EFFECTS OF ALTERNATIVE CONIFER RELEASE TREATMENTS ON A SOIL SEED BANK IN A BOREAL SPRUCE PLANTATION

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FACULTY OF FORESTRY AND THE FOREST ENVIRONMENT

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A CAUTION TO THE READER

This M. Sc. F. thesis has been through a semi-formal process of review and comment by at least two faculty members.

It is made available for loan by the faculty for the purpose of advancing the practise of professional and scientific forestry.

The reader should realize that opinions expressed in this document are the opinions and conclusions of the student and do not necessarily reflect the opinions of the supervisor, the faculty or the University.

ABSTRACT

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Keywords: Fallingsnow Ecosystem Project, Release®, triclopyr, Vision®, glyphosate, seed, vegetation management,).

This soil seed bank study was carried out as part of the Fallingsnow Ecosystem Project, located near Thunder Bay, Ontario. The project is an operational scale, integrated, multi-disciplinary study that was established in 1993. It evaluates the effects of 5 alternative conifer release treatments (cutting with brushsaws and a mechanical cleaning machine; applying herbicides (Release ® [a.e. triclopyr] and Vision ® [a.e. glyphosate]) by helicopter and untreated control) on environmental components in a young spruce plantation. In addition, the project documents the effects of clear cutting on the environmental components by comparing post-harvest changes with changes in adjacent unharvested forests. This study compares the treatment effects on the soil seed bank.

Samples of the soil seed bank were collected in 1996 and green house grown during the winter of 1997. The resulting germinants were identified and quantified by species and treatment. Thirty-four species were identified, two of which were tree species: White birch (*Betula papyrifera* Marsh.) and trembling aspen (Populus tremuloides Michx.). Species richness, abundance and evenness indices clearly show that there was a treatment effect on the seed bank. Analysis further shows a significant difference in richness (number of species) between treatments. Species abundance curves were completed and are typical for the Northern Hemisphere. Orthogonal comparisons also show significant differences in species abundance between the forest and the cutover, the brushsaw treatment compared to the Silvana Selective treatment, and the treated cutover (brushsaw, Silvana Selective, Release®, Vision® in comparison to the untreated cutover and the forest combined. These seed bank germination differences resulting from applied silvicultural treatments could play a role in future forest management practices that strive to emulate forest fire effects.

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DEDICATION

This report is dedicated to Ole Pedersen

May 9, 1920 – December 25, 2001.

When someone we love becomes a memory,

the memories become a treasure.

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INTRODUCTION

The release of conifer plantations from unwanted competition is an important part of Ontario's reforestation program (Bell *et al.* 1997). This soil seed bank study is part of the Fallingsnow Ecosystem Project, a long term, multi-disciplinary project established in 1993. The Fallingsnow Ecosystem Project investigates the ecological impacts of alternative conifer release treatments (mechanical [Silvana Selective/Ford Versatile tractor], motor-manual [clearing/brush saw], helicopter-applied herbicides Release ® [a.e. triclopyr], Vision ® [a.e. glyphosate], and control [no treatment]) in young spruce (*Picea* spp.) plantations (Lautenschlager *et al.* 1997).

Information on the role of forest soil seed banks is limited (Hills and Morris 1992). The purpose of this soil seed bank study was to characterize the seed banks of spruce (Picea spp.) plantations by conifer release treatment as an initial step in understanding the successional dynamics of the applied release treatments. The specific objective was to compare and contrast the species composition in the soil seed banks of areas subjected to different conifer release treatments. These comparisons are completed using standard indices for richness, abundance, diversity, and evenness. These components are explored and their weaknesses discussed.

LITERATURE REVIEW

Plant populations are highly influenced by seed banks following a disturbance such as fire, windstorm, harvesting, or any upheaval that creates gaps or openings in a forest stand. These areas of disturbance are primarily repopulated by plants that come from vegetative propagation, a seedling bank, seed rain, or a seed bank (Kellman 1974). Vegetative reproduction and propagation results from basal sprouting, layering, and root suckers (Zasada 2000). The normal process for seedling establishment is shown in Figure 1.

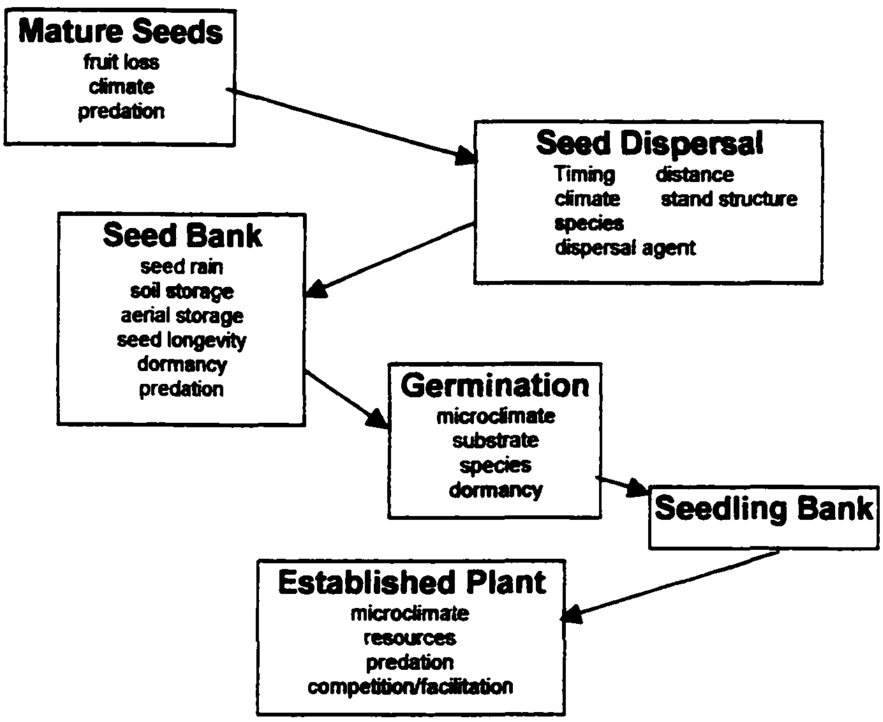


Figure 1. Seed process for seedling establishment (adapted from Zasada 2000).

Ideally the mature seed disperses to the seed bank and germinates into the seedling bank resulting in an established plant. In nature this process is full of obstacles such as predation, unacceptable environmental factors, timing *etc.* (Figure 1). A seed bank is a reservoir of ungerminated seed with the potential of replacing mature plants (Leck *et al.* 1989). It comprises all the seed on or in the soil and the associated litter. Seed banks are generally divided into two types: transient (seeds that germinate within a year of dispersal) or persistent (seeds that remain in the soil more than a year (Thompson and Grime 1979; Grime 1981; Simpson *et al.* 1989; Houle and Payette 1990, 1991; Hills and Morris 1992). Seed banks on a microsite are a source of continuous propagules that ensure the site potential is utilized (Kellman 1974). Survival of seeds and varying seed rains (seed dropped to the seed bank by: the parent plant, the fruit eating animals, the wind *etc.*) result in a difference between the species of the present vegetation and the species of the seed bank (Johnson 1975; Nakagoshi 1984). Not all seed deposited to a seed bank germinate. Noticeable seed loss results from predation, decomposers, natural loss of viability, destruction and even genetically controlled resistance to germination (Bewley and Black 1985; Priestley 1986). In the final analysis, dispersal, predation and all the other factors influencing fecundity or abundance and productivity become important only if the adult plant population is below the level dictated by site limitations and /or density-dependent mortality (Harper 1977). Figure 2 shows a model of the seed bank detailing the seed input and output.

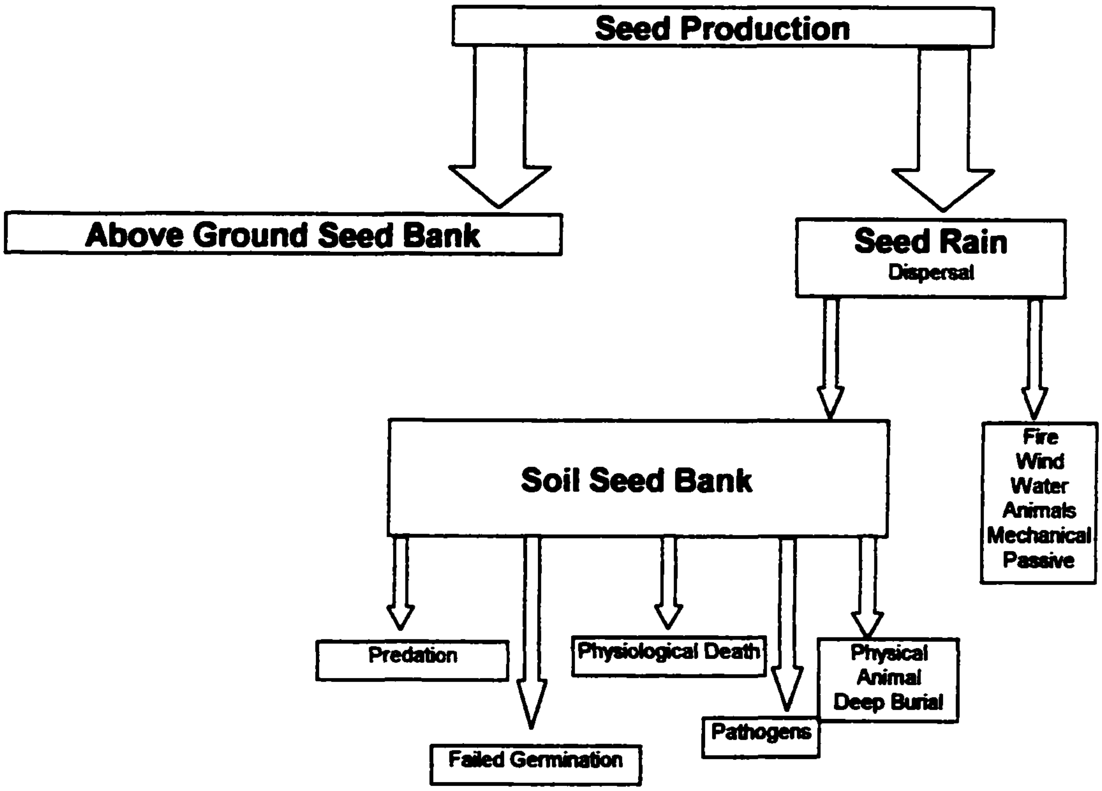


Figure 2. Model of a soil seed bank input/output (adapted from Simpson *et al.* 1989).

SEED ECOPHYSIOLOGY IN RELATION TO SEED BANKS

Seed ecophysiology revolves around germination and seedling establishment (Farmer 1997). There are four factors that influence germination:

1. dormancy,
2. temperature
3. light, and
4. age.

Dormancy

There are viable seeds that will not germinate even when supplied with oxygen, water, and the ideal temperature. Dormancy characteristics of seed are thought to be an evolutionary design to match germination with the suitable environment for seedling establishment. Farmer (1997) classifies dormancy in the following three ways:

Conditional dormancy, where species-specific seed will germinate given water and oxygen but only under certain environmental conditions; most of the North American tree species are conditionally dormant.

Primary dormancy, where a conditioning environment is required before the seed will germinate; this dormancy is usually caused by a seed coat that restricts imbibition of water until a physical or chemical treatment has affected the seed coat to allow imbibition. In nature, North American tree seeds overcome primary dormancy through their length of stay on the forest floor or in the soil. This is usually over winter, which provides a chilling environment after the seeds imbibition. This process is known as moist stratification (3 ° C for 30 to 60 days) and is a common artificial practice used to break primary dormancy.

Morphological or physiological dormancy classifies seed dormancy by the morphological or physiological factors, caused by characteristics such as seed coat impermeability and embryo development. Generally seeds with hard seed coats have a long viability period (Bass 1980; Priestley 1986).

Many seeds exhibit annual dormancy/nondormancy cycles (Vleeshouwers *et al.* 1995; Farmer 1997). For example summer annuals, which germinate only in the spring, become nondormant during the winter and germinate in the spring only if the required environmental conditions (light and moisture) are met. Seeds that fail to germinate because of environmental limitations reenter dormancy in late spring or early summer and become nondormant the following spring (Courtney 1968; Baskin and Baskin 1980). Baskin and Baskin (1986) also found that nondormant annuals subjected to low winter temperatures could be induced to dormancy. Some seeds can be conditionally dormant initially and then become nondormant and exhibit the cyclic conditional dormancy/nondormancy state (Baskin and Baskin 1981a; Roberts and Neilson 1982; Bouwmeester and Karssen 1992). There are other seeds in seed banks that are conditionally dormant that may become and remain nondormant (Baskin and Baskin 1985; Baskin *et al.* 1987). There are also seeds (*Populus* spp, *Salix* spp.) that when they are nondormant they either germinate or die [Zasada (in litt.,05, May 2002)].

The varied dormancy characteristics of seed are considered to be the major factor in influencing germination (Angevine and Chabot 1979; Farmer 1997). Also, with the complexity involved, all seeds of one species may not behave alike and the collective responses of different species in a community have an even greater variability (Leck *et al.* 1989).

Temperature

A chilling temperature on imbibed dormant seed results in the seed being capable of germinating (Farmer 1997). This does not mean all seeds respond the same way. Some seed develop the capacity to germinate at low temperatures and then progressively higher temperatures with time (Farmer 1997). Also some species require multiple chilling periods separated by warm periods before germination will take place. Thus temperature acts as both a germination condition and as a conditioning agent. For freshly dispersed seed, when the temperature is high and the conditions are right, germination will take place; if the temperature is low it causes conditioning through chilling.

Light

Light is not essential for germination but in nearly all cases germination is promoted when light is present (Baldwin 1942; Farmer 1997). This positive effect is also more noticeable with an increase in temperature (Farmer 1997). The lack of light allows for nondormant seeds to remain viable in the seed bank until their light requirement is met (Baskin and Baskin 1983a, 1983b, 1984, 1985). On the other hand, some seeds undergo annual changes in which they are capable of germinating in the dark during the winter but require a high temperature. In the summer they lose the ability to germinate in the dark but still require a high temperature to germinate (Baskin and Baskin 1980, 1981a, 1981b). Thus the photoperiod seems to be ecologically important in reducing fall germination (Bevington 1986).

Sunlight filtered by leaves is known to have a lower red/far-red photon flux ratio than unfiltered sunlight (Smith 1982). Numerous studies (Leck *et al.* 1989) have shown that leaf-filtered sunlight inhibits germination of nondormant seeds. Thus germination inhibition through the effect on the red/far-red photon flux ratio would be alleviated with leaf abscission.

Age

Seed aging is defined as the progressive deterioration of the functions and structures of the seed over time (Mohamed- Yasseen *et al.* 1994). The number of viable seeds decreases exponentially with time at different rates for different species and even within species (Roberts 1962).

Aging does not in itself cause death, but it increases the probability of death by decreasing resistance to a variety of stresses (Mohamed- Yasseen *et al.* 1994). Should a seed survive predators, molds, *etc.*, it could still fail to germinate from a loss of metabolic capability, resulting in seed death (Farmer 1997). The degeneration or deterioration results from the wear and tear that accumulates over time (Leopold 1975; Nooden and Leopold 1978). More moisture and higher temperature (singly or in combination) will result in a shorter longevity of the seed (Roberts 1973). Species that are most likely to die of old age are the ones of limited viability (*e.g.*, *Populus* and *Salix*), seeds with complex dormancy requirements that prevents germination (*e.g.*, *Fraxinus*) and seeds with highly protective seed coats (*e.g.*, *Prunus*) (Farmer 1997).

SEED BANKS AND VEGETATION PROCESSES IN CONIFEROUS FORESTS

The general consensus is that the species composition of seed banks and the present vegetation differ considerably. The successional stage, ground cover, and the measurement of species in both richness and diversity influence the results.

Successional Stages

Leck *et al.* (1989) suggests that annuals and perennials make different contributions to the seed bank. The soil seed bank of annuals is considered to be disproportionately represented by the species that were highly successful or had good years. Conversely, the seed bank of perennials will be made up of the more persistent species.

Soil seed banks differ from the standing vegetation at the site (Pickett and McDonnell 1989; Numata *et al.* 1964). These studies found seed banks contained species from earlier and later successional stages but did not contain all of the species of the present stage. The general consensus is that species composition of soil seed banks and the present vegetation differ considerably; this is well documented for deciduous forest seed banks (Oosting and Humphreys 1940; Livingston and Allessio 1968; Brown and Oosterhuis 1981; Hill and Stevens 1981; Fenner 1985; Nakagoshi 1985). It seems that only in repeatedly disturbed cultivated fields does the present vegetation and the seed bank composition match (Jensen 1969; Wilson *et al.* 1985). Species that are excluded from the mature coniferous forest because of unfavorable growing conditions are usually represented in the soil seed bank (Archibold 1989).

Ground Cover Restrictions

The abundance of plants can be restricted by environmental factors (Harper 1977). Ground cover has been shown to be a major component in restricting seedling emergence (Putwain and Harper 1970; Gross and Werner 1982; Reader and Buck 1986). Four mechanisms have been suggested as to why ground cover restricts seedling emergence:

1. Restriction of light and temperature requirements (Rice 1985; Keizer *et al.* 1985).
2. Ground cover that inhibits seed germination by changing the soil chemistry (Werner 1975).
3. The physical barrier to shoot extension from ground cover on germinating seeds (Sydes and Grime 1981).
4. Reduced seedling emergence by removing seeds because of groundcover providing a habitat for seed predators (Reader 1991).

Species Abundance, Diversity and Richness

The spatial pattern is an important characteristic and fundamental property of ecological communities (Connell 1963). One of the most obvious parameters for ecological community data is abundance. Abundance is based on the number of individuals per species. With a large sample of species abundances, the data can be summarized in a variety of ways to help examine relationships between abundance and the number of species having that abundance and the impacts of various treatments on the abundance. Frequency distribution can be determined, abundances can be plotted in order of its rank from the most to the least (rank abundance diagrams) and when species abundances are summarized these ways, certain patterns emerge (Ludwig and Reynolds 1988). All of this is important in order to test hypotheses about the underlying organization or effect of treatments on the ecological community. Three measures are commonly used to describe the variety of species:

1. Species richness or species density: the count of the number of species occurring in a given region or area.
2. Species diversity: includes the abundance of species.
3. Species evenness: is a measure of how similar the abundances of different species are.

Abundance is simply a count of the total number of individuals in the sample. Diversity accounts for the number of species and the number of individuals per species. Diversity indices can be used to characterize species abundance relationships in communities (Ludwig and Reynolds 1988). Diversity indices vary from a minimum, when all the individuals present in a community belong to a single species, to a maximum where all individuals belong to different species (Shafi and Yarranton 1973). But the range of diversity indices and models that go beyond species richness is evidence of the importance of information on the abundance of species.

Species richness is a comprehensible diversity indicator. It appeals to ecologists as long as care is taken with sample size (Magurran 1988). Species richness represents the number of species occurring in a habitat or in a defined sampling unit (Grassle *et. al.* 1979; Magurran 1988). Generally, species richness increases with sample size. Kempton (1979) states that the species abundance distribution is usually a more sensitive measure for environmental disturbance than species richness alone. Magurran (1988) further states that stressed communities are characterized by a change in species abundance. Therefore the measurement of the effect of silviculture treatments and or harvesting or environmental monitoring of plant communities must include a measure of species abundance.

Diversity indices allow for comparisons between two habitats, before and after treatments, before and after disasters, *etc.* Factors affecting species diversity are:

1. time,
2. spatial heterogeneity,
3. competition,
4. predation,
5. environmental stability, and
6. productive habitats (Farmer 1997).

Generally, ecologists recognize three levels of diversity:

1. Alpha - the number of species that live in a homogenous habitat. The size of the habitat influences the number of species because of the species-area relationship *i.e.*, species richness and diversity can increase with sample size (Magurran 1988).

2. Gamma - the number of species that live in a heterogeneous region. Region is a broad area that has similar climatic and topographical features but may have different habitats. Within the region organisms are adapted for the general conditions, but within different habitats they may have specialized to exploit different resources. The species may be different among habitats (Magurran 1988).
3. Beta - the species turnover in a heterogeneous region. It is very difficult to measure beta diversity, but it can be estimated by simply dividing gamma diversity by alpha diversity. When the same species are found in all habitats of a region then gamma diversity equals alpha diversity and the beta diversity will be 1. Increasing the turnover increases the beta diversity because gamma diversity is increasing. Gamma diversity can never be less than alpha diversity (Whittaker 1977).

When measuring diversity (whether it is alpha or gamma) we need to take the abundance of species into account (Whittaker 1977). There are numerous mathematical expressions for diversity that take both into account. Some of the more common indices are:

1. Margalef's - Although this index is based on species richness, it doesn't have as much information in it as the others. Its ease of use makes it possible to use summary data recorded by other people to compare values (Magurran 1988: Ludwig and Reynolds 1988).
2. Menhinck - This index is similar to Margalef's and is also based on species richness.

3. Shannon - Shannon Diversity Index (also known as the Shannon-Weaver or Shannon-Wiener Index) is based on probabilities. It measures the average degree of uncertainty of predicting the species of a given individual picked at random from a community. The index varies from 0 for communities with only a single species to high values for communities having many species, each with a few individuals (Smith 1986; Barbour *et. al.* 1987; Ludwig and Reynolds 1988). This index is very similar to Simpson's Index except for the underlying distribution. This index assumes that the habitat contains an infinite number of individuals.
4. Simpson – This index is really two indices: Simpson's Dominance and Simpson's Diversity. Simpson's Dominance assumes that the proportion of individuals in an area adequately weights their importance to diversity. That is, the index assumes that the probability of observing an individual is proportional to their frequency in the habitat. This index goes from zero to the total number of species. An index of one indicates that all of the individuals in the area belong to a single species, and when $D = S$ then every individual belongs to a different species. It is the probability of drawing a pair of individuals of the same species (Ludwig and Reynolds 1988). The Simpson Dominance Index measure of diversity is sensitive to the abundances of the 1 or 2 most common species of a community and can be regarded as a measure of "dominance concentration". The Simpson Diversity Index (which ranges from 0 to 1) is most appropriately

used when the relative degree of dominance of a few species in the community is of primary interest, rather than the overall evenness of the abundance of all species. Thus the index varies inversely with heterogeneity *i.e.* index values decrease (or increase) as diversity increases (or decreases).

5. Pielou –The Pielou index is a measure of evenness. Incorporated within the dual-component concept of diversity is the feature concerning the evenness with which individuals are distibuted among the species present (Smith 1986; Barbour *et al.* 1987). This component, termed equitability is independent of the first component, species richness. The quantity of evenness is also referred to as homogeneity or relative diversity. It is a measure of how similar the abundances of different species are. When there are similar proportions of all species then evenness is at a maximum (one) and decreases towards zero as the relative abundances of the species becomes unequal (Ludwig and Reynolds 1988). When the abundances are very dissimilar (some rare and some common species) then the value also increases above zero.
6. Sheldon – This index also relates to evenness. The Sheldon Evenness index (Ludwig and Reynolds 1988) is an exponentiated form of the Pielou Index.

FOREST MANAGEMENT AND SOIL SEED BANKS

Soil and stand disturbances that increase light are likely germination stimulators (Farmer 1997). Fire, harvesting, mechanical site preparation, and vegetation management all have effect on the forest floor.

Undisturbed Forest Floor

To successfully regenerate from seed, the majority of seedlings are dependent on the local cover of the established vegetation being disturbed, and is partly due to their small size relative to the established plants (Grubb 1977). If temperature and moisture conditions are suitable, all tree species seed will germinate on the floor of mature undisturbed forests. An exception is pin cherry (*Prunus pensylvanica* L.), which requires a disturbance to germinate from the seed bank (Farmer 1997). The actual establishment of a seedling is further controlled by the interaction of the forest floor seedbed condition or litter type (Ahlgren and Ahlgren 1981) and shade tolerance of the species (Farmer 1997). Schupp (1995) describes the seed-seedling requirements as "concordant" when the regeneration niche is suitable to both and "discordant" if the requirements differ.

Farmer (1997) describes the components of a seedbed or regeneration niche to include:

- moisture holding and delivery capacity,
- temperature and light requirements,
- mineral nutrient availability,

- chemical status,
- root penetration ability, and
- predation susceptibility.

Mineral soils are more reliable in delivering water to seed than litter and it also provides anchorage for radicles (Farmer1997). This in turn means that small germinants in the litter have a low probability of survival and a higher probability of surviving in mineral soil. Therefore higher species diversity can be expected in forest gaps where mineral soil has been exposed and light increased as opposed to the undisturbed forest floor (Farmer1997).

In the coniferous boreal forest, seeds tend to fall into well-aerated, thick, partially decomposed feather mosses and leaves. Generally the cool climate of the boreal forest causes the coniferous litter to accumulate (Farmer 1997). These deep LFH layers limit seedling establishment by providing a barrier to seedling establishment (Moore 1926; Farmer1997). Litter disturbance or site preparation techniques enhance seedling establishment by reducing this barrier; however, some studies have found that seedlings readily established themselves through pine litter of depths up to 4 cm (Gemmer 1941; Liming 1945; Grano 1949) providing the radicles are able to establish in favourable mediums before desiccation occurs (Pomeroy 1949; Cain 1991; Shelton 1995).

Spruce seed establishment is limited after 5 cm of undecomposed litter, while 7 cm is the maximum for fir seed (Place 1955). Boreal hardwoods and mixed woods have LFH layers that are generally thinner or nonexistent whereas the L layer dominates in broadleaf stands with balsam fir (*Abies balsamea* [L.] Mill.) easily establishing on these sites; spruce is less frequent but not uncommon. This advance regeneration may be considerably reduced after conventional harvesting (Harvey and Bergeron 1989). Sparse hardwood litter (areas with less than 25% leaf litter cover) had better seedling survival than areas with more leaf litter cover (Davis and Hart 1961). The depth of soil disturbance (*e.g.*, burning, removal, or redistribution of the forest floor) is directly correlated with the species established from the soil seed bank (McGee and Feller 1993). Studies in mid-United States on old-field locations have shown species richness and density to decline with the increase in time (more than 5 years) since disturbance (Oosting and Humphreys 1940; Livingston and Allessio 1968; Roberts *et al.* 1984; Numata *et al.* 1964). The highest seed density of common secondary species in coastal British Columbia, eastern Oregon, New Brunswick, and central Idaho was found in the 0 to 5-cm layer of organic soil (Kellman 1970; Strickler and Edgerton 1976; Moore and Wein 1977; Kramer and Johnson 1987).

Post-harvest seed bank studies on coniferous and mixedwood forests in British Columbia, New Brunswick, Ontario, Central Idaho, and Sweden showed both a decrease in species richness and seed density with increase in depth of organic soil (Moore and Wein 1977; Granstrom 1982; Kramer and Johnson 1987; Archibold 1989; McGee and Feller 1993; Qi and Scarratt 1998).

The density and species richness of the soil seed bank is highly influenced by soil characteristics (Cavers and Benoit 1989). Clay soils in Finland showed a higher frequency of Nipplewort (*Lapsana communis* L.); in peaty soils sedges (*Carex* spp.) were dominant (Paatela and Ervio 1971). Moore and Wein's (1977) study in New Bruswick showed the highest number of viable seed in the deciduous-dominated forest, decreasing in numbers in the conifer-dominated forest and decreasing even more in the organic sites. A study in Alaska showed spruce and green alder seed occurring only in the organic layer of the undisturbed forest, while sedge was found in both the organic and mineral layers (Conn *et al.* 1984). These differences in seed banks results from weed soil/site preferences (Cavers and Benoit 1989).

Fire Disturbance

Fire is the major natural disturbance throughout the coniferous and boreal forests (Archibold 1989; Johnson *et al.* 1998). The boreal forests of Canada are estimated to have a fire frequency of 50 to 100 years (Heinselman 1973; Van Wagner 1978; Zackrisson 1977). Virtually all areas in the boreal forest have burned at least once in a 300 to 400 year period (Johnson *et al.* 1998), thereby limiting old-growth forests (older than 200 years) to less than five to ten percent of the landscape (Johnson *et al.* 1995).

The impact of fire on the forest floor is dependent on the amount and type of fuel, burning conditions, structure and composition of the overstory (Farmer 1997). Depending on the intensity, frequency and depth of burn, competing vegetation will either increase or decrease immediately following the burn (Van Wagner 1983; Farmer 1997). One study of a formerly conifer dominated system and a system formerly dominated by broadleaf species showed nearly identical species composition before and after a fire (Ohmann and Grigal 1979). Fire can decrease the litter layer, improve moisture conditions, increase light and soil temperature and provide increased nutrients and an increased soil pH (Farmer 1997).

Often the first plants to establish following fire are the opportunistic species. These species are characterized by their ability to produce numerous readily dispersible seeds (Archibold 1989). However, it is also possible that the heat of the fire or the ash content of the soil can stimulate or inhibit germination of certain species (Ahlgren 1960). Ahlgren (1960) found that the majority of seed reproduced species was most prominent on the moist, severely burned sites where vegetatively reproduced species were killed by fire and subsequent moist conditions favoured seed germination.

Rowe (1983) recognizes five groups of species that have developed fire survival strategies in northern coniferous forests:

1. shade-intolerant invaders; these produce numerous wind dispersed propagules that establish quickly on burned sites.
2. evaders; these store seed in the canopy, duff or mineral soil. Within the evaders are the shade intolerant evaders that have rapid germination and the late successional perrennial evaders that accumulate in the soil. The evaders are well represented in the seed bank especially in areas with short fire cycles.
3. avoiders; these are late successional species that only establish from dispersed seed under ideal environmental conditions.
4. resisters; these are shade intolerant species whose mature plant stage can survive low severity fires.
5. endurers; are those species that can regenerate through sprouting.

Few species in coniferous forests depend on the soil seed bank for regeneration. Thus on a world scale, the coniferous forest soil seed bank is considered small (Archibold 1989).

Many seeds are tolerant to heat (Daubenmire 1968) and if covered even slightly with soil, they can survive an intense fire. Other aspects of regeneration involving the response to fire are species specific and highly specialized such as species that are dependent on fire for seed dispersal (Kozlowski and Ahlgren 1974; O'Dowd and Gill 1984), germination and establishment (Hartesveldt *et al.* 1969), and/or seed bank formation (Wellington and Noble 1985). Frequency and timing of fire also affects regeneration of certain species (Wright and Klemmedson 1965).

At climax, when the vegetation is at equilibrium with the environment and therefore stable, diversity should be high. Species diversity is considered the product of a stable environment and therefore only in environments not subjected to frequent catastrophic events [every part of the boreal forest clay belt has burnt within the last 140 years (Maclean and Bedell 1955)] are evolutionary pressures such that high diversity can evolve (Loucks 1970). Environmental stability allows the evolution of community diversity and subsequently community stability. Thus communities are expected to show an increase in stability with succession. Some authors noted an increase in ecological diversity from the poles to the tropics where the polar successions are arrested by environmental catastrophes such as fire (Shafi and Yarranton 1973). Thus diversity following fire could be considered the base line in the boreal forest and subsequent community variations from the base line with succession would lead to stability and an even composition. Therefore forest management practices that emulate fire are a more natural management approach in the order of succession than conventional harvesting.

Harvesting

Conventional clear-cut harvesting (removal of all merchantable timber) of the forest dramatically alters the forest floor but unlike with fire, not all the seeds are removed from the site. There is some removal of forest tree seeds during harvesting but most are broken off during the process and left on site. The main environmental changes on the forest floor following a conventional harvest are the changes in the radiation balance and energy budget, increased air movement and fluctuations in surface water (Farmer 1997). Because the litter layer remains relatively intact, the natural seeding of conifers and light-seeded hardwoods into clearcuts is usually not successful. A seed bank study in Ontario boreal mixedwoods (Qi and Scarratt 1998) looked at harvesting methods and found low conifer seed frequency in both the seed rain and seed banks and high densities of white birch (*Betula papyrifera* Marsh.) seed in both the seed rain and seed bank following conventional harvesting.

In areas where there is mineral soil exposure, vegetative competition develops rapidly from residual plants, sprouts, and seed banks. Johnson (1975) found that vegetative reproduction or rapid germination of seed was an adaptation in plants that have to establish during a brief growing season.

Mechanical Site Preparation

In many species-rich plant communities, co-existence is possible because each species is adapted to exploit a different type of habitat disturbance. Thus, where the management objectives are to enhance or maintain species diversity, it may be necessary to apply a variety of disturbance regimes to the site (Grime 1981). Additionally, the number of viable seeds on farmland declined with time and intensity of disturbance (Roberts and Dawkins 1967). Granstrom (1987) estimated that the rate of decline was several percent a year, on his study of 14 species over a five-year period on forest soil.

Some studies have examined the vertical distribution of seed in the soil seed bank (Kellman 1970; Strickler and Edgerton 1976; Moore and Wein 1977; Granstrom 1982; Pratt *et al.* 1984; Krammer and Johnson 1987; Fyles 1989; Qi and Scarratt 1998). The majority of studies identified the seed deposition based on the organic and mineral soil layers and not on depth or positioning. Seedling emergence decreases with depth of burial (McGee and Feller1993; Qi and Scarratt 1998). Thus site preparation or mixing of the mineral soil will expose some seeds and also bury some seeds to a point where successful germination is not possible.

In north-central British Columbia study, Mackinnon and McMinn (1988) observed that site preparation which removed only the vegetation layer resulted in a poorer seed bed for the regeneration of birch (*Betula spp.*) and willow (*Salix spp.*) compared to mechanical site preparation which exposed mineral soil. Sutherland and Foreman (1995) also found similar results. Removal of the organic layer during site preparation will enhance germination of the deeply buried seeds (Qi and Scarratt 1998).

However, the resurgence of vegetation following a disturbance is usually due to vegetative reproduction (sprouts, layering, underground stems, and root suckers) and not reproduction by seed (Bell 1991). Localized removal of vegetation in narrow strips or patches and exposing the mineral soil through removal or mixing with the organic layer results in a different species composition on the disturbed site as compared to the pretreatment vegetation (Bell 1991). Extensive removal of subsurface vegetation where large areas of mineral soil are exposed through heavy site preparation such as dozer blading, (*i.e.*, passing a bull dozer back and forth over the land base with specially made blades such as angle blades or shear blades and shearing off the vegetation and some of the litter layer to expose mineral soil), are soon occupied by pioneer species that arise from seed (Sutherland and Foreman 1995) and from vegetative reproduction of species already present on the site. Scarification may also release unwanted vegetation such as the large seed reserve of graminoids usually found in mineral soil (Qi and Scarratt 1998). Thus artificial crop tree planting should take place as soon as the scarification is completed to allow the seedlings to become established prior to the ingrowth of graminoids from the seed bank. However, where disturbance has caused the removal of surface organics, *e.g.*, recreational disturbance through paths or compactions such as play areas, the species in the soil seed bank can be adversely affected through the decrease in the density of the vegetation on site (Zabinski *et al.* 2000) and a loss of seed entrapment surface area which subsequently determines if the seed is dispersed by wind, water or entrapped (Chambers *et al.* 1991; Chambers and MacMahon 1994).

Sutherland and Foreman (1995) attempted to predict vegetation response to site preparation or disturbance as shown in Table 1. They considered vegetative and sexual reproduction on all soils, upland mineral soils and on lowland organic soils. Table 1 suggests that the removal of the overstory alone promotes vegetative as well as sexual reproduction on mineral soil; slight screefing (*i.e.*, removal of the litter layer to expose the mineral soil) aids both types of reproduction and disturbance of the mineral soil either screefing or mounding (*i.e.*, scooping a 'chunk' of soil and flipping it over) promotes wind-borne seed reproduction but not seed bank or vegetative reproduction. For organic soils they suggest that drainage through ditching would positively affect vegetative and sexual reproduction.

Studies have shown a correlation between the size of the disturbance and proximity to standing vegetation with seed bank density, *i.e.*, seed bank density declines as distance from established vegetation increases (Ingersoll and Wilson 1993; Zabinski *et al.* 2000). In general, site preparation can promote germination of windblown or seed bank species because of increased light and temperature (Sutton 1985; Kramer and Johnson 1987).

Table 1. Influence of site preparation by microsite on noncrop vegetation (adapted from Sutherland and Foreman 1995).

Microsite Description	Vegetative Reproduction			Sexual Reproduction	
	from shoots	from roots in organic soil	from roots in mineral soil	wind-borne	seed bank
All soils					
Undisturbed mature stand	0	0	0	0	0
Upland mineral soils					
Overstory removed – cutover					
Organic and mineral soil undisturbed	++	+	+	0 to +[a]	+
L layer and part of F layer removed or displaced (shallow screef)	+	+	+	+	++
LFH removed, mineral soil intact (screefed)	-- to –[b]	-	++	++	-
LFH removed, some mineral soil removed (deep screef)	--	--	-- to -[c]	++	--
LFH removed, mineral mound on mineral soil	--	--	-- to -[d]	+	--
LFH and mineral layers inverted (mineral mound on organic layer)	+ to ++	- to +[e]	- to +	+	- to +[f]
LFH and mineral mixed (tilled)[g]	- to +	- to +	- to +	++	++
Lowland organic soils[h]					
Part of Of removed (shearblading)	-[i]	- to +[j]	Not applicable	+	+
Drainage of layer (ditching)	+	+	Not applicable	0	+

+ = promotes (++ = strongly) **0 = no effect** **- = discourages (-- = strongly)**

[a] will promote if organic layer is shallow and/or moist.
[b] control of sprouting is improved for species that tend to root in the organic layer
[c] control of sprouting depends on removal of root systems
[d] control depends on removal of root systems below ground and mineral mound sufficiently deep to suppress sprouting
[e] control of sprouting increases with increased depth of capping
[f] a thin cap of mineral soil encourages germination of seeds in the organic layer; a thick cap discourages
[g] control depends on degree of mix: fine mixing discourages and coarse mixing encourages
[h] Of, Om, and Oh represent fibric, mesic, and humic organic horizons, respectively
[i] will promote *Ledum* and *Vaccinium* species
[j] control depends on degree of removal of root systems and stimulation of residuals

Vegetation Management – Pesticides

The use of herbicides for vegetation management has been and continues to be a contentious silvicultural practice (Smith 1986; Lautenschlager 1993; Wagner 1994; Lautenschlager *et al.* 1997). The use of pesticides has traditionally been applied to suppress early successional vegetation for a period of time in order to ensure survival and growth of forest crop trees (Ogner 1987). Sutton (1984) reported that the summer application of glyphosate at 2 kg active ingredient (a.i.) per hectare resulted in death of herbaceous cover, and an invasion of fireweed the following summer. In contrast, the use of glyphosate on wheat seed did not inhibit germination (Sprankle *et al.* 1975) and was also shown to rapidly become inactive in the soil. Horsley's (1981) study on the effect of bromacil, glyphosate, hexazinone, picloram and simazine applied at four different application rates and five different application dates had no effect on the germination of black cherry (*Prunus serotina* L. fil.) seed that were stored in the forest floor.

SEED BANKING DETAILS

Representations of tree, shrubs, and herbs in numerous seed bank studies have varying results.

Tree Species

Viable conifer seeds are generally absent from seed banks (Farmer 1997). Fraser (1976); Zasada *et al.* (1983); Thomas and Wein (1985); Granstrom (1987) completed conifer seed viability studies with results showing that seeds are transient and germinate or die within 10 to 16 months of dispersal. Conifer seeds are considered to reside for one growing season in the soil seed bank (Frank and Safford 1970). There have also been other reports of low conifer germination numbers (Frank and Safford 1970; Pratt *et al.* 1984; Fyles 1989; McGee and Feller 1993; Qi and Scarratt 1998), but Archibold (1979) found high numbers of white spruce (*Picea glauca* [Moench] Voss) seeds germinating in a Saskatchewan soil seed bank study.

Studies show that *Populus* spp. (Farmer 1997) and *Salix* spp. (Grime 1981) do not store seed in the seed bank. Other studies (Collins 1985; Ahlgren 1979a, 1979b; Archibold 1979; 1980; Granstrom 1987, 1988; Granstrom and Fries 1985) show that red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh), yellow birch (*Betula alleghaniensis* Britt.), white birch, and green ash (*Fraxinus americana* L.) remain in the seed bank for a minimum of three years. In a northern conifer forest study in Maine the tree seedlings that germinated in the first year after a disturbance were predominately birch seedlings (Frank and Safford 1970). The soil samples were further disturbed the second year and germinants included a few birch, but primarily sedge, raspberry and violet (*Viola spp.*). Their study further suggested that seeds of northern conifers do not retain viability in the forest floor longer than one year.

Moore (1926) noted that white spruce requires two years in the seedbed before prolific germination can occur which has been confirmed by more recent studies (Creasey and Myland 1992; Nienstaedt and Zasada 1990). These authors further recommend stratification before artificial seeding. Seed from spruce (*Picea* spp.) is considered short-lived as the seeds normally germinate immediately after dispersal if the germination requirements are met (Qi and Scarratt 1998). Table 2 depicts selected species germination requirements and strategies. The data indicate large seed crops of white spruce, poplar and white birch are produced every two to six years with the hardwoods dependent on current seed crops for seed regeneration.

Species normally not present in the mature coniferous forest are usually evident in the mature coniferous forest soil seed bank, and the opposite is true where the dominant species in the mature forest is usually sparse in its own forest soil seed bank (Kellman 1970). Additionally, species present in the understory of the forest are not well represented in the Boreal mixedwood forest soil seed bank (Qi and Scarratt 1998). This lack of correspondence between the seed bank composition and the existing vegetation is common in many plant communities (Numata *et al.* 1964; Moore and Wein 1977; Piroznikow 1983; Pickett and McDonnell 1989; Coffin and Lauenroth 1989; Ungar and Woodell 1993).

Table 2. Seed germination requirements and strategies of selected species (adapted from OMNR 1998).

Species †	Stratification required yes/no	Optimum Germination Temperature	Periodicity of large seed crops (years)	Seedling Regeneration Strategy	Time of seed ripening	Time of seed dispersal
white spruce	recommended	10°C - 24 °C	2 - 6	current seed crop	Aug. – Sept.	Sept. - Jan
trembling aspen	no	2°C - 30 °C	4 - 5	current seed crop	June	June
white birch	yes	18°C - 30 °C	2	current seed crop	July – Sept.	July –Sept.
wild raspberry	yes (at least 120 days)*	10°C - 25 °C*	annually	soil seed bank- (viable 50+years)**	July - October	July - October
large leaf aster			annually	current seed crop	September	
grasses			annually	soil seed bank	July – Sept.	Aug.-Sept.
sedges			annually	soil seed bank	July – Sept.	Aug.-Sept.

† Scientific names provided in Appendix 1
* Haeussler *et al.* 1990
**Whitney 1982

Shrubs and Herbs

Understory species were not well represented in the northwestern Ontario boreal mixedwood soil seed bank study by Qi and Scarratt (1998). Willowherbs (*Epilobium* spp.), Bicknell's crane's-bill (*Geranium bicknellii* Britt.) and sedges were present in the seed bank but not in the vegetation of this study. Fyles (1989) found similar results in coniferous forest in Alberta in that seeds of red raspberry (*Rubus idaeus* L.), Bicknell's crane's-bill and sedges were present in the soil seed bank but not in the current vegetation. Moore and Wein (1977) found wild red raspberry (*Rubus strigosus* Michx.) to be the dominant species to regenerate from nine soil seed bank study sites ranging from deciduous-dominated forest to bogs. Their study also showed large ungerminated seed reservoirs of birch, especially on the deciduous-dominated forest. Pine (*Pinus* spp.) seed remained in the seed bank at least three years. Other species in the boreal forest are noted for relying on the soil seed bank to establish themselves on the landscape: pin cherry (> 40 years), bush honeysuckle (*Diervilla lonicera* Mill.), dwarf raspberry (*Rubus pubescens* Raf.) and wild red raspberry (Farmer 1997). Most of the seeds germinate in the first growing season after dispersal; the "long term seed bankers" are early successional herbs and shrubs especially wild red raspberry (Farmer 1997). Grasses, sedges and raspberry are seed bankers while the large- leaved aster (*Aster macrophyllus* L.) is dependent on the current seed production (Table 2).

Most of the seed found in studies carried out in the fall and spring are part of the highly transient population in the litter layer and form the long term storage species that are more persistent in the lower mineral layer (Houle and Payette 1990). These seeds are depleted in the spring and summer months through unsuccessful germination, predation, pathogens and viability loss (Farmer 1997).

The varied dormancy characteristics of seed are considered to be the major factor in germination (Angevine and Chabot 1979; Farmer 1997). Also, with the complexity involved, all seeds of one species may not behave alike and the collective responses of different species in a community have an even greater variability (Leck *et al.* 1989). It seems that only in repeatedly disturbed cultivated fields does the present vegetation and the seed bank composition match (Jensen 1969; Wilson *et al.* 1985). Species that are excluded from the mature coniferous forest because of unfavorable growing conditions are usually represented in the soil seed bank (Archibold 1989). This lack of correspondence between the seed bank composition and the existing vegetation is common in many plant communities (Numata *et al.* 1964).

MATERIALS AND METHODS

SITE DESCRIPTION

The study is a component of the Fallingsnow Ecosystem Project, which is located in the Greenmantle Forest, approximately 60 km southwest of Thunder Bay, Ontario (Figure 3). The project is in the transition zone between the Great Lakes-St. Lawrence and Boreal forest regions (Rowe 1972). The objective of the project (started in 1993) was to document the abiotic and biotic (ecological) differences among commonly used conifer release treatments on spruce plantations (Lautenschlager and Bell 1995). Detailed descriptions of the Fallingsnow Ecosystem Project and experimental site are provided in Bell *et al.* (1997). The project area is located at 89° 49-53' West/48° 8-13' North at 380 to 550 m above sea level and is in the Quetico Section of the Great Lakes-St. Lawrence Forest Region (map reference: Ontario Ministry of Natural Resources Provincial Map Series - Thunder Bay NTS 52 A/SW 1:100 000).

Species that are common within the project include: white birch, beaked hazel (*Corylus cornuta* Marsh.), red-osier dogwood (*Cornus stolonifera* Michx.), bush honeysuckle, trembling aspen (*Populus tremuloides* Michx.), pin cherry , bracken fern (*Pteridium aquilinum* (l.) Kuhn), thimbleberry (*Rubus parviflorus* Nutt.), and red raspberry (*Rubus idaeus* L. spp. *melanolasius* [Dieck] Focke).

The project area was dominated by 75- to 101-year-old trembling aspen and was clearcut between 1986 and 1988. Bareroot white spruce and black spruce (*Picea mariana* [Mill.] B.S.P.) were planted three to eight years before the project began in 1993. By 1993, the harvested areas had approximately 1,700-planted spruce/ha, averaging 82 cm in height. The area was dominated by multilevel competing vegetation comprising predominantly trembling aspen, red raspberry, and graminaceous/herbaceous groundcover. The area is representative of site and stand conditions in which release treatments are typically applied in northwestern Ontario (Bell *et al.* 1997). Table 3 gives a brief history of the site by block prior to harvesting and the subsequent treatments following harvest. These blocks were conventionally clearcut between 1986 and 1988 followed by site preparation and planting.

Treatment plots range from four to twelve ha blocks, and plots within blocks, vary in elevation between 380 and 550 m above sea level and occur on a range of topographic positions. The soil is predominately imperfectly drained silty loam. Soil texture ranged from very fine sandy loam to silty clays with poor to excessive drainage and with shallow-to-bedrock areas throughout (Simpson *et al.* 1997).

Figure 3. Map showing the project location (source Bob Sinclair Ontario Forest Research Institute).

Table 3. Fallingsnow Ecosystem Project - Site history (source: Bell *et al.* 1997).

	Block 1	Block 2	Block 3	Block 4
Pre-harvest[2]				
Species[3]	$Po_3Sw_2B_1Sb_1Bw_1A_1$	$Po_6B_2Bw_1Sw_1$	Po_{10}	$Pj_8Po_1B_1$
Study area (ha)	38.0	27.7	52.4	29.3
Age at harvest (yr)	79	101	75	84
Height (m)	22	23	22	21
Stocking (%)	60	70	70	70
Site class[4]	3	3	2	3
Harvest[2]				
Harvest	Winter 1988	Summer 1988	Summer 1986	Summer 1987
Method	Conventional cut & skid	Conventional cut & skid	Conventional cut & skid	Conventional cut & skid
System	Clearcut	Clearcut	Clearcut	Clearcut
Renewal[2]				
Site preparation	1990 – Powered disc trencher 1.8 m between furrows 1991	1989 - Young's teeth (D8) 2.0 m between furrows	1986-Disc trencher & Young's teeth (D8) 2.0 m between furrows	1988-Young's teeth (D8) 2.0 m between furrows
Year planted	Sw - 2+2	1990	1987	1989
Stock planted	Sb - 1 1/2 + 1 1/2 Pj - OW paperpot	Sw - 2+2	Sw - 2+2	Sw -2+2
Survival assessment[2]				
Date	August 1992	October 1992	October 1992	Not assessed
Survival (%)	86	86	86	
Crop ht. (cm)	36	52	86	
Competition (CI)[5]	poplar (600) & mountain maple (142)	poplar (182), willow (27), hazel (26), fireweed (18), raspberry (17), birch (20), maple (14) & grass (10)	poplar (580), willow (73), alder (51), fireweed (20), raspberry (20) & white birch (20)	
Recommendations	Immediate release	Immediate release	Could defer release by 1 year	

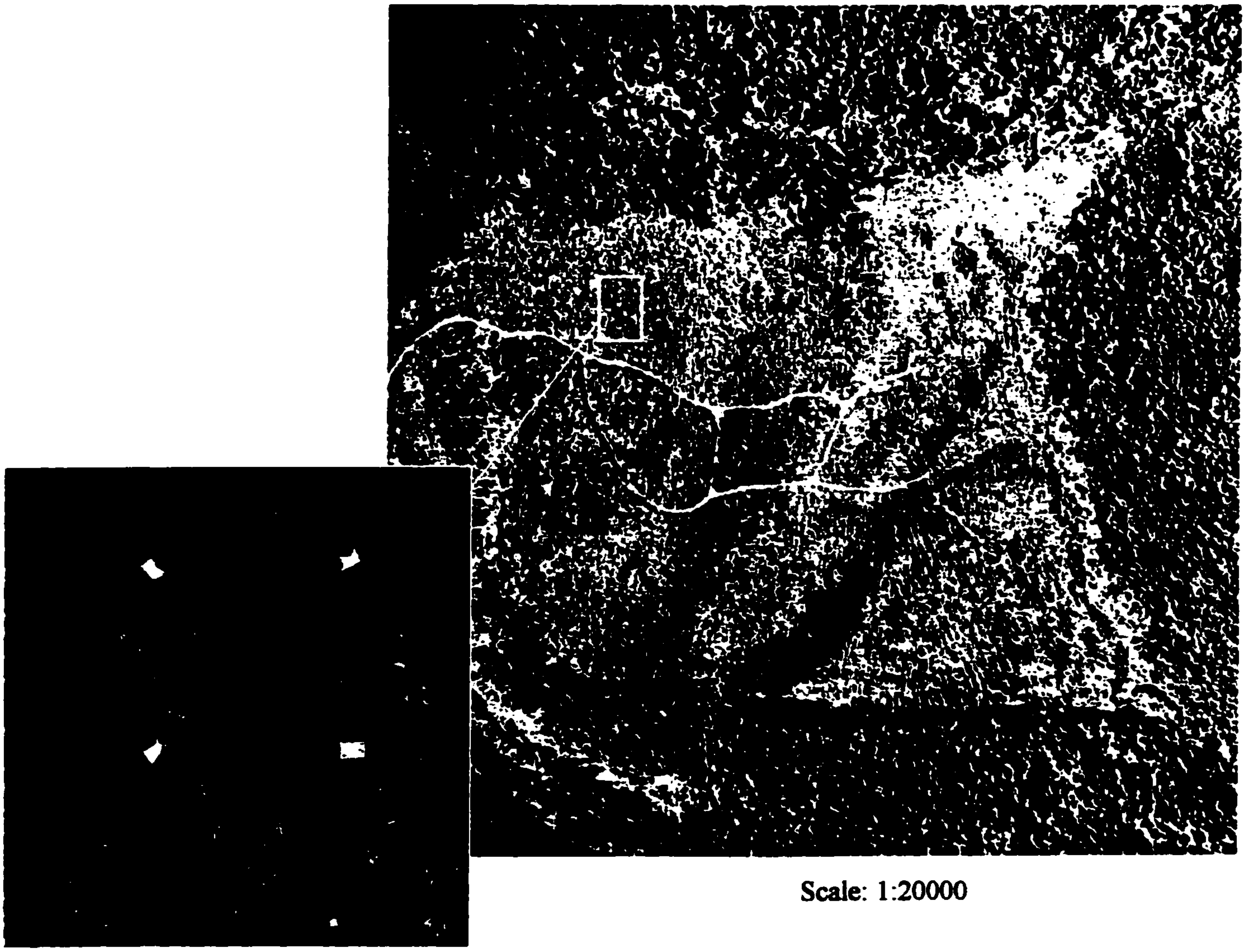
[1] Prepared by: Fred Dewsberry, Ontario ministry of natural Resources.
[2] Source: Thunder Bay Crown Management Unit Forest Resource Inventory and Silvicultural Files
[3] Species abbreviations: A = ash, B = balsam fir, Bw = white birch, Pj = jack pine, Po = poplars, Sb = black spruce, and Sw = white spruce
[4] Site Class is based on Plonski (1981).
[5] CI = Cover (%) x ht (cm)

PROJECT DESIGN

Fallingsnow Ecosystem Project is a randomized complete block design, with four separate 28 to 52 ha blocks of spruce plantations that were four to seven years old when the study commenced. Each block comprises five post-harvest treatments (including untreated) and an adjacent uncut five to ten ha aspen/spruce stand (unharvested forest). The treatments were:

- motor-manual cutting at 18 cm above the ground with brush saws in mid-October 1993 (referred to as Brushsaw treatment);
- mechanical brush cutting at 33 cm above the ground with a Silvana Selective /Ford Versatile tractor in late October to early November 1993. Refer to St.-Amour and Ryans (1992) for a detailed description of the machine and its performance capabilities (referred to as Silvana Selective);
- helicopter application of Release® (a registered trademark of Dow Elanco) at a rate of 1.9 kg acid equivalent (a.e) triclopyr/ha in 31 l/ha solution in August 1993 (referred to as Release treatment);
- helicopter application of Vision® (a registered trademark of Monsanto) at a rate of 1.5 kg a.e. glyphosate/ha in 30 l/ha solution in August 1993 (referred to as Vision treatment), and
- control with no treatments applied in the plantation and adjacent unharvested forest (referred to as Control and Forest treatments respectively).

Eight 10 m by 10 m vegetation plots were established to provide long-term sites for the collection of vegetation data in each of the six treatment types on each of the four blocks in a random stratified manner (192 plots in total). Figure 4 shows a typical vegetation plot of 100 m² (note the white sheets marking each corner) and its location within the block.



Scale: 1:20000

Figure 4. Aerial photos showing a 10m by 10m vegetation plot (corner posts marked with white sheets) and its location within Block 2 (photos courtesy of John Block).

Through time, some plots will be discarded because of unforeseen impacts such as trails, road disturbance, overlapping effects, *etc*. By 1996, there were 191 plots remaining.

Thompson and Grime (1979) recommend that the sampling date for seed bank studies be after the spring germination and before the seed dispersal period of most species. The soil seed bank collection of 191 samples was completed from June 10 to June 28, 1996. At each northwest post of the vegetation plots a number between one and six was randomly chosen to determine the number of meters east that the collection would be taken. At each location a soil core (7 cm diameter with a core depth sufficient to include the organic layer and 10 cm of mineral soil) was collected. The samples were separated into two collection bags; organic LFH material and mineral soil. Every attempt was made to collect from all the variable conditions within each treatment; however, if this was not possible because of rock, stumps, water *etc.* or it was not representative of the treatment area as a whole, the collection was taken at the next possible easterly location. These samples were temporarily stored at –2 °C until a greenhouse was available for growing the samples.

In January 1997, the samples were placed in peat pots 14 cm x 18 cm x 6 cm. The pots were labeled and placed on garden trays in one of Lakehead University's green houses (Figure 5). Peat pots were used as it was felt that some moisture would be trapped in the pots and could be available should the germinants require it.

High-pressure sodium lamps (400-watt) were used to augment natural light to create an 18-hour photoperiod from 06:00 to 24:00 hour. The greenhouse temperature ranged from a nighttime minimum of 21.1 °C to a daytime maximum of 30 °C with an average of 26.7 °C.

The soil seed bank samples were watered on an "as needed basis" keeping the samples moist at all times. The pure clay samples were difficult to keep moist and if after three weeks there was no germination, they were broken up and mixed with sterilized peat to aid moisture retention for germination enhancement.

Figure 5. Soil seed bank samples in greenhouse.

Once per week, for 12 weeks, the number of germinants was recorded by plot number, species, block and treatment. If the germinant was identifiable, it was uprooted to determine recruitment origin, entered into the data and then discarded.

DATA ANALYSIS

Species richness, diversity and evenness by block and by treatment were characterized using Margalef, Menhinck, Shannon, Simpson, Pielou and Sheldon indices (Whittaker 1977; Smith 1986; Barbour *et al.* 1987; Ludwig and Reynolds 1988). These descriptors were all looked at as a tool to describe the overall effect of treatments on the block because when they are used singly they each have their own limitation(s). For example: species richness has the statistical weakness of a potentially large sampling bias (Fisher et al 1941; McIntosh 1967). The large sampling bias results from rare species being absent even in large samples or exhaustive surveys (Ludwig and Reynolds 1988; Lande 1996) also similar diversity index values can be obtained for a community with a low richness and high evenness as for a community with high richness and low evenness and then it is impossible to interpret the relative importance of species richness and evenness (Ludwig and Reynolds 1988). Therefore multiple indices and statistical methods were used to detect if there were treatment differences.

The equation for Margalef's Richness Index is:

$$R = (S-1)/\ln(N) \qquad [1]$$

Where: R = Margalef Richness

S = Total number of *taxa* represented in sample

N = Total number of individuals in sample

Menhinick Richness Index is expressed by:

$$R = S/\sqrt{n} \qquad [2]$$

Where: R = Menhinick Richness

S = Total number of *taxa* represented in sample

N = Total number of individuals in sample

The formula used for the Shannon Diversity Index is expressed by:

$$H' = -\sum_{i=1}^{S} (p_i)(\log 2\, p_i) \qquad [3]$$

Where: H' = Shannon Diversity

S = number of species

p_i = proportion of individuals of the total sample belonging to the *i*th species calculated as *ni*/N for each *i*th species with *ni* being the number in species *i* and N being the total number of individuals in the sample.

Simpson's dominance is expressed by:

$$\lambda = -\sum_{i=1}^{S} p_i^{\,2} \qquad [4]$$

Where: λ = Simpson's dominance

S = number of species

p_i = proportion of individuals in sample that belong to the *i*th species calculated as *ni* /N

Where: ni = individuals/species

N = sample size (total number of individuals)

As formulated above, Simpson's diversity is then derived from:

Simpson's Diversity = 1/ Simpson's dominance [5]

The Pielou Evenness Index is expressed by:

$$E = H'/\ln(S) \qquad [6]$$

Where: E = Pielou Evenness index

H' = Shannon Index

ln (*S*) = natural log of the number of species

The Sheldon Evenness Index is expressed by:

$$E = e^{H} / S \qquad [7]$$

Where: E = Sheldon Evenness Index

H' = Shannon index

S = number of species

Differences in species richness, diversity and evenness among blocks and among treatments were determined by analysis of variance (ANOVA) at a 95% confidence level with a model that is appropriate for a randomized complete block design (Steele and Torrie 1980). Residuals were examined to verify that the assumptions of homogeneity of variance and normality were met which resulted in the data being reexpressed to a log 10 scale. Often the simplest explanations of the patterns seen in the ANOVA table do not completely describe the important features of the data. Thus box plots were created using Data Desk 6 (Data Description Inc.1997) to discern patterns/relationships among treatments and among blocks. The box plots display the variability across groups (Data Description Inc. 1997). Box plots are described by the median and hinges of a collection of numbers (Data Description Inc. 1997). The hinges are the medians of the data from the minimum to the median (like a 25th percentile) and of the data from the medium to a maximum (like a 75th percentile). The "box" in a box plot encloses the low point (approximately 25%) to the high point (approximately 75%) of the medians of the data. The horizontal line across the box marks the median. The shaded area represents 95% confidence interval for comparing medians and is placed symmetrically around the median at;

Median $\pm$ 1.58 (high hinge – low hinge) $\sqrt{n}$. [8]

Boxplots were used because of their ability to visually depict differences by showing:

1. differences among medians (shown with a bar across the box),
2. differences in the overall level of the boxes, and
3. differences in the spread through the size and extent of the boxes and of the whiskers (distantly connected data) and the outliers.

Orthogonal comparisons were completed using SAS (SAS Institute 1982). In addition the number of germinants by species by sample was determined to give a percent species frequency of occurrence by treatment.

Species rank abundance diagrams were completed for each block and for all blocks combined. With the relative abundance plotted by block and by treatment characteristic patterns emerge. The species germinated in each treatment were ranked according to their abundance and graphed to give a visual representation of the data as opposed to an index value. The number of germinants by species was used as abundance and expressed in a log 10 scale.

Post hoc tests *i.e.*, LSD, Duncan and Bonferroni for comparing treatment means within and between blocks (Steel and Torrie 1980) were performed using Data Desk 6 (Data Description Inc.1997) and SPSS/ PC 6.1 software (Norusis 1992).

Orthogonal comparisons of richness, abundance and log 10 richness were used to help determine if the treatments were different and if combinations of the treatments were different. Restrictions for the orthogonal comparisons (Zar 1984) were met and the analyses were run in SAS. With five degrees of freedom for this study, five independent comparisons could be completed. The choice of comparisons was based on;

1. comparisons of treatments with similar modes of action,
2. treatments that are contentious issues in forest management such as the use of herbicides (Wagner 1994; Decision Research 1995), and
3. the treatments with a poor public image *e.g.* harvesting

The treatments compared were;

1. Brushsaw vs. Silvana Selective;

2. Vision vs. Release;
3. Cut (Brushsaw and Silvana Selective) vs. Herbicide (Vision and Release);
4. Treated (Brushsaw, Silvana, Vision, Release) vs. Control (untreated cut over and Forest); and
5. Forest vs. Cutover (untreated cut over, Brushsaw, Silvana Selective, Release, and Vision).

Appendix V shows the data, SAS algorithm and the results for the orthogonal comparisons.

RESULTS

SPECIES RICHNESS

Of the 2263 germinants grown in this study, 57 % were identified as one of 34 species, an additional 40 % were identified to one of two families (*i.e*., grasses or sedges), and only 3% were unidentified (Table 4). Grasses, sedges and four other species were common to all treatments: northern willow herb (*Epilobium ciliatum* Raf. spp. *gladulosum* [Lehm.] Hoch & Raven), red raspberry, Bicknell's crane's-bill and wood strawberry (*Fragaria vesca* L. spp. *americana* [Porter] Staudt). Five species were common only to the clearcuts: panicled hawkweed (*Hieracium paniculatum* L.), common dandelion (*Taraxacum officinale* G. Weber), large leaved aster, field pussytoes (*Antennaria neglecta* Greene), and fireweed (*Epilobium angustifolium* L.). Other species that were observed, but were not strongly associated with any treatment included: common yarrow (*Achillea millefolium* L. spp. *Millefolium)*, upland white aster (*Solidago ptarmicoides* [Nees] B. Boivin), small white aster (*Aster lateriflorus* [L.] Britton *var. lateriflorus)*, pearly everlasting (*Anaphalis margaritacea* [L.] Benth. & Hook. F. ex C.B. Clarke), white birch, ox –eye daisy (*Chrysanthemum leucanthemum* L.), Canada thistle (*Cirsium arvense* [L.] Scop.), rough avens (*Geum laciniatum* Murray), stiff marsh bedstraw (*Galium tinctorium* L.), white sweet –clover (*Melilotus alba* Medik)., trembling aspen, tall buttercup (*Ranunculus acris* L.), cow vetch (*Vicia cracca* L.), sweet white violet (*Viola blanda* Willd.), spotted touch -me –not (*Impatiens* *capensis* Meerb.), upright yellow wood –sorrel (*Oxalis stricta* L.), shrubby false -indigo (*Amorpha fruticosa* L.), downy rattlesnake plantain (*Goodyera pubescens* [Willd.] R. Br.), wild strawberry (*Fragaria virginiana* Miller spp. Virginiana), common evening – primrose (*Oenothera biennis* L., *Coptis trifolia* [L.] Salisb.), field bindweed (*Convolvulus arvensis* L.), wild sarsaparilla (*Aralia nudicaulis* L.), and old –field cinquefoil (*Potentilla simplex* Michx.). The greatest number of species germinated was observed in the Silvana Selective treatment followed by, in descending order, the Vision, Release, Brushsaw, Control and Forest treatments (Table 4).

Table 5 depicts the species frequency of occurrence by treatment for the core samples. The percentage is based on 191 of samples. Overall, the northern willow herb occurred the most often in the total samples, grasses occurred 31% of the time with a 50% occurrence in the release treatment. Red raspberry had a 15% total frequency of occurrence and a 20% occurrence in the Control treatment. Large leaf aster was 18% in the Vision treatment and white birch was less than 1 % occurrence in all treatments except the forest where it was 7.8% (Table 5).

Table 4. Total germinants by species and treatment.

Species†	Forest	Control	Brushsaw	Silvana	Vision	Release	Total
Grasses	21	75	158	218	164	225	861
Sedges	4	6	1	15	13	11	50
UNKNOWN	4	7	12	14	10	19	66
HEPIciG	6	116	78	158	169	119	646
WRUBidM	10	63	29	31	40	46	219
HHIEpan		4	4	12	36	7	63
HASTmac		2	3	8	39	7	59
HEPIang		9	2	10	23	11	55
HFRAveA	6	2	10	19	5	1	43
HTARoff		2	2	2	10	10	26
HANTneg		5	1	1	4	13	24
HVIObla	3		1	4	7	8	23
HGERbic	2	1	5	10	1	3	22
HSOLpta					13	2	15
HCHRleu			3	4	6	1	14
HMELalb			3	6	4		13
WBETpap	7		1	1			9
HPOPtre	4			1	2	1	8
HPOTsim				1	4		5
WAMOfru				3		1	4
HASTlaf		2			2		4
HRANacr		1		3			4
HANAmar		1				2	3
HCONarv			3				3
HGALtin	1					2	3
HOENbie					3		3
HACHmiM		1			1		2
HGEUlac	1				1		2
HGOOpub			2				2
HIMPcap				1		1	2
HLECint						2	2
HOXAstr				2			2
HVICcra			1	1			2
HARAnud						1	1
HCIRare		1					1
HCOPtri				1			1
HFRAvir			1				1
Total no. germinants	69	298	320	526	557	493	2263
Total no. species	9	14	17	21	19	19	34

† Scientific and common names are provided in Appendix I.

Table 5. Species frequency of occurrence by treatment

Species†	Forest	Control	Brushsaw	Silvana	Vision	Release	Total
HEPIciG	9.38%	30.47%	32.03%	35.83%	35.71%	38.28%	32.13%
Grasses	3.13%	22.66%	34.38%	30.83%	35.71%	50.00%	31.84%
WRUBidM	7.81%	20.31%	15.63%	13.33%	14.29%	19.53%	15.85%
Unknown	4.69%	4.69%	7.03%	9.17%	4.76%	9.38%	6.77%
HASTEmac	0.00%	1.56%	3.13%	2.50%	18.25%	3.91%	5.33%
HFRAveA	6.25%	0.78%	3.91%	7.50%	1.59%	0.78%	3.17%
HEPIang	0.00%	3.13%	0.78%	2.50%	6.35%	3.13%	2.88%
HTARoff	0.00%	1.56%	1.56%	1.67%	4.76%	4.69%	2.59%
HHIEpan	0.00%	0.78%	1.56%	2.50%	3.97%	3.91%	2.31%
HANTneg	0.00%	3.91%	0.78%	0.83%	2.38%	4.69%	2.31%
HVIObla	3.13%	0.00%	0.78%	3.33%	3.17%	3.91%	2.31%
Sedges	1.56%	2.34%	0.78%	2.50%	3.17%	2.34%	2.16%
HGERbic	3.13%	0.78%	2.34%	3.33%	0.79%	1.56%	1.87%
HCHRleu	0.00%	0.00%	1.56%	2.50%	3.97%	0.78%	1.59%
WBETpap	7.81%	0.00%	0.78%	0.83%	0.00%	0.00%	1.01%
HSOLpta	0.00%	0.00%	0.00%	0.00%	3.17%	1.56%	0.86%
HMELalb	0.00%	0.00%	0.78%	2.50%	0.79%	0.00%	0.72%
WPOPtre	1.56%	0.00%	0.00%	0.83%	0.79%	0.78%	0.58%
WAMOfru	0.00%	0.00%	0.00%	1.67%	0.00%	0.78%	0.43%
HASTlaf	0.00%	0.78%	0.00%	0.00%	1.59%	0.00%	0.43%
HANAmar	0.00%	0.78%	0.00%	0.00%	0.00%	1.56%	0.43%
HIMPcap	0.00%	0.00%	0.00%	0.83%	0.00%	0.78%	0.29%
HLECint	0.00%	0.00%	0.00%	0.00%	0.00%	1.56%	0.29%
HGEUlac	1.56%	0.00%	0.00%	0.00%	0.79%	0.00%	0.29%
HVICcra	0.00%	0.00%	0.78%	0.83%	0.00%	0.00%	0.29%
HGALtin	1.56%	0.00%	0.00%	0.00%	0.00%	0.78%	0.29%
HRANacr	0.00%	0.78%	0.00%	0.83%	0.00%	0.00%	0.29%
HACHmilM	0.00%	0.78%	0.00%	0.00%	0.79%	0.00%	0.29%
HPOTsim	0.00%	0.00%	0.00%	0.83%	0.79%	0.00%	0.29%
HOXAstr	0.00%	0.00%	0.00%	0.83%	0.00%	0.00%	0.14%
HGOOpub	0.00%	0.00%	0.78%	0.00%	0.00%	0.00%	0.14%
HFRAviV	0.00%	0.00%	0.78%	0.00%	0.00%	0.00%	0.14%
HCONarv	0.00%	0.00%	0.78%	0.00%	0.00%	0.00%	0.14%
HOENbie	0.00%	0.00%	0.00%	0.00%	0.79%	0.00%	0.14%
HCOPtri	0.00%	0.00%	0.00%	0.83%	0.00%	0.00%	0.14%
HCIRare	0.00%	0.78%	0.00%	0.00%	0.00%	0.00%	0.14%
HARAnud	0.00%	0.00%	0.00%	0.00%	0.00%	0.78%	0.14%

The number of species observed in a treatment plot ranged from a low of four in the Forest on Block 4 to a high of 14 in the Silvana Selective on Block 4 and the Vision on Block 2 (Table 6).

Table 6. Species abundance, richness, diversity and evenness indices by block and treatment.

Treatment	Block	Richness: No. Species	Richness: Margalef	Richness: Menhinck	Abundance (No. Germ.)	Diversity: Shannon	Diversity: Simpson	Evenness: Pielou	Evenness: Sheldon
Forest	1	6	1.44	1.06	32	1.69	0.43	0.65	0.28
	2	5	1.82	1.67	9	2.28	0.21	0.98	0.46
	3	8	2.47	1.94	17	2.73	0.18	0.91	0.34
	4	4	1.25	1.21	11	1.68	0.36	0.84	0.42
	χ	12	2.60	1.44	69	3.11	0.15	0.87	0.26
Control	1	10	2.07	1.13	78	2.37	0.27	0.71	0.24
	2	11	2.26	1.20	84	2.32	0.30	0.67	0.21
	3	5	0.90	0.54	85	1.78	0.31	0.77	0.36
	4	7	1.53	0.98	51	2.12	0.27	0.76	0.30
	χ	17	2.81	0.98	298	2.41	0.26	0.59	0.14
Brushsaw	1	7	1.37	0.78	80	1.77	0.44	0.63	0.25
	2	13	2.53	1.21	115	2.35	0.30	0.63	0.18
	3	6	1.14	0.67	81	1.90	0.34	0.74	0.32
	4	8	1.85	1.21	44	1.98	0.36	0.66	0.25
	χ	20	3.29	1.12	320	2.37	0.31	0.55	0.12
Silvana Selective	1	12	2.76	1.63	54	2.50	0.30	0.70	0.21
	2	12	2.38	1.19	102	2.31	0.31	0.64	0.19
	3	11	1.90	0.79	193	1.85	0.38	0.53	0.17
	4	14	2.51	1.05	177	2.49	0.32	0.65	0.18
	χ	24	3.67	1.05	526	2.63	0.27	0.57	0.11
Vision	1	12	2.26	1.06	129	2.59	0.22	0.72	0.22
	2	14	2.44	0.97	207	2.59	0.26	0.68	0.18
	3	9	1.62	0.76	139	2.31	0.28	0.73	0.26
	4	11	2.27	1.21	82	2.57	0.27	0.74	0.23
	χ	22	3.32	0.93	557	3.00	0.20	0.67	0.14
Release	1	12	2.27	1.06	127	2.50	0.26	0.70	0.21
	2	13	2.54	1.22	113	2.73	0.22	0.74	0.21
	3	13	2.45	1.13	133	1.89	0.44	0.51	0.15
	4	8	1.46	0.73	120	2.10	0.30	0.70	0.26
	χ	22	3.39	0.99	493	2.56	0.28	0.57	0.12

χ Represents the treatment total *e.g.* the Release treatment (22) had 19 different species identified (plus grasses, sedges and unknown) giving 3.39 Margalef richness indices and 493 total germinants.

The following box plots show species richness (number of different species) by block (A) and by treatment (B) (Figure 6). The whiskers or "T 's" (depicted in Figure 6 A on all blocks) extending from the box are to the highest data value (Figure 6A Blocks 2, 3 and 4) not greater than the high point (75%) + 1.5 (difference of high and low point) or conversely where the whiskers extend below the low point (Figure 6A Bocks 1, 3 and 4) to the lowest value providing it is not less than the low point (25%) – 1.5 (difference of high and low point). The circle in Figure 6A Block 2 indicates data outside of the low point limits but still inside the lowest range *i.e.* low point-3.0 (difference of high and low point).

The box plots indicate that Block 2 is richer in species than Block 4. The Silvana Selective treatment is ($P \leq 0.05$) richer in number of species than the Forest. There are no other statistical differences among treatments or blocks.

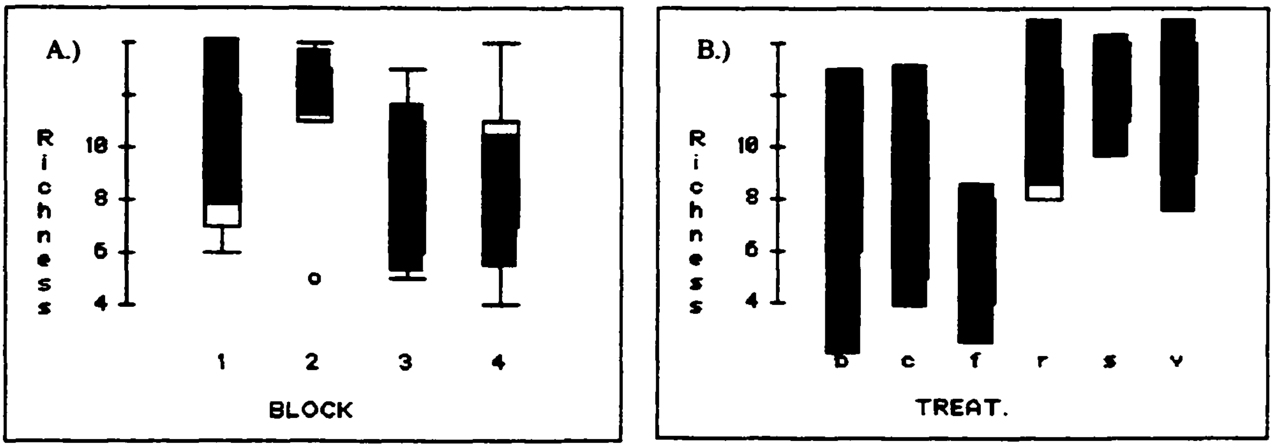


Figure 6. Box plots of richness by: A) Block and B) Treatment where; b = Brushsaw, c = Control, f = Forest, r = Release, s = Silvana Selective and v = Vision.

The analysis of variance of the number of species indicates a significant difference (P = 0.0036) among treatments but not among blocks (P = 0.2026) (Table 7).

Table 7. Analysis of variance of log 10 richness.

Source	Df	Sums of Squares	Mean Square	F-Ratio	Probability
Main	1	22.0129	22.0129	1847.6	0.0001
Treatments	5	0.344481	0.0688963	5.7827	0.0036
Blocks	3	0.0620401	0.02068	1.7357	0.2026
Error	15	0.178713	0.0119142		
Total	23	0.585235			

Figure 7 plots the post hoc test results. From the post hoc tests of the number of species, it seems that the more conservative tests all show that the number of species in the Forest, Control and Brushsaw treatments are not significantly different ($P \leq 0.05$). The solid line indicates the treatment similarities in all three tests (Figure 7 a, b and c). Details of the ANOVA and Post Hoc tests are provided in Appendix III.

A)

Forest	Control	Brushsaw	Release	Vision	Silvana
0.746	0.896	0.910	1.052	1.055	1.086

B)

Forest	Control	Brushsaw	Release	Vision	Silvana
0.746	0.896	0.910	1.052	1.055	1.086

C)

Forest	Control	Brushsaw	Release	Vision	Silvana
0.746	0.896	0.910	1.052	1.055	1.086

Figure 7. Results of post-hoc tests of log 10 of number species with significance level 0.05: A) LSD test, B) Duncan and C) Bonferroni tests ($P \leq 0.05$).

The species count (s), Margalef's index and Menhinck index (Table 6), show differing results for species richness. Margalef's index ranged from a low of 0.90 for the control in Block 3 to a high of 2.76 in the Silvana Selective on Block 1. Treatment means for Margalef index had a range of 2.60 in the Forest to 3.67 in the Silvana Selective treatments. Menhinck index results indicate Block 3 control as the lowest and Block 3 Forest as the highest in species richness. Treatment means for Menhinck index ranged from a low of 0.93 in the Vision treatments to a high of 1.44 in the Forest. Margalef's index had the same four block treatments in the top 25% richness class as the actual number of species identified for the individual treatments (Block 2 Release, Block 2 Brushsaw, Block 4 Silvana Selective and Block 3 Release). Menhinck index has three similar treatments in the top 25% when compared to the number of species (Block 1

Silvana Selective, Block 2 Release and Block 2 Brushsaw). In comparing Margalef index with Menhinck index, they have four block treatment combinations that match in the top 25% richness class (Block 1 Silvana Selective, Block 2 Release, Block 3 Forest and Block 2 Brushsaw). Margalef index compared with Menhinck index, also has the same four block treatment combinations in the lowest 25% richness class (Block 4 Release, Block 1 Brushsaw, Block 3 Brushsaw, and Block 3 Control). For this study, the Margalef index is a better match with the actual species count (richness). For the treatment summaries, Margalef's index has the same ranking of treatment means for richness as the actual species count (from highest to lowest was; Silvana Selective, Release, Vision, Brushsaw, Control and Forest). Menhinck's index was different and in the case of the forest treatment, totally opposite in indexing it as the richest and Vision as the least rich in species.

SPECIES ABUNDANCE

Twenty five percent of all germinants were found in the Vision treatments followed by 23% in the Silvana Selective 22% in the Release, 14% in the Brushsaw, 13% in the Control and 3% in the Forest (Table 4). Grasses, northern willow herb, and red raspberry account for 76% of the germinants. These species were in the top four most abundant species in all treatment plots except in the Forest where white birch ranked as third most abundant species.

The box plot diagrams by block shows that there appears to be little difference between blocks in abundance (Figure 8A). The Forested areas are different or have fewer germinants than the Release and Control areas (Figure 8B).

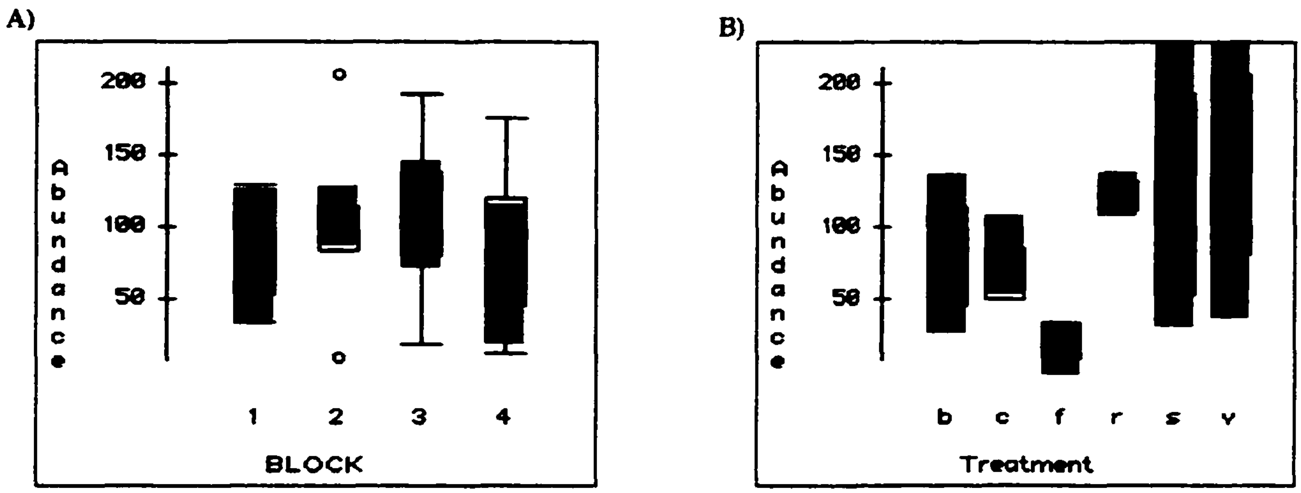


Figure 8. Box plots of total germinants by A) Block and B) Treatment where; b = Brushsaw, c = Control, f = Forest, r = Release, s = Silvana and v = Vision treatment

The ANOVA by block and by treatment of the germinant abundance clearly indicates a significant difference (P = 0.0027) between treatments but not between blocks (P = 0.480) (Table 8).

Table 8. Analysis of variance of abundance.

Source	Df	Sums of Squares	Mean Square	F-Ratio	Probability
Treatments	5	43102.70	8620.54	6.1824	0.0027
Blocks	3	3622.79	1207.60	0.8660	0.4802
Error	15	20915.50	1394.36		
Total	23	67641.00			

The post hoc tests show that the abundance in the treatments Control, Brushsaw and Release were not significantly different ($P \leq 0.05$) (Figure 9). The more conservative tests for the abundance (Figure 9B.) group the Forest, Control and Brushsaw as similar or no significant difference ($P \leq 0.05$). Brushsaw, Release, Silvana

Selective and Vision are also grouped as being similar in species abundance (Figure 9B,C). Details of the ANOVA and Post Hoc tests are provided in Appendix IV.

A.)	Forest	Control	Brushaw	Release	Silvana	Vision	
	17.25	74.5	80.0	123.25	131.5	139.25	
B.)	Forest	Control	Brushaw	Release	Silvana	Vision	17.25
		74.5	80.0	123.25	131.5	139.25	
C.)	Forest	Control	Brushaw	Release	Silvana	Vision	17.25
		74.5	80.0	123.25	131.5	139.25	

Figure 9. Results of A) LSD test, B) Bonferroni, and C) Duncan test with significance level 0.05.

Species rank abundance diagrams are one method of presenting abundance data (May 1975). These diagrams depict treatment patterns by block and averaged treatment patterns (Figures 10 and 11). The rank abundance curves are based on the number of germinants by species. Figure 10 and 11 show the Forest treatment as the bottom curve (the least abundant). The Control treatment in Block 3 (Figure 10 C) intersects the Forest treatment curve and in the treatment totals, Control and Brushsaw treatments intersect the Forest treatment (Figure 11). The Forested area consistently has a lower initial starting value of number of germinants than all of the other treatments. It also drops to the base line (rare species or low abundance) before all other treatments (Figure 11) and in all blocks except Block 3 (Figure 10 C). For communities consisting of a large assembly of species, the resulting plot is almost always like that illustrated in Figure 10 and 11 (May 1975, 1981).

Appendix II gives the rank abundance treatment data within the blocks and then as a total.

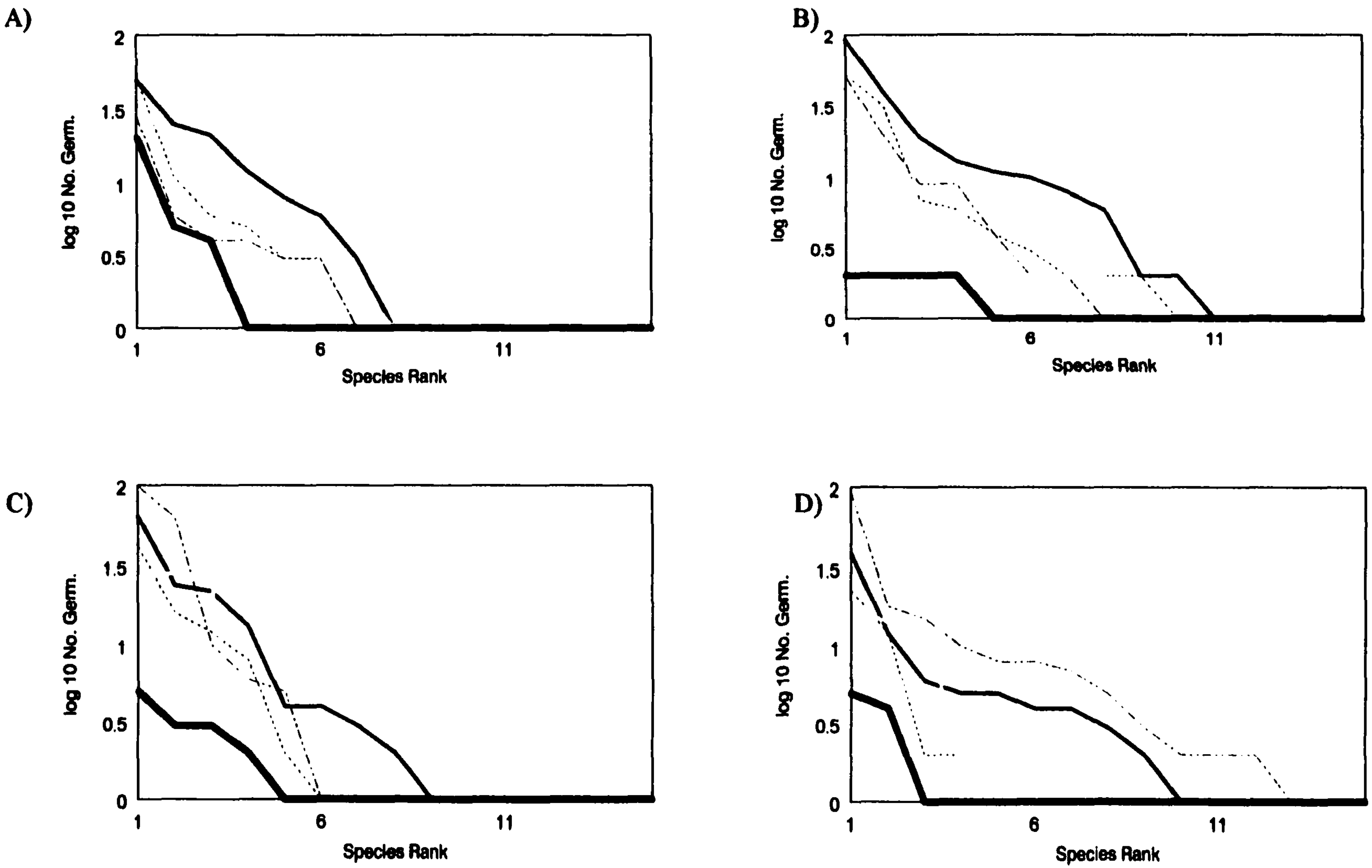


Figure 10. Species rank abundance diagram for each treatment in A.) Block 1., B) Block 2, C) Block 3, and D.) Block 4 Where: is Forest, is Control, is Brushsaw, is Silvana, is Vision and is Release.

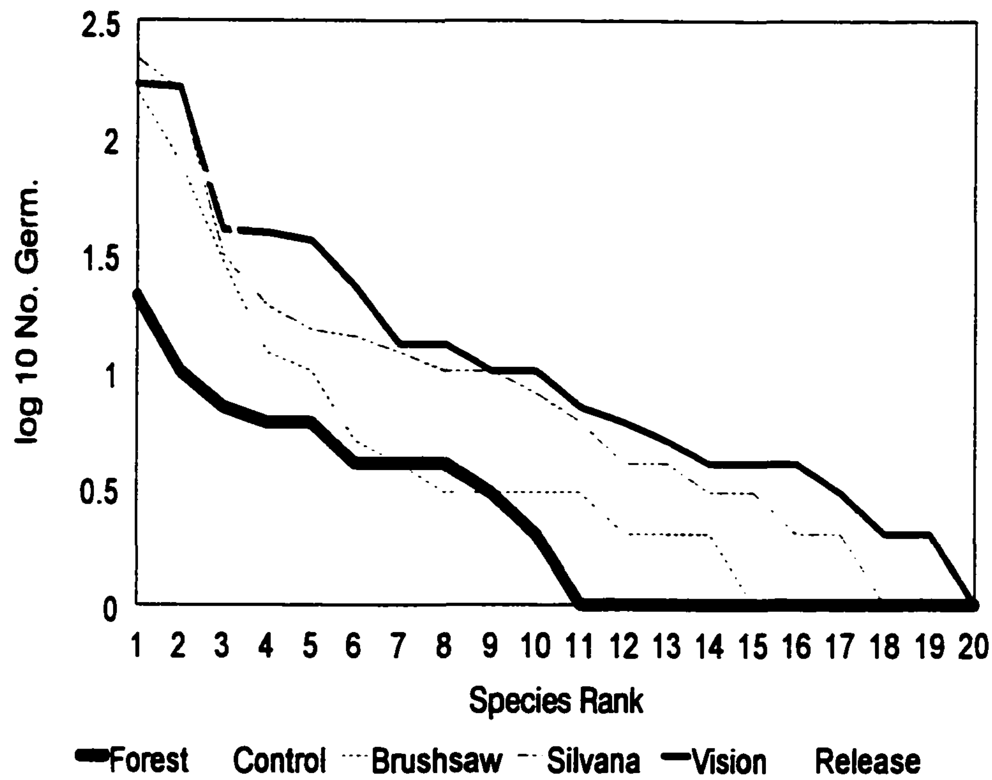


Figure 11. Species rank abundance diagram for the combined data of all blocks for each treatment.

SPECIES DIVERSITY

The Shannon and Simpson diversity indices, calculated by block and treatment are shown in Table 6. The Shannon index is usually between 1.5 and 3.5 and only rarely surpasses 4.5 (Magurran 1988). In Table 6, the index ranges from 2.73 in Block 2 in Release treatment to 1.68 in Block 4 in the Forest treatment. The Simpson index (where closer to 0 means more diversity) ranges from 0.18 in Block 3 Forest Treatment to 0.44 in Block 3 Release treatment. Both indicators depict the same 5 treatments by block combinations as the most diverse. That is, they suggest that Block 3 Forest, Bock 2 Vision and Release and Block 1 Vision and Release treatments have the highest diversities. Conversely they show Block 1 Brushsaw and Forest, Block 3 Silvana Selective and Release and Block 4 Forest treatments as the lowest in species diversity. Table 6 also shows the average diversity (χ) by treatment. Both diversity indices (Shannon and Simpson) show similar ratings with the highest diversity in the Forest and the lowest in the Brushsaw treatment areas.

SPECIES EVENNESS

Pielou and Sheldon's species evenness indices calculated by block and by treatment, are shown on Table 6. The results show both indices having the same treatment combinations in the top 25% as being the most even. The combinations are: Block 4 Control and the Forest treatments, Block 3 Control and the Forest treatments and Block 2 Forest treatment. Both indices depicted Block 3 Release and Silvana Selective treatments, and Block 2 Silvana Selective and Brushsaw treatments as the lowest (25%) in evenness.

Table 6 also gives the evenness indices for all blocks combined. Both the Pielou and Sheldon indices show the Forest treatment as the highest in species evenness (closest to one). The Brushsaw treatment has the lowest Pielou index whereas the Silvana Selective had the lowest Sheldon index.

Even though one treatment or block has the same number of germinants and the same number of species, the block or treatment with an equal spread of germinants by species is more diverse (Magurran 1988). For example, the Forest treatment would be the most diverse as it has a lesser amount of species and germinants compared to the other treatments and it results in a more equal spread of germinants by species. This is also reflected in the higher indices numbers in Pielou and Sheldon Indices (Table 5).

ORTHOGONAL COMPARISONS

Table 9, 10 and 11 give the general linear models procedure results for each of the analysis and orthogonal comparisons. Cut is brushsaw and Silvana selective, while herbicide is Release and Vision combined. Treated is brushsaw, Silvana selective, Vision and Release. Control is untreated cut over and forest. Cutover is untreated cutover, brushsaw, Silvana Selective, tryclopyr, and Vision.

Table 9. General linear models procedure for number of species.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Brushsaw vs Silvana	1	28.125	28.125	6.35	0.024
Vision vs. Release	1	< 0.000	< 0.000	<0.01	1.000
Cut vs Herbicide	1	5.062	5.062	1.14	0.302
Treated vs Control	1	23.112	23.112	5.22	0.037
Forest vs Cutover	1	72.075	72.075	16.27	0.001

As seen in Table 9, there is a highly significant difference between the contrasts of; Forest (Forest) vs. Cutover (untreated cut over, Brushsaw, Release, Vision, and Release) (P = 0.001) and significant difference between the Brushsaw vs. Silvana Selective (P = 0.024) and the Treated (Brushsaw, Silvana Selective, Vision, and Release) vs. Control (untreated cut over and Forest) (P = 0.037).

Table 10 (log of the number of species), gives the same highly significant and significant results as Table 9.

Table 10. General linear models procedure for log number of species.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Brushsaw vs Silvana	1	0.062	0.062	5.22	0.037
Vision vs Release	1	0.000	0.000	0.00	0.973
Cut vs. Herbicide	1	0.012	0.012	1.04	0.324
Treated vs Control	1	0.053	0.053	4.52	0.050
Forest vs. Cutover	1	0.216	0.216	18.13	0.001

Table 11, used the abundance results and shows a highly significant difference between Forest vs. Cutover (Control, Brushsaw, Silvana Selective, Release, and Vision) ($P = 0.0004$).

Table 11. General linear models procedure for abundance of species.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Brushsaw vs Silvana	1	5304.500	5304.500	3.80	0.070
Vision vs Release	1	512.000	512.000	0.37	0.554
Cut vs. Herbicide	1	2601.000	2601.000	1.87	0.192
Treated vs. Control	1	6195.200	6195.200	4.44	0.052
Forest vs. Cutover	1	28490.008	28490.008	20.43	< 0.000

DISCUSSION

From the literature (Farmer 1997; Leck *et al.* 1989; Harper 1977) it is evident that not all seeds can be forced nor are capable to germinate. Factors such as the timing of the sample collection, providing a germination environment that meets the needs of all the seeds and species requirements for germinating and even allowing the germinants enough time to grow for identification by fruit or flowers all contribute to the success of the seed bank representation. This study shows the results of species that germinated under acceptable parameters (Farmer 1997; Qi and Scarratt 1997) and thus conclusive in the broad sense but inconclusive if one is looking for outliers.

The seed bank collections were individually placed in peat containers, watered, submitted to a temperature regime considered applicable to most species (Whitney 1982; Haeussler *et al.* 1990; Farmer 1997; Qi and Scarratt 1997; OMNR 1998) and given an acceptable amount of time to germinate. The sampling and growing method also resulted in some mixing (organic with mineral). The mixing is similar to cultivating or site preparation that mixes organic with mineral soil in a cutover and strongly promotes seed bank reproduction (Sutherland and Foreman 1995). But, because of the varied dormancy characteristics of seed (Angevine and Chabot 1979; Farmer 1997; Leck *et al.* 1989) the collective responses of a seed bank study are variable.

For northern coniferous forests, few species depend on the soil seed bank for regeneration (Archibold 1989) and thus it is not surprising that the results of this study had 2263 germinants with 34 recognizable species, only 2 of which were trees, (white birch and trembling aspen). These results were similar to Qi and Scarratt (1998), where coniferous seeds were absent in their northern boreal soil seed bank mixedwood study; only seeds from white birch were present in the soil seed bank.

The presence of species in equal abundance in any community is not possible in the natural world (Magurran 1988). Instead, the majority of species are rare while a number of species are common and a few species are abundant. This is the case for this study with 34 species in total, and excluding the grasses and sedges, only four species (northern willow herb, red raspberry, wood strawberry and Bicknell's Crane's-bill) were common to all treatments and none of the four species were equally abundant in all treatments. This was also apparent from the rank abundance diagrams that started high on the abundance axis and quickly fell to showing a presence of species but rare in numbers.

Since individual species responses were highly variable, it seems relevant to discuss plausible reasons for these responses. Species of interest include white spruce, white birch, trembling aspen, red raspberry, grasses and sedges.

White spruce is an annual cone (not a seed banker) with prolific seed years every two to six years (Bell 1991). Although white spruce was present in all treatments in the vegetation (Table 12), it did not germinate in the soil seed bank collection. The most plausible reason for a lack of white spruce germinants may be that there were simply very few to no seed. The planted spruce were simply too immature to produce seed. The mature trees were harvested in all of the treatments (except the Forest treatment) leaving no immediate seed source except in the surrounding forest. Since white spruce has a limited dispersal distance of 61 to 122 m (Ahlgren 1979 a, b) it would not under the best of conditions have been broadly distributed in the clearcuts. The seed source would also have difficulties dispersing via snow movement across the cutover as the cutovers in 1995 and 1996 had dead standing shrubs from herbicide applications (Newmaster and Bell 2002) which would create barriers to seed movement. In addition, there were also shrubs and trees on the site in areas that were not treated (either missed in the herbicide application as there was some banding or not brushed in the Silvana Selective and Brushsaw treatments as brushing was only applied if there were crop trees in the immediate vicinity). These missed or green areas would also interrupt blowing wind and snow movement, limiting the seed dispersal. The surrounding forest would also not be a large seed source as it has low incidence of white spruce (Table 3), which is normal as white spruce does not naturally grow in pure stands in the boreal forest (Rowe 1972). So therefore with white spruce having a potentially low seed crop year, being an annual seeder, having poor movement capabilities across the blocks, combined with the lack of significant amounts of mature white spruce in the surrounding forest, it is not surprising that there was no white spruce germinating from the soil seed bank.

White birch is a prolific seed producer, but it is not a long-term seed banker (Bell 1991, Farmer 1997). White birch was present in the vegetation cover (Table 12). It had a higher percent cover in the Forest and Control treatments, which is to be expected, as it was a targeted competition species and planned to be eradicated from the site through the treatments. Its presence in the seed bank was in the Forest, Brushsaw and Silvana Selective treatments. The lack of white birch in the herbicide treatments is expected as white birch is very susceptible to Vision® and Release® (Bell *et al.* 1997). The seed source for the germinants in the seed bank on the Brushsaw and Silvana Selective treatments is probably saplings on site that are mature enough to produce seed. These large seeds normally disperse 91 to 183 m (Kellman 1974) but they too would have difficulties similar to the white spruce in moving across the cutover. Thus there is a need to document and monitor:

1. seed production in adjacent forests and
2. the movement of seed onto the site with respect to dead standing shrubs and missed strips (green areas).

Trembling aspen is an annual seeder, but not a long-term seed banker (Farmer 1997). It is a shade intolerant hardwood that rapidly establishes on burned over areas and recently disturbed sites with airborne seed and root suckering (Bell 1991). It was present in all six treatments in the vegetation plots in 1995 (Table 12). It was not present in the Control and Brushsaw seed bank treatments and had limited presence on the remaining seed bank treatments. Since the aspen in the clearcut were juvenile and therefore unlikely to produce seed, then most likely the seed in the seed bank seeded in from surrounding forests as it disperses many kilometers (Graber and Thompson 1978). Mature seed-bearing poplar is present in the surrounding forest; Block 3 Forest is pure aspen and it also makes up 10% of the stand composition in Block 4 (Table 3).

Red raspberry is a long-term seed banking species (Graber and Thompson 1978, Isaac 1982, Rowe 1983). It requires two years of growth before it produces seed (Bell 1991). Good seed crops occur nearly every year (Anon. 1974) and seed production during the first four years following disturbance can exceed 26,000 seed/m^2 (Whitney 1978). Raspberries appear in a cutover, thrive, complete their life cycles and decline in importance all within the first few years following disturbance (Marks 1974). It was present in all of the vegetation cover treatments (Table 12) and it also germinated in all of the seed bank treatments. Raspberry was present in the Forest treatment in low numbers for both the vegetation and the seed bank germinants. Clear cutting would have provided opportunity for the seed to germinate and its presence in the harvested area is higher in both the vegetation cover and the seed bank information. The harvesting of the area would have stimulated its germination from the seed bank and the additional effect of the site preparation would have strongly promoted its germination (Sutherland and Foreman 1995). Other studies (Putwain and Harper 1970; Gross and Werner 1982; Reader and Buck 1986) suggest that the abundance of plants is restricted by ground cover because ground cover provides habitat for seed predators. This could account for some of the differences between treatments where both herbicide treatments (which resulted in temporary ground cover removal) had more red raspberry germinants than the other treatments.

Members of the *Graminaceae* family made up a large proportion of the seed bank; however, individual species could not be identified. Grasses are a mixture of wind borne and on site seeders [Bell (pers. comm., 09, May 2002)]. They were present in all treatments for both the vegetation cover and the seed bank (Table 12). The highest grass presence in the vegetation cover was in the Release treatment and this is undoubtedly because Release® has no effect on grasses or sedges (monocots) (Bell *et al.* 1997). Sedges are all on-site seeders with extremely limited seed movement [Bell (pers. comm., 09, May 2002)]. The Forest treatment had the lowest vegetation cover and seed bank germination of sedges and grasses compared to all the other treatments. This is probably due to ground cover restrictions (Farmer 1997) or the lack of disturbance in the Forest treatments (Sutherland and Foreman 1995).

The number of species in the Forest, Control and Brushsaw treatments was not significantly different but there were significant differences in the number of species (richness) in the Release, Vision and the Silvana Selective treatments. Additionally, the Silvana Selective treatment is richer in species than the Forest treatment. The Forest treatment is the most even and if the treatment with an equal spread of germinants is the most diverse (Magurran 1988), then the Forest treatment is the most diverse. Both of the diversity indices used (Shannon and Simpson) are in agreement that the Forest treatment is the most diverse.

Table 12. 1995 Vegetation data compared to 1996 soil seed bank species frequency of occurrence.

	Treatment											
	Forest %		Control %		Brushsaw %		Silvana %		Vision %		Release %	
Species	Veg. *	Freq. **	Veg. *	Freq. **	Veg. *	Freq. **	Veg. *	Freq. **	Veg. *	Freq. **	Veg. *	Freq. **
white spruce	0.19	0.00	7.31	0.00	10.31	0.00	9.88	0.00	9.53	0.00	10.56	0.00
trembling aspen	46.03	1.56	35.94	0.00	17.88	0.00	20.28	0.83	10.85	0.79	19.38	0.78
white birch	15.47	7.81	11.12	0.00	2.62	0.78	4.53	0.83	1.91	0.00	2.35	0.00
red raspberry	2.44	7.81	25.22	20.31	20.12	15.63	23.72	13.33	14.47	14.29	14.78	19.53
Grasses	1.06	3.13	9.69	22.66	15.50	34.38	19.00	30.83	20.00	35.71	30.00	50.00
Sedges	0.31	1.56	3.19	2.34	2.98	0.78	3.10	2.50	2.43	3.17	5.29	2.34

Where:

* %Veg. = % cover of species by vegetation plot in 1995 [Winters (in litt., 09 May 2002)]

** % Freq. = % specie occurred in soil seed bank core samples

The results of this study agree with the literature (Ludwig and Reynolds 1988; Sutherland and Foreman 1995; Farmer 1997) in showing that the forest does not promote seed germination from the seed bank but harvesting promotes germination. The addition of Brushsaw, Silvana Selective treatments and herbicide applications promotes and strongly promotes, respectively, germination from the seed bank (Table 13). The Silvana Selective treatment was significantly different from the Forest treatment and it also had the second highest number of germinants and the highest number of species (Table 4).

Table 13 suggests that the most germinants would be in the Vision and Release treatments, but the ground disturbance created by the Silvana Selective Ford tractor may have been similar to light site preparation and in this instance the disturbance was enough to strongly promote seed bank germination compared to the Brushsaw treatment. The Silvana Selective Ford tractor could have mixed some seed deeper into the soil from churning/mixing the mineral with organic, where this seed did not germinate until the collection of the samples. Also the exposed mineral soil would have provided a microsite for wind-borne annuals in 1994 (one year after treatment), which in turn could have been prolific seeders in 1995, resulting in large seed deposits in the seed bank collection of June 1996. If this is the case then the silvicultural treatments following harvest need to be carefully applied if the forest manager is not looking to enhance the vegetation on site. Further study of this is required.

Table 13. Vegetation and seed bank response to treatment.

		Sexual Reproduction	
Treatment	Vegetative Reproduction	Wind Borne Seed	Seed Bank
Forest	no effect	no effect	no effect
Control	strongly promotes	promotes	promotes
Brushsaw	strongly promotes	promotes	promotes
Silvana Selective	strongly promotes	promotes	promotes
Vision	strongly discourages	promotes	strongly promotes
Release	strongly discourages	promotes	strongly promotes

The results of this study support the findings of previous studies (Oosting and Humphreys 1940; Numata *et al.* 1964; Roberts and Dawkins 1967; Livingston and Allessio 1968; Roberts *et al.* 1984; Granstrom 1987) in which species richness and abundance declined with the increased time since disturbance *i.e.*, the Forest treatment is the least rich and abundant in species (there was a significant difference) compared to all the other treatments (clear cut). There were also significant differences (more total germinants and species) between the Silvana Selective, Vision, Release, and Brushsaw treatments compared to the Control treatment in the clearcuts. Therefore it can be concluded from this study that harvesting affected the seed bank and that silvicultural treatments applied to the harvest areas gave an additional affect on the seed bank. Therefore species diversification can be enhanced or maintained by applying a variety of disturbance regimes (*e.g.*, red raspberry).

To get a true operational effect, a pre- harvest seed bank collection is required in addition to linkage with existing vegetation and soils with the seed bank data. This type of information could then be used for successional modeling to make operational decisions.

Forest species evolution with respect to ecosystem development is the result of the reproductive strategy in response to periodic disturbance resulting in development of response to other environmental factors being less pronounced (Ohmann and Grigal 1979). This study area was disturbed four times over a six to eight year period. It was harvested, site prepared, planted and then treated in 1993 as part of this study. The multiple disturbances over a short period of time affected the results of this study. The extent of effect of each disturbance is unknown and would require comparisons with similar studies under various disturbance regimes to understand if the differences in species abundance and diversity that can be attributed to the different treatments versus the effect of the multiple disturbances. Cavers and Benoit (1989) suggest that the difference in seed banks results from weed soil/site preferences.

Further study on this project comparing the mature forests and present understory, together with soil classification and characteristics with the soil seed bank needs to be carried out to see if the presence of species in the overstory is markedly absent from the soil seed bank as it is commonly seen in other studies (Kellman 1970; Scarratt 1998; Numata *et al.* 1964; Moore and Wein 1977; Piroznikow 1983; Pickett and McDonnell 1989; Coffin and Lauenroth 1989; Ungar and Woodell 1993). Without a thorough assessment and classification of the soil on the project area, seed germination from the seed bank collection cannot be adequately correlated to disturbance and / or conifer release treatments. Soil type does have a controlling factor in seed bank composition. Factors such as pH, organic versus mineral, and permeability are all characteristics that have been linked with smaller seed banks, (Brown and Oosterhuis 1981; Moore and Wein 1977; Hill and Stevens 1981).

Forest certification, management principles and practices require detailed forest management planning whereby season of harvest, silvicultural prescription and expected renewal results are planned well in advance of the harvesting. This study suggests species diversification can be enhanced or maintained by applying a variety of disturbance regimes. Therefore, if a forest management objective is to enhance or increase certain species, time of harvest, equipment used, and the silviculture treatments applied could aid in obtaining the desired results as this study clearly indicates there was a significant difference between treatments.

The lack of tree seeds in the seed bank is expected as a seed bank study by Qi and Scarratt (1998) in boreal mixedwoods looked at harvesting methods and found low conifer seed frequency in both the seed rain and seed banks following conventional harvesting. Viable conifer seeds are essentially absent from seed banks (Farmer 1997). In a study in Maine, the tree seedlings that germinated in the first year after a disturbance were predominately birch seedlings (Frank and Safford 1970). The soil samples were further disturbed the second year and germinants included a few birch, but primarily sedge, raspberry, and violet. These results are similar to this study with white birch and trembling aspen being the only tree species to germinate from the seed bank. Also, sedges, raspberries and violets were present in all treatments, with the exception that violets were not found in the Control treatment.

It would seem from the results of this study in comparison with previous studies that the only unequivocal way to study alternative conifer release treatments on soil seed banks is to create the desired disturbance in permanent sample plots established for long term sampling strategies and to repeatedly sample these at regular intervals. This would all have to be linked with other factors such as vegetation, soil types, climate data, small mammals *etc.* Carleton (1982) suggests an early peak of species diversity would be expected and through time a steady decline thus the initial floristic effects would best be accounted by considerable replication. Shafi and Yarranton (1973) suggest a linear increase in richness and equitability to a plateau sometime in the fourth to tenth year following a disturbance with a subsequent decline with crown closure. Successional modeling would be based on these results and then operational conclusions readily made and field-tested.

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APPENDICES

APPENDIX I

SPECIES LIST

Code	Scientific Name[1]	Common Name
WAMOfru	*Amorpha fruticosa* L.	Shrubby false-indigo
WBETpap	*Betula papyrifera* Marsh.	White birch
WPOPtre	*Populus tremuloides* Michx.	Trembling aspen
WRUBidM	*Rubus idaeus* L. ssp. *melanolasius* (Dieck) Focke	Red raspberry
HACHmiM	*Achillea millefolium* L. ssp. *millefolium*	Common yarrow
HANAmar	*Anaphalis margaritacea* (L.) Benth. & Hook. F. ex C.B. Clarke	Pearly everlasting
HANTneg	*Antennaria neglecta* Greene	Field pussytoes
HARAnud	*Aralia nudicaulis* L.	Wild sarsaparilla
HASTmac	*Aster macrophyllus* L.	Large-leaved aster
HASTlaf	*Aster lateriflorus* (L.) Britton *var. lateriflorus*	Small white aster
HCHRleu	*Chrysanthemum leucanthemum* L.	Ox -eye daisy
HCIRare	*Cirsium arvense* (L.) Scop	Canada thistle
HCONarv	*Convolvulus arvensis* L.	Field bindweed
HCOPtri	*Coptis trifolia* (L.) Salisb.	Goldthread
HEPIang	*Epilobium angustifolium* L.	Fireweed
HEPIciG	*Epilobium ciliatum* Raf. ssp. *gladulosum* (Lehm.) Hoch & Raven	Northern willow herb
HFRAveA	*Fragaria vesca* L. ssp. americana (Porter) Staudt	Wood strawberry
HFRAviV	*Fragaria virginiana* Miller ssp. virginiana	Wild strawberry
HGALtin	*Galium tinctorium* L.	Stiff marsh bedstraw
HGERbic	*Geranium bicknellii* Britton	Bicknell's Crane's-bill
HGEUlac	*Geum laciniatum* Murray	Rough avens
HGOOpub	*Goodyera pubescens* (Willd.) R. Br.	Downy rattlesnake plantain
HHIEpan	*Hieracium paniculatum* L.	Panicled hawkweed
HIMPcap	*Impatiens capensis* Meerb.	Spotted touch-me-not
HLECint	*Lechea intermedia* Legg.	Large-podded pinweed
HMELalb	*Melilotus alba* Medik.	White sweet-clover
HOENbie	*Oenothera biennis* L.	Common evening-primrose
HOXAstr	*Oxalis stricta* L.	Upright yellow wood -sorrel
HPOTsim	*Potentilla simplex* Michx.	Old -field cinquefoil
HRANacr	*Ranunculus acris* L.	Tall buttercup
HSOLpta	*Solidago ptarmicoides (*Nees) B. Boivin	Upland white aster
HTARoff	*Taraxacum officinale* G. Web.	Common dandelion
HVICcra	*Vicia cracca* L.	Cow vetch
HVIObla	*Viola blanda* Willd.	Sweet white violet
Grasses	*Poaceae* species.	Grasses
Sedges	*Cyperaceae* species	Sedges
UNKNOWN	Unknown	Unknown

[1]Scientific names and codes are according to Newmaster, S.G., A. Lehela, P.W.C. Uhlig, S. McMurray, and M.J. Oldham. 1998. Ontario Plant List. Ontario Forest Research Institute. Sault Ste. Marie, ON. Forest Research Paper No. 123. 550 pp. + appendices.

APPENDIX II

NUMBER OF GERMINATES RANKED BY BLOCK

Ranked species abundance for all Blocks combined (No. of germinates in a log 10 scale).

Species	Brushsaw	Species	Control	Species	Forest	Species	Release	Species	Silvana	Species	Vision
Grasses	2.199	HEPILciG	2.064	Grasses	1.322	Grasses	2.352	Grasses	2.338	HEPILciG	2.228
HEPILciG	1.892	Grasses	1.875	HRUBidM	1.000	HEPILciG	2.0756	HEPILciG	2.199	Grasses	2.215
HRUBidM	1.462	HRUBidM	1.799	WBETpap	0.845	HRUBidM	1.663	HRUBidM	1.491	HRUBidM	1.602
UNKNOWN	1.079	HEPIang	0.954	HEPILciG	0.778	UNKNOWN	1.279	HFRAveA	1.279	HASTmac	1.591
HFRAveA	1.000	UNKNOWN	0.845	HFRAveA	0.778	HANTneg	1.114	Sedges	1.176	HHIEpan	1.556
HGERbic	0.699	Sedges	0.778	UNKNOWN	0.602	HEPIang	1.041	UNKNOWN	1.146	HEPIang	1.362
HHIEpan	0.602	HANTneg	0.699	Sedges	0.602	Sedges	1.041	HHIEpan	1.079	HSOLpta	1.114
HASTmac	0.477	HHIEpan	0.602	WPOPtre	0.602	HTARoff	1.000	HGERbic	1.000	Sedges	1.114
HCHRleu	0.477	HTARoff	0.301	HVIObla	0.477	HVIObla	0.903	HEPIang	1.000	HTARoff	1.000
HCONarv	0.477	HASTmac	0.301	HGERbic	0.301	HHIEpan	0.845	HASTmac	0.903	UNKNOWN	1.000
HMELalb	0.477	HFRAveA	0.301	HHIEpan	0	HASTmac	0.845	HMELalb	0.778	HVIObla	0.845
HTARoff	0.301	HASTlaf	0.301	HTARoff	0	HGERbic	0.477	HVIObla	0.602	HCHRleu	0.778
HGOOpub	0.301	HIMPcap	0	HASTmac	0	HLECint	0.301	HCHRleu	0.602	HFRAveA	0.699
HEPIang	0.301	HVIObla	0	HANTneg	0	HSOLpta	0.301	HAMOfru	0.477	HANTneg	0.602
HANTneg	0	HLECint	0	HIMPcap	0	HGALtin	0.301	HRANacr	0.477	HMELalb	0.602
HIMPcap	0	HGERbic	0	HLECint	0	HANAmar	0.301	HTARoff	0.301	HPOTsim	0.602
HVIObla	0	HOXAstr	0	HOXAstr	0	HIMPcap	0	HOXAstr	0.301	HOENbie	0.477
HLECint	0	HGEUlac	0	HGEUlac	0	HOXAstr	0	HANTneg	0	HASTlaf	0.301
HOXAstr	0	HVICcra	0	HVICcra	0	HFRAveA	0	HIMPcap	0	WPOPtre	0.301
HGEUlac	0	HAMOfru	0	HAMOfru	0	HGEUlac	0	HLECint	0	HIMPcap	0
HVICcra	0	HSOLpta	0	HSOLpta	0	HVICcra	0	HGEUlac	0	HLECint	0
HAMOfru	0	HGOOpub	0	HGOOpub	0	HAMOfru	0	HVICcra	0	HGERbic	0
HSOLpta	0	HGALtin	0	HGALtin	0	HGOOpub	0	HSOLpta	0	HOXAstr	0
HGALtin	0	FRAGvir	0	FRAGvir	0	FRAGvir	0	HGOOpub	0	HGEUlac	0
FRAGvir	0	WBETpap	0	HEPIang	0	WBETpap	0	HGALtin	0	HVICcra	0
WBETpap	0	HRANacr	0	HRANacr	0	HRANacr	0	FRAGvir	0	HAMOfru	0
HRANacr	0	HACHmiM	0	HACHmiM	0	HACHmiM	0	WBETpap	0	HGOOpub	0
Sedges	0	HOENbie	0	HOENbie	0	HOENbie	0	HACHmiM	0	HGALtin	0
HACHmiM	0	HCHRleu	0	HCHRleu	0	HCHRleu	0	HOENbie	0	FRAGvir	0
HOENbie	0	HCOPtri	0	HCOPtri	0	HCOPtri	0	HCOPtri	0	WBETpap	0
HCOPtri	0	HANAmar	0	HASTlaf	0	HASTlaf	0	HASTlaf	0	HRANacr	0
HASTlaf	0	HCONarv	0	HANAmar	0	HCONarv	0	HANAmar	0	HACHmiM	0
HANAmar	0	HCIRare	0	HCONarv	0	HCIRare	0	HCONarv	0	HCOPtri	0
HCIRare	0	HARAnud	0	HCIRare	0	HARAnud	0	HCIRare	0	HANAmar	0
HARAnud	0	HMELalb	0	HARAnud	0	HMELalb	0	HARAnud	0	HCONarv	0
WPOPtre	0	WPOPtre	0	HMELalb	0	WPOPtre	0	WPOPtre	0	HCIRare	0
HPOTsim	0	HPOTsim	0	HPOTsim	0	HPOTsim	0	HPOTsim	0	HARAnud	0

Ranked species abundance for Block 1 (No. germinates in a log 10 scale).

Species	Brushsaw	Species	Control	Species	Forest	Species	Release	Species	Silvana	Species	Vision
Grasses	1.708	HEPILciG	1.530	Grasses	1.301	Grasses	1.724	HEPILciG	1.447	HEPILciG	1.690
HEPILciG	1.041	Grasses	1.300	WBETpap	0.699	HEPILciG	1.531	HRUBidM	0.778	HHIEpan	1.400
HRUBidM	0.778	HRUBidM	0.850	WPOPtre	0.602	Sedges	1.000	Grasses	0.602	Grasses	1.320
HGERbic	0.699	HHIEpan	0.600	HHIEpan	0	HEPIang	0.845	UNKNOWN	0.602	HASTmac	1.080
UNKNOWN	0.477	UNKNOWN	0.600	HEPILciG	0	HRUBidM	0.778	HRANacr	0.477	HTARoff	0.900
HMELalb	0.477	Sedges	0.600	HTARoff	0	UNKNOWN	0.699	Sedges	0.477	HRUBidM	0.780
HHIEpan	0	HEPIang	0.300	HASTmac	0	HTARoff	0.602	HHIEpan	0	HEPIang	0.480
HTARoff	0	HTARoff	0	HRUBidM	0	HHIEpan	0.301	HTARoff	0	UNKNOWN	0
HASTmac	0	HASTmac	0	UNKNOWN	0	HASTmac	0.301	HASTmac	0	HANTneg	0
HANTneg	0	HANTneg	0	HANTneg	0	HGALtin	0.301	HANTneg	0	HVIObla	0
HVIObla	0	HVIObla	0	HVIObla	0	HANTneg	0	HVIObla	0	HGERbic	0
HFRAveA	0	HGERbic	0	HGERbic	0	HVIObla	0	HGERbic	0	HFRAveA	0
HAMOfru	0	HFRAveA	0	HFRAveA	0	HGERbic	0	HFRAveA	0	HAMOfru	0
HGALtin	0	HAMOfru	0	HAMOfru	0	HFRAveA	0	HAMOfru	0	HGALtin	0
WBETpap	0	HGALtin	0	HGALtin	0	HAMOfru	0	HGALtin	0	WBETpap	0
HEPIang	0	WBETpap	0	HEPIang	0	WBETpap	0	WBETpap	0	HRANacr	0
HRANacr	0	HRANacr	0	HRANacr	0	HRANacr	0	HEPIang	0	Sedges	0
Sedges	0	HACHmiM	0	Sedges	0	HACHmiM	0	HACHmiM	0	HACHmiM	0
HACHmiM	0	HCHRleu	0	HACHmiM	0	HCHRleu	0	HCHRleu	0	HCHRleu	0
HCHRleu	0	HCOPtri	0	HCHRleu	0	HCOPtri	0	HCOPtri	0	HCOPtri	0
HCOPtri	0	HASTlaf	0	HCOPtri	0	HASTlaf	0	HASTlaf	0	HASTlaf	0
HASTlaf	0	HMELalb	0	HASTlaf	0	HMELalb	0	HMELalb	0	HMELalb	0
WPOPtre	0	WPOPtre	0	HMELalb	0	WPOPtre	0	WPOPtre	0	WPOPtre	0

Ranked species abundance for Block 2 (No. germinates in a log 10 scale).

Species	Brushsaw	Species	Control	Species	Forest	Species	Release	Species	Silvana	Species	Vision
Grasses	1.724	HEPILciG	1.623	HRUBidM	0.301	HEPILciG	1.580	HEPILciG	1.710	HEPILciG	1.960
HEPILciG	1.505	Grasses	1.204	UNKNOWN	0.301	Grasses	1.505	Grasses	1.300	Grasses	1.600
HRUBidM	0.845	HRUBidM	0.903	HGERbic	0.301	HRUBidM	1.000	HHIEpan	0.950	HEPIang	1.280
UNKNOWN	0.778	HEPIang	0.845	WBETpap	0.301	HANTneg	1.000	HEPIang	0.950	HSOLpta	1.110
HHIEpan	0.602	HTARoff	0.301	Grasses	0	HHIEpan	0.699	UNKNOWN	0.600	HHIEpan	1.040
HCONarv	0.477	UNKNOWN	0.301	HHIEpan	0	HASTmac	0.602	HRUBidM	0.300	Sedges	1.000
HTARoff	0.301	HANTneg	0.301	HEPILciG	0	UNKNOWN	0.602	HCHRleu	0.300	HASTmac	0.900
HEPIang	0.301	HASTlaf	0.301	HTARoff	0	HTARoff	0.477	HTARoff	0	HCHRleu	0.780
HCHRleu	0.301	HHIEpan	0	HASTmac	0	HGERbic	0.301	HASTmac	0	HANTneg	0.300
HASTmac	0	HASTmac	0	HANTneg	0	HSOLpta	0.301	HANTneg	0	HVIObla	0.300
HANTneg	0	HIMPcap	0	HIMPcap	0	HIMPcap	0	HIMPcap	0	HTARoff	0
HIMPcap	0	HVIObla	0	HVIObla	0	HVIObla	0	HVIObla	0	HRUBidM	0
HVIObla	0	HGERbic	0	HFRAveA	0	HFRAveA	0	HGERbic	0	UNKNOWN	0
HGERbic	0	HFRAveA	0	HGEUlac	0	HGEUlac	0	HFRAveA	0	HIMPcap	0
HFRAveA	0	HGEUlac	0	HVICcra	0	HVICcra	0	HGEUlac	0	HGERbic	0
HGEUlac	0	HVICcra	0	HSOLpta	0	WBETpap	0	HVICcra	0	HFRAveA	0
HVICcra	0	HSOLpta	0	HEPIang	0	HEPIang	0	HSOLpta	0	HGEUlac	0
HSOLpta	0	WBETpap	0	Sedges	0	Sedges	0	WBETpap	0	HVICcra	0
WBETpap	0	Sedges	0	HACHmiM	0	HACHmiM	0	Sedges	0	WBETpap	0
Sedges	0	HACHmiM	0	HCHRleu	0	HCHRleu	0	HACHmiM	0	HACHmiM	0
HACHmiM	0	HCHRleu	0	HASTlaf	0	HASTlaf	0	HASTlaf	0	HASTlaf	0
HASTlaf	0	HANAmar	0	HANAmar	0	HANAmar	0	HANAmar	0	HANAmar	0
HANAmar	0	HCONarv	0	HCONarv	0	HCONarv	0	HCONarv	0	HCONarv	0
WPOPtre	0	WPOPtre	0	WPOPtre	0	WPOPtre	0	WPOPtre	0	WPOPtre	0

Ranked species abundance for Block 3 (No. germinants in a log 10 scale).

Species	Brushsaw	Species	Control	Species	Forest	Species	Release	Species	Silvana	Species	Vision
Grasses	1.623	HRUBidM	1.462	HFRAveA	0.700	Grasses	1.929	Grasses	1.996	Grasses	1.810
HRUBidM	1.204	HEPILciG	1.447	HEPILciG	0.480	HEPILciG	1.362	HEPILciG	1.806	HEPILciG	1.380
HEPILciG	1.079	Grasses	1.398	HVIObla	0.480	HRUBidM	0.778	HFRAveA	1.000	HRUBidM	1.340
HFRAveA	0.903	HTARoff	0	HRUBidM	0.300	HVIObla	0.602	HMELalb	0.778	HASTmac	1.110
UNKNOWN	0.301	HASTmac	0	Grasses	0	HTARoff	0.477	HRUBidM	0.699	HMELalb	0.600
HTARoff	0	UNKNOWN	0	HTARoff	0	HANTneg	0.477	HTARoff	0	HPOTsim	0.600
HASTmac	0	HANTneg	0	HASTmac	0	HASTmac	0	HASTmac	0	UNKNOWN	0.480
HANTneg	0	HVIObla	0	UNKNOWN	0	UNKNOWN	0	UNKNOWN	0	WPOPtre	0.300
HVIObla	0	HFRAveA	0	HANTneg	0	HFRAveA	0	HANTneg	0	HTARoff	0
HGEUlac	0	HGEUlac	0	HGEUlac	0	HGEUlac	0	HVIObla	0	HANTneg	0
HAMOfru	0	HAMOfru	0	HAMOfru	0	HAMOfru	0	HGEUlac	0	HVIObla	0
HGALtin	0	HGALtin	0	HGALtin	0	HGALtin	0	HAMOfru	0	HFRAveA	0
HCHRleu	0	HCHRleu	0	HCHRleu	0	HCHRleu	0	HGALtin	0	HGEUlac	0
HANAmar	0	HANAmar	0	HANAmar	0	HANAmar	0	HCHRleu	0	HAMOfru	0
HCIRare	0	HCIRare	0	HCIRare	0	HCIRare	0	HANAmar	0	HGALtin	0
HARAnud	0	HARAnud	0	HARAnud	0	HARAnud	0	HCIRare	0	HCHRleu	0
HMELalb	0	HMELalb	0	HMELalb	0	HMELalb	0	HARAnud	0	HANAmar	0
WPOPtre	0	WPOPtre	0	WPOPtre	0	WPOPtre	0	WPOPtre	0	HCIRare	0
HPOTsim	0	HPOTsim	0	HPOTsim	0	HPOTsim	0	HPOTsim	0	HARAnud	0

Ranked species abundance for Block 4 (No. germinants in a log 10 scale).

Species	Brushsaw	Species	Control	Species	Forest	Species	Release	Species	Silvana	Species	Vision
HEPILciG	1.362	HRUBidM	1.279	HRUBidM	0.700	Grasses	1.740	Grasses	1.978	Grasses	1.590
Grasses	1.079	Grasses	1.146	Sedges	0.600	HEPILciG	1.380	HRUBidM	1.255	HRUBidM	1.080
HASTmac	0.301	HEPILciG	1.079	Grasses	0	HRUBidM	1.380	HEPILciG	1.176	HASTmac	0.780
HFRAveA	0.301	HANTneg	0.301	HHIEpan	0	UNKNOWN	0.954	HGERbic	1.000	UNKNOWN	0.700
HGOOpub	0.301	HFRAveA	0.301	HEPILciG	0	HVIObla	0.602	HFRAveA	0.903	HVIObla	0.700
HHIEpan	0	HHIEpan	0	HTARoff	0	HLECint	0.301	Sedges	0.903	HEPILciG	0.600
HTARoff	0	HTARoff	0	HASTmac	0	HHIEpan	0	HASTmac	0.845	HFRAveA	0.600
HRUBidM	0	HASTmac	0	UNKNOWN	0	HTARoff	0	UNKNOWN	0.699	HOENbie	0.480
UNKNOWN	0	UNKNOWN	0	HANTneg	0	HASTmac	0	HVIObla	0.477	HTARoff	0.300
HANTneg	0	HVIObla	0	HVIObla	0	HANTneg	0	HHIEpan	0.301	HHIEpan	0
HVIObla	0	HLECint	0	HLECint	0	HGERbic	0	HOXAstr	0.301	HANTneg	0
HLECint	0	HGERbic	0	HGERbic	0	HOXAstr	0	HAMOfru	0.301	HLECint	0
HGERbic	0	HOXAstr	0	HOXAstr	0	HFRAveA	0	HTARoff	0	HGERbic	0
HOXAstr	0	HVICcra	0	HFRAveA	0	HVICcra	0	HANTneg	0	HOXAstr	0
HVICcra	0	HAMOfru	0	HVICcra	0	HAMOfru	0	HLECint	0	HVICcra	0
HAMOfru	0	HGOOpub	0	HAMOfru	0	HGOOpub	0	HVICcra	0	HAMOfru	0
FRAGvir	0	FRAGvir	0	HGOOpub	0	FRAGvir	0	HGOOpub	0	HGOOpub	0
HEPIang	0	HEPIang	0	FRAGvir	0	HEPIang	0	FRAGvir	0	FRAGvir	0
Sedges	0	Sedges	0	HEPIang	0	Sedges	0	HEPIang	0	HEPIang	0
HOENbie	0	HOENbie	0	HOENbie	0	HOENbie	0	HOENbie	0	Sedges	0

APPENDIX III

ANALYSIS OF VARIANCE OF SPECIES RICHNESS BY BLOCK AND BY TREATMENT

DESIGN Dependent variables Name Code Log Richness
LRh Type of analysis: OLS ANOVA Factors Name Code Nested in F/R Kind TREAT.
TR. () Fix Disc BLOCK BLK () Fix Disc Partial
(Type 3) Sums of Squares Design Help Interactions up to 1 - way No Modifications
RESULTS: General Results 24 total cases ANOVA Analysis of Variance for Log Richness
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	22.0129	22.0129	1847.6 ²	0.0001
TR.	5	0.344481	0.0688963	5.7827	0.0036
BLK	3	0.0620401	0.02068	1.7357	0.2026
Error	15	0.178713	0.0119142		
Total	23	0.585235			

Results for factor TREATMENTS. Coefficients Coefficients of: Log Richness on TREATMENT.

Level of TR.	Coefficient	std. err.	t Ratio	prob
b	-0.04764	0.04982	-0.9562	0.3541
c	-0.06134	0.04982	-1.231	0.2372
f	-0.2121	0.04982	-4.258	0.0007
r	0.09483	0.04982	1.903	0.0764
s	0.1288	0.04982	2.585	0.0207
v	0.09753	0.04982	1.958	0.0692

Expected Cell Means Expected Cell Means of: Log Richness on TREATMENT.

Level of TR.	Expected Cell Mean	Cell Count
b	0.9101	4
c	0.8964	4
f	0.7456	4
r	1.053	4
s	1.086	4
v	1.055	4

Scheffe

Post Hoc Tests	Difference	std. err.	Prob
c - b	-0.0137055	0.07718	0.999988
f - b	-0.164503	0.07718	0.501258
f - c	-0.150797	0.07718	0.590021
r - b	0.142469	0.07718	0.644463
r - c	0.156174	0.07718	0.554894
r - f	**0.306972**	**0.07718**	**0.0379527**
s - b	0.1764	0.07718	0.427818
s - c	0.190106	0.07718	0.350147
s - f	**0.340903**	**0.07718**	**0.0182344**
s - r	0.0339313	0.07718	0.998996
v – b	0.145165	0.07718	0.626884
v - c	0.158871	0.07718	0.537391
v – f	**0.309668**	**0.07718**	**0.0358279**
v - r	0.00269663	0.07718	1.0000000
v - s	-0.0312347	0.07718	0.999327

Bonferroni

Post Hoc Test	Difference	std. err.	Prob
c - b	-0.0137055	0.07718	1
f - b	-0.164503	0.07718	0.536774
f - c	-0.150797	0.07718	0.661314
r - b	0.142469	0.07718	0.735046
r - c	0.156174	0.07718	0.612351
r - f	**0.306972**	**0.07718**	**0.0180603**
s - b	0.1764	0.07718	0.434173
s - c	0.190106	0.07718	0.330104
s - f	**0.340903**	**0.07718**	**0.00747018**
s - r	0.0339313	0.07718	1
v - b	0.145165	0.07718	0.71162
v - c	0.158871	0.07718	0.587737
v - f	**0.309668**	**0.07718**	**0.0168311**
v - r	0.00269663	0.07718	1
v - s	-0.0312347	0.07718	1

Variable LOG RICH By Variable TREAT

Multiple Range Tests: LSD test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 2.97

(*) Indicates significant differences which are shown in the lower triangle

```
                  G G G G G G
                  r r r r r r
                  p p p p p p

                  3 2 1 4 6 5
Mean    TREAT

 .7456  Grp 3
 .8964  Grp 2
 .9101  Grp 1
1.0525  Grp 4     *
1.0552  Grp 6     *
1.0865  Grp 5     * * *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6
Mean	.8964	.9101	1.0525	1.0552

Subset 3

Group	Grp 4	Grp 6	Grp 5
Mean	1.0525	1.0552	1.0865

Variable LOG RICH
By Variable TREAT

Multiple Range Tests: Modified LSD (Bonferroni) test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 4.78

(*) Indicates significant differences which are shown in the lower triangle

```
               G G G G G G
               r r r r r r
               p p p p p p

               3 2 1 4 6 5
  Mean    TREAT

  .7456   Grp 3
  .8964   Grp 2
  .9101   Grp 1
 1.0525   Grp 4    *
 1.0552   Grp 6    *
 1.0865   Grp 5    *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.8964	.9101	1.0525	1.0552	1.0865

Variable LOG RICH By Variable TREAT

Multiple Range Tests: Duncan test with significance level .05

The difference between two means is significant if

MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	2.97	3.11	3.22	3.27	3.32

(*) Indicates significant differences which are shown in the lower triangle

```
          G G G G G G
          r r r r r r
          p p p p p p

          3 2 1 4 6 5
Mean    TREAT

 .7456   Grp 3
 .8964   Grp 2
 .9101   Grp 1
1.0525   Grp 4    *
1.0552   Grp 6    *
1.0865   Grp 5    * *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6
Mean	.8964	.9101	1.0525	1.0552

Subset 3

Group	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.9101	1.0525	1.0552	1.0865

Variable LOG RICH By Variable TREAT

Multiple Range Tests: Student-Newman-Keuls test with significance level .050

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	2.97	3.60	3.99	4.27	4.49

(*) Indicates significant differences which are shown in the lower triangle

```
          G G G G G G
          r r r r r r
          p p p p p p

          3 2 1 4 6 5
```

Mean TREAT

.7456 Grp 3
.8964 Grp 2
.9101 Grp 1
1.0525 Grp 4 *
1.0552 Grp 6 *
1.0865 Grp 5 *

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.8964	.9101	1.0525	1.0552	1.0865

Variable LOG RICH By Variable TREAT

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 4.49

(*) Indicates significant differences which are shown in the lower triangle

G G G G G G
r r r r r r
p p p p p p

3 2 1 4 6 5

Mean TREAT

.7456 Grp 3
.8964 Grp 2
.9101 Grp 1
1.0525 Grp 4 *
1.0552 Grp 6 *
1.0865 Grp 5 *

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.8964	.9101	1.0525	1.0552	1.0865

Variable LOGRICH
By Variable TREAT

Multiple Range Tests: Tukey-B test with significance level .050
The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	3.73	4.05	4.24	4.38	4.49

(*) Indicates significant differences which are shown in the lower triangle

```
                 G G G G G G
                 r r r r r r
                 p p p p p p
                 3 2 1 4 6 5
Mean    TREAT
 .7456  Grp 3
 .8964  Grp 2
 .9101  Grp 1
1.0525  Grp 4    *
1.0552  Grp 6    *
1.0865  Grp 5    *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

- -

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.8964	.9101	1.0525	1.0552	1.0865

- -

Variable LOG RICH
By Variable TREAT

Multiple Range Tests: Scheffe test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= .0818 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 5.27

(*) Indicates significant differences which are shown in the lower triangle

```
G G G G G G
r r r r r r
p p p p p p

3 2 1 4 6 5
```

Mean	TREAT	
.7456	Grp 3	
.8964	Grp 2	
.9101	Grp 1	
1.0525	Grp 4	*
1.0552	Grp 6	*
1.0865	Grp 5	*

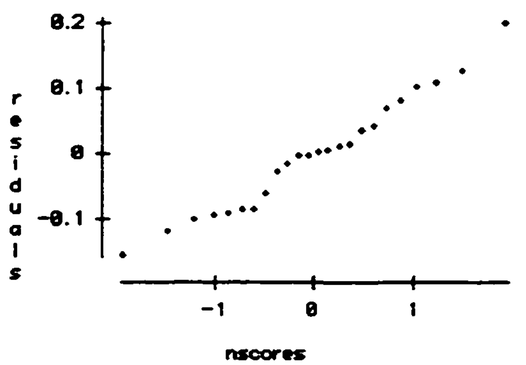
Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

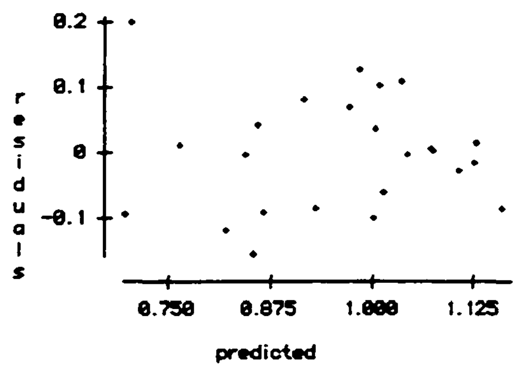
Group	Grp 3	Grp 2	Grp 1
Mean	.7456	.8964	.9101

Subset 2

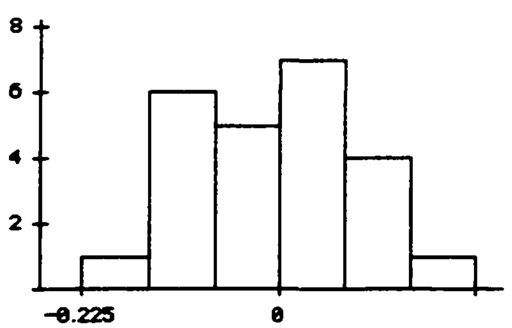
Group	Grp 2	Grp 1	Grp 4	Grp 6	Grp 5
Mean	.8964	.9101	1.0525	1.0552	1.0865



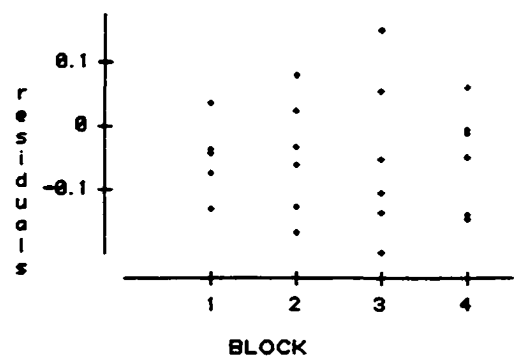
Normal probability plot of transformed log richness residuals.



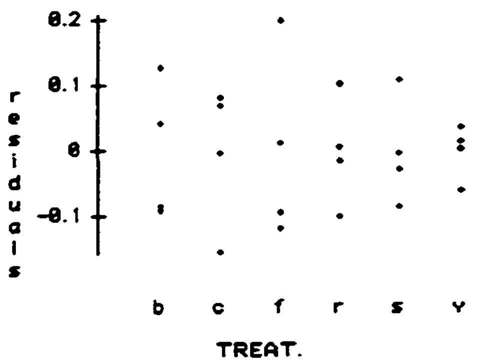
Scatterplot of log richness residuals against predicted



Histogram plot of log richness residuals by frequency.



Scatterplot of log richness residuals by block.



Dotplot of log species richness residual by treatment.

APPENDIX IV

ANALYSIS OF VARIANCE FOR TOTAL GERMINATES BY BLOCK AND BY TREATMENT

DESIGN Dependent variables
Name Code
Total Germinates
TGType of analysis: OLS ANOVA

Factors	Name	Code	Nested in F/R	Kind
TREAT.	TR.	()	Fix	Disc
BLOCK	BLK	()	Fix	DiscPartial (Type 3)

Sums of Squares
Design Help Interactions up to 1 - way No Modifications
RESULTS General Results
24 total cases ANOVA

Analysis of Variance For Total Germinates No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	213382	213382	153.03 [2]	0.0001
TR	5	43102.7	8620.54	6.1824	0.0027
BLK	3	3622.79	1207.6	0.86606	0.4802
Error	15	20915.5	1394.36		
Total	23	67641			

Results for factor TR. Coefficients
Coefficients of: Total Numbers on TR.Level of

TR.	Coefficient	std. err.	t Ratio	prob
b	-14.29	17.04	-0.8385	0.4149
c	-19.79	17.04	-1.161	0.2637
f	-77.04	17.04	-4.52	0.0004
r	28.96	17.04	1.699	0.1099
s	37.21	17.04	2.183	0.0453
v	44.96	17.04	2.638	0.0186

Expected Cell Means Expected Cell Means of: Total Germinates on TR.

Level of TR.	Expected Cell Mean	Cell Count
b	80	4
c	74.5	4
f	17.25	4
r	123.3	4
s	131.5	4
v	139.3	4

Scheffe

Post Hoc Tests	Difference	std. err.	Prob
c - b	-5.5	26.4	0.999974
f - b	-62.75	26.4	0.386947
f - c	-57.25	26.4	0.483291
r - b	43.25	26.4	0.745654
r - c	48.75	26.4	0.644251
r - f	**106**	**26.4**	**0.0356895**
s - b	51.5	26.4	0.591707
s - c	57	26.4	0.487885
s - f	**114.25**	**26.4**	**0.0212076**
s - r	8.25	26.4	0.99981
v - b	59.25	26.4	0.447137
v - c	64.75	26.4	0.354626
v - f	**122**	**26.4**	**0.0129343**
v - r	16	26.4	0.995393
v - s	7.75	26.4	0.99986

Bonferroni

Post Hoc Tests	Difference	std.	Prob
c - b	-5.5	26.4	1
f - b	-62.75	26.4	0.37863
f - c	-57.25	26.4	0.51147
r - b	43.25	26.4	0.858499
r - c	48.75	26.4	0.734766
r - f	**106**	**26.4**	**0.0167517**
s - b	51.5	26.4	0.663643
s - c	57	26.4	0.517933
s - f	**114.25**	**26.4**	**0.00893952**
s - r	8.25	26.4	1
v - b	59.25	26.4	0.460898
v - c	64.75	26.4	0.335924
v - f	**122**	**26.4**	**0.00498611**
v - r	16	26.4	0.999994
v - s	7.75	26.4	1

Variable TOTAL GERM.
By Variable TREAT

Multiple Range Tests: LSD test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 2.97

(*) Indicates significant differences which are shown in the lower triangle

```
                G G G G G G
                r r r r r r
                p p p p p p

                3 2 1 4 5 6
 Mean     TREAT

 17.2500  Grp 3
 74.5000  Grp 2   *
 80.0000  Grp 1   *
123.2500  Grp 4   *
131.5000  Grp 5   * *
139.2500  Grp 6   * * *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3
Mean	17.2500

Subset 2

Group	Grp 2	Grp 1	Grp 4
Mean	74.5000	80.0000	123.2500

Subset 3

Group	Grp 1	Grp 4	Grp 5
Mean	80.0000	123.2500	131.5000

Subset 4

Group	Grp 4	Grp 5	Grp 6
Mean	123.2500	131.5000	139.2500

Variable TOTAL GERM.
By Variable TREAT

Multiple Range Tests: Modified LSD (Bonferroni) test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 4.78

(*) Indicates significant differences which are shown in the lower triangle

Mean	TREAT	G r p 3	G r p 2	G r p 1	G r p 4	G r p 5	G r p 6
17.2500	Grp 3						
74.5000	Grp 2						
80.0000	Grp 1						
123.2500	Grp 4	*					
131.5000	Grp 5	*					
139.2500	Grp 6	*					

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	17.2500	74.5000	80.0000

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 5	Grp 6
Mean	74.5000	80.0000	123.2500	131.5000	139.2500

- -

Variable TOTAL GERM.
By Variable TREAT

Multiple Range Tests: Duncan test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	2.97	3.11	3.22	3.27	3.32

(*) Indicates significant differences which are shown in the lower triangle

```
                 G G G G G G
                 r r r r r r
                 p p p p p p

                 3 2 1 4 5 6
 Mean      TREAT

 17.2500   Grp 3
 74.5000   Grp 2   *
 80.0000   Grp 1   *
 123.2500  Grp 4   *
 131.5000  Grp 5   *
 139.2500  Grp 6   * *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3
Mean	17.2500

- - - - - -

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 5
Mean	74.5000	80.0000	123.2500	131.5000

- -

Subset 3

Group	Grp 1	Grp 4	Grp 5	Grp 6
Mean	80.0000	123.2500	131.5000	139.2500

- -

Variable TOTAL GERM.
By Variable TREAT

Multiple Range Tests: Student-Newman-Keuls test with significance level .050

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))

with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	2.97	3.60	3.99	4.27	4.49

(*) Indicates significant differences which are shown in the lower triangle

```
               G G G G G G
               r r r r r r
               p p p p p p

               3 2 1 4 5 6
  Mean      TREAT

 17.2500   Grp 3
 74.5000   Grp 2
 80.0000   Grp 1
123.2500   Grp 4     *
131.5000   Grp 5     *
139.2500   Grp 6     *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	17.2500	74.5000	80.0000

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 5	Grp 6
Mean	74.5000	80.0000	123.2500	131.5000	139.2500

Variable TOTAL GERM.
By Variable TREAT

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 4.49

(*) Indicates significant differences which are shown in the lower triangle

```
               G G G G G G
               r r r r r r
               p p p p p p

               3 2 1 4 5 6
  Mean      TREAT

 17.2500   Grp 3
 74.5000   Grp 2
 80.0000   Grp 1
123.2500   Grp 4     *
131.5000   Grp 5     *
139.2500   Grp 6     *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	17.2500	74.5000	80.0000

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 5	Grp 6
Mean	74.5000	80.0000	123.2500	131.5000	139.2500

Variable TOTALGERM
By Variable TREAT

Multiple Range Tests: Tukey-B test with significance level .050

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE:

Step	2	3	4	5	6
RANGE	3.73	4.05	4.24	4.38	4.49

(*) Indicates significant differences which are shown in the lower triangle

```
              G G G G G G
              r r r r r r
              p p p p p p

              3 2 1 4 5 6
  Mean      TREAT

  17.2500   Grp 3
  74.5000   Grp 2
  80.0000   Grp 1
 123.2500   Grp 4     *
 131.5000   Grp 5     *
 139.2500   Grp 6     *
```

Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

Group	Grp 3	Grp 2	Grp 1
Mean	17.2500	74.5000	80.0000

Subset 2

Group	Grp 2	Grp 1	Grp 4	Grp 5	Grp 6
Mean	74.5000	80.0000	123.2500	131.5000	139.2500

Variable TOTALGERM
By Variable TREAT

Multiple Range Tests: Scheffe test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 26.1078 * RANGE * SQRT(1/N(I) + 1/N(J))

with the following value(s) for RANGE: 5.27

(*) Indicates significant differences which are shown in the lower triangle

```
G G G G G G
r r r r r r
p p p p p p

3 2 1 4 5 6
```

Mean	TREAT	
17.2500	Grp 3	
74.5000	Grp 2	
80.0000	Grp 1	
123.2500	Grp 4	*
131.5000	Grp 5	*
139.2500	Grp 6	*

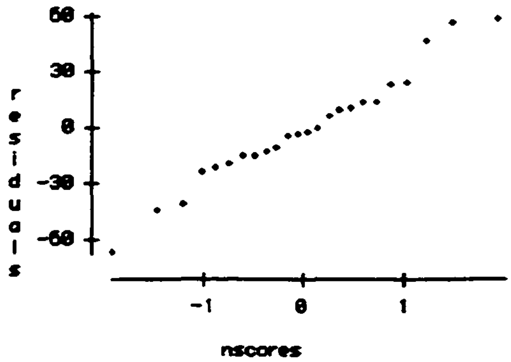
Homogeneous Subsets (highest and lowest means are not significantly different)

Subset 1

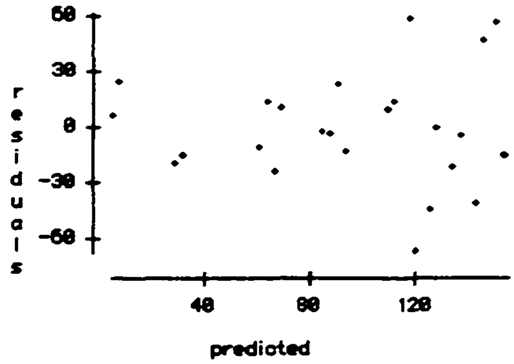
Group	Grp 3	Grp 2	Grp 1
Mean	17.2500	74.5000	80.0000

Subset 2

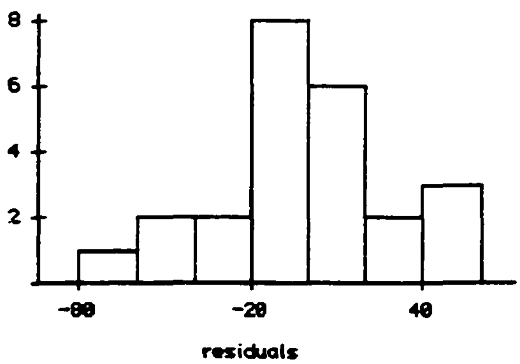
Group	Grp 2	Grp 1	Grp 4	Grp 5	Grp 6
Mean	74.5000	80.0000	123.2500	131.5000	139.2500



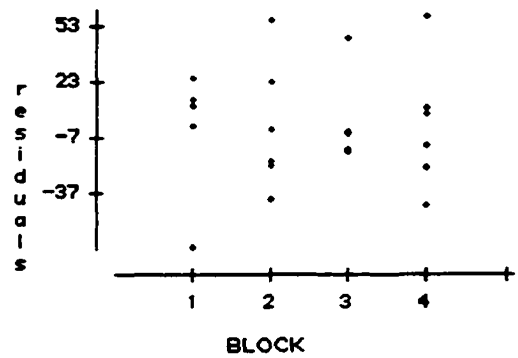
Probability plots of total species residuals.



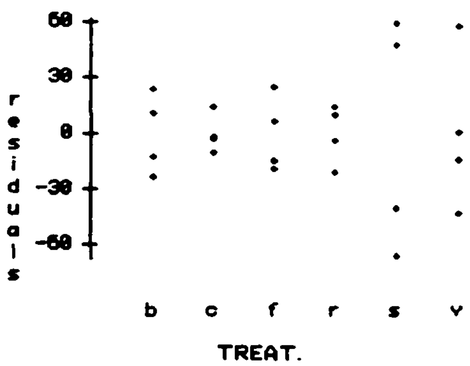
Scatterplot of residual species total against predicted.



Histogram plot of total species residuals by frequency.



Scatterplot of total species residuals by block



Dotplot of total species residual by treatment.

APPENDIX V

SAS PROGRAM, DATA, AND OUTPUT FOR ORTHOGONAL COMPARISONS

DATA:

Treatment †	Block	Species (#)	# Germinants (#)
1	1	6	32
1	2	5	9
1	3	8	17
1	4	4	11
2	1	10	78
2	2	11	84
2	3	5	85
2	4	7	51
3	1	7	80
3	2	13	115
3	3	6	81
3	4	8	44
4	1	12	54
4	2	12	102
4	3	11	193
4	4	14	177
5	1	12	129
5	2	14	207
5	3	9	139
5	4	11	82
6	1	12	127
6	2	13	113
6	3	13	133
6	4	8	120

† Treatments are: 1 = Forest, 2 =Control, 3 =Brushsaw, 4 =Silvana Selective, 5 = Vision and 6 = Release

```
options ps=55 ls=85 pageno=1;
data a;
        infile 'w:\wood\fallsnow.txt' expandtabs;
        input TREAT BLOCK NUMB ABUND;
        LOGNO=LOG10(NUMB);

data b;
        set a;
        proc glm;
                title1 'Analysis of Numbers';
                title2 '===================';
                class TREAT BLOCK;
                model NUMB=TREAT BLOCK;
                lsmeans TREAT /stderr;
                means TREAT/ tukey lines;
                /************************ TREAT  1  2  3  4  5  6 ******/
                /************************        =  =  =  =  =  = ******/
                contrast 'BS vs SYLV     ' TREAT  0  0  1 -1  0  0;
                contrast 'GLY vs TRI     ' TREAT  0  0  0  0  1 -1;
                contrast 'CUT vs HERB    ' TREAT  0  0  1  1 -1 -1;
                contrast 'TREAT vs CONT  ' TREAT  0  4 -1 -1 -1 -1;
                contrast 'FOR vs CUTOVER' TREAT  5 -1 -1 -1 -1 -1;

                output out=CHECK residual=RESID predicted=PRED;
                proc plot data=CHECK;  /* Note: residual plots look symetrical because
n=2 for everything */
                        plot RESID*PRED / vref=0;
                proc univariate data=CHECK normal plot;
                        var RESID;

data c;
        set a;
        proc glm;
                title1 'Analysis of LOG(Numbers)';
                title2 '========================';
                class TREAT BLOCK;
                model LOGNO=TREAT BLOCK;
                lsmeans TREAT /stderr;
                means TREAT/ tukey lines;
                /************************ TREAT  1  2  3  4  5  6 ******/
                /************************        =  =  =  =  =  = ******/
                contrast 'BS vs SYLV     ' TREAT  0  0  1 -1  0  0;
                contrast 'GLY vs TRI     ' TREAT  0  0  0  0  1 -1;
                contrast 'CUT vs HERB    ' TREAT  0  0  1  1 -1 -1;
                contrast 'TREAT vs CONT  ' TREAT  0  4 -1 -1 -1 -1;
                contrast 'FOR vs CUTOVER' TREAT  5 -1 -1 -1 -1 -1;

                output out=CHECK residual=RESID predicted=PRED;
                proc plot data=CHECK;  /* Note: residual plots look symetrical because
n=2 for everything */
                        plot RESID*PRED / vref=0;
                proc univariate data=CHECK normal plot;
                        var RESID;
```

```
data d;
      set a;
      proc glm;
            title1 'Analysis of Abundance';
            title2 '====================';
            class TREAT BLOCK;
            model ABUND=TREAT BLOCK;
            lsmeans TREAT /stderr;
            means TREAT/ tukey lines;
            /************************* TREAT  1  2  3  4  5  6 ******/
            /*************************        =  =  =  =  =  = ******/
            contrast 'BS vs SYLV    ' TREAT  0  0  1 -1  0  0;
            contrast 'GLY vs TRI    ' TREAT  0  0  0  0  1 -1;
            contrast 'CUT vs HERB   ' TREAT  0  0  1  1 -1 -1;
            contrast 'TREAT vs CONT ' TREAT  0  4 -1 -1 -1 -1;
            contrast 'FOR vs CUTOVER' TREAT  5 -1 -1 -1 -1 -1;

            output out=CHECK residual=RESID predicted=PRED;
            proc plot data=CHECK;  /* Note: residual plots look symetrical because
n=2 for everything */
                  plot RESID*PRED / vref=0;
            proc univariate data=CHECK normal plot;
                  var RESID;
run;
```

```
                              Analysis of Numbers                             1
                              ===================  15:02 Friday, February 12, 1999
                         General Linear Models Procedure
                            Class Level Information
                         Class     Levels    Values
                         TREAT        6      1 2 3 4 5 6
                         BLOCK        4      1 2 3 4

                    Number of observations in data set = 24
```

```
                              Analysis of Numbers                             2
                              ===================  15:02 Friday, February 12, 1999
                         General Linear Models Procedure
Dependent Variable: NUMB
Source                  DF      Sum of Squares      Mean Square  F Value    Pr > F
Model                    8        157.16666667      19.64583333     4.43    0.0064
Error                   15         66.45833333       4.43055556
Corrected Total         23        223.62500000

              R-Square                C.V.           Root MSE          NUMB Mean
              0.702813            21.86897         2.10488849         9.62500000

Source                  DF           Type I SS      Mean Square  F Value    Pr > F
TREAT                    5        128.37500000      25.67500000     5.79    0.0036
BLOCK                    3         28.79166667       9.59722222     2.17    0.1346

Source                  DF         Type III SS      Mean Square  F Value    Pr > F
TREAT                    5        128.37500000      25.67500000     5.79    0.0036
BLOCK                    3         28.79166667       9.59722222     2.17    0.1346
```

```
                              Analysis of Numbers                             3
                              ===================  15:02 Friday, February 12, 1999
                         General Linear Models Procedure
                               Least Squares Means
              TREAT           NUMB        Std Err       Pr > |T|
                            LSMEAN         LSMEAN    H0:LSMEAN=0
              1          5.7500000      1.0524442         0.0001
              2          8.2500000      1.0524442         0.0001
              3          8.5000000      1.0524442         0.0001
              4         12.2500000      1.0524442         0.0001
              5         11.5000000      1.0524442         0.0001
              6         11.5000000      1.0524442         0.0001
```

```
                              Analysis of Numbers                             4
                              ===================  15:02 Friday, February 12, 1999
                         General Linear Models Procedure
            Tukey's Studentized Range (HSD) Test for variable: NUMB
         NOTE: This test controls the type I experimentwise error rate, but
               generally has a higher type II error rate than REGWQ.
                     Alpha= 0.05  df= 15  MSE= 4.430556
                  Critical Value of Studentized Range= 4.595
                    Minimum Significant Difference= 4.8357
```

Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	TREAT
	A	12.250	4	4
	A			
	A	11.500	4	5
	A			
	A	11.500	4	6
	A			
B	A	8.500	4	3
B	A			
B	A	8.250	4	2
B				
B		5.750	4	1

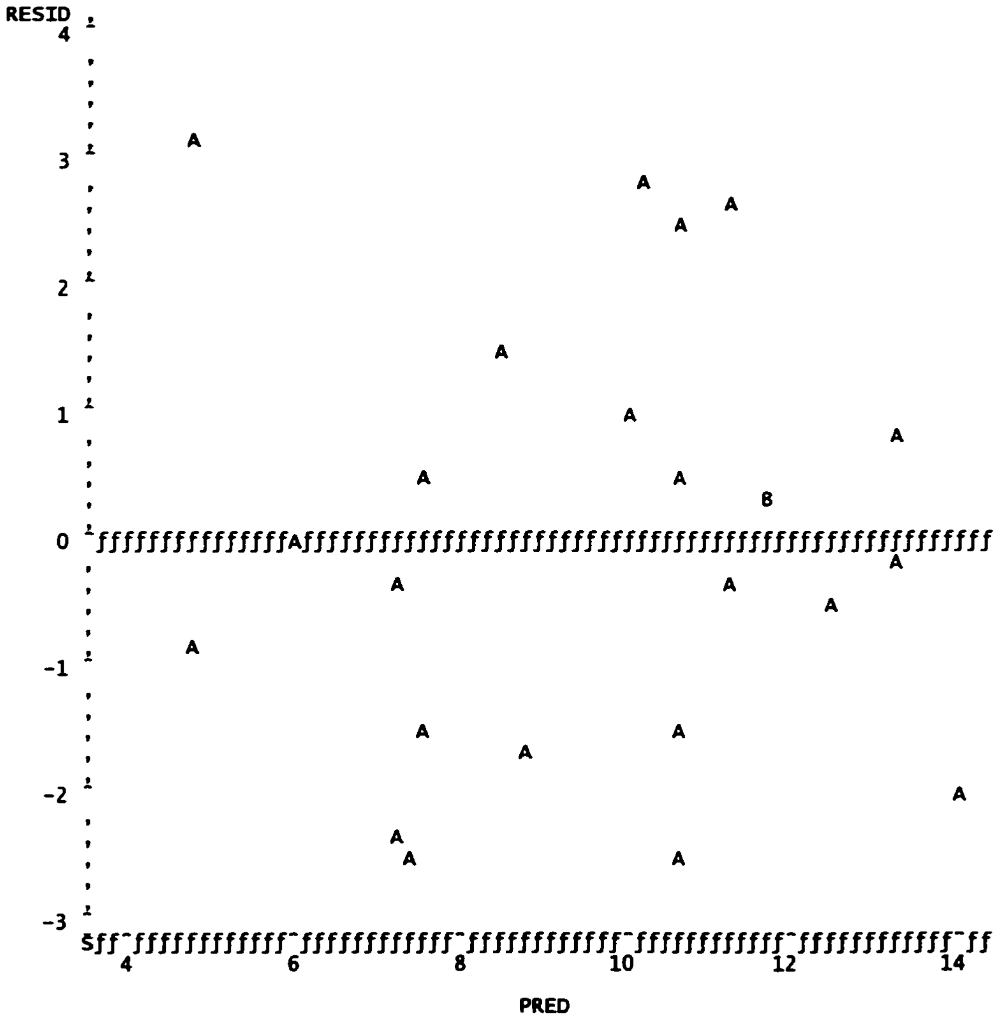
Analysis of Numbers 5
15:02 Friday, February 12, 1999
General Linear Models Procedure

Dependent Variable: NUMB

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
BS vs SYLV	1	28.12500000	28.12500000	6.35	0.0236
GLY vs TRI	1	0.00000000	0.00000000	0.00	1.0000
CUT vs HERB	1	5.06250000	5.06250000	1.14	0.3020
TREAT vs CONT	1	23.11250000	23.11250000	5.22	0.0374
FOR vs CUTOVER	1	72.07500000	72.07500000	16.27	0.0011

Analysis of Numbers 6
15:02 Friday, February 12, 1999

Plot of RESID*PRED. Legend: A = 1 obs, B = 2 obs, etc.



```
                                 Analysis of Numbers                                    7
                                 ===================  15:02 Friday, February 12, 1999
                               Univariate Procedure
Variable=RESID
           Moments                                         Quantiles(Def=5)
N              24  Sum Wgts        24         100% Max  3.208333       99%  3.208333
Mean            0  Sum              0          75% Q3   0.916667       95%  2.791667
Std Dev  1.699851  Variance  2.889493          50% Med  -0.08333       90%  2.708333
Skewness 0.301772  Kurtosis  -0.69504          25% Q1   -1.54167       10%  -2.29167
USS      66.45833  CSS       66.45833           0% Min  -2.54167        5%  -2.45833
CV              .  Std Mean  0.346981                                   1%  -2.54167
T:Mean=0        0  Pr>|T|      1.0000         Range         5.75
Num ^= 0       24  Num > 0         12         Q3-Q1     2.458333
M(Sign)         0  Pr>=|M|     1.0000         Mode      -1.54167
Sgn Rank        2  Pr>=|S|     0.9558
W:Normal 0.951125  Pr<W        0.2937
```

```
                          Extremes
          Lowest    Obs    Highest    Obs
       -2.54167(     24) 1.541667(      5)
       -2.45833(      2) 2.458333(     23)
       -2.29167(      7) 2.708333(     16)
       -1.95833(     14) 2.791667(     10)
       -1.70833(      9) 3.208333(      3)

     Stem Leaf                     #             Boxplot
        3 2                        1                |
        2 578                      3                |
        1 05                       2                |
        0 033558                   6             +--+--+
       -0 85332                    5             *-----*
       -1 755                      3             +-----+
       -2 5530                     4                |
          ----+----+----+----+

                              Normal Probability Plot
      3.5+                                                          +*++++
         |                                                  * *++*++
         |                                              +*+*++
      0.5+                                       +****+*
         |                                   ***+*
         |                           +**+*+
     -2.5+          * ++*++*
          +----+----+----+----+----+----+----+----+----+----+
               -2        -1         0        +1        +2
```

```
                              Analysis of LOG (Numbers)                              8
                              =========================
                                                       15:02 Friday, February 12, 1999

                        General Linear Models Procedure
                            Class Level Information
                        Class     Levels    Values
                        TREAT          6    1 2 3 4 5 6
                        BLOCK          4    1 2 3 4

                    Number of observations in data set = 24
```

Analysis of LOG(Numbers) 9

15:02 Friday, February 12, 1999

General Linear Models Procedure

Dependent Variable: LOGNO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.40652143	0.05081518	4.27	0.0076
Error	15	0.17871310	0.01191421		
Corrected Total	23	0.58523452			

R-Square	C.V.	Root MSE	LOGNO Mean
0.694630	11.39723	0.10915222	0.95770834

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	0.34448129	0.06889626	5.78	0.0036
BLOCK	3	0.06204014	0.02068005	1.74	0.2026

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	5	0.34448129	0.06889626	5.78	0.0036
BLOCK	3	0.06204014	0.02068005	1.74	0.2026

Analysis of LOG(Numbers) 10

15:02 Friday, February 12, 1999

General Linear Models Procedure
Least Squares Means

TREAT	LOGNO LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0
1	0.74556781	0.05457611	0.0001
2	0.89636518	0.05457611	0.0001
3	0.91007066	0.05457611	0.0001
4	1.08647080	0.05457611	0.0001
5	1.05523612	0.05457611	0.0001
6	1.05253948	0.05457611	0.0001

Analysis of LOG(Numbers) 11

15:02 Friday, February 12, 1999

General Linear Models Procedure
Tukey's Studentized Range (HSD) Test for variable: LOGNO
NOTE: This test controls the type I experimentwise error rate, but
generally has a higher type II error rate than REGWQ.
Alpha= 0.05 df= 15 MSE= 0.011914
Critical Value of Studentized Range= 4.595
Minimum Significant Difference= 0.2508
Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	TREAT
	A	1.08647	4	4
	A			
	A	1.05524	4	5
	A			
	A	1.05254	4	6
	A			
B	A	0.91007	4	3
B	A			
B	A	0.89637	4	2
B				
B		0.74557	4	1

Analysis of LOG(Numbers) 12

15:02 Friday, February 12, 1999

General Linear Models Procedure

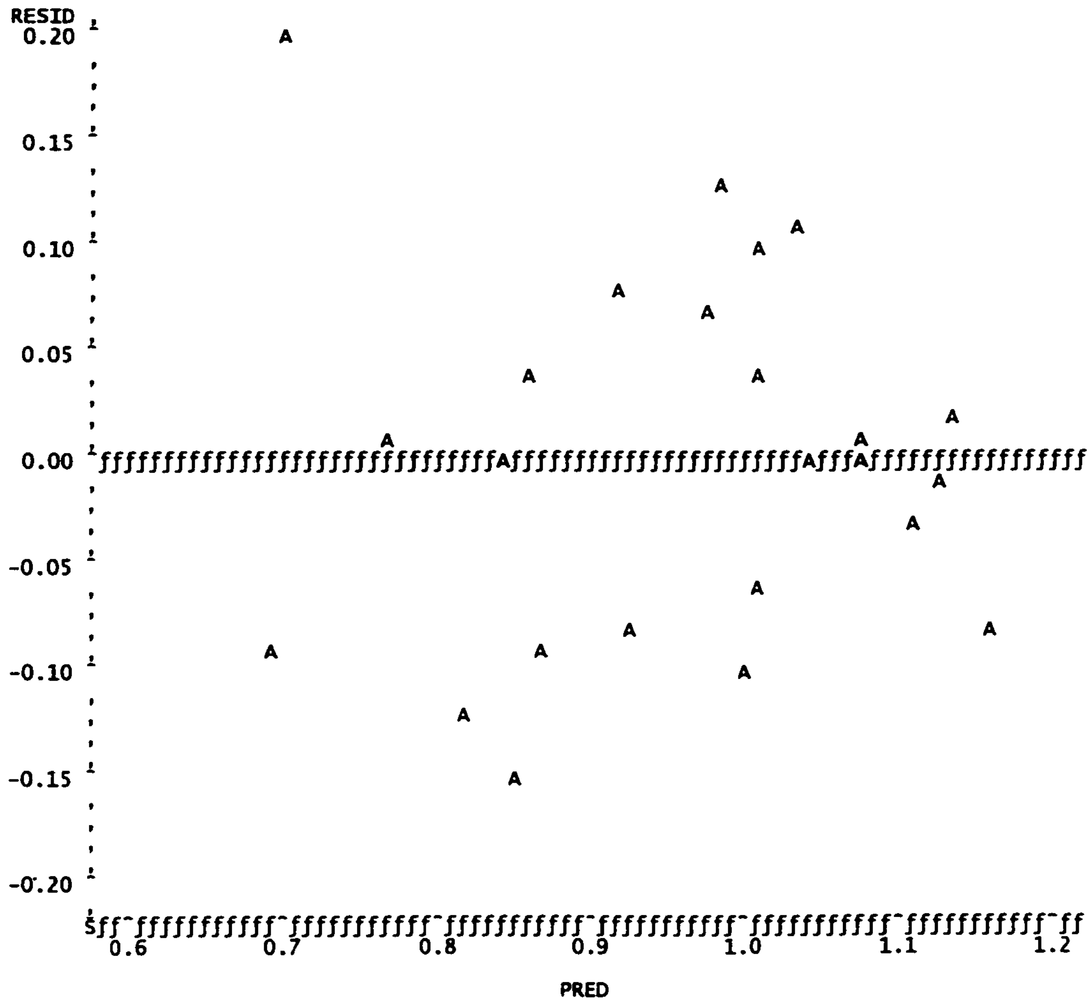
Dependent Variable: LOGNO

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
BS vs SYLV	1	0.06223402	0.06223402	5.22	0.0373
GLY vs TRI	1	0.00001454	0.00001454	0.00	0.9726
CUT vs HERB	1	0.01237303	0.01237303	1.04	0.3243
TREAT vs CONT	1	0.05384238	0.05384238	4.52	0.0505
FOR vs CUTOVER	1	0.21601731	0.21601731	18.13	0.0007

Analysis of LOG(Numbers) 13

15:02 Friday, February 12, 1999

Plot of RESID*PRED. Legend: A = 1 obs, B = 2 obs, etc.



```
                              Analysis of LOG(Numbers)                        14
                              ========================
                                                  15:02 Friday, February 12, 1999
                                 Univariate Procedure
Variable=RESID

              Moments                                    Quantiles(Def=5)
N                 24  Sum Wgts         24      100% Max  0.200266        99%  0.200266
Mean               0  Sum               0       75% Q3   0.057197        95%  0.129321
Std Dev     0.088148  Variance    0.00777       50% Med  0.002243        90%  0.110556
Skewness    0.309883  Kurtosis   -0.29066       25% Q1   -0.08295        10%  -0.09855
USS         0.178713  CSS        0.178713        0% Min  -0.15465         5%  -0.12115
CV                 .  Std Mean   0.017993                                 1%  -0.15465
T:Mean=0           0  Pr>|T|       1.0000      Range     0.354917
Num ^= 0          24  Num > 0          12      Q3-Q1     0.140149
M(Sign)            0  Pr>=|M|      1.0000      Mode      -0.15465
Sgn Rank           1  Pr>=|S|      0.9779
W:Normal    0.976212  Pr<W         0.8104


                                    Extremes

                      Lowest    Obs     Highest    Obs
                    -0.15465(     7) 0.084544(      5)
                    -0.12115(     2) 0.104147(     23)
                    -0.09855(    24) 0.110556(     16)
                    -0.09261(     4) 0.129321(     10)
                    -0.08918(    11) 0.200266(      3)

                 Stem Leaf                    #             Boxplot
                    2 0                       1                |
                    1                                          |
                    1 013                     3                |
                    0 78                      2             +-----+
                    0 011244                  6             *--+--*
                   -0 3100                    4             |     |
                   -0 99886                   5             +-----+
                   -1 20                      2                |
                   -1 5                       1                |
                      ----+----+----+----+
                 Multiply Stem.Leaf by 10**-1
```

```
                              Analysis of LOG(Numbers)                        15
                              ========================
                                                  15:02 Friday, February 12, 1999

                                 Univariate Procedure
Variable=RESID

                                Normal Probability Plot
            0.225+                                                *   +++
                 |                                              +++++
                 |                                         *  *++*++
                 |                                      +*+*++
            0.025+                                  +******
                 |                              +****
                 |                        *+**+***
                 |                   ++*+++
           -0.175+  +++*+
                  +----+----+----+----+----+----+----+----+----+----+
                      -2        -1         0        +1        +2
```

```
                             Analysis of Abundance                            16
                             ===================== 15:02 Friday, February 12, 1999
                         General Linear Models Procedure
                             Class Level Information

                         Class     Levels    Values
                         TREAT          6    1 2 3 4 5 6
                         BLOCK          4    1 2 3 4

                      Number of observations in data set = 24
```

Analysis of Abundance 17
15:02 Friday, February 12, 1999

General Linear Models Procedure

Dependent Variable: ABUND

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	46725.50000000	5840.68750000	4.19	0.0082
Error	15	20915.45833333	1394.36388889		
Corrected Total	23	67640.95833333			

R-Square	C.V.	Root MSE	ABUND Mean
0.690787	39.60178	37.34118221	94.29166667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	43102.70833333	8620.54166667	6.18	0.0027
BLOCK	3	3622.79166667	1207.59722222	0.87	0.4802

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	5	43102.70833333	8620.54166667	6.18	0.0027
BLOCK	3	3622.79166667	1207.59722222	0.87	0.4802

Analysis of Abundance 18
15:02 Friday, February 12, 1999

General Linear Models Procedure
Least Squares Means

TREAT	ABUND LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0
1	17.250000	18.670591	0.3702
2	74.500000	18.670591	0.0012
3	80.000000	18.670591	0.0007
4	131.500000	18.670591	0.0001
5	139.250000	18.670591	0.0001
6	123.250000	18.670591	0.0001

Analysis of Abundance 19
15:02 Friday, February 12, 1999

General Linear Models Procedure
Tukey's Studentized Range (HSD) Test for variable: ABUND
NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.
Alpha= 0.05 df= 15 MSE= 1394.364
Critical Value of Studentized Range= 4.595
Minimum Significant Difference= 85.786
Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	TREAT
	A	139.25	4	5
	A			
	A	131.50	4	4
	A			
	A	123.25	4	6
	A			
B	A	80.00	4	3
B	A			
B	A	74.50	4	2
B				
B		17.25	4	1

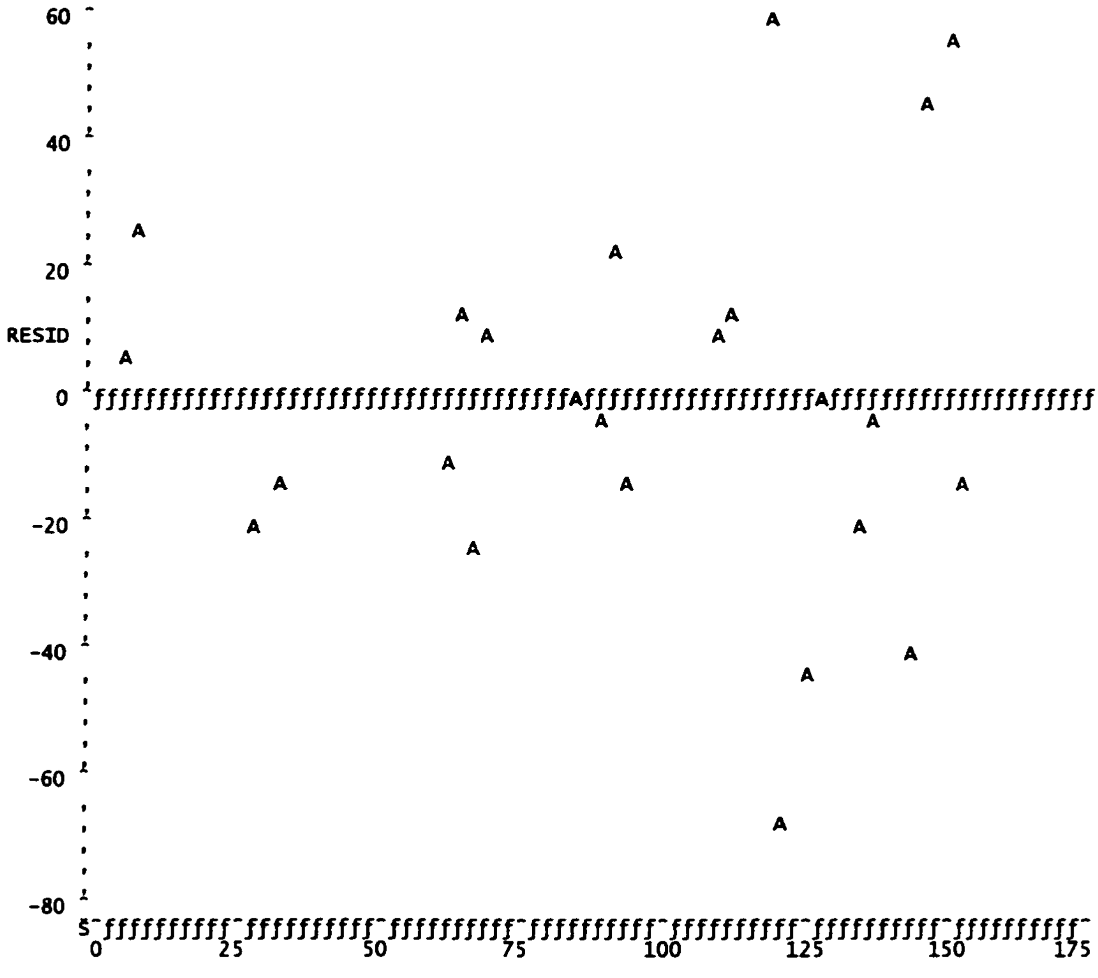
Analysis of Abundance 20
15:02 Friday, February 12, 1999
General Linear Models Procedure

Dependent Variable: ABUND

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
BS vs SYLV	1	5304.50000000	5304.50000000	3.80	0.0701
GLY vs TRI	1	512.00000000	512.00000000	0.37	0.5536
CUT vs HERB	1	2601.00000000	2601.00000000	1.87	0.1921
TREAT vs CONT	1	6195.20000000	6195.20000000	4.44	0.0523
FOR vs CUTOVER	1	28490.00833333	28490.00833333	20.43	0.0004

Analysis of Abundance 21
15:02 Friday, February 12, 1999

Plot of RESID*PRED. Legend: A = 1 obs, B = 2 obs, etc.



Analysis of Abundance 22
15:02 Friday, February 12, 1999
Univariate Procedure

Variable=RESID

Moments

N	24	Sum Wgts	24
Mean	0	Sum	0
Std Dev	30.15573	Variance	909.3678
Skewness	0.104285	Kurtosis	0.346357
USS	20915.46	CSS	20915.46
CV	.	Std Mean	6.155512
T:Mean=0	0	Pr>|T|	1.0000
Num ^= 0	24	Num > 0	11
M(Sign)	-1	Pr>=|M|	0.8388
Sgn Rank	-3	Pr>=|S|	0.9338
W:Normal	0.97225	Pr<W	0.7198

Quantiles(Def=5)

100% Max	58.95833	99%	58.95833
75% Q3	14.58333	95%	57.04167
50% Med	-2.20833	90%	47.79167
25% Q1	-16.4583	10%	-40.2083
0% Min	-66.5417	5%	-43.7917
		1%	-66.5417
Range	125.5		
Q3-Q1	31.04167		
Mode	-66.5417		

```
                    Extremes
    Lowest    Obs      Highest    Obs
  -66.5417(     13) 24.29167(      10)
  -43.7917(     20) 25.70833(       1)
  -40.2083(     14) 47.79167(      15)
  -22.5417(     12) 57.04167(      18)
  -20.9583(     22) 58.95833(      16)
```

```
Stem Leaf                     #             Boxplot
   4 879                      3                |
   2 46                       2                |
   0 170145                   6             +--+--+
  -0 94430431                 8             *-----*
  -2 31                       2                |
  -4 40                       2                |
  -6 7                        1                0
     ----+----+----+----+
 Multiply Stem.Leaf by 10**+1
```

```
                   Normal Probability Plot
 50+                                              * +*+++*
   |                                         ++**+++
   |                                    ++******
-10+                               ******* *
   |                          +++**++
   |                     ++++*+ *
-70++++++++*
    +----+----+----+----+----+----+----+----+----+----+
        -2        -1         0        +1        +2
```