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The Short and Long-term Effects of Herbicide Application in Maine Clearcuts on Ant Communities (*Hymenoptera: Formicidae*)

Kerry Frances Lough

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**THE SHORT AND LONG-TERM EFFECTS OF HERBICIDE APPLICATION IN
MAINE CLEARCUTS ON ANT COMMUNITIES (HYMENOPTERA:
FORMICIDAE)**

By

Kerry Frances Lough

B.S. Colorado State University, 1997

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Advisory Committee:

Francis A. Drummond, Professor of Biological Sciences, Advisor

Stephen Woods, Associate Professor of Biological Sciences, Co-Advisor

Constance Stubbs, Assistant Scientist of Applied Ecology and Environmental Sciences

Alan White, Associate Professor of Forest Resources

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An Abstract of the Thesis Presented
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The short and long-term effects of glyphosate application on the diversity and abundance of ants in Maine clearcuts was assessed in a two-year study. Glyphosate is applied to release coniferous trees from suppression by competition with deciduous vegetation after a forest is clearcut. Previous research indicates glyphosate has limited immediate and long-term effects on non-target fauna, though specific species can be affected. Limited research on the effects of herbicides on insects indicates some initial decrease in insect populations. Beneficial insects, such as pollinators and predators, positively influence the forest ecosystem, but little research has examined the effects of herbicide application on those insects. Ants are predators of a variety of insects, including those considered pest insects. The presence of ants in the forest may influence pest population abundance and thus indirectly affect the abundance and diversity of vegetation. Therefore, land managers need to understand the effects of herbicide application on ants to determine the impacts of their land management strategies.

To observe the effects of herbicide application, eighteen to twenty study sites located in western Maine including young (3-5 years since harvest) glyphosate treated, young non-treated, old (10-15 years since harvest) glyphosate treated, old non-treated, plantations (old glyphosate treated then planted), and mature sites (not harvested) were utilized. In 2000 and 2001, pitfall traps were used to assess the diversity and abundance of ants. Soil pH, soil percent organic matter, soil moisture, and the density of herbaceous and woody vegetation were measured in each site to quantify the effects of these factors on ant communities.

In 2000, a total of 2168 ants and in 2001, a total of 2045 ants were collected. Six genera and 13 species were found in both years. In 2000, significantly more ants were found in young herbicide sites than young non-herbicide and in old herbicide than in non-herbicide sites, but there was no difference in ant diversity. Similarly in 2001, there were significant age*herbicide interactions, indicating an herbicide effect. Ant populations in old herbicide sites and plantations were significantly more abundant than those in young herbicide and young non-herbicide sites in both years. There were also significantly more ants in young herbicide than non-herbicide in both years. The total ant captures in old sites was significantly higher than in young sites indicating the age since harvest affects ant abundance. In 2001, ant diversity was higher in old herbicide than in young herbicide sites. Soil pH, percent organic matter, soil moisture, hardwood density and floral density did not affect the diversity or abundance of ants in either year. Softwood density was positively correlated to total ant abundance in both years as well as to the abundance of specific ant species. Softwood density may explain the pattern of both glyphosate and age effects.

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Chapter 1

LITERATURE REVIEW

The Effects of Glyphosate in Forest Ecosystems

Herbicide application on clearcuts is a common forest management practice. Broad-leaf herbicides such as glyphosate, imazapyr, triclopyr, sulfometuron methyl, and metsulfuron methyl are sprayed to eradicate or retard growth of deciduous trees and shrubs, which may compete with coniferous trees for light, water, space and nutrients (Steward et al 1984). Herbicide application encourages early regeneration and rapid growth of conifer species (Pitt et al 1993, Newton et al 1992). As the practice became more common, interest in the short and long-term effects of broad-leaf herbicides such as glyphosate on vegetation, as well as, concerns for effects on non-target organisms were raised.

Several studies have researched the short-term effects of glyphosate on deciduous and herbaceous vegetation. In general, glyphosate reduces plant cover and diversity in the short-term with recovery beginning in the first 2 – 3 years post-spray (MacKinnon and Freedman 1993, May et al 1982, Santillo et al 1989b). Contradictory results have indicated there is a short-term increase in herbaceous vegetation as a result of glyphosate application (Freedman et al 1993). MacKinnon and Freedman (1993) noted the recovery of vegetation began in the second year post-spray, but some recovery did not occur until the fourth year-post spray. Plant species may not be eliminated from glyphosate treated sites (Freedman et al 1993), but a change in the abundance of deciduous vegetation is evident in the increased presence and success of conifers. Newmaster and Bell (2002)

examined the role of several vegetation management treatments on the diversity of cryptogams (ferns and other non-flowering plants). Results indicate herbicide applications more than mechanical clearing or clearcutting impacted the diversity of cryptogams, though recovery was evident 5 years after treatment.

Newton et al (1992) observed long-term effects on the shrub and hardwood height and vegetation cover of 7-year-old clearcuts sprayed with triclopyramine, glyphosate or 2,4,5-T. Hardwood and shrub cover were reduced by 50% or more for 2 years after treatment. Differences in height and cover remained for at least 9 years after herbicide treatment, with conifers growing faster than the deciduous species on herbicide treated sites. Miller et al (1999) observed no difference in richness or diversity of woody or herbaceous vegetation eleven years after treatment with any of the following herbicides: hexazinone liquid, hexazinone pellets, glyphosate, triclopyr, picloram and a mixture of dicamba or 2,4-dichlorophenoxyacetic acid. However, the proportion of pines relative to hardwoods was greater and the shrub density was higher in herbicide-treated sites. Therefore, in the short-term, deciduous and herbaceous vegetation is reduced by herbicide-application, but recovery begins within the first 2 – 4 years post treatment. In the long-term, species of woody and herbaceous vegetation may not be eliminated, though differences in height, cover and density of herbaceous, deciduous, and coniferous vegetation remains.

Concern over the effects of glyphosate applications on non-target animals has led to a wide range of research including effects on birds, small and large mammals, fish, amphibians, microfauna, and invertebrates. Santillo et al (1989b) observed songbirds, including common yellowthroats (*Geothlypis trichas*), Lincoln's sparrows (*Melospiza lincolnii*), ruby-throated hummingbirds (*Archilochus colubris*), and palm warblers (*Dendroica palmarum*); and found colonization in unsprayed plots occurred earlier than sprayed. This was attributed to the change in vegetation succession following glyphosate application in which sprayed clearcuts were several years behind the control. Lautenschlager (1993) reviewed 8 studies concerning the effect of herbicide treatments on northern songbird populations and found total songbird populations were rarely reduced during the first growing season post-spray.

Santillo et al (1989a) observed a decrease in some small mammal populations following glyphosate application. Herbivores (Microtinae) were less abundant on treated plots for the first 2 years following application, while insectivores (Soricidae) were less abundant for at least the first 3 years post-spray. There was no difference in the abundance of omnivores (Cricetinae and Zapodidae) among the treated and control plots. Sullivan et al (1998) observed no changes in the diversity of small mammal communities in the first 5 years post-spray. Gagne et al (1999) found the abundance of the red-backed vole (*Clethrionomys gapperi* (Vigors)) was lower on herbicide treated sites for 2 growing seasons post-spray. This was associated with reduced cover during these seasons. Lautenschlager (1993) reviewed fourteen studies relating to the effect of herbicide treatments on small mammals and found responses were species specific. Some were unaffected, while some select and others avoid herbicide-treated sites. Results

demonstrated visitors were reluctant to choose disturbed sites, but residents of disturbed sites were not affected by the disturbance. Short-term decreases in song birds or small mammals is caused by changes in habitat due to herbicide treatment, though there may not be any direct effects on bird or mammal populations.

Eschholz et al (1996) studied the short and long-term effects of glyphosate application on clearcut use by moose (*Alces alces*) in Maine. In the short-term (1-2 years post-spray), moose tracks were significantly less abundant on treated sites, but in the long-term (7-11 years post-spray) they were significantly more abundant on treated sites. It was theorized this was because increased conifer density in the long-term would increase habitat for bedding and foraging. Vreeland et al (1998) examined the effects of glyphosate on summer forage for deer in Maine. Results indicate the abundance of deciduous leaves was greater on untreated sites 1 year post-treatment, but the differences were smaller 7-10 years post-treatment. Lautenschlager (1993) reviewed fourteen studies on the effect of herbicide use on moose and deer food and habitat. Results indicated moose browse could be reduced for up to 4 growing seasons post-spray. Deer use remained unchanged or increased during the first growing season after treatment, but 8 years post-spray deer browse was 3 – 7 times more abundant on herbicide treated sites (depending on herbicide and rate). Short-term effects of herbicide on browse and cover may indirectly reduce populations of moose and deer, but in the long-term treated sites may have more available browse and bedding.

Reynolds et al (1993) studied the short-term effects of glyphosate spray on coho salmon (*Oncorhynchus kisutch*). A smaller catch per unit effort for 2 weeks post-spray was the only impact observed. When looking at the short-term impacts of aerial spraying

on rainbow trout (*Oncorhynchus mykiss*), Morgan et al (1992) found no effect of a two-month exposure. Cole et al (1997) researched the short-term effects of glyphosate on capture rates of amphibians in Oregon clearcuts. There was no significant difference found in the capture rates of amphibians including ensatinas (*Ensatina eschscholtzii*), Pacific giant salamanders (*Dicamptodon tenebrosus*), and western redback salamanders (*Plethodon vehiculum*).

Previous research on post-spray effects on invertebrates has been limited. Invertebrates play key roles in a forest ecosystem, including herbivory, pollination and predation. Herbivores consume plant material, which can affect primary production, restrict the geographic range of plants and influence nutrient availability by leaching nutrients from damaged plant surfaces (Schowalter 2000). Herbivores may augment plant species diversity both during insect outbreaks and when insect damage enhances light penetration sufficiently to increase the fecundity of non-host plant species (Carson and Root 2000). Pollinators increase the spread and help maintain the survival of host plants (Dibble and Drummond 1997, Stubbs and Drummond 2001). Pollinators and their host plants help maintain biodiversity and sustainability in the ecosystem (Kerns and Inouye 1997, LaSalle and Gauld 1993). It has been shown that pollinators may rely on the floral community to survive (Bugg et al 1989, Jervis et al 1993). Preston and Trofymow (1989) observed no toxic effects of glyphosate on soil microbes or microfauna. Busse et al (2001) perceived little or no effect of glyphosate application on soil microbial communities in ponderosa pine plantations. Simenstad et al (1996) researched the effects of glyphosate application on mudflats to control *Spartina alterniflora*. They found no short or long-term effects on benthic microflora. Santillo et

al (1989b) noticed the number of invertebrates captured was 29% less on treated sites 1 and 3 years post-treatment. Kreutzweiser et al (1989) perceived no major disturbance in stream invertebrate populations caused by aerial glyphosate application. Duchesne et al (1999) detected no effect of glyphosate on total catches of ground beetles in clearcuts 7-9 years post-treatment, though species richness and diversity was higher on glyphosate treated sites.

In general, the application of glyphosate in forest landscapes to suppress the growth of deciduous shrubs and trees appears to have limited immediate effects on non-target fauna. Long-term effects of glyphosate also appear to be limited in scope, although some species are affected. These long-term effects are most likely an indirect effect of the altered plant community and light penetration levels on the animals. Many of the documented effects are contrary to what has initially been hypothesized in that the density of the non-target species has been observed to increase relative to non-treated clearcuts.

One of the dominant taxa associated with forested landscapes are the ants, both in terms of biomass and ecosystem function. The effects of glyphosate on their community structure and dynamics have not been reported. Because they have been found to be sensitive to disturbance and are considered good bioindicators of ecosystem change, it is appropriate to hypothesize that glyphosate used as a forest management tool might impact them. The remainder of this literature review addresses the role of ants in forest ecosystems, specific aspects of their biology likely to be affected by environmental change, and their potential use as bioindicators of disturbance.

The importance of Ants in Forest Ecosystems and Their Role as Bioindicators

Predatory Behavior of Ants

Predation is a role that Formicidae (ants) perform in forested ecosystems. In the Formicidae, there are 11 subfamilies, 297 genera, and approximately 8,800 species currently identified (Hölldobler and Wilson 1990). Abiotic factors, as well as human management, may influence ant communities and in turn influence the performance of ants as predators. Ants are known predators of herbivores, parasites and other predators. Weseloh (1989) observed tethered gypsy moth larvae (*Lymantria dispar* L.) in New England and found larvae were preyed on more often by ants than any other invertebrate. Weseloh (1993) studied plots manipulated so that varying levels of ant suppression resulted. Young gypsy moth larvae were lower in abundance on plots in which ants were not suppressed. Sudd and Lodhi (1981) observed differences in arthropod abundance in ant-rich areas or low ant population areas in pine plantations. Their results indicate the abundance of Araneae, Coleptera, Collembola, Arthropleona, Myriapoda and larval Diptera were less on ant-rich sites. However, Young and Campbell (1984) detected a number of ant species, including *Formica podzolica* Francoeur, *Formica neorufibarbis* Emery, other *Formica* spp., and *Camponotus* sp., preying on pupae of the western spruce budworm in the coniferous trees utilized by the ants for foraging. Contrary findings (Sanders and Pang 1992) determined *Camponotus* spp. were not major predators of spruce budworm in boreal forests. Fernandes et al (1999) observed ant presence increased the survival of the gall making wasp *Disholcaspis edura* Weld on *Quercus tubinella* Green in the face of parasitism by *Platygaster* sp. Woodman and Price (1992) researched the impact of generalist predatory ants on gall insects in willows. In willow,

ants prey indiscriminately on leaf and petiole gall makers (which exit galls in late summer), while stem gall makers (which remain within galls to overwinter) are not affected by predation. Karhu (1998) observed the role of predation by wood ants (*Formica* sp.) on defoliators and sapsuckers on birch trees. In trees where ants were not excluded, the autumnal moth was reduced by 45-67% and the birch aphid was reduced by 77%. These populations were negatively correlated with ant numbers. The percentage of leaf area damaged by moth larvae was 34% lower in ant-foraged trees. Van Mele and Cuc (2001) noted the predatory activities of *Dolichoderus thoracicus* Smith in sapodilla trees. The damage by the fruit borer *Alophia* sp. was less in ant-abundant trees. In return for protection from parasites and herbivores, ants may be given shelter and/or food resources by plants (Kleinfeldt 1978, Oliveira 1997). Therefore, ants may have beneficial impacts on populations of other organisms.

Other Roles Ants Play in the Forest Ecosystem

Ants as Prey

Another role ants play in the forest is prey for wildlife (Hölldobler and Wilson 1990). Ants are known to be the primary prey of pileated woodpeckers (Torgersen and Bull 1995). Bull et al (1992) determined that *Camponotus* spp. and *Formica* spp. comprised 97% of the woodpeckers diet. Bears are also known to prey on ant species. Bull et al (2001) examined the diet of black bears in Oregon. Insects, including *Camponotus* spp, *Formica* spp, *Lasius* sp., *Tapinoma* sp., *Aphaenogaster* sp. and yellow jackets, comprised approximately 24% of the volume of black bear diet. Mattson (2001) observed grizzly bears consumed ants during years when high quality food was scarce.

Ants as Soil Modifiers

Nesting and foraging activities by ants alter soil characteristics around their nests, which may impact vegetation. The influence ants have on the alteration of their vegetative microhabitat has been studied by Beattie and Culver (1977). They observed plant species were associated with proximity to ant mounds, which was associated to soil alteration by ants through subterranean excavations and “garbage” dumps of plant and animal materials by worker ants. These activities increase the nutrient content of the soil and allow plants to flourish. Kristiansen and Amelung (2001) examined the persistence of soil modification in abandoned mounds in temperate deciduous wood. Soils under anthills were enriched with organic matter, but the C/N ratio and soil pH were not affected. The quality of the organic matter decreased with time since abandonment, but changes were detectable for up to 20 years. Lenoir et al (2001) examined the nests of *Formica rufa* Linnaeus in comparison to the surrounding forest floor. Results indicate that nests were always drier, had a higher C/N ratio and often had higher $\text{NH}_4^{(+)}$ than the surrounding forest. Lobry de Bruyn (1999) reviewed current research concerning ant /soil relationships and found ants may influence water movement, nutrient cycling, and soil movement are areas.

Ants as Pollinators

Ants can act as pollinators (Puterbaugh 1998, Gomez 2000, Schurch et al 2000). Gomez et al (1996) observed the role of ants as pollinators depended on the relative abundance of ants with respect to other pollinators. Ant pollination was evident when ants outnumbered other floral visitors. Gomez (2000) noted ants were as effective as winged insects in the pollination of *Lobularia maritima* (L.) Desv. Garcia et al (1995)

studied the importance of ants as pollinators of *Borderea pyrenaica* Miegeu. in northeast Iberian Peninsula. Their results indicated that ants were more effective pollinators than lady beetles and Diptera, even though they were less abundant.

Abiotic and Biotic Factors that Influence Ant Activities

Vegetation

In forests, ants may utilize vegetation resources as foraging and nesting sites (Wilson and Hölldobler 1990). As discussed in the previous section, foraging for prey in woody vegetation is common. For example, ants utilize fruit tree canopies to forage for insect prey that consists of both beneficial insects (James et al 1999) and pest insects (Paulson and Akre 1992, Rieux et al 1999). Weseloh (2000) studied the ant, *Formica neogagates* Viereck, and its use of plants to forage. Results indicate that up to 150 ants can utilize a tree at one time and some will forage up to four hours. Ants did not recognize leaves already visited and no matter what size or species of vegetation explored, the same proportion of a leaf will be searched.

The structural diversity of vegetation may impact the availability of ant nesting sites, foraging sites, insolation of the ground and food supply that indicates the balance of ant functional groups changes with the predominant vegetation, land use and disturbance (New 2000). Deslippe and Savolainen (1994) researched the differences in *Formica* spp. nest densities and reproductive output of colonies in forest edge, intermediately grazed meadow, and overgrazed meadow habitats. The forest edge had the highest nest density and reproductive output while the overgrazed meadow had the lowest. Intermediately grazed meadows fell in between the forest edge and overgrazed meadow. It was also noted that alate production was higher in the forest edge. Herbers (1989) observed that

limited nest sites and microhabitat, including soil and vegetation differences, influence the spacing and species diversity of northern temperate ants. Greenslade and Greenslade (1977) noted ant diversity in forest habitats increased as vegetation mass increased, except in areas of dense, long grass. Tschinkel and Hess (1999) studied the ant community in longleaf and slash pine forests. They found a relationship between the identity and abundance of ants and the mean tree diameter, suggesting that ant communities change as trees grow. The total number of species was similar in all tree sizes, but the identity of those species was different. Torgersen and Bull (1992) observed similar results with the utilization of downed wood by ants. Their results revealed large-end diameter logs were preferred by *Camponotus* sp., though other species did not demonstrate a preference.

Temperature, Soil Characteristics, and Other Factors

Environmental factors, including temperature, soil moisture, soil type, latitude and elevation, have been found to impact ant presence and density. Catangui et al (1996) showed that soil properties influence the distribution of ants on mixed grass rangelands, resulting in an aggregated dispersion. Ant distribution depended on soil factors such as percent clay, percent organic matter, available water capacity, and pH. Wang et al (2001a) reported a negative correlation between ant abundance, diversity, richness; and elevation and soil moisture. Lynch et al (1988) found that the seasonal differences in abundance and diversity of soil and litter ants were mostly independent of soil moisture, but significantly correlated with seasonal ground surface temperatures. Temperature changes had a greater effect on ant foraging activity early in the season. Soil moisture was correlated to ant abundance and richness on a daily basis, but mean soil moisture

levels were not correlated with ant abundances and richness. Albrecht and Gotelli (1999) noted the abundance of 6 of 7 species of ants (including *Crematogaster punctulata* Emery, *Lasius neoniger* Emery, *Monomorium minimum* Buckley, and *Pheidole dentate* Mayr) was positively correlated with average ambient temperature on a monthly time scale. Bernstein and Gobbel (1979) noted in cooler environments, such as higher latitudes, brood are found in areas of direct solar radiation, which may limit nest site availability. Weseloh (1995) studied several variables including temperature, basal area of trees in wet sites, latitude and soil moisture and their effect on ants in Connecticut. Ant abundance was lower in areas of high latitude and in more moist sites. Ants on the ground were positively correlated with temperature, but those found in bait traps and on leaves were not. Crist and Williams (1999) simulated foraging activity using temperature-activity responses of ant colonies to a soil temperature model and found that soil temperature is a good predictor of colony foraging.

Human Management Practices and Ant Communities

Mechanical Forest Management Activities

Research on the management of forests for the lumber and the pulp and paper industries has shown there to be impacts on ant communities by these practices. Punttila et al (1991) compared new clearcuts (0-2 years old), old clearcuts (10 years old) and mature stands (120 years old) to determine the effect of clearcutting on ant community composition. Clearcuts reduced ant abundance compared to mature stands. Species richness was higher in old clearcuts than in new clearcuts or mature stands. Jennings et al (1986) researched the impact of clearcut strips on ant abundance and diversity in comparison with residual strips and dense mature spruce stands. The first year results

suggested there were significantly more species and greater abundance in the mature stands than in the uncut residual or clearcut strips. The second year showed no difference between clearcuts and dense stands, but significantly higher ant abundance and more ant species in clearcuts than in uncut residual plots. The age of the clearcuts (1-6 years) had no significant effect on mean ant catches or on the number of ant species. Floren and Linsenmair (2001) examined regenerating forests 5, 15, and 40 years after clearcut, as well as an uncut forest plot, in Malaysia. Ants dominated the uncut forest, while there were no differences in the proportions of ants and other invertebrates in the 5-year-old forest. As the age since clearcut increased, insect diversity increasingly resembled that of the uncut forest and ant communities increased in structural complexity. Whitford and Gentry (1981) studied the species diversity and richness of ants in longleaf pine plantations. The highest diversity and richness occurred in recently replanted plantations, not in mature, thinned or burned plantations.

The Use of Insecticides in Management Activities

Research on the effect of chemical methods of insect control and their effect on ant populations has also been performed. Studies have observed no long-term effects of insecticides on ant populations and few short-term results. Catangui et al (1996) found aerial applications of Dimlin 2F, Dimlin 25W, and Sevin 4-oil, all used to control grasshoppers in grasslands, had no long-term effect on diversity or abundance of ant populations. The diversity of the ants decreased in the first 13-19 days post treatment of the insecticide Dimlin 25W, but diversity recovered quickly. The five most abundant ants found in this study included *Lasius neoniger* Emery, *Monomorium minimum* (Buckley), *Solenopsis molesta* (Say), *Tapinoma sessile* (Say), and *Formica neogagates*

Emery. Wang et al (2000) studied the effect of the microbial insecticide *Bacillus thuringiensis* Berliner variety Kurstaki, used in gypsy moth management in forests. No change in the richness, diversity, abundance or composition of the ants was detected during the study. Murphy and Croft (1990) studied the effect of carbaryl application for control of the western spruce budworm on forest ants. There was a decrease in ant species diversity in sprayed plots and a decrease in ant foraging was found in all plots, (but a more rapid decrease in sprayed plots). Ant foraging remained low for at least 76 weeks before rebounding. Wikteliu et al (1999) examined the effects of the organochlorine insecticide, lindane and endosulfan, on non-target arthropods. Lindane reduced the numbers of collembola 80% for an average of 6 weeks, spiders 53% for 2.8 weeks and ants 64% for an average of 2.5 weeks. Endosulfan had no effect.

Impacts on the Dominance Hierarchy in Ant Communities

Dominance hierarchies in ant communities have been well documented (Hölldobler and Wilson 1990). Dominant ant species influence the composition and abundance of other ant species in the ecosystem through competition and interference behaviors. Morrison (1996) observed negative interspecific interactions helped maintain territories of dominant ant species though dominant species were sometimes positively associated with specific subordinate ant species. Several studies have found a relationship between the daily activities of ants and their position in the dominance hierarchy. Cerda et al (1998, 1997) determined subordinate species were more active during the day when temperatures were extreme while dominant species were active during the more moderate temperatures of afternoon and night. The thermal intolerance of dominant species allowed greater dominance by subordinate species than would be

expected from their relative abundance and fighting abilities. Bestelmeyer (2000) also observed a trade-off between dominance and thermal tolerance in ant communities. Retana and Cerda (2000) examined the factors affecting community structure in the Spanish Mediterranean. The relative abundance of dominance groups showed a seasonal pattern relating to vegetation cover and temperature. In grasslands, subordinates increased and dominants decreased their relative abundance from spring to summer, but in shrublands/forests, the opposite pattern occurred. Kemel et al (2001) examined the effect of low and high impact logging in Brazil on the dominance hierarchy of ants. At the genus and species level, both logging techniques impacted the ant community composition by reducing the dominance of ants in the genus *Pheidole*. Vanderwoude et al (1997) looked at the effects of fire regimes on ant community structure in Australia. The relative abundance of dominant species was positively related to fire frequency while opportunistic ants comprised more of the ant community in unburned sites. Samways et al (1997) examined ant communities in relation to their distance from a major urban highway in Africa. Dominant species, adapted for disturbance, appeared to influence the presence and abundance of the more rare species through competition.

Ants as Bioindicators

The question of whether ants can serve the role of a bioindicator and indicator of environmental change can be important to future studies of biodiversity as it relates to environmental impacts from disturbance. Indicator species have been defined as those that can be easily sampled, represent fairly diverse groups, have known relationships to the diversity of other taxa, and respond to environmental change similarly to other taxa (Agosti 2000, Oliver and Beattie 1996). One of the most noted use of ants as

bioindicators is their use in mine reclamation sites (Anderson 1996, Majer 1996, 1992, Majer 1983, Majer et al 1984). Ants were tested as possible indicators because of their importance to soil fertility and structure. Ant abundance correlated positively with plant species richness, diversity, percent cover, time since rehabilitation, percent litter cover and the presence of large logs. Compared to the ant community composition of nearby native forests, generalist species were more common in rehabilitation sites. Results indicated ant diversity and abundance were indicators of recovery and successful rehabilitation of bauxite mines. Peck et al (1998) researched whether ants are good bioindicators in agroecosystems by examining ant populations in agricultural fields. Ant abundance was higher in field margins than cultivated fields for all species found except the invasive *Solenopsis invicta*. Ant abundance was correlated with tillage type, soil variables, and crop conditions. Ants appeared to be potential indicators of environmental change in agroecosystems, though their association with specific levels of disturbance of agroecosystems is unknown. However, New (2000) observed no difference between the number of ant morphospecies in native grassland and disturbed sites in Australia. He theorized either this was because small-scale heterogeneity remained high enough for ant populations or ants may not be sufficiently sensitive to floristic change. The use of ants as indicators of environmental change stems from several ideas. As already discussed, ants are sensitive to soil, temperature, and moisture changes. Agosti et al (2000) discusses that many ants have narrow tolerances for changes in environmental factors and their populations may respond quickly. Ants are thermoregulators and their dependence on temperature makes them very susceptible to microhabitat changes, which indicates their vulnerability and potential responsiveness to change. Ants have been used to

reflect changes in environmental gradients such as net aboveground productivity (NAP). Kaspari et al (2000) described ant density as a positive, decelerating function of NAP. Net aboveground productivity was converted to a measure of ant colony density with an efficiency that increased with summer temperatures and decreased with precipitation. Anderson (1997) noted the predictive power of ants as bioindicators in land management is not possible at the species level but may be possible at the functional level, which varies predictably with climate, soil, vegetation and disturbance.

The effects of glyphosate on insect communities in clearcuts have not been thoroughly studied. Previous research indicates both negative and neutral short-term effects of glyphosate on insect communities, but further investigation into the short and long-term effects is needed. Ant communities in Maine are the focus of this research because 1) glyphosate use is a common forest management practice in Maine; 2) the important roles ants potentially occupy in the forest ecosystem including predators and soil manipulators; and 3) the potential use of ants as bioindicators of environmental change. With this research, I hope to assess the short and long-term effects of glyphosate on ant communities and to determine the impact forest management has on these potentially beneficial insects.

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Chapter 2

THE SHORT AND LONG-TERM EFFECTS OF HERBICIDE APPLICATION AND CLEARCUT AGE ON ANT COMMUNITIES

Introduction

The use of herbicides after clearcutting is a common forest management practice. In 2002 approximately 21,700 acres of clearcut land were treated with herbicide in Maine (Batteese, pers. comm.). Herbicides such as glyphosate, imazapyr, triclopyr, sulfometuron methyl, and metsulfuron methyl are applied to recently harvested landscapes in Maine to eradicate or reduce the growth of deciduous trees and shrubs, which compete with coniferous trees for light, water, space and nutrients. The herbicide application allows early regeneration and rapid growth of conifer species, which are preferred by the pulp and paper industry, by suppressing other vegetation (Stewart et al 1984, Pitt et al 1993).

Glyphosate reduces the abundance of deciduous trees, shrubs and herbaceous vegetation through the first year after treatment (May et al 1982, Santillo et al 1989b, MacKinnon and Freedman 1993, Newmaster 2002). However, deciduous and herbaceous vegetation appear to make a substantial recovery beginning in the second post-spray year (May et al 1982, MacKinnon and Freedman 1993). Contradictory findings suggest that shortly after herbicide application, the herbaceous cover of treated clearcuts can either increase (Freedman et al 1993) or decrease (Santillo et al 1989b). Deciduous shrubs and trees are not eliminated from a treated clearcut, but changes in abundance are evident from the increase in conifer density (Freedman et al 1993). In the

long-term, Newton et al (1992) noted a difference in woody and herbaceous vegetation height and cover between treated and untreated sites for up to 16 years. Miller et al (1999) observed no difference in richness or diversity of woody or herbaceous vegetation 11 years after glyphosate treatment, but the proportion of pines to hardwoods and the shrub stem density were influenced by herbicide treatment.

Concerns over the effects of glyphosate on non-target fauna have been raised. Short-term (0-2 years) decreases were observed in populations of songbirds (Santillo et al 1989b, Lautenschlager 1993), small mammals (Santillo et al 1989a, Sullivan et al 1998, Gagne et al 1999), deer browse (Vreeland et al 1998), and coho salmon (Reynolds et al 1993). Changes in the abundance of songbirds, small mammals, and deer browse were attributed to changes in vegetation following an herbicide application, not to fatalities caused by the herbicide. Long-term effects of glyphosate have been minimally studied. No short or long-term effects were noted in populations of rainbow trout (Morgan et al 1992), amphibians (Cole et al 1997), soil microbes (Preston and Trofymow 1989, Busse et al 2001), or benthic microflora (Simenstad et al 1996). Eschholz (1996) studied the short and long-term effects of glyphosate on moose activities in clearcuts. In the short-term there were significantly less moose on treated sites, but in the long-term there were significantly more moose on treated sites because of increased foraging and bedding potential. Research on the effects of glyphosate on invertebrates has been limited. Santillo (1989b) noted invertebrates were 29% lower on treated sites 1 and 3 years post-treatment. Kreutzweiser et al (1989) perceived no major disturbance in stream invertebrate populations after aerial glyphosate application. Duchesne et al (1999)

observed no affect on total catches of ground beetles 7 to 9 years after clearcut and herbicide, though richness and diversity increased on herbicide treated sites.

Invertebrates play many key roles in the forest ecosystem, including herbivory, pollination, and predation, so the effect of forest management practices, especially herbicide applications, may be dramatic. Approximately 50% of insect species diversity is comprised of herbivores (Daley et al 1998). Insect herbivores influence ecosystems by consuming a variety of plant organs, which can affect primary production, restrict the geographic range of plants and influence nutrient availability by leaching nutrients from damaged plant surfaces (Schowalter 2000). Carson and Root (2000) observed that insect herbivores augmented plant species diversity both during insect outbreaks and when insect damage enhanced light penetration sufficiently to increase the reproductive success of non-host plant species. Pollinators increase the spread and help maintain the fitness of host plant populations, so the conservation of pollinator communities is central to plant biodiversity in most ecosystems (LaSalle and Gauld 1993, Kearns and Inouye 1997, Stubbs and Drummond 2001). It has been shown that pollinators rely on the floral community both for adult flight energy resources and larval food (Bugg *et al* 1989, Jervis *et al* 1993). Predation can relieve stress placed on vegetation by regulating population densities of insect herbivores. Insects including dragonflies, true bugs, beetles, lacewings, and syrphid flies are important predators (Messina and Sorenson 2001, Michaud and Belliure 2001, Wang and Tsai 2001, Griffin and Yeargan 2002, Hentz and Nuessly 2002).

Ants are common predators of herbivores, detritivores, parasites and other predators in forest ecosystems (Sudd and Lodhi 1981, Youngs 1983, Weseloh 1989, 1993, Woodman and Price 1992, Oliveira 1997, Fernandes et al 1999, Van Mele and Cuc 2001). It is currently estimated that ants constitute a high proportion of the biomass of many landscapes, making them the predominant predator in an ecosystem. For example, it has been estimated that one-third of the animal biomass of the Amazon rain forest is composed of ants and termites. Combined with bees and wasps, ants and termites make up more than 75 percent of the total insect biomass on earth (Hölldobler and Wilson 1990). The presence of ants in the forest may influence herbivore population abundance, pollination of flowering plants, seed dispersal, and nutrient dynamics in the soil and thus indirectly affect the abundance and diversity of vegetation.

Ant populations are influenced by changes to their environment. Temperature, soil moisture, soil characteristics, latitude and elevation impact the presence, activity and density of ant populations (Bernstein and Gobbel 1979, Lynch 1988, Hölldobler and Wilson 1990, Weseloh 1995, Catangui et al 1996, Albrecht and Gotelli 1999, Wang 2001). Vegetation affects the availability of nesting and foraging sites. Nest site availability may be limited by the composition, mass, size, density and complexity of vegetation (Greenslade and Greenslade 1977, Herbers 1989, Torgerson and Bull 1992, Deslippe and Savolainen 1994, Tschinkel and Hess 1999, New 2000). Ant populations also utilize vegetation as foraging sites. Thus the composition, size and density of vegetation may influence ant population dynamics (Paulson and Akre 1992, James et al 1999, Rieux et al 1999, Weseloh 2000). Competition can affect the presence and distribution of ant colonies in a habitat. If resources, such as food or nest sites, are

limited or habitat quality is poor, the distribution, number and size of ant colonies is likely to be affected by competition (Levings and Traniello 1981, Ryti and Case 1984, 1986, Gordan 1995, Crist and Wiens 1996). Many of the environmental factors affecting ant colonies are expected to be influenced by applications of herbicides to forest landscapes.

Human alteration of the environment and its impact on ant populations has previously been researched. Clearcutting and strip cutting have both shown a negative impact on ant abundance (Jennings 1986, Punttila 1991, Floren and Linsenmair 2001). Initially clearcutting appears to diminish ant populations significantly when compared to non-cut plots or mature stands. Several studies have looked at the non-target effect of insecticides on ant communities. Both direct and indirect effects have been observed for several insecticides including lindane, endosulfan, carbaryl, and Dimilin 25 W. Direct effects included a decrease in diversity (Murphy and Croft 1990, Catangui et al 1996) and a decrease in abundance (Wikteliu et al 1999). One indirect effect of these insecticides was a short-term decrease in foraging activity on treated sites (Murphy and Croft 1990). Wang et al (2000) observed no effects of the microbial insecticide, *Bacillus thuringiensis* Berliner variety *kurstaki*, on the richness, diversity, or abundance of ants. No long-term effects on ant communities were observed in the above studies. To our knowledge no studies have evaluated the effects of herbicides on ant communities.

Dominance hierarchies in ant communities have been well documented (Hölldobler and Wilson 1990). Dominant species influence the composition and abundance of subordinate species in the ecosystem through competition and interference behaviors (Morrison 1996). Environmental factors such as temperature, vegetation cover

and season all impact the abundance and activities of dominant ant species in relation to subordinate species (Bestelmeyer 2000, Retana and Cerda 2000, Cerda et al 1998, 1997). Impacts on the structure of ant communities have been found for disturbances including logging (Kemel et al 2001), fire (Vanderwoude et al 1997) and highways (Samways et al 1997).

The use of ants as bioindicators of disturbance or environmental change is increasingly being investigated. Ants have been studied as bioindicators in mine reclamation sites (Majer 1983, Majer et al 1984, Majer 1992, 1996, Anderson 1996) and agroecosystems (Peck et al 1998, Lobry de Bruyn 1999). They are effective at reflecting changes in environmental gradients (Kaspari et al 2000). The use of ant communities as indicators of environmental change stems from the idea that ant species are differentially sensitive to changes in their environment and will react quickly to those changes resulting in a shifting of the species hierarchy within the community (Hölldobler and Wilson 1990, Oliver and Beattie 1996, Agosti et al 2000). At the species level, ants may not be sufficiently sensitive to change to serve as bioindicators (Anderson 1997, New 2000), since individual species are not commonly eradicated from disturbed landscapes except in the case of introduced invasive ant species (Holway 1999, Porter and Savignano 1990).

There are two objectives of this study. The first is to observe the short and long-term effects of glyphosate applications on the ant community in clearcuts of western Maine. The effects of glyphosate on invertebrates have not been thoroughly studied and the question of whether current forest management practices are damaging populations of natural predators to the detriment of the forest ecosystem has not been addressed. The second objective is to assess the effects of vegetation composition and soil type on forest

ant communities. Since glyphosate use in Maine has been shown to affect the density and diversity of vegetation, any herbicide effect on the ant community may be due to change in the vegetation community. Therefore, our question is: will the ant community be an effective bioindicator of herbicide-induced change in the plant community?

Methodology

Study Sites

To analyze the short and long-term effects of herbicide application on ant communities, study sites were chosen in four townships (Bald Mountain, Mayfield, Moscow and Caratunk TWP) in Somerset Co., Maine on land owned by Plum Creek Paper Company. Twenty sites were selected for the 2000 sampling season and eighteen sites were utilized in the 2001 season (Table 2.1). After analysis of vegetation data for 2000 (Georgitis 2001) was performed, it was determined sites 8, 9, 11, 19, and 20 contained vegetation unlike any other site, including a high abundance of moss and grasses. These sites were categorized as atypical and were eliminated with several replaced with new sites for the 2001 season. All other study sites were used in both years. Study sites ranged in size from 0.2 – 2 ha. Elevation of sites varied from 368 to 485 meters above sea level. No USDA soil survey has been conducted for the study area; therefore a soil classification was not available for the sites (Anonymous, 1972).

Young clearcuts were characterized as those cut 3-5 years before this study. In both years, the same six young clearcuts were utilized to assess the short-term effects of glyphosate application on ants. Three of the six young clearcuts had been sprayed with glyphosate 2-4 years before this study. Vegetation on the young clearcuts included herbaceous species and saplings such as cherry (*Prunus* spp.), yellow birch (*Betula lutea* Michx. f.), gray birch (*Betula populifolia* Marsh), red maple (*Acer rubrum* L.), balsam fir (*Abies balsamea* L. Mill), and spruce (*Picea* spp.). Old clearcuts were categorized as those harvested 10-15 years before this study. In 2000, eight old clearcuts were utilized in observing the long-term effects and in 2001 six old clearcuts were studied, with three

Table 2.1 List of study sites. The study year, treatment type, year site was clearcut and the year herbicide was applied are listed.

Site Number	Study Year Used	Treatment	Year Clearcut	Year Herbicide
1	Both	Young / Herbicide	1995	1997
2	Both	Young / Not Herbicide	1995	None
3	Both	Young / Not Herbicide	1997	None
4	Both	Young / Herbicide	1996	1998
5	Both	Young / Not Herbicide	1996	None
6	Both	Young / Herbicide	1996	1997
7	Both	Old / Herbicide	1986	1989
8	2000	Old / Not Herbicide	1985	None
9	2000	Old / Not Herbicide	1986	None
10	Both	Old / Herbicide	1986	1993
11	2000	Old / Herbicide	1985	1987
12	Both	Old / Not Herbicide	1985	None
13	Both	Plantation	1983	1986
14	Both	Plantation	1986	1989
15	Both	Plantation	1986	1990
16	Both	Mature	N/A	None
17	Both	Mature	N/A	None
18	Both	Mature	N/A	None
19	2000	Old / Not Herbicide	*	None
20	2000	Old / Herbicide	1979	1984
21	2001	Old / Herbicide	1986	1989
22	2001	Old / Not Herbicide	1983	1987
23	2001	Old / Not Herbicide	1980	1985

* The year site 19 was clearcut is unknown, but based upon vegetation it is assumed to have been harvested approximately 15 years prior to study

that were different from 2000. Only six old clearcuts were used in 2001 as opposed to the eight in 2000, because of the lack of suitable study sites. In both years, half of the clearcuts studied had been treated with herbicide 9-14 years before the study. Vegetation on old clearcuts included a mixture of herbaceous species, deciduous trees (*Prunus* spp., *Betula* spp., and *Acer* spp.) and conifers (*Abies balsamea*, and *Picea* spp.). Three plantations were also chosen for study in 2000 and 2001. Plantations represented old, herbicide clearcuts that had been planted with black spruce. Three mature sites characterized as stands that had not been cut recently (>50 years) were also studied. Vegetation in these sites included balsam fir and spruce species. The sites and the associated treatment combinations represented a random design.

Ant Sampling

In both years, at each of the study sites, 4 pitfall traps were installed to collect ground foraging ants. Wang (2001) compared pitfall and bait traps with results indicating that pitfall traps resulted in a faster accumulation of ant species in 3 years of study, as well as, higher species diversity. Our traps were placed at 20 m apart in a square pattern at the center of each site to minimize edge effects. Ward (2001) observed no significant difference in abundance or composition of the catches of pitfall traps placed with 1, 5, or 10 meters distance between them.

The pitfall traps (Van den Berghe 1992) were constructed using 20 oz. plastic soda bottles. The top 1/3 of the bottle was removed with scissors. The bottom of the bottle was punctured with holes to allow rainwater to escape. A collection cup filled with 70 ml propylene glycol was placed in the bottom of the soda bottle. The top of the soda bottle was inverted and placed leading into the collection cup to act as a ramp. Traps

were placed into 15 cm deep holes so that the top edge of the trap was level with the ground. Care was taken to minimize disturbance of surrounding soil and vegetation. Aluminum flashing rain covers (13 cm x 13 cm) were secured by placing two nails in opposite corners of the flashing then inserting them into the ground to minimize flooding. Traps were placed in the sites from 1 June through 23 August in 2000 and from 21 May through 30 August 2001. A total of 7 samples were taken each year. Samples were collected every two weeks with a new collection cup placed in the trap and the old cup returned to the lab for insect sorting. Ants were sorted to genus and species using keys by Bolton (1994) and Creighton (1950) and identifications were verified by Stefan Cover at the Harvard Museum of Comparative Zoology, Cambridge, MA.

During the 2000 sampling year, 4 extra pitfall traps were placed randomly in every site for two sampling periods, one in July and one in August. These were placed to assess whether ant species might exist in the sites that were not collected by the stationary pitfall traps, due to the foraging range or nest spacing of ants. The random pitfalls placed in each site during the 2000 sampling period were not analyzed for abundance. Using ANOVA it was determined that the richness of the extra pitfall traps did not differ from the stationary pitfall traps for each site ($P = 0.954$). Thus the stationary pitfall traps were considered to provide a reliable estimate of richness of the ant community. Therefore in 2001, instead of utilizing randomly placed pitfall traps to sample species richness, we decided that moving the four stationary pitfall traps after the first six weeks of sampling would accomplish the same goal.

Vegetation Sampling

Flowering herbaceous and woody shrub vegetation was sampled using line transects (Eberhardt 1978). Four line transects of 40 meters were sampled every two weeks coinciding with insect trap collection. A meter tape was used to mark the distance and the transect line. A compass was used to assure transects were parallel to each other and on a straight trajectory. Every sample date, transects were randomly shifted to minimize trampling damage. A plant was included if any part of a flowering plant touched the vertical plane defined by the transect line. Information including species, flower number, stem number, and the shape of a horizontal cross-section (circle, rectangle or triangle) was recorded. The probability of a plant being included was higher for large plants when viewed from above than for small plants. To compensate for this, a variable size transect was calculated utilizing the plant cross-sectioned area at its widest point, recorded as its length x width for a rectangular and square cross-sectioned shaped plant and as the diameter for a circular cross-sectioned shaped plant. The contribution of each plant to the overall density was calculated as the number of flowers per quadrat equal to 40 m x the radius of a circle that has comparable area to that of the plant sampled.

Tree density was estimated using four 2 m x 20 m belt transects (Eberhardt 1978). For each transect, trees over 1 meter tall and with a trunk at least half inside of the transect were counted. The tree species was recorded. Samples were taken in September 2000 and for new sites in 2001. Each site was sampled only once as the tree density was unlikely to significantly change during the two-year project. Density was calculated as trees/ha.

Soil Sampling

Five random soil samples were taken at every site during the 2001 field season using a soil auger. Samples were taken to a depth of 30 cm as prescribed by the Maine Soil Testing Service. These 5 samples were pooled and mixed in a plastic bucket. A half-pint sample was taken from the bucket and submitted to the Maine Soil Testing Service at the University of Maine for analysis of pH, percent organic matter, and levels of calcium, potassium, magnesium, phosphorous, aluminum, sodium, and zinc.

During the summer of 2001, two soil samples were taken at each sample date with a soil auger to measure soil moisture. The samples were taken to a depth of approximately 30 cm and weighed in the field. Upon returning to the laboratory, the samples were placed in paper bags in a soil drying room, where they were dried for six months then re-weighed. The soil moisture was calculated. An average was taken for the two samples per site per date.

Data Analysis

Discrete parametric data analysis was used on the pitfall trap count data representing a randomized design. Poisson regression was used to determine the effects of herbicide and age on the ant abundance (PROC GENMOD, SAS Institute 1996), based upon an alpha level of 0.05.

Sites 19 and 20 were removed from all year 2000 statistical analysis. Site 19 was removed because its clearcut age could not be verified. Site 20 was removed because during the second sampling period it was heavily thinned and therefore drastically altered. Mature sites were excluded from analysis. Ant catch in mature sites was very low and the distribution of the ant catch within the mature treatment would not conform

to the Hessian matrix and therefore precluded viable analysis (PROC Genmod, Sas Institute 1996).

Planned linear contrasts (Poisson regression) were used to determine the significance of the differences found in the herbicide*age and age*herbicide*taxa interactions. The five age*herbicide interactions analyzed were old herbicide (OH), old non-herbicide (ONH), young herbicide (YH), young non-herbicide (YNH), and plantation (P). Though plantations are old herbicide sites, they were categorized as a separate category in the model because they had been planted with spruce and we wanted to assess if planted sites differed in ant abundance from non-planted sites. For each year, ant taxa (a categorical factor in the Poisson regression) were divided into groups for analysis in order to simplify interpretation of the ant community response depending on the effect of age, herbicide and age*herbicide interaction. Ant taxa were placed into groups whose distributions across the sites were similar to that of other groups members, but different from the distributions of other groups based on the results of linear contrasts (Table 2.2). Each year, several species could not be analyzed due to their low abundance (absence in more than half of the study sites).

To visualize the species diversity in each age*herbicide interaction, rank-abundance curves were plotted. A rank was assigned to each species for each age*herbicide interaction, with the most abundant species having a value of 1 and the least abundant species having a value of 13. These ranks were plotted against the relative abundance of ants in each age*herbicide interaction. The evenness and richness were then assessed from the shape of the slopes (Begon et al 1986, Magurran 1988). The Shannon-Weiner index of diversity was calculated to evaluate the differences in ant taxon

diversity across age and herbicide treatments using analysis of variance (PROC GLM, Sas Institute 1996). The Shannon-Weiner (H) index combines richness and evenness within the treatments to assess levels of diversity (Zar 1996). The calculation used for this index was $H = -\sum [(p_i)(\ln p_i)]$, where p_i is the proportion of the total ant community comprised of taxon. A two-way factorial analysis of variance was used to compare the diversity indices for the age, herbicide, and age*herbicide interactions, with sites as a replicate in a randomized design ($P \leq 0.05$).

To determine if age or herbicide affects the dominance hierarchy of ant communities in northern temperate forests, each species was assigned a rank based on the total abundance captured in each year (with the most abundant species assigned a rank of 1). The mean rank across all species for each site was calculated. ANOVA and linear contrasts performed on transformed data were utilized to determine the effects of age, herbicide, and age*herbicide interactions using the calculated rank mean. The mean ranks were log transformed to conform to the assumptions of ANOVA. Plantations were excluded from this analysis since our question of interest was on the effects of age and herbicide on dominance hierarchy shifts in the ant community and we did not want planting to influence the results.

Detrended Correspondence Analysis (DCA) (McCune and Medford 1999) was used to investigate the occurrence of ant taxa in relation to each other and the study sites. The abundance of ants in each taxa at each site was used. All species that were analyzed by Poisson regression were included.

A full analysis of age and herbicide effects on herbaceous vegetation was performed by Georgitis (2001). Linear contrasts were used to evaluate the relationship of

floral density, tree density, soil moisture, soil pH and percent organic matter among clearcut age and herbicide treatments (PROC GLM, Sas Institute 1996). Linear correlation (Bonferroni corrected) was used to observe if these same factors were associated with the total abundance of ants captured and the abundance of each ant taxon per site. Linear correlation was also used to assess the similarities in occurrence among the ant taxa.

Results

Short and Long-Term Effects of Herbicide on Ant Populations

Thirteen species of ants were collected in 2000 and 2001 (Table 2.2). In 2000, 8 of 13 species, divided into 4 groups, were numerous enough that they could be statistically analyzed by taxon. In 2001, 9 of 13 species, divided into five groups, were numerous enough that they could be analyzed.

Results indicate the total ant abundance was highest in the old herbicide clearcuts and plantations, lowest in young non-herbicide clearcuts, and intermediate in old non-herbicide and young herbicide sites. In 2000, there were significant herbicide ($P > 0.001$), age ($P < 0.001$), age*herbicide interactions ($P < 0.001$), and age*herbicide*taxa interactions ($P < 0.001$). Planned linear contrast results (Figure 2.1a) indicated that old herbicide clearcuts and plantations had significantly more total ants than young herbicide (OH: $P < 0.001$ and P: $P < 0.001$), young non-herbicide (OH: $P < 0.001$ and P: $P < 0.001$), and old non-herbicide clearcuts (OH: $P < 0.012$ and P: $P < 0.020$). There were no differences between old herbicides and plantations ($P = 0.378$). Old non-herbicide sites had significantly more ants than young non-herbicide sites ($P = 0.029$) but not young herbicide clearcuts ($P = 0.987$). Young herbicide sites had more total ants than young non-herbicide sites ($P = 0.034$).

The abundance of ants across all species tended to be lower in the young non-herbicide sites and higher in old herbicide sites with variations on this theme that were specific to individual species or groups of species (Table 2.3). *F. aserva* Forel (group 1) were most abundant in old clearcuts, both herbicide and non-herbicide, lowest in young

Table 2.2 List of ant species found in 2000 and 2001. Mean capture abundance of each species \pm 1 standard deviation. Species are grouped by non-significant differences in age and herbicide interactions. N/A applies to those species not used in the Poisson regression.

Species List	2000 Abundance	2000 Group	2001 Abundance	2001 Group
<i>Camponotus herculeanus</i> Linné	3.611 \pm 3.632	Group 3	4.611 \pm 7.317	Group 3
<i>Camponotus noveboracensis</i> Fitch	8.722 \pm 8.071	Group 4	14 \pm 18.387	Group 4
<i>Camponotus pennsylvanicus</i> DeGeer	5.444 \pm 4.189	Group 3	4.111 \pm 5.109	Group 3
<i>Formica aserva</i> Forel	30.222 \pm 49.025	Group 1	27.5 \pm 30.289	Group 1
<i>Formica fusca</i> Linné	2.789 \pm 8.256	N/A	1.5 \pm 2.526	Group 3
<i>Formica neorufibarbis</i> Pergande	5.294 \pm 12.102	N/A	3.611 \pm 6.269	Group 3
<i>Formica podzolica</i> Francoeur	2.944 \pm 4.987	Group 3	5.722 \pm 9.034	Group 3
<i>Leptothorax</i> sp.	0.117 \pm .485	N/A	0.777 \pm 1.699	N/A
<i>Myrmica detritinodis</i> Emery	46.722 \pm 43.542	Group 2	32.166 \pm 23.892	Group 2
<i>Myrmica emeryana</i> Forel	9.111 \pm 9.946	Group 2	16 \pm 12.611	Group 5
<i>Myrmica incompleta</i> Provancher	1.666 \pm 2.057	Group 3	2.555 \pm 5.238	N/A
<i>Stenamma diecki</i> Emery	0.166 \pm 0.514	N/A	0.055 \pm 0.235	N/A
<i>Tapinoma Sessile</i> Say	3.777 \pm 5.966	N/A	1 \pm 1.782	N/A

Table 2.3 Results of planned linear contrasts in age*herbicide interactions for 2000 and 2001 ant species' abundance. Significant P values are in bold. Age*herbicide interactions are defined as YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old herbicide and P: plantation.

Species		OH vs.				ONH vs.			P vs.		YH vs.
		YH	YNH	ONH	P	YH	YNH	P	YH	YNH	YNH
2000											
Group 1	<i>F. aserva</i> Forel	0.021	<0.001	0.714	0.008	0.037	<0.001	0.008	0.070	0.001	<0.001
Group 2	<i>M. emeryana</i> Forel	<0.001	<0.001	<0.001	0.196	0.218	0.295	<0.001	<0.001	<0.001	0.852
	<i>M. detritinodis</i> Emery	<0.001	<0.001	<0.001	0.933	0.103	0.883	<0.001	<0.001	<0.001	0.138
Group 3	<i>C. herculeanus</i> Linné	0.669	0.127	0.105	0.076	0.271	0.064	0.067	0.104	0.062	0.653
	<i>C. pennsylvanicus</i> DeGeer	0.091	0.402	0.128	0.0622	0.731	0.072	0.601	0.857	0.084	0.572
	<i>F. podzolica</i> Francoeur	0.101	0.104	0.234	0.334	0.306	0.653	0.275	0.101	0.080	0.5599
	<i>M. incompleta</i> Provancher	0.101	0.095	0.409	0.249	0.150	0.180	0.738	0.350	0.080	0.011
Group 4	<i>C. noveboracensis</i> Fitch	<0.001	<0.001	<0.001	<0.001	0.047	0.005	<0.001	<0.001	<0.001	0.403
2001											
Group 1	<i>F. aserva</i> Forel	0.619	0.044	<0.001	<0.001	0.684	0.001	0.001	0.004	<0.001	0.020
Group 2	<i>M. detritinodis</i> Emery	<0.001	<0.001	<0.001	0.001	0.304	0.003	0.029	0.173	<0.001	<0.001
Group 3	<i>C. herculeanus</i> Linné	0.155	0.125	0.158	0.196	0.299	0.263	0.903	0.246	0.215	0.935
	<i>C. pennsylvanicus</i> DeGeer	0.135	0.140	0.120	0.203	0.265	0.108	0.789	0.403	0.210	0.859
	<i>F. neorufibarbis</i> Pergande	0.105	0.156	0.162	0.178	0.115	0.309	0.899	0.385	0.215	0.910
	<i>F. fusca</i> Linné	0.201	0.185	0.209	0.306	0.308	0.499	0.699	0.375	0.356	0.798
	<i>F. podzolica</i> Francoeur	0.455	0.103	0.325	0.405	0.406	0.502	0.895	0.204	0.185	0.652
Group 4	<i>C. noveboracensis</i> Fitch	<0.001	<0.001	0.688	0.002	<0.001	<0.001	<0.001	0.184	<0.003	0.077
Group 5	<i>M. emeryana</i> Forel	<0.001	<0.001	0.001	0.065	0.009	0.002	0.176	<0.001	<0.001	0.600

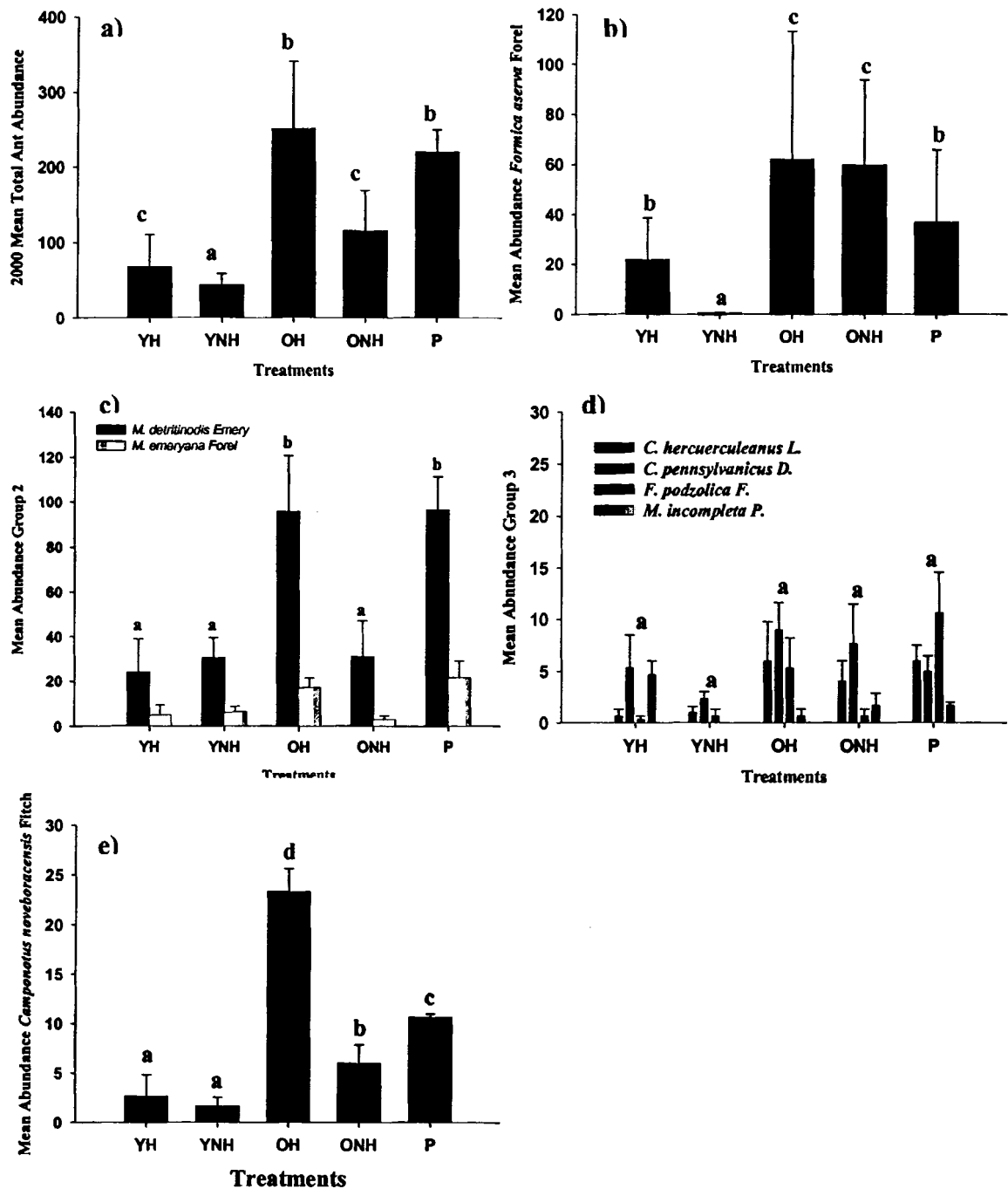


Figure 2.1 Results of 2000 sampling of age*herbicide interactions on the mean abundance per interaction of a) total ants, b) Group 1: *F. aserva* Forel, c) Group 2: *M. detritinodis* Emery and *M. emeryana* Forel d) Group 3: *C. herculeanus* Linnè, *C. pennsylvanicus* DeGeer, *F. podzolica* Francoeur, and *M. incompleta* Provancher e) Group 4: *C. noveboracensis* Fitch. Treatments are defined as YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old herbicide and P: plantation. Letters above bars (a-d) indicate significant differences. Error bars represent one standard error of the mean.

non-herbicide sites and intermediate in young herbicide and plantations (Figure 2.1b) . *M. detritinodis* Emery and *M. emeryana* Forel (group 2) had the same pattern of abundance in each age*herbicide interaction. These two species were the most abundant in old herbicide and plantations and the least abundant in young herbicide, young non-herbicide and old non-herbicide sites (Figure 2.1c). Group 3 was comprised of the following 4 taxon: *C. herculeanus* Linné, *C. pennsylvanicus* DeGeer, *F. podzolica* Francoeur, and *M. incompleta* Provancher. We found no evidence to suggest effects of age*herbicide interactions on group 3, but group 3 followed a similar trend seen in group 2 (Figure 2.1d). *C. noveboracensis* Fitch (group 4) were more abundant in old herbicide sites than in any other age*herbicide interaction. This species was also more abundant in plantations and old non-herbicide clearcuts than young herbicide or non-herbicide sites, though they were more abundant in plantations than in old non-herbicide sites (Figure 2.1e).

In 2001, there was also significant age effect ($P < 0.001$), age*herbicide interaction ($P < 0.001$) and age*herbicide*taxa interaction ($P < 0.001$), but not a significant herbicide effect ($P = 0.959$). Similar to our 2000 findings, linear contrast results indicate old herbicide clearcuts and plantations had significantly more ants than young herbicide (OH: $P = 0.016$ and P: $P = 0.005$), young non-herbicide (OH: $P = 0.001$ and P: $P = 0.003$), and old non-herbicide (OH: $P = 0.023$ and P: $P = 0.042$) clearcuts. There was no difference found between old herbicide and plantations. There were significantly more ants in old non-herbicide clearcuts than young herbicide clearcuts ($P = 0.036$) and young non-herbicide clearcuts ($P < 0.001$). There were significantly more ants in young herbicide clearcuts than young non-herbicide ($P < 0.001$) clearcuts (Figure 2.2a).

In 2001, significant age*herbicide*taxa interactions indicated ant species had different abundances across the age*herbicide interactions (Table 2.3). For most groups the trend was toward fewer ants in old non-herbicide sites than old herbicide as in 2000. Plantations were generally variable but equal or greater than young herbicide or young non-herbicide. The highest abundance of *F. aserva* Forel (group 1) was observed in plantations and the lowest abundance in young non-herbicide sites (Figure 2.2b). More *F. aserva* Forel were noted old non-herbicide sites than in old herbicide or either of the young sites. *M. detritinodis* Emery (group 2) were the most abundant in old herbicide sites and the least abundant in young non-herbicide sites, with young herbicide, old non-herbicide and plantations falling in the middle (Figure 2.2c). Group 3 represented by the following five taxa: *C. herculeanus* Linné, *C. pennsylvanicus* DeGeer, *F. neorufibarbis* Pergande, *F. fusca* Linné, and *F. podzolica* Francoeur has no significant effects of age or herbicide (Figure 2.2d). *C. noveboracensis* Fitch (group 4) were more abundant in old herbicide and old non-herbicide sites than in plantations, young herbicide sites, and young non-herbicide sites (Figure 2.2e). Young non-herbicide sites had the lowest abundance of *C. noveboracensis* Fitch. The highest abundance of *M. emeryana* Forel (group 5) was observed in old herbicide and plantations and the lowest abundance in young herbicide and non-herbicide sites. Though there was a higher abundance in old herbicide than in old non-herbicide, the abundance of *M. emeryana* Forel in plantations was not different from either old herbicide or non-herbicide sites (Figure 2.2f).

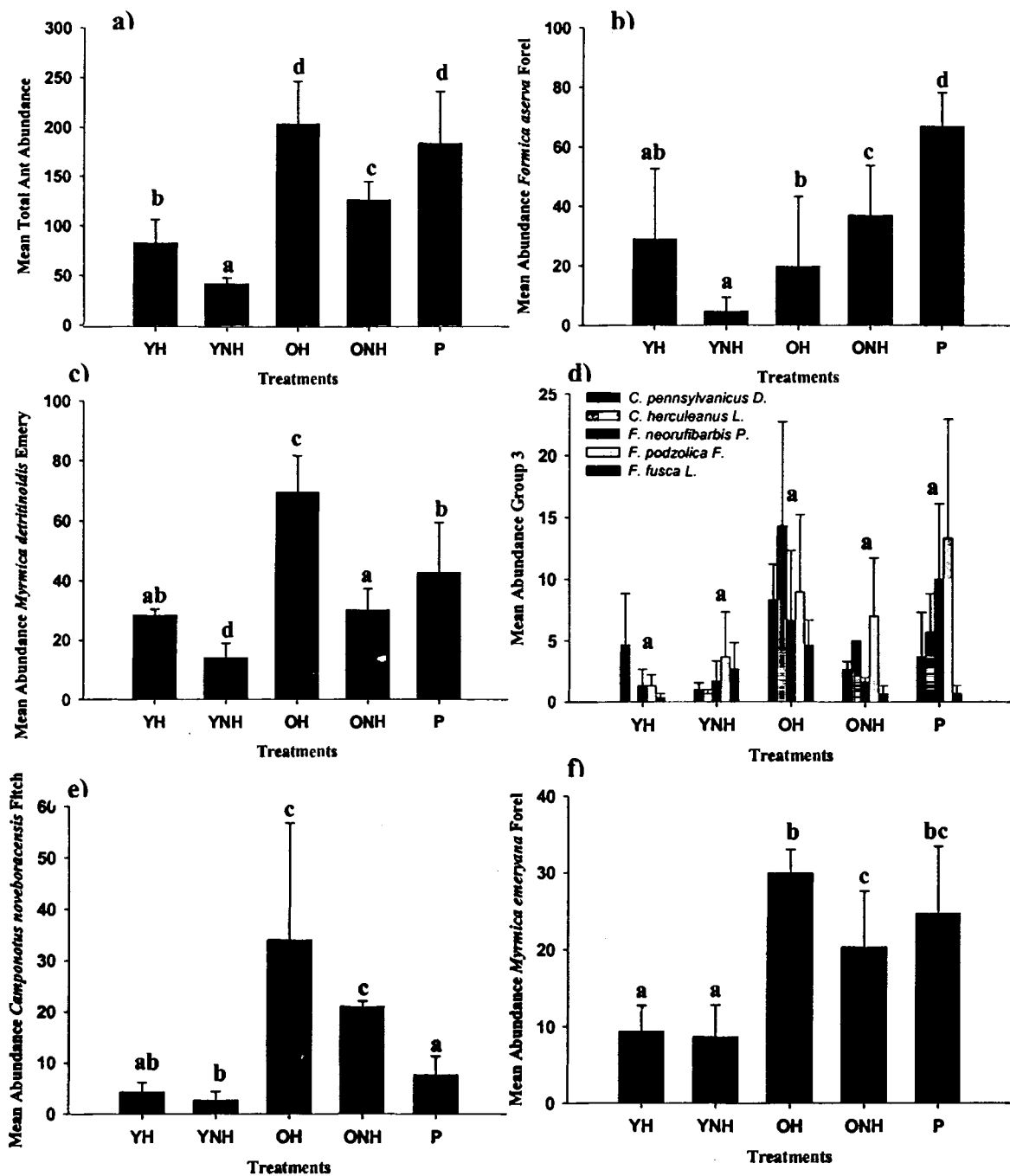


Figure 2.2 Results of 2001 sampling of age*herbicide interactions on the mean abundance per interaction for a) total ants captured, b) Group 1: *F. aserva* Forel, c) Group 2: *M. detritinodis* Emery d) Group 3: *C. pennsylvanicus* DeGeer, *C. herculeanus* Linnè, *F. neorufibarbis* Pergande, *F. fusca* Linnè, and *F. podzolica* Francoeur, e) Group 4: *C. noveboracensis* Fitch, f) Group 5: *M. emeryana* Forel. Treatments are defined as YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old herbicide and P: plantation. Letters above bars (a-d) indicate significant differences. Error bars represent one standard error of the mean.

Ant Population Distributions

Rank abundance curves indicate the richness and evenness of ant species is comparable for each age*herbicide interaction in both years (Figure 2.3). It appears that young herbicide sites were the most diverse in 2000 and old herbicide sites were the most diverse in 2001, while mature sites were the least diverse. Evenness appears similar between the treatments. The Shannon-Weiner diversity index was used to assess the diversity of ants for the age and herbicide treatments. There was no difference in the diversity indices for age ($P = 0.178$), herbicide ($P = 0.115$) or age*herbicide ($P = 0.793$). If placed in order of the most diverse to the least diverse, the interactions would be sorted as: plantations ($H = 1.928$) > young herbicide > old herbicide > old non-herbicide > mature > young non-herbicide ($H = 1.247$). In 2001, there was no difference in the diversity indices for age ($P = 0.626$) or herbicide ($P = 0.142$) but there was a significant trend ($P = 0.082$), alpha level of 0.10, for age*herbicide interactions that was investigated with linear contrasts. The diversity of the mature sites was significantly less than old herbicide ($P = 0.007$), old non-herbicide ($P = 0.047$), plantations ($P = 0.040$), and young non-herbicide ($P = 0.031$). The diversity of old herbicide clearcuts was significantly higher than young herbicide sites ($P = 0.031$). If placed in order of highest to lowest diversity, the pattern would be: young non-herbicide ($H = 2.127$) > old herbicide > plantation > old non-herbicide > mature > young herbicide ($H = 1.632$).

When comparing the rank frequencies of ant species, in both years, *M. detritinodis* Emery was the dominant species, with *F. aserva* Forel, *M. emeryana* Forel, and *C. noveboracensis* Fitch following in decreasing dominance. The other 9 species

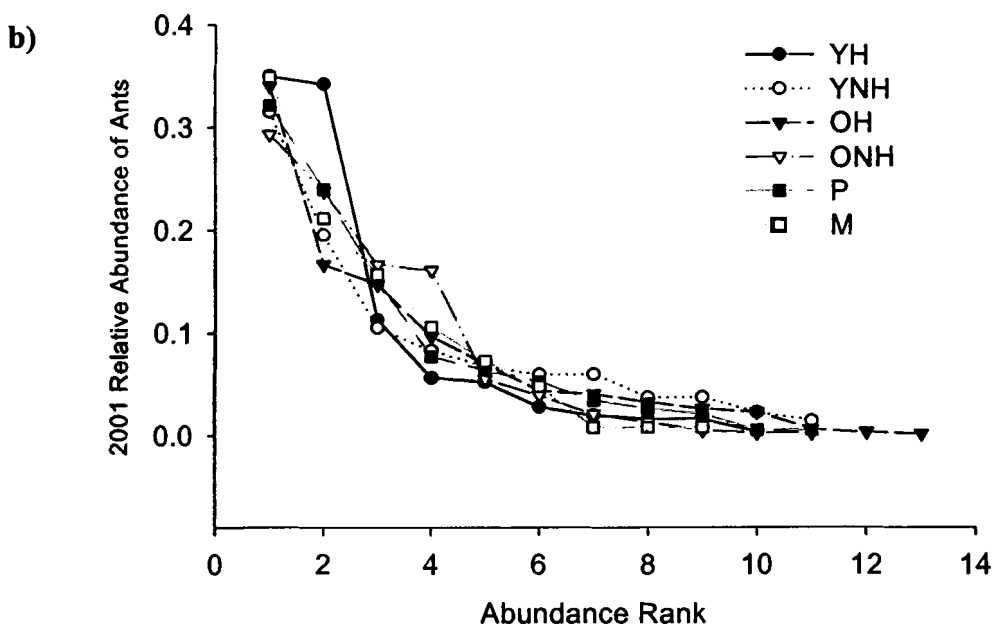
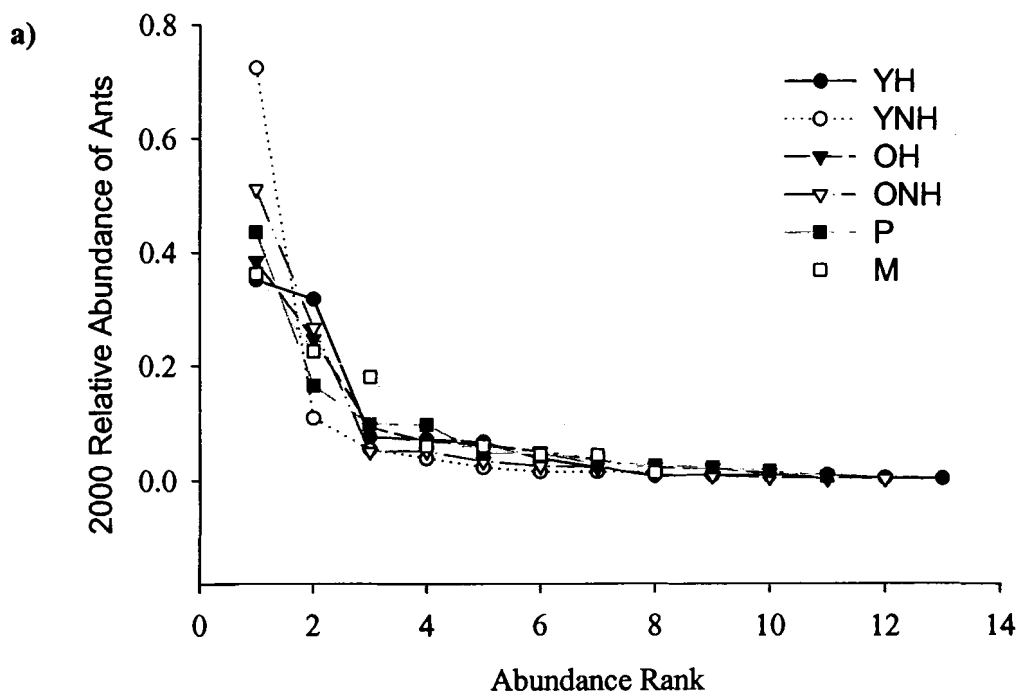


Figure 2.3 Rank Abundance Curves for a) 2000 and b) 2001 ant abundance in each age*herbicide interaction. Treatments are defined as YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old herbicide, P: plantation, and M: mature.

varied in their rank from 2000 to 2001. In 2000, herbicide ($P = 0.024$) affected the overall rank frequency distribution of ant species, but age ($P = 0.702$) (Figure 2.4a-b) and age*herbicide interactions ($P = 0.351$) did not. In herbicide sites (Figure 2.4c) the calculated mean rank was 3.03, or between *M. emeryana* Forel and *C. noveboracensis* Fitch. In non-herbicide sites (Figure 2.4d), the mean rank equaled 2.419, between *F. aserva* Forel and *M. emeryana* Forel. This implies that *M. detritinodis* Emery and *F. aserva* Forel were more dominant in non-herbicide sites. When comparing herbicide versus non-herbicide sites, there were also slight changes in the abundance of *C. pennsylvanicus* DeGeer, *C. noveboracensis*, and *T. sessile* Say, which altered their rank in the ant community.

In 2001, age ($P = 0.044$), herbicide ($P = 0.04$) and the age*herbicide ($P = 0.004$) interaction effected the mean rank of the frequency distribution of ants. Results from linear contrasts indicate some evidence of a significant trend ($\alpha = 0.10$) between old herbicide sites and young herbicide sites ($P = 0.062$), and young non-herbicide sites ($P = 0.054$) (Figure 2.5). The calculated mean rank of old herbicide sites equals 3.43, which falls between the mean rank of young herbicide (mean rank = 2.713) and young non-herbicide (mean rank = 4.067). Thereby *M. detritinodis* Emery and *F. aserva* Forel are more dominant in young herbicide sites and less dominant in young non-herbicide sites than old non-herbicide sites. Old non-herbicide sites were significantly different from young herbicide ($P = 0.009$) and young non-herbicide sites ($P = 0.002$). The mean rank of old non-herbicide sites (mean rank = 2.859) indicates the same pattern of dominance as the mean rank of old herbicide sites as relates to young herbicide and non-herbicide sites.

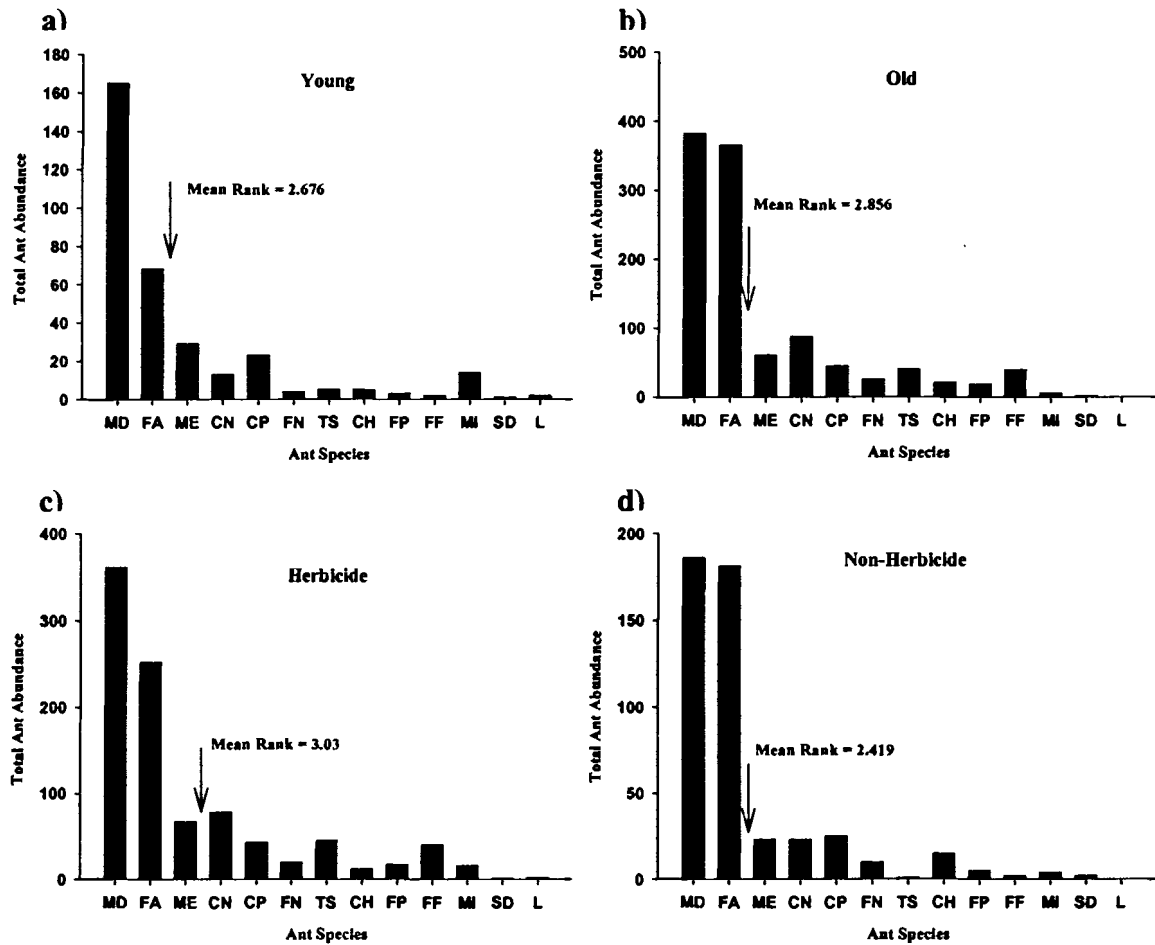


Figure 2.4 The total abundance of ants captured by species in 2000. For a) Young clearcuts vs. b) old clearcuts and c) herbicide clearcuts vs. d) non-herbicide clearcuts. Species are graphed from the overall most dominant to the least dominant species. MD: *M. detritinodis* Emery, FA: *F. aserva* Forel, ME: *M. emeryana* Forel, CN: *C. noveboracensis* Fitch, CP: *C. pennsylvanicus* DeGeer, FN: *F. neorufibarbis* Pergande, TS: *T. sessile* Say, CH: *C. herculeanus* Linné, FP: *F. podzolica* Francoeur, FF: *F. fusca* Linné, MI: *M. incompleta* Provancher, SD: *Stenamma diecki* Emery, and L: *Leptothorax* sp.

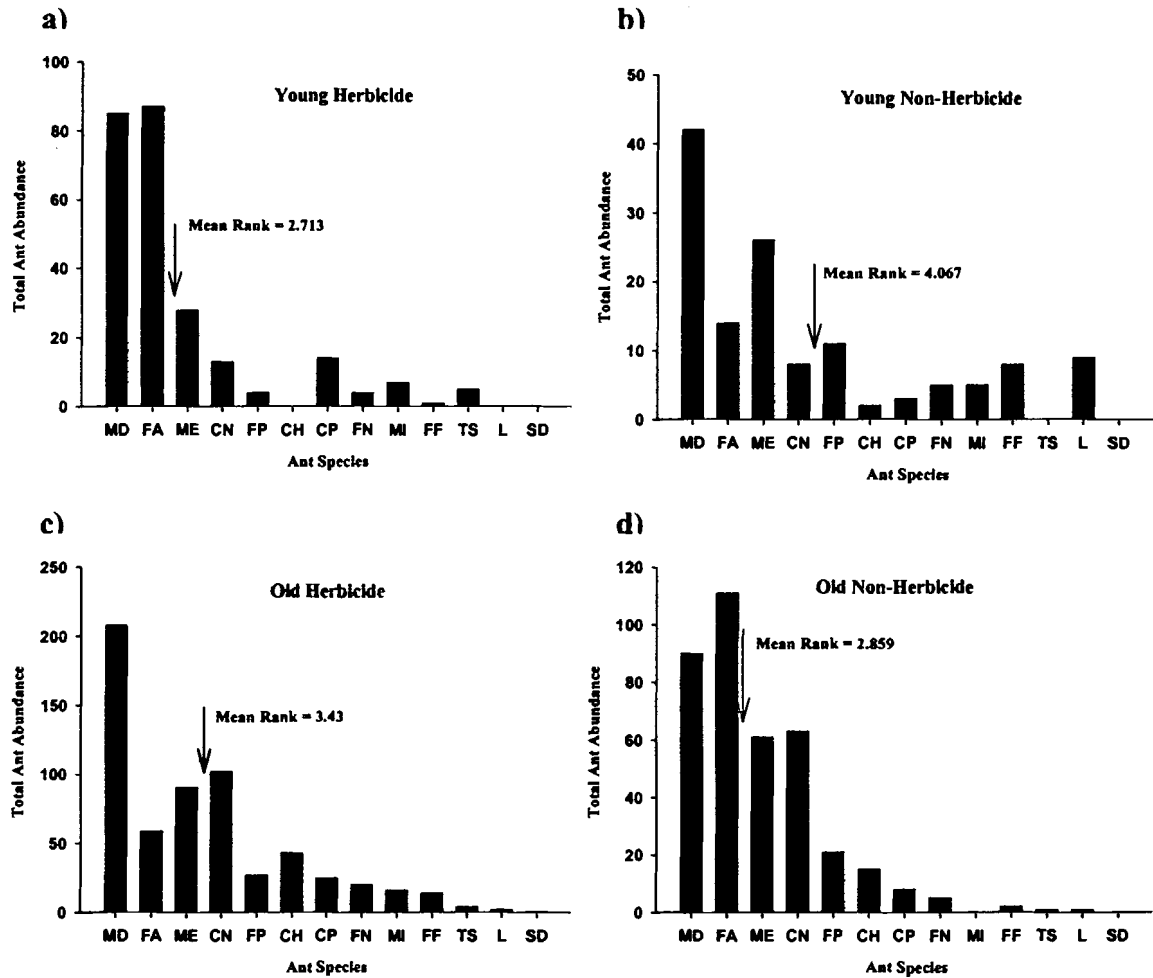


Figure 2.5 The total abundance of ants captured by species in 2001. For a) young herbicide sites, b) young non-herbicide sites, c) old herbicide sites, and d) old non-herbicide sites. Species are graphed from the overall most dominant to the least dominant species. MD: *M. detritinodis* Emery, FA: *F. aserva* Forel, ME: *M. emeryana* Forel, CN: *C. noveboracensis* Fitch, FP: *F. podzolica* Francoeur, CH: *C. herculeanus* Linné, CP: *C. pennsylvanicus* DeGeer, FN: *F. neorufibarbis* Pergande, MI: *M. incompleta* Provancher, FF: *F. fusca* Linné, TS: *T. sessile* Say, L: *Leptothorax* sp., SD: *Stenamma diecki* Emery.

A DCA was performed to assess the distribution of ant species and sites by the number of ants captured. In 2000 (Figure 2.6), *F. aserva* Forel had a distinctly different distribution than the seven other species. The three *Camponotus* species and *M. incompleta* Provancher are loosely associated with each other. *M. emeryana* Forel, *M. detritinodis* Emery and *F. podzolica* form a weak grouping. The young non-herbicide sites form a strong grouping based on ant abundance where as old non-herbicide sites form a weak grouping. Mature, old herbicide, plantations and young herbicide clearcuts form very weak groups. Similarly in 2001 (Figure 2.7) *F. aserva* Forel had a different distribution than the other eight species. The three *Camponotus* species were again loosely grouped. *F. podzolica* Francoeur and *F. neorufibarbis* Pergande had a similarly distributed abundance. *M. emeryana* Forel, *M. detritinodis* Emery and *F. fusca* Linné were loosely associated with each other. As in 2000, the young non-herbicide clearcuts were strongly grouped by ant abundance. Plantations were also weakly grouped. Mature sites, old herbicide and non-herbicide, and young herbicide clearcuts were very weakly grouped.

The Relationship of Floral Density to Ant Populations

Results of ANOVA of floral densities indicate significant age*herbicide interactions in 2000 ($P = 0.001$) (Figure 2.8a) and in 2001 ($P = 0.023$) (Figure 2.8b). The floral density was highest in young clearcuts in both years of this study. Young herbicide clearcuts had a higher floral density than old herbicide (2000: $P = 0.004$ and 2001: $P = 0.007$) and old non-herbicide clearcuts (2000: $P = 0.005$ and 2001: $P = 0.005$) in both years. Young non-herbicide clearcuts also had a significantly higher floral density than old herbicide

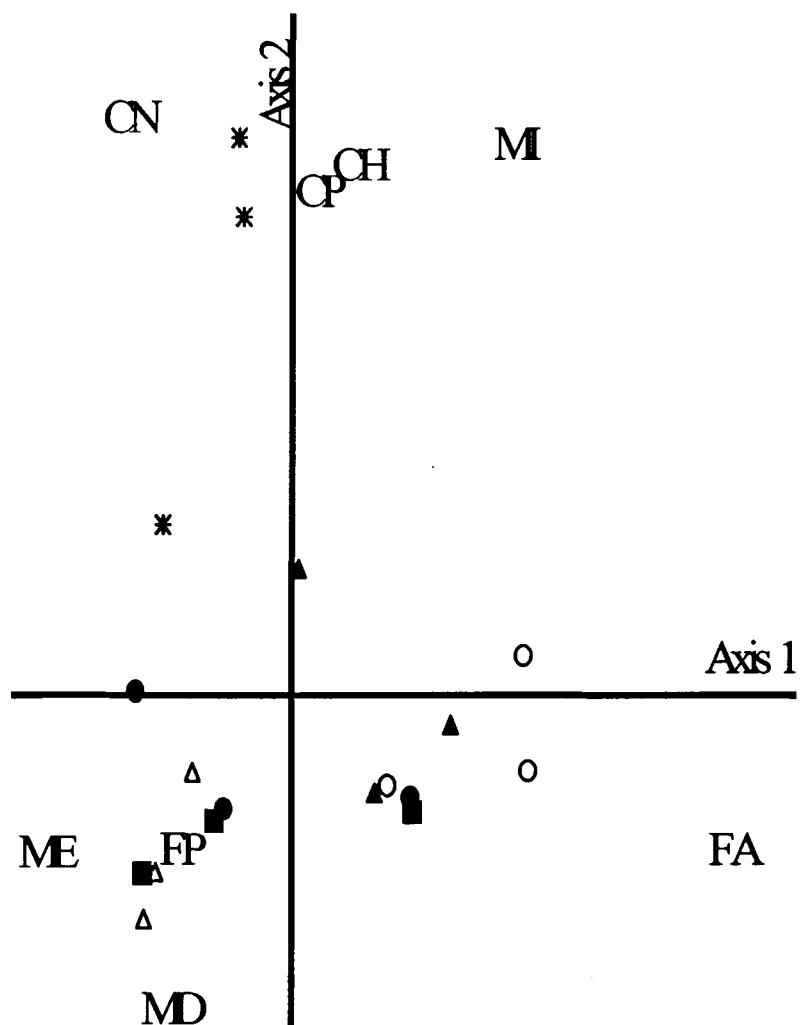


Figure 2.6 Results of detrended correspondence analysis for 2000 results of the total abundance of ants captured of each species and in each site. Symbols represent sites by treatments. Old herbicide: ●, Old non-herbicide: ○, Young herbicide: ▲, Young non-herbicide: △, Plantations: ■, Matures: *. Letters represent species. *C. herculeanus* Linné: CH, *C. noveboracensis* Fitch: CN, *C. pennsylvanicus* DeGeer: CP, *F. aserva* Forel: FA, *F. podzolica* Francoeur: FP, *M. detritinodis* Emery: MD, *M. emeryana* Forel: ME, and *M. incompleta* Provancher: MI. Eigenvalues: Axis 1 = 0.202, Axis 2 = 0.149, and Axis 3 = 0.055.

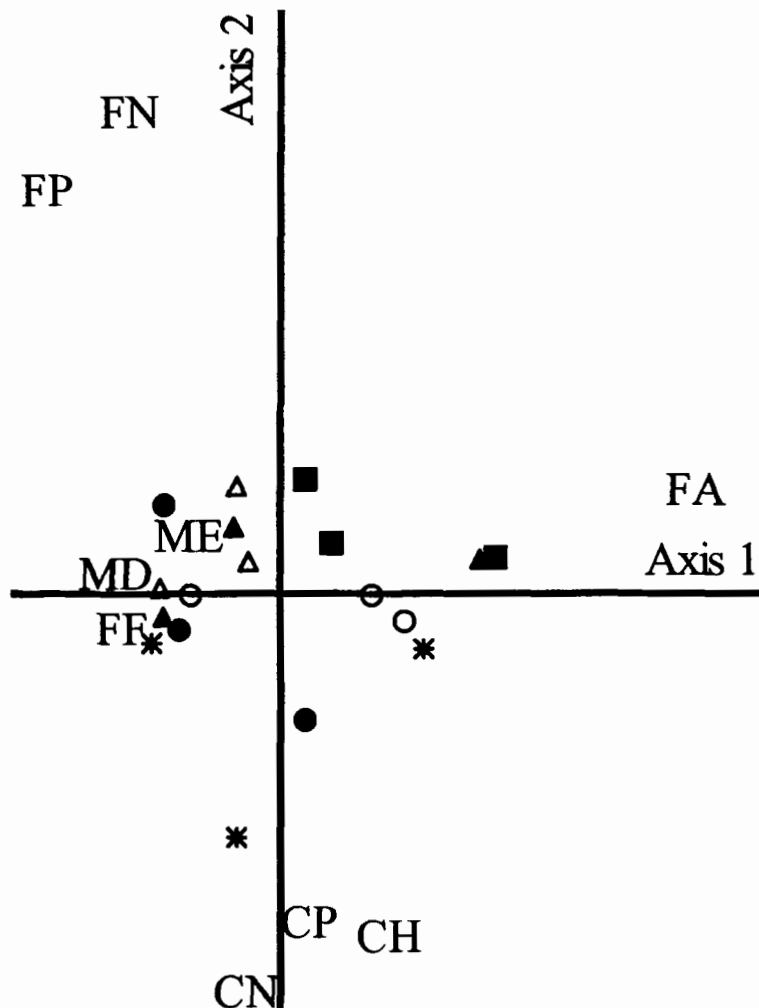


Figure 2.7 Results of detrended correspondence analysis for 2001 results of the total abundance of ants captured of each species and in each site. Symbols represent sites by treatments. Old herbicide: ●, Old non-herbicide: ○, Young herbicide: ▲, Young non-herbicide: △, Plantations: ■, Matures: *. Letters represent species. *C. herculeanus* Linné: CH, *C. noveboracensis* Fitch: CN, *C. pennsylvanicus* DeGeer: CP, *F. aserva* Forel: FA, *F. fusca* Linné: FF, *F. neorufibarbis* Pergande: FN, *F. podzolica* Francoeur: FP, *M. detritinodis* Emery: MD, and *M. emeryana* Forel: ME. Eigenvalues: Axis 1 = 0.244, Axis 2 = 0.116, and Axis 3 = 0.034.

(2000: $P < 0.001$ and 2001: $P = 0.002$) and old non-herbicide (2000: $P = 0.002$ and 2001: $P = 0.007$) clearcuts in both years. Plantations had a higher floral density than old herbicide ($P = 0.004$) and old non-herbicide ($P = 0.003$) in 2000, but not in 2001 (OH: $P = 0.182$ and ONH: $P = 0.137$). There was no significant difference among young herbicide, young non-herbicide and plantations in either year.

Linear correlation analysis (Bonferroni corrected) was used to analyze the association between the floral density and the abundance of each ant species by site. There were no significant correlations between the total ants captured or the total of each species with the total floral density per site in either year.

The Relationship of Tree Density to Ant Populations

Linear contrasts after ANOVA were used to determine the distribution of the mean softwood density per treatment combination. In 2000, the older clearcut sites and plantations had higher softwood density than the younger clearcuts (Figure 2.9a). The mean softwood density in old herbicide clearcuts was significantly higher than young non-herbicide clearcuts ($P = 0.051$) but not young herbicide, old non-herbicide, or plantations. Plantations were significantly denser than young herbicide ($P = 0.031$) and young non-herbicide ($P = 0.012$) clearcuts. There was no significant difference among old non-herbicide, young herbicide, and young non-herbicide clearcuts.

Linear correlation analysis was used to determine the relationship of softwood density to the abundance of total ants and each species captured in each site (Table 2.4). The total abundance of captured ants per site was significantly correlated to the softwood density per site in 2000. Nine of eleven species analyzed had a positive correlation with tree density, though several of the species only had a linear trend ($0.10 \leq P < 0.05$).

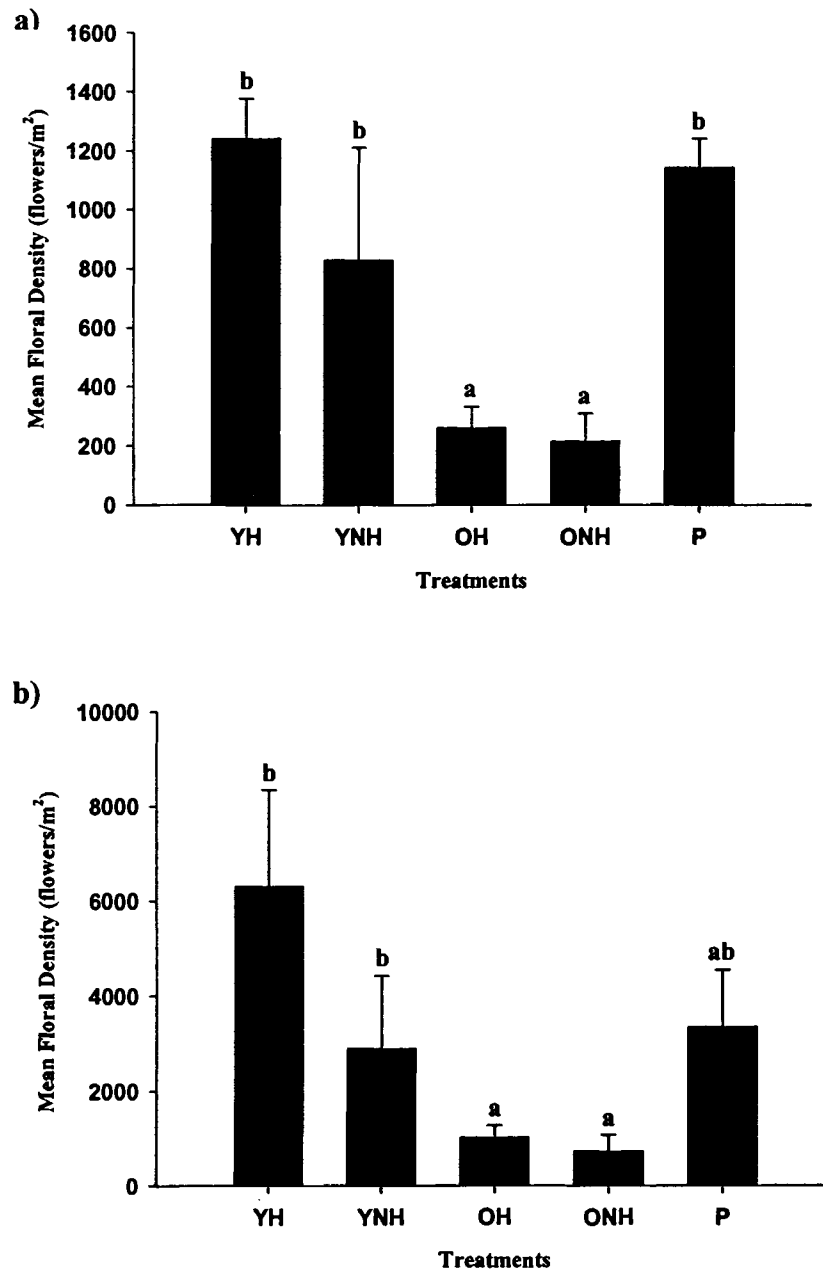


Figure 2.8 The mean floral density (flowers/m²) per treatment for a) 2000 and b) 2001. Treatments represent age*herbicide interactions of YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old herbicide, and P: plantation. Error bars represent one standard error of the mean.

Table 2.4 Results of statistically significant linear correlation analysis on softwood density and the total abundance of each ant species in each site. R is the correlation coefficient and P represents the Bonferroni probability.

Species	2000		2001	
	r	P	r	P
<i>C. herculeanus</i> Linnè	0.708	0.001	0.639	0.001
<i>C. noveboracensis</i> Fitch	0.597	0.009	0.653	0.003
<i>C. pennsylvanicus</i> DeGeer	0.436	0.071	----*	----
<i>F. aserva</i> Forel	0.563	0.015	0.610	0.007
<i>F. fusca</i> Linnè	----	----	----	----
<i>F. neorufibarbis</i> Pergande	0.599	0.001	----	----
<i>F. podzolica</i> Francoeur	0.649	0.011	----	----
<i>M. detritinodis</i> Emery	0.590	0.010	----	----
<i>M. emeryana</i> Forel	0.487	0.041	0.549	0.018
<i>M. incompleta</i> Provancher	----	----	----	----
<i>T. sessile</i> Say	0.499	0.035	----	----
Total abundance	0.730	0.001	0.642	0.004

*----non-significant correlation, $P > 0.10$

In 2001 (Figure. 2.9b), the mean softwood density in old herbicide and old non-herbicide clearcuts were significantly higher than young herbicide (OH: $P = 0.0494$ and ONH: $P = 0.023$) and young non-herbicide clearcuts (OH: $P = 0.0229$ and ONH: $P = 0.0049$), but not plantations. Results among plantations, young herbicide and young non-herbicide were the same as 2000. In 2001 (Table 2.4), only four of the eleven species were positively correlated with softwood density. These four species had similar correlations in both years. As in 2000, the total abundance of ants captured per site was also positively correlated to softwood density.

In 2000, site 8 was an old non-herbicide clearcut that we considered an outlier when evaluating the differences in hardwood density among age and herbicide treatments. It is approximately four times greater in hardwood density than the next highest site. It was removed from the analysis to better evaluate the differences among treatments. Linear contrasts results indicate a significant difference in the mean

hardwood density among age*herbicide interactions for 2000 ($P = 0.008$) and 2001 ($P = 0.004$). In 2000 and 2001, plantations had a significantly higher hardwood density than old herbicides (2000: $P = 0.007$ and 2001: $P = 0.005$), old non-herbicides (2000: $P = 0.013$ and 2001: $P = 0.002$), young herbicides (2000: $P = 0.001$ and 2001: $P < 0.001$), and young non-herbicide (2000: $P = 0.002$ and 2001: $P = 0.001$). There were no significant differences among the other four treatments. There were no significant correlations of total ant abundance or the abundance of ant species with hardwood density in 2000 or 2001.

The Relationship of Soil Properties to Ant Populations

Soil properties such as percent organic matter, soil pH, and soil moisture were measured for all treatments. ANOVA resulted in no significant difference among treatments for these three variables in 2000 and 2001.

Correlation analysis was used to observe the relationship between soil properties and the abundance of each species and the total ant abundance in each site. Soil pH was not significantly correlated to the total ant capture or the abundance of each species captured in either year. The percent organic matter was slightly negatively correlated to several species in 2000 and 2001. *M. detritinodis* Emery was slightly negatively correlated in 2000 ($r = -0.478$, $P = 0.045$) and 2001 ($r = -0.435$, $P = 0.071$). *M. emeryana* Forel also was slightly negatively correlated in 2000 ($r = -0.491$, $P = 0.038$) and in 2001 ($r = -0.411$, $P = 0.090$). *F. aserva* Forel ($r = -0.522$, $P = 0.026$), *C. noveboracensis* Forel ($r = -0.500$, $P = 0.035$), and *T. sessile* Say ($r = -0.444$, $P = 0.065$) were slightly negatively correlated in 2000 but not 2001. Soil moisture was only measured in 2001. There were no correlation of the total abundance of ants or of ant taxa per site with the soil moisture.

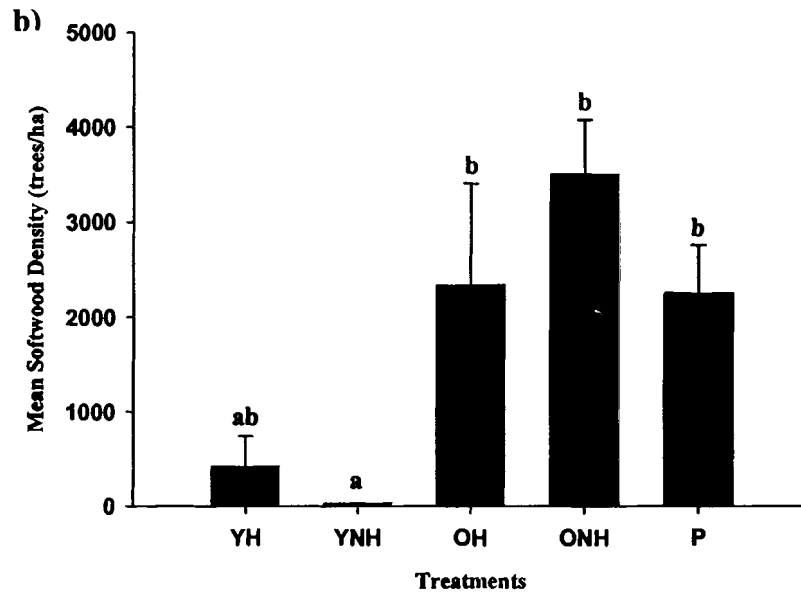
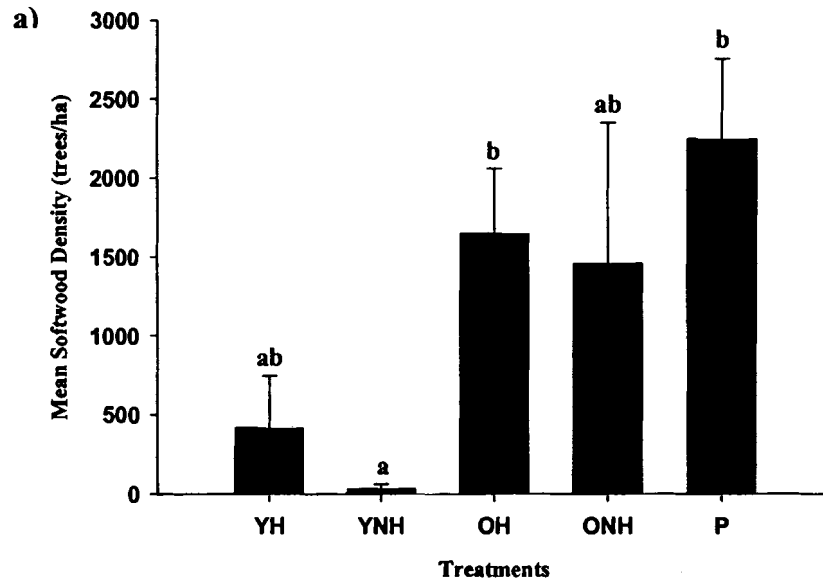


Figure 2.9 The mean softwood density per treatment for a) 2000 and b) 2001. Treatments represent age*herbicide interactions of YH: young herbicide, YNH: young non-herbicide, OH: old herbicide, ONH: old non-herbicide and P: plantation. The error bars represent one standard error of the mean.

Discussion

Results indicate that glyphosate has a positive effect on the abundance of ants in clearcuts of western Maine, but no apparent effect on ant species diversity. In the short-term (3-5 years) there were more total ants in young herbicide than in young non-herbicide clearcuts in both years. These results are different than other short-term effects on ant communities observed after insecticide applications in that the influence of herbicides appears beneficial to ant communities (Braman and Pendley 1993, Catangui et al 1993, Wang et al 2001). Results are also contrary to Santillo et al (1989b), who observed short-term decreases in invertebrate abundance (including ant species) after glyphosate application, but their investigation into insects was only a minor portion of a larger project and was not investigated thoroughly. The results of this study indicate that after several years of re-growth, clearcuts may provide better habitat for ant communities when compared with mature stands and herbicides may enhance this habitat. The floral density, though not significant, was higher in young herbicide clearcuts in both years. Since ants use flowers as foraging and food sources (Hölldobler and Wilson 1990), ants may prefer a more floral dense area, though this may be species specific. In the long-term (10-15 years), we found a positive glyphosate effect on ant abundance in 2000, but no effect on the diversity of ants in either year. Though there were no overall herbicide effects in 2001, there were age*herbicide interactions, indicating glyphosate has an influence on ant abundance. More ants were present in herbicide sites in both years of the study, though this was only significant at $P < 0.05$ in 2000. Similarly, Duchesne et al (1999) found long-term effects of herbicides on carabid beetles, but their results reflect an

increase in richness and diversity and not an increase in abundance. Age*herbicide interactions were significant in both years. Old herbicide sites and plantations had higher ant abundance than old non-herbicide, young herbicide and young non-herbicide sites. Old non-herbicide sites contained more ants than young non-herbicide in both years but only more than young herbicide sites in 2001. Results of interactions indicate herbicide may not be the only influence on ant populations. Other habitat factors, such as the vertical stand structure (Humphrey et al 1999) and temperature (Weseloh 1995), can influence the abundance of insects and need to be further assessed to determine the possible causes of this pattern.

The age since clearcut has an impact on the abundance and the diversity of ants. In both years, the abundance of ants was greater in old clearcuts than in young. The diversity of ants in 2001 was higher in old herbicide clearcuts than young herbicide clearcuts, which is consistent with the research of Puntila et al (1991) on the short and long-term effects of clearcutting. Other previous research has demonstrated the use and preference of forested areas by ants when compared to clearcuts or agricultural fields (Jennings 1989, Deslippe et al 1994, Weseloh 2000). The pattern of ant abundance and diversity found in this study may be the result of softwood density in old clearcuts. Hardwood density was highest in plantations, but there were no correlations with ant abundance. In both years, there was a positive correlation between the total ant abundance and softwood density. Old clearcuts (including plantations) contain higher softwood densities than young clearcuts. In 2000 and 2001, several ant species including *Camponotus* spp., *Formica* spp., and *Myrmica* sp. were positively correlated to softwood density. Previous research has demonstrated the use by ants of trees as foraging and

nesting sites (Agosti 2000, Weseloh 2000). Tschinkel and Hess (1999) and Torgerson and Bull (1992) both found ant abundance, especially *Camponotus* spp., increased with the increasing diameter of tree and fallen dead wood. Therefore, high tree density and increasing tree diameter in old clearcuts may encourage ant colonization and augment colony size. It appears, though not statistically tested, that the abundance of ants in mature sites was similar to that of young sites. The softwood density is high in mature sites, but the light penetration into the mature sites appeared minimal in comparison with our selected old clearcut sites. Old clearcuts had not yet achieved the canopy closure of mature sites. There are more gaps and shorter trees in our selected old clearcuts than in the mature stands, which allows for higher floral density and increased habitat heterogeneity in old clearcuts that can benefit ant community abundance and diversity (New 2000). Light penetration affects the amount of direct solar radiation the ground receives and therefore the temperature. Temperature is known to influence ant abundance and activity (Albrecht and Gotelli 1999, Weseloh 1995, Lynch 1988, Bernstein and Gobbel 1979). Therefore, light penetration, temperature, and vegetation diversity may influence the abundance of ants in young, old, and mature sites.

Thirteen ant species were collected. Samples of *Leptothorax* sp. and *Stenamma diecki* Emery, and *Tapinoma sessile* Say were not abundant enough to analyze. Of the ten other species, several responded to the stand age and glyphosate treatments. Though species varied in their exact response, the general trend was higher abundance in old herbicide or plantation sites. For instance, *F. aserva* Forel was the most abundant in plantations in 2001 and more abundant in old sites than young sites in both years. This species was positively correlated to the softwood density in both years and to the percent

organic matter in 2000. The DCA results indicated that *F. aserva* responds to the age and herbicide differently than any other species. *F. podzolica* Francoeur and *F. neorufibarbis* Pergande were positively correlated with each other. These two species were more abundant in old herbicide than in young herbicide and non-herbicide clearcuts in 2001. These two species were also positively correlated to softwood density in 2000. Neither age nor herbicide had an effect on *F. fusca* Linnè, nor was this species correlated with vegetation or soil characteristics measured. *Formica* spp. are well known predators of various invertebrates in the forest ecosystem (Young and Campbell 1984, Weseloh 1989, 1993, 1996, Hölldobler and Wilson 1990, Karhu 1998). *Formica* spp. utilize trees to forage and their presence in old and plantation sites may be explained by the density of trees in these areas as compared to young sites.

M. detritinodis Emery and *M. emeryana* Forel were more abundant in old herbicide and plantations than young sites in both years. *M. detritinodis* Emery was positively correlated to softwood density in 2000 and *M. emeryana* Forel was positively correlated in both years. Both species were negatively correlated to percent organic matter in both years. *M. emeryana* Forel was positively correlated with *F. podzolica* Francoeur. *M. jncompleta* Provancher did not appear to be influenced by the age, herbicide, or softwood density of the study sites. *Myrmica* species in general prefer nesting and foraging in areas with taller vegetation and more insolation (Elmes and Wardlaw 1982). Sites with higher softwood density may provide the necessary habitat for these species. The fact that the percent organic matter is negatively correlated in both years may reflect nesting preferences, though there was no difference in organic matter

among treatments in either year. Further investigation into the nesting preferences of these species would further explain these results.

The three *Camponotus* species responded to age and herbicide effects in a similar manner, as detected by the results of the DCA in both years. *C. noveboracensis* Fitch was statistically more abundant in old sites and plantations in both years. *Camponotus* spp. are known to utilize trees and woody debris for nesting and foraging (Agosti et al 2000, Sanders and Pang 1992, Torgerson and Bull 1992, Youngs and Campbell 1984). All three *Camponotus* species were correlated with softwood density in 2000 and two of the three species were correlated in 2001. Though results of linear contrasts indicate significant age*herbicide interactions in 2000 and 2001 for *C. noveboracensis* Fitch, the low capture rate for these ants may indicate these results are statistically valid but not biologically. Further study on this species will indicate if the statistical results can be translated into ecological significance.

The rank frequency distribution of ant species was different in herbicide and non-herbicide sites in both years. *M. detritinodis* Emery and *F. aserva* Forel were dominant in both years. In 2000, the dominance hierarchy was different in herbicide and non-herbicide sites, with *M. emeryana* Forel having more of a role in herbicide sites. In 2001, there was a difference in the rank frequency distribution of ants within the age*herbicide interactions. In old herbicide sites, the abundance of *F. aserva* Forel is higher than *M. detritinodis* Emery, but not in old non-herbicide or young herbicide. From 2000 results, it appears herbicide increases the dominance of *M. detritinodis* Emery. But 2001 results of age*herbicide interactions indicate herbicide may not be directly effecting the abundance of species. Other factors such as floral density, which was very different

between the two study years, could be influencing the dominance hierarchy of ant communities and our results.

Floral density, tree density, soil pH, percent organic matter in the soil, and soil moisture are habitat factors that were recorded for each study site. Previous studies have researched the relationships between ants and vegetation. Ants are known to utilize vegetation as foraging and nesting sites ((Hölldobler and Wilson 1990, Weseloh 2000). Floral density was highest in the young clearcuts . Though there were no correlations between the floral density and the total ants captured, there appears to be a pattern in that young herbicide sites have higher floral density and lower ant abundances than old sites. Whether ants utilize specific flowers in this habitat is unknown and further study may reveal patterns of association between ant species and flowering plants. The density of softwood trees appears to have the most significant impact on the abundance of ants in this study. The total abundance and the abundance of individual species are positively correlated in both years. The correlations of some species with softwood density are not consistent in both years. This may be the result of having a combination of some new sites and some old sites in 2001. Temperature may also play a role in site preference. Young clearcuts have fewer trees and therefore less shade and insulation. The harsher habitat of young clearcuts may deter ant colonization. Previous research has correlated ant abundance and diversity with soil characteristics such as pH, organic matter, and moisture (Albrecht and Gotelli 1999, Bernstein and Gobbel 1979, Wang 2001a, Weseloh 1995). This study revealed no effect of pH or soil moisture, though these sites are geographically close which may minimize soil differences. Several ant species were negatively correlated with the percent organic matter, but more information is needed on

the nesting preference of these ant species to fully understand patterns relating to organic matter. Though ant species are known to alter the structure of soil near their nests (Lenoir et al 2001, Lobry de Bruyn 2000, Beattie and Culver 1977), it would appear to be disadvantageous to alter soil in a way that negatively impacts the colony.

The potential use of ants as bioindicators of environmental change is a current debate. In the rehabilitation of bauxite mines (Majer 1983, 1992, 1996, Majer et al 1984), an increase in plant diversity, density and cover can be positively correlated to ant species, meaning that as the mines recover so does ant diversity and abundance. In this study, ant abundance can be correlated positively with increasing softwood density, as the woody vegetation recovers from the clearcut so does the ant abundance. Ant communities have previously been shown to increase as the years since clearcut increase (Jennings 1986, Punttila 1991). Since the glyphosate application influenced the vegetation structure of the sites, ants may also be predictors of recovery from herbicide. Ants appear to be more abundant in young and old clearcuts treated with herbicide than in non-herbicide sites of both ages, but further investigation of the life histories of these ants is needed to explain why the herbicide sites are preferential. Since the diversity is the same between treated and untreated sites, the difference in the abundance is most likely related to the changes in vegetation composition. The problem with assessing this is the lack of ant community information from pre-herbicide application and from the first 3 years after application. Clearly there is potential for the use of ant communities as bioindicators of forestry land management. Further study on the relationship between ants and vegetation recovery after land use forest disturbance is needed to completely assess the potential to use ants as indicators of recovery.

Conclusion

Glyphosate application after clearcutting does have short and long-term effects on the total ant abundance as well as the abundance of several species, including *Camponotus* spp., *Formica* spp., and *Myrmica* spp. As the age of the clearcut increases, the abundance of ants and potentially the diversity also increases. There was no observed influence of soil pH, percent soil organic matter, or soil moisture on ant populations. From the environmental variables tested, vegetation appears to be the dominant influence on ant populations. Because factors such as light penetration, temperature, prey abundance, foraging, and nesting sites are affected by vegetation density and composition these factors could also be responsible for the ant community composition and abundance, possibly more than glyphosate application. Other studies have discussed the potential to use ants as bioindicators of land management. The correlation of ant diversity and abundance with vegetation composition and density has previously been demonstrated to successfully represent indications of site recovery. In this case, it is clear that ants respond and are related to the recovery of vegetation after clearcut, but further study is needed to see if there is a measurable response of vegetation change and the development of ant communities.

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Appendix A. List of Families and Species of Flowering Plants Sampled during the 2000 and 2001 field season.

Table A.1 The families and species of flowering plants sampled during the 2000 and 2001 field seasons. The numerical entry for each species is the total number of flowers counted for all fields in each age*herbicide treatment. Nomenclature follows Haines and Vining (1998). Data from the year 2000 is sourced from Georgitis (2001).

Species	Old		Young		Old		Young		Plantation		Mature	
	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	2000	2001	2000	2001
	2000	2000	2000	2000	2001	2001	2001	2001	2000	2001	2000	2001
Adoxaceae												
<i>Sambucus racemosa</i> L.	0	0	0	0	0	0	30	0	0	0	0	0
<i>Viburnum lentago</i> L.	0	0	0	0	530	0	0	0	0	0	0	0
<i>V. cassinoides</i> (L.) T. & G.	650	3450	0	0	0	0	0	0	0	0	0	0
<i>V. lantanoides</i> Michx.	0	0	0	0	0	0	0	0	0	19	0	6
Asteraceae												
<i>Anaphalis margaritacea</i> L.	371	150	2760	3701	1096	181	4116	3219	3068	4478	0	0
<i>Ambrosia</i> sp. L.,	133	0	0	0	0	0	0	0	0	0	0	0
<i>Aster</i> sp. L.	235	6	571	301	0	0	15	100	383	24	4	0
<i>A. dumosus</i> L.,	0	0	0	0	0	0	0	0	144	0	0	0
<i>A. prananthoides</i>	0	0	0	0	26	0	0	0	0	22	0	11
<i>A. puniceus</i>	0	0	0	0	11	0	0	61	0	5	0	0
<i>A. simplex</i> Willd.	0	0	0	0	0	0	0	0	16	0	0	0
<i>A. umbellatus</i> Miller	0	0	255	528	152	494	422	2846	3071	4559	0	5
<i>A. vimineus</i> Lam.	0	0	0	59	0	0	0	0	41	0	0	0
<i>Cirsium</i> sp. Miller	0	0	9	0	0	0	0	0	0	0	0	0
<i>Conyza canadensis</i> (L.) Cronq.	0	0	262	0	0	0	0	0	0	0	0	0
<i>Erigeron annuus</i> (L.) Pers.	0	0	1	0	0	0	0	0	2	0	0	0
<i>Eupatorium maculatum</i> L.	0	0	0	74	0	0	0	25	485	315	0	0
<i>Hieracium caespitosum</i> Dumort.	279	284	893	870	117	14	99	122	1040	157	0	0
<i>H. aurantiacum</i> L.	22	0	46	10	21	1	2	2	9	1	0	0
<i>H. gronovii</i> L.	0	0	0	0	0	0	0	0	2	0	0	0
<i>H. pilosella</i> L.	0	0	0	0	0	0	3	3	1	0	0	0
<i>H. scabrum</i> Michx.	0	7	0	0	0	0	0	0	0	0	0	0
<i>Lactuca canadensis</i> L.	0	3	12	14	0	0	0	0	0	0	0	0
<i>Lactuca biennis</i> (Moench) Fern.	0	0	28	12	2	0	0	1	43	0	0	0
<i>Senecio paupereulus</i> Michx	0	0	0	0	0	26	0	0	0	0	0	0
<i>Solidago</i> sp. L.	9563	6810	43583	27508	9604	7336	72177	29260	60942	31538	0	0

Table A.1 Continued

Species	Old		Young		Old		Young		Plantation		Mature	
	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	2000	2001	2000	2001
	2000	2000	2000	2000	2001	2001	2001	2001	2000	2001	2000	2001
<i>Symphytotrichum puniceum</i> (L.) A. & D. Löve	0	0	0	0	11	0	0	61	0	5	0	0
<i>Taraxacum officinale</i> Wiggers.	0	0	0	0	0	0	0	0	0	1	0	0
<i>Tussilago fargara</i> L.	0	0	0	0	0	0	0	2	0	0	0	0
Balsaminaceae												
<i>Impatiens capensis</i> Meerb.	0	0	0	0	4	0	0	0	0	0	0	0
Campanulaceae												
<i>Lobelia siphilitica</i> L.	0	0	22	0	0	0	0	0	0	0	0	0
<i>L. inflata</i> L.	0	2	215	5	0	0	18	0	0	0	0	0
Caprifoliaceae												
<i>Diervilla lonicera</i> Miller.	0	0	0	0	0	0	0	1	0	0	0	0
<i>Linnaea borealis</i> L.	2	0	0	47	102	74	0	8	4	0	29	6
Clusiaceae												
<i>Hypericum canadense</i> L.	0	0	9	5	0	0	183	0	0	0	0	0
<i>H. ellipticum</i> Hook.	0	0	0	0	0	0	0	0	2	0	0	0
<i>H. muttlm</i> L.	0	0	0	0	32	0	4	0	0	0	0	0
Cornaceae												
<i>Cornus canadensis</i> L.	67	40	1	2	191	209	9	10	60	421	3	3
Ericaceae												
<i>Epigaea repens</i> L.	0	0	0	0	1	0	0	0	0	0	0	0
<i>Gaultheria procumbens</i> L.	80	0	0	16	0	0	0	0	0	0	0	0
<i>Kalmia angustifolia</i> L.	120	857	0	0	0	0	0	0	0	0	0	0
<i>Vaccinium angustifolium</i> Aiton	42	0	0	0	150	0	0	1	18	0	0	0
Iridaceae												
<i>Iris versicolor</i> L.	0	0	0	0	0	0	3	0	0	0	0	0
Lamiaceae												
<i>Galeopsis tetrahit</i> L.	0	35	0	0	0	0	0	0	10	0	0	0
<i>Lycopus americanus</i> Muhl.	0	0	11	0	0	0	0	0	0	0	0	0
<i>L. uniflorus</i> Michx.	24	0	551	0	0	0	69	0	110	0	0	0
<i>Prunella vulgaris</i> L.	0	0	773	0	0	0	14	0	0	18	34	0
<i>Scutellaria lateriflora</i> L.	0	0	32	0	0	0	0	0	0	0	0	0
Liliaceae												
<i>Clintonia borealis</i> (Aiton) Raf.	0	0	0	0	2	3	0	4	0	15	0	0
<i>Maianthemum canadense</i> Desf.	125	0	0	20	453	83	95	99	0	28	96	72
<i>Medeola virginiana</i> L.	2	0	1	0	0	0	0	0	0	0	0	0

Table A.1 Continued

Species	Old		Young		Old		Young		Plantation		Mature	
	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	Herbicide	Non-herbicide	2000	2001	2000	2001
<i>Trillium undulatum</i> Willd.	0	0	0	0	3	0	10	2	0	5	0	0
<i>Uvularia perfoliata</i> L.	0	0	11	0	0	0	0	3	10	0	0	4
Monotropaceae												
<i>Monotropa uniflora</i> L.	0	2	0	0	0	0	0	0	0	0	0	0
Onagraceae												
<i>Epilobium angustifolium</i> L.	53	5	35	1	9	4	3	33	22	39	0	0
<i>E. leptophyllum</i> Raf.	0	0	2	15	0	0	0	0	0	0	0	0
<i>Oenothera biennis</i> L.	0	0	0	0	0	0	3	0	0	0	0	0
<i>O. tetragona</i> Roth.	0	0	21	0	2	0	11	0	0	0	0	0
Orchidaceae												
<i>Cypripedium reginae</i> Walt.	0	0	0	0	1	0	0	0	0	0	0	0
<i>Orchis</i> sp. L.	4	0	0	0	0	0	0	0	0	0	0	0
Oxalidaceae												
<i>Oxalis acetosella</i> L.	0	0	0	1	0	0	0	0	1	1	104	21
<i>O. stricta</i> L.	0	0	1	0	1	0	0	0	0	24	0	0
Polygonaceae												
<i>Persicaria lapathifolia</i> (L.) S.F. Gray	0	0	0	0	0	0	0	0	1	0	0	0
<i>Polygonum ciliinode</i> Michx	0	551	0	1066	0	0	0	0	90	0	0	0
<i>Rumex acetosella</i> L.	0	640	0	500	0	0	0	0	0	35	0	0
Primulaceae												
<i>Trientalis borealis</i> Raf.	0	0	0	0	1	0	0	0	0	0	0	0
Pyrolaceae												
<i>Moneses uniflora</i> (L.) A. Gray	0	0	0	0	0	0	0	0	0	0	3	0
<i>Pyrola rotundifolia</i> L.	0	0	0	0	0	0	0	0	0	50	0	0
Ranunculaceae												
<i>Clematis virginiana</i> L.	0	0	193	0	0	0	22	0	0	0	0	0
<i>Thalictrum pubescens</i> Pursh.	0	0	40	0	0	60	0	0	0	0	0	0
Rosaceae												
<i>Agrimonia gryposepala</i> Wallr.	0	0	0	0	0	0	0	0	121	0	0	0
<i>Dalibarda repens</i> L.	125	0	21	36	6	14	0	1	0	0	10	1
<i>Fragaria</i> spp. L.	4	0	1	3	84	1	33	90	15	210	3	0
<i>F. vesca</i> L.	0	0	0	0	1	0	0	0	0	13	0	0
<i>Rubus allegheniensis</i> T.C. Porter	122	432	501	295	0	85	13	113	115	11	0	0
<i>R. idaeus</i> L.	211	122	835	1304	20	12	64	78	485	107	1	0

Table A.1 Continued

Species	Old		Young		Old		Young		Plantation		Mature	
	Herbicide	Non-herbicide	Herbicide	Non-Herbicide	Herbicide	Non-Herbicide	Herbicide	Non-herbicide	2000	2001	2000	2001
<i>R. pubescens</i> Raf.	0	2	0	0	1	0	1	18	1	4	0	0
<i>Potentilla simplex</i> Michx.	10	6	2	3	4	0	0	0	13	4	0	0
<i>P. norvegica</i> L.	18	0	73	0	1	0	0	0	0	0	0	0
<i>Prunus</i> sp. L.	0	0	0	0	0	0	0	236	0	0	0	0
<i>Spiraea latifolia</i> Aiton Dippel	0	0	0	4	0	0	0	255	0	0	0	0
<i>S. tomentosa</i> L.	0	0	900	100	48	0	46	350	0	0	0	0
<i>Waldsteinia fragarioides</i> (Michx). Tratt.	0	0	0	0	15	5	2	16	0	51	0	0
Rubiaceae												
<i>Galium boreale</i> L.	0	0	0	3	0	0	0	0	0	0	0	0
<i>G. triflorum</i> Michx.	18	0	35	10	0	0	0	0	5	0	21	0
<i>G. trifidum</i> L.	0	0	16	0	0	0	0	0	0	0	0	0
Saxifragaceae												
<i>Tiarella cordifolia</i> L.	0	0	0	0	0	0	0	0	20	5	0	0
Scrophulariaceae												
<i>Veronica officinalis</i> L.	10	6	319	32	0	0	70	0	0	0	83	0
Violaceae												
<i>Viola pallens</i> (Banks) C. L. Hitchc.	0	0	0	0	0	0	15	1	0	0	0	0
Zingiberaceae												
<i>Aralia nudicauli</i> L.	0	0	0	0	21	0	0	0	0	0	0	30
<i>Aralia</i> . Vent.	15	56	627	122	0	24	15	295	0	0	60	0

Appendix B

Bait Trapping of Ants

During 2001 two experiments using bait traps (Baker et al 1985, Weseloh 1993, Wang 2001) to sample ants were performed. The experiments were designed to determine the use of shrubs and trees by ants; and if food resources were being partitioned amongst the ant community. Results from these studies were not statistically analyzed due low ant capture. Data collected are listed below (Table B.1 and Table B.2).

Methods

The first experiment was conducted to assess the ground dwelling species recruitment to animal oil and sugar in the managed forest sites. Six sites were chosen, one from each of the age*herbicide treatments (young herbicide, young non-herbicide, old herbicide, old non-herbicide, plantation and mature sites). Sites 3, 4, 10, 12, 13, and 16 were utilized. To examine the use of bait traps by ants, in the first experiment (Table B.1) a 25 x 25 m quadrant was laid out using 2 measuring tapes (100 m) at the center of each site. A rope was laid straight across the quadrant at every 5 meters to create a grid. In the center of each grid square a glass vial (5 x 1.2 cm) was placed containing one of two baits. The two baits used were sugar water (70%) saturated gauze and cat food (Weseloh 1993). The baits were placed in the grid using an alternating pattern of cat food and sugar water (13 vials of cat food and 12 vials of sugar water). Aluminum flashing rain covers (13 x 13 cm) were used to shade the vials from direct sun. The vials were left in place for 1 hour before collection. Samples were returned to the lab for insect sorting to genus and species. This study was performed on two dates, 23 July 2001 and 9 August 2001. There was no capture of ants on the August sampling date.

A second experiment (Table B.2) used bait traps to examine the foraging of ants in trees and shrubs compared to the ground in the clearcut sites. In each of the six selected sites, 1 vial of cat food and 1 vial of sugar water were placed in 2 conifers (*Abies balsamea*, and *Picea* spp.), 2 deciduous shrubs (*Acer* spp., *Betula* spp., *Prunus* spp.) and 2 areas on the ground. In the conifers vials were placed 1 m high within the tree, while in the shrubs vials were placed 0.5 meters high. Vials were secured to the tree and shrub with tape then collected after 1 hour of sampling time. Two trials of this experiment were conducted on , 23 July 2001 and 7 August 2001.

Table B.1 Results of bait experiment one in 2001. The number of ants collected after one hour as well as the number of vials ants were found (V) is listed. There were 13 vials in each treatment of cat food and 12 vials of 70% sugar water.

Species	Old Herbicide				Old Non-Herbicide				Young Herbicide				Young Non-Herbicide				Plantation				Mature			
	Cat Food		Sugar Water		Cat Food		Sugar Water		Cat Food		Sugar Water		Cat Food		Sugar Water		Cat Food		Sugar Water		Cat Food		Sugar Water	
	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V	Ant	V
<i>Camponotus herculeanus</i> Linné	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camponotus noveboracensis</i> Fitch	13	3	2	2	20	7	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camponotus pennsylvanicus</i> DeGeer	3	1	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica aserva</i> Forel	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica fusca</i> Linné	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica neorufibarbis</i> Pergande	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica podzolica</i> Francoeur	2	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leptothorax</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Myrmica detritinodis</i> Emery	0	0	0	0	0	0	20	2	1	1	1	1	0	0	2	2	0	0	0	0	0	0	0	0
<i>Myrmica emeryana</i> Forel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Myrmica incompleta</i> Provancher	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stenamma diecki</i> Emery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tapinoma sessile</i> Say	0	0	1	1	0	0	48	3	0	0	0	0	3	2	1	1	0	0	0	0	0	0	0	0

Table B.2 Results of bait experiment two in 2001. The number of ants recruiting to baited vials. Sampling occurred in T: coniferous tree, S: deciduous shrub, or G: on the ground. Baits used were C: cat food and S: 70% sugar water.

Species	Old Herbicide						Old Non-Herbicide						Young Herbicide						Young Non-Herbicide						Plantation						Mature					
	T		Sh		G		T		Sh		G		T		Sh		G		T		Sh		G		T		Sh		G		T		Sh		G	
	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
<i>Camponotus herculeanus</i> Linné	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camponotus noveboracensis</i> Fitch	0	0	1	0	13	0	0	0	3	0	12	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camponotus pennsylvanicus</i> DeGeer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica aserva</i> Forel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica fusca</i> Linné	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica neorufibarbis</i> Pergande	2	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Formica podzolica</i> Francoeur	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6	0	2	12	0	0	0	0	0	0
<i>Leptothorax</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Myrmica detritinodis</i> Emery	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Myrmica emeryana</i> Forel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Myrmica incompleta</i> Provancher	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stenamma diecki</i> Emery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tapinoma sessile</i> Say	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C

Canonical Correspondence Analysis

Methods

Canonical Correspondence Analysis (CCA) (McCune and Medford 1999) was used to determine the distribution of ant taxa in response to herbicide use and age since clearcut. Ant taxa counts were used in this analysis for those taxa analyzed in the Poisson regression. Mature and plantations were not used in this analysis. Mature sites where neither clearcut or sprayed with herbicide and plantations were planted, resulting in neither category fitting hypothesis regarding clearcut age or herbicide.

Results

A CCA was used to observe the response of ant species distributions to herbicide and age. In 2000 and 2001, the Monte Carlo test results suggest there is no significant difference in ant distribution among herbicide and non-herbicide clearcuts (2000: $P = 0.740$ and 2001: $P = 0.841$) or among young and old clearcuts (2000: $P = 0.214$ and 2001: $P = 0.518$). Results for the CCA are different from the results of the Poisson regression by age in both years and by herbicide in 2000. Reasons for this may include the absence of the plantations from the CCA analysis, as well as the inability to test the results of the age*herbicide interaction in the CCA.

BIOGRAPHY OF THE AUTHOR

Kerry Frances Lough was born in Chicago, Illinois on January 1, 1975. She was raised in Chicago until 1987 when her family moved to New York City, New York. She graduated from Mount Tabor High School in Winston-Salem, North Carolina. She attended Colorado State University and graduated in 1997 with a Bachelor's degree in wildlife biology. Kerry took several years off from school and spent them gaining experience from the National Park Service, non-profit organizations, and a forestry consulting firm. She entered the Ecology and Environmental Sciences M. S. program at the University of Maine in the summer of 2000. Kerry is a candidate for the Master of Science degree in Ecology and Environmental Sciences from The University of Maine in May, 2003.