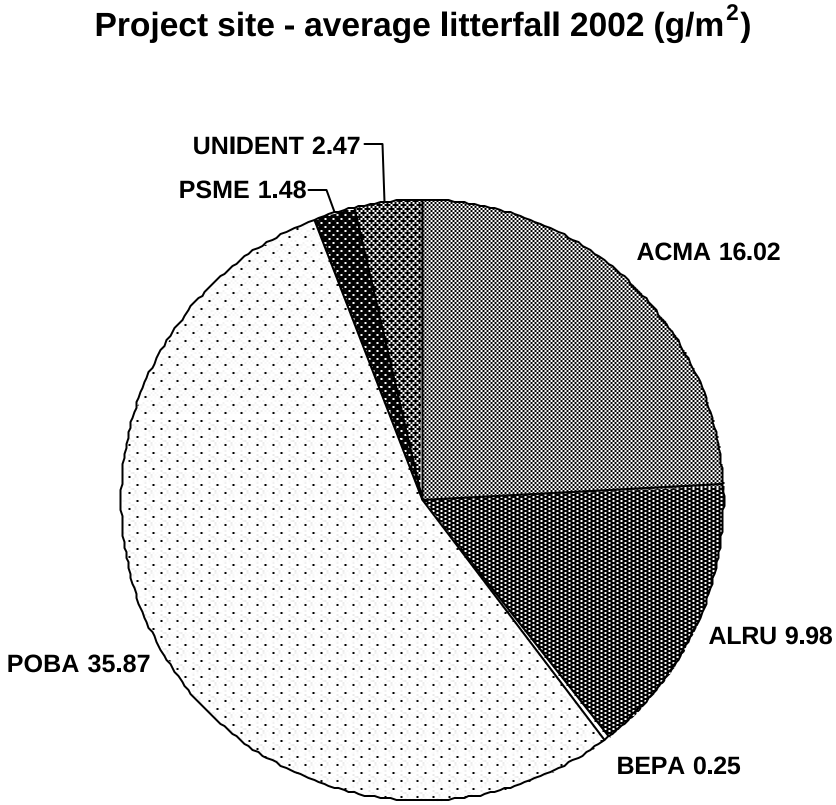


Figure 43: Goodell Creek restoration project site mean litterfall March-November 2002