

**MOTH DIVERSITY IN YOUNG JACK PINE-DECIDUOUS FORESTS
AFTER DISTURBANCE BY WILDFIRE OR CLEAR-CUTTING**

by

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**A thesis submitted in conformity with the requirements
for the degree of Master of Science in Forestry
Graduate Faculty of Forestry
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ABSTRACT

Moth Diversity in Young Jack Pine-Deciduous Forests After Disturbance by Wildfire or Clear-Cutting. Master of Science in Forestry. 1999. Rosalind Frances Cordes Chaundy. Faculty of Forestry, University of Toronto.

Moth diversity was compared between four to eight year-old jack pine-deciduous forests that had been burned by wildfire or clear-cut. Field work took place north of Sudbury, Ontario between June and August 1997. Diversity under the two disturbance types was not significantly different based on comparisons of the number of individuals and species, rank abundance curves, diversity indices, DCA ordinations and species rankings. Exceptions to this were: *Nemoria rubrifrontaria* and four other geometrids which were found significantly more frequently in burned sites, and *Acrionicta innotata* and *Euxoa* species which were found more frequently in cut sites. Plant composition appeared to be influential in determining moth composition. Additionally, increasing numbers of moths were caught as night temperature increased. In terms of the response by nocturnal macrolepidopterans, clear-cutting appears to be emulating the natural disturbance, fire, in these young jack pine-birch-poplar-spruce forests.

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INTRODUCTION

North American and Scandinavian foresters have recently been interested in practicing forestry in a manner that attempts to imitate natural disturbance. In some jurisdictions, such as Ontario, the recently enacted Bill 171 to revise the Crown Timber Act in Ontario, requires that 'within the limits of silvicultural requirements' forest practices should 'emulate natural disturbances and landscape patterns' (35th Legislature, Ontario 1994). Thus, it is critical to examine the similarities between plant and animal communities of logged and of naturally disturbed areas at similar times after disturbance. Although many researchers have observed the changes undergone in mature forests as they respond to disturbance (for instance, plant diversity before and after a clear-cut), relatively few studies have compared natural disturbance to logging disturbance. Contributions to this field are fairly recent and only a couple of studies have focussed on invertebrates (McCullough & Kulman 1991, Lafreniere 1994). My thesis research was chosen to address this gap. It seemed particularly important to examine the effect of clear-cutting on insect diversity because clear-cutting is the principal cutting method used in the boreal forest (CFS 1996).

The research was conducted in mixed jack pine (*Pinus banksiana* Lamb.) and deciduous forests located at the southern edge of the boreal forest. This is an important forest type from an economic point of view because jack pine is second only to spruce in the amount that is logged in Ontario forests each year (OMNR 1991). When human influence is not present, jack pine forests are often burnt through wildfire and replaced naturally, as this species has strong adaptations for fire regeneration (Rowe & Scotter 1973, Cayford & McRae 1983). Fire is considered one of the most important natural disturbances occurring in the boreal forest (Barney & Stocks 1983, Haila 1994).

The main objective of my study was to compare the macro-moth diversity of young mixed

jack pine-deciduous forests in the southern boreal region following clear-cutting or wildfire. To do this, it was also important to determine which of several environmental variables (vegetation, pre-disturbance vegetation, amount of woody debris, depth of organic soils, and the landscape context of the site) were most important in influencing the resulting composition of moth species. The results would help provide more quantified information as to whether clear-cutting emulates fire, the major natural disturbance. Throughout the thesis, composition, whether of insect or plant, refers to a suite of species and their relative abundance. Information was also obtained on various factors that influence the collection of moths, such as temperature and the repeated use of light-traps on one site.

Moths were selected as the study animal for several reasons. First, this group is very speciose, usually with an order of magnitude more moth species than butterflies in any given region of the world (Heppner 1989, Roberts 1996, Handfield *et al.* 1997). In Québec, for instance, there are 131 species of butterflies and 2,446 species of moths (Handfield *et al.* 1997). Secondly, moths are a practical group to study because large numbers can be efficiently collected in light-traps. Third, some species of moths, such as spruce budworm (*Choristoneura fumiferana* (Clem.)), eastern pine shoot borer (*Eucosma gloriola* Heinr.) and jack pine budworm (*Choristoneura pinus* Free.) are serious pests of timber-producing trees (Scarr 1995, Jones *et al.* 1996). A greater understanding of the moth community as a whole may be useful in managing these pest species. Additionally, moths play an important role in forest ecosystems; in their larval stage as herbivores, and in both larval and adult stages as food for birds, small mammals and other small predatory animals (Bellocq *et al.* 1994, Young 1997). Finally, no such comparative studies of this sort have been conducted using moths, and little work has examined moth diversity in temperate and boreal forests (Butler & Kondo 1991, Grimble & Beckwith 1992, Thomas 1996).

The thesis starts with detailing the background to the main research problem and includes

a discussion of the emulation of natural disturbance by forestry practices. The study sites, materials and methods used to carry out the study are then presented, followed by the results. The latter begins with a description of various factors that influence the collection of moths. These include: the length of flight time for adult moths, the effects of temperature on adult moth activity and effects of repeated light-trapping in one place. The main body of the results continues with a comparison of moth communities in burned versus cut forests, using several means including rank abundance plots, diversity indices and ordinations. Included in the results is a presentation of the environmental factors that are important correlates of moth abundance, as well as comments on the probable larval food plants of the common moth species found in the study sites. The thesis ends with a discussion, a conclusion, references, and appendices that include a full list of species found.

LITERATURE REVIEW

Jack Pine Autecology

Jack pine is a widespread and common tree species in the boreal region of North America, and is also found through much of the Great Lakes St. Lawrence forest region of Ontario. It grows in pure as well as mixed stands along with other boreal tree species such as black spruce (*Picea mariana* (Mill.)), white birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.) (Zoladeski & Maycock 1990). It is found in a wide variety of site conditions, and does best on fresh to moderately moist soils composed of fine sands through clays (Galloway 1986). It is also found frequently in pure stands on dry sandy plains and is known as one of the few species able to produce commercially viable wood under extremely poor, dry site conditions (Cayford & McRae 1983).

It is not a particularly long-lived tree, before 200 years have passed a jack pine stand will have either been burned or will die out as other species come to dominate the forest. In areas with little human influence, a fire will spread through a jack pine forest on average every 22 to 100 years, depending on the region (Heinselman 1973, Wein & MacLean 1983, Frelich & Reich 1995). The trees in a jack pine forest are usually killed by wildfire, yet these forests usually regenerate to jack pine. This occurs because the tree is highly adapted to fire (Rowe and Scotter 1973), since the cones are usually sealed with a serotinous resin that will only open on exposure to high heat. The lowest temperature at which the resin bond will be dissolved is 60°C (Kimmins 1987). After heat of the fire has opened the cones, the seeds fall to the ground, often in great abundance (Cayford & McRae 1983).

Fire also creates ideal soil and site conditions for jack pine seedling establishment (Cayford & McRae 1983). A fire often burns some of the top humus layer of soil exposing the

mineral soil below; this combination of mostly mineral soil, with a small amount of organic matter makes the soil highly suitable for jack pine germination. The great increase in warmth and sun reaching the ground also provide good conditions for germination and seedling growth.

Under some circumstances, a jack pine forest will not regenerate itself. An extremely severe burn can be so hot that it consumes not only the duff layer, but also the seed source. This type of fire usually occurs in young forests less than 20 years old, in forests that are burned twice by the same fire or in forests on ridge-tops (Brown 1984, Weber 1988). Jack pine cannot reproduce vegetatively, thus if the seed source is destroyed, regeneration cannot occur. Moderately light fires that are not hot enough to open the cones, but are hot enough to kill the trees by scorching can also lead to a change in the stand composition (Brown 1984).

An absence of fire can also lead to a change in stand composition. If 130 to 220 years have passed since the establishment of a jack pine stand and no fire has occurred, then the jack pine will die, due to aging (Woods & Day 1977, Gauthier *et al* 1993). Species such as balsam fir (*Abies balsamea* (L.)), black spruce, white birch and white cedar (*Thuja occidentalis* L.), which can tolerate shadier growing conditions, grow up through the understory and replace the jack pine (Cayford & McRae 1983, Frelich & Reich 1995). Sometimes these species establish themselves after the fire, but stay suppressed in the understory until the pine start to decline. If a forest which is in transition from a jack pine forest to jack pine forest mixed with spruce, poplars, birch, cedar and fir is burned, it could become a mixed forest like the ones studied in this thesis. Balsam fir and eastern white cedar generally do not survive fire (Methven & Murray 1974, Farrar 1995, Frelich & Reich 1995), and thus a mixture of seeded jack pine and spruce, and suckered or seeded birch and poplar, is a probable result of fire.

Jack Pine Silviculture

Jack pine has been harvested in Ontario and across Canada and the northern USA almost exclusively using the clear-cut system (USDA 1973, Smith & Brown 1984). Although the seed source may be left on the site in the form of slash, most cones remain closed. A hot summer sun may open some cones and at least one author thinks that enough cones on the slash will be opened by the sun to lead to sufficient pine regeneration (Walker & Sims 1984). However, most feel that there will be insufficient release of seeds from the slash (Moore 1984, Galloway 1986) and that the majority of cones will either not open or rot quickly (D. McRae, Canadian Forest Service, Sault Ste. Marie, pers. comm.). Using prescribed burns to burn the slash has been found to be unsuitable as a means of jack pine regeneration because these fires burn for a long time and thus consume most of the seeds found in the slash (Chrosiewicz 1988, D. McRae, Canadian Forest Service, Sault Ste. Marie, pers.comm.).

Advanced growth abundant enough to form a new jack pine stand occurs in only 4 to 7 % of pure jack pine forests, and in only 33% of mixed jack pine forests in Quebec (Béland & Bergeron 1993). Advanced growth refers to the presence of young saplings in a forest that are left behind after cutting, which potentially can grow to form the next stand. Thus, leaving behind advanced growth cannot generally be considered a suitable means of natural regeneration for jack pine, whereas it is sometimes suitable for regenerating species such as black spruce.

Thus, because little natural regeneration occurs after clear-cutting, planting and aerial seeding are the principal means used to return jack pine to a site (Abrams & Dickmann 1984, Smith & Brown 1984, Galloway 1986). Before this happens, most clear-cuts are 'site prepared'; that is, scarified with heavy machinery to expose some of the mineral soil (Sutherland and Foreman 1995). A few years after the cut, the site is often examined for undesirable (from a timber point of view) woody species, such as birch, poplar and cherry. The site is sprayed with a

herbicide such as glyphosate, if these species are deemed to be too much in competition with the pine (Dennis 1984).

In Ontario, these silvicultural methods are fairly successful in terms of regenerating jack pine. The Ontario Independent Forest Audit Committee of 1992 found that of all types of forest stands that were harvested between 1970 and 1985, 10% were originally jack pine and 15% were regenerating to jack pine. Of the more recently cut jack pine stands, 64% were considered to be returning to a jack pine cover type; the other stands were judged to be either mixed softwood or mixed wood (Hearnden *et al.* 1992).

Chrosciewicz (1988) suggested an alternative to the clear-cut method for harvesting jack pine. This is a seed tree method where about 20 uniformly spaced seed trees per hectare are left uncut, then a prescribed burn is used to open the cones on the remaining trees. Abundant jack pine regeneration took place after a trial of this method. This method has not been used in practice due to the small windows of time when prescribed burns can take place and the current economic cost of prescribed burns. The practice of prescribed burning has declined in usage with the industry and the Ontario Ministry of Natural Resources in recent decades (Elliot 1988, McRae, Canadian Forest Service, Sault Ste. Marie pers. comm.), thus the seed tree option seems unlikely to be widely used in the near future.

The Emulation of Natural Disturbances in Forestry

While jack pine appears to be regenerating sufficiently in Ontario, this does not mean that jack pine silvicultural practices need go unexamined. Interest in organisms other than the timber-producing trees that live in forested environments is an important reason to examine the effects of human-caused disturbances such as silviculture. If silvicultural practices truly emulate natural disturbances, then one assumes that the boreal organisms which are adapted to living in an

environment with natural disturbances will be able to survive under a regime of similar human disturbances. In the words of the new Forest Practices Code of British Columbia, 'the more that managed forests resemble the forests that were established from natural disturbances, the greater the probability that all native species and ecological processes will be maintained' (BCMOF 1995). This concern for biodiversity is especially important for logged areas, since as Bondrup-Neilsen (1995) notes, the majority of biodiversity will always be outside parks and thus timber management should not be our only concern for forests outside of parks.

Numerous governments and scientists agree that the emulation of natural disturbances is the best way that we know at the moment of conducting forestry with an eye to non-timber species and ecosystem function. There is general agreement in Sweden (Angelstam & Mikusiński 1994) and among numerous North American scientists and agencies that this is either the way to proceed or is at least an approach that merits serious consideration (Franklin & Forman 1987, Hunter 1992, Hunter 1993, 35th Legislature, Ontario 1994, BCMOF 1995, Bondrup-Neilsen 1995, Daust 1995, Lautenschlager 1995, Delong and Tanner 1996, Gluck *et al.* 1996, Niemälä 1997). While agreeing with the idea of basing silviculture on natural ecosystem dynamics, Bergeron and Harvey (1997) go one step further and suggest incorporating a mixture of clear- and partial cutting into boreal silviculture. Their scheme would have appropriate portions of each forest type across the landscape, but, because one stand type is not always replaced by the same stand type in nature, tree composition could change in one location by employing a mixture of silvicultural methods.

Although there are other important natural disturbances in the boreal forest such as insect outbreaks and wind-caused blowdown, fire is generally accepted as the primary disturbance in this region, especially in jack pine forests. The silvicultural system of clear-cutting is an obvious choice for comparison with fire because: 1) it is the major logging method used in boreal forests

(CFS 1996) and 2) like fire, clear-cutting removes most of the tree canopy, causing large amounts of light and warmth to reach the ground and exposing some of the mineral soil through scarification.

While examining the effects of different disturbance on forest moth fauna was the main aim of this thesis, I thought that the effects of clear-cutting were particularly worthwhile examining because clear-cutting continues to be a controversial practice in the eyes of both the public and most environmental groups (CFA 1994). Due to a general dislike of clear-cutting, some environmental groups in their publications have inaccurately compared fire and clear-cutting (PPL 1998). For instance, in one publication, while clear-cuts were accurately described as occasionally promoting erosion and leading to the generation of a different forest type than that prior to cutting, it was not stated that erosion and stand composition changes can also be an outcome of fire (PPL 1998). Any studies that can shed further light on the non-timber impacts of this silvicultural method should help people to reach a better understanding of the effects of clear-cutting. The statement that fire and clear-cutting do not have identical effects on the forest community seems obvious. I suggest that the focus should be on how they differ, whether these differences can be changed, and if they cannot be changed, whether we can accept the differences.

Fire and Clear-cut Comparisons

Comparisons between fire and clear-cutting can be usefully divided into several categories. First, comparisons can be made of the physical characteristics of the disturbances, such as size and consistency of disturbance. Secondly, the non-living features, such as the amount of woody debris and soil characteristics of the two disturbance types can be investigated. The effects on the soil structure and nutrient composition are varied (MacLean *et al.* 1983, Sutherland and Foreman 1995, Munson *et al.* 1997), but are beyond the scope of this introduction. Finally, the plants and

animals living within the disturbed areas can be examined.

Unlike clear-cuts, fires in the boreal forest are very varied in size. There are many thousands of tiny fires, many middle-sized fires and a small number of huge fires annually in a region like Ontario (Rowe & Scotter 1973, Payette *et al.* 1989, Ward & Tithecott 1993). Even in areas where fire suppression activities occur, a few large fires burn tens of thousands of hectares each year. These fires usually account for a large majority of the total amount burned each year, despite being few in number (Rowe & Scotter 1973, Ward & Tithecott 1993). On the other hand, in some jurisdictions there has been an attempt to not have large-scale clear-cuts. Recently in Ontario, a conscious decision was made not to emulate the size range of fire, reflecting concern for our ability to successfully regenerate forests as well as public opposition to large clear-cuts. Thus, the Environmental Assessment Board decision of 1994 stated that clear-cuts should be restricted to 260 ha maximum size (EAB 1994). This size limit is somewhat blurred in practice because it is difficult to enforce, larger salvage cuts are allowed, and clear-cuts only a few years difference in age are sometimes situated adjacent to one another.

The effect of disturbance on the physical structure of forests is another important aspect of disturbance ecology. Fires tend to leave more standing snags behind than logging (Daust 1995). Also, fires are inconsistent in their intensity and pattern of burn, often leaving behind unburned or lightly burned patches within the fire boundary (Rowe & Scotter 1973, Eberhart & Woodward 1987). Furthermore, there is an assumption by some that after clear-cutting either no trees are left, or the number and distribution pattern of trees left behind are more regular than burns (Welsh 1994, Wuerther 1995). In fact, consistency in shape of cuts and size of uncut patches are not inherent in the clear-cut system, as two studies from different parts of Canada show. In British Columbian spruce-pine forests, wildfire was found to create a more complex landscape pattern with a greater range in patch size than clear-cuts (DeLong and Tanner 1996). On the other hand, a

similar study in northwestern Ontario revealed that clear-cuts were more irregular in shape than wildfires and contained larger undisturbed patches than fires (Gluck *et al.* 1996). This suggests that the shape of clear-cuts is determined by forest managers and 'regularity' is not inherent in the clear-cut system. Therefore, it should be possible to emulate patterns of wildfire at the landscape level if this is a chosen objective.

Studies comparing the occurrence and diversity of plant and animal species in naturally burned or clear-cut areas are of course particularly relevant to my thesis. There are several studies concerning trees and herbaceous plants, but few concerning animals. Studies concerning plant response to these disturbances have included woody plant composition, herbaceous plant composition, and growth of black spruce trees. Most of them have found some differences between logged and clear-cut sites. One of the few studies that examined more than a dozen sites was Carleton and MacLellan's (1994) study in northeastern Ontario of sites that were black spruce-dominated prior to disturbance. In the post-logged stands, they found a noticeable shift towards stands dominated by trembling aspen, balsam poplar (*Populus balsamifera* L.) and white birch. Some of the post-wildfire stands were also composed of deciduous species, but many more burned forests became conifer-dominated forests than did cut forests. Ordination of data from similar ages post-disturbance, showed a much greater variety of forest types resulting from fires than from clear-cut logging. This suggested that there was a greater heterogeneity in fire-induced stands than in clear-cut stands.

Another study in boreal black spruce forests detected differing plant compositions in single sites of each disturbance type (Johnston & Elliott 1996). *Polytrichum spp.* and *Epilobium angustifolium* L. were found in greater abundance in the burned site than in the cut site while more *Pleurozium schreberi* Brid. and *Cornus canadensis* L. were found on the cut site than the burned site. The authors suggested this may have been primarily due to differences in nutrient

levels.

A third black spruce study looked at the growth of black spruce trees that grew from seed after fire or from advanced growth after clear-cutting (Lussier *et al.* 1992). The researchers found that the trees originating from seeds had a greater height, dbh (diameter at breast height), and specific volume increment than the trees originating from advanced growth (Lussier *et al.* 1992). These differences existed for 50 years after stand establishment, after which there was no difference.

Other comparative studies explored vegetation composition after disturbance in jack pine forests. Carlsson and Courtin's (1997) preliminary results showed a greater total diversity of plant species in burned sites than in cut sites. This may reflect a greater habitat heterogeneity in post-fire sites than in post-cut sites. Although only studying a small number of sites, Abrams and Dickmann (1982) and Abrams *et al.* (1985), believed that different successional pathways were occurring after cutting and wildfire in jack pine forests in Michigan. No mention was made of site preparation nor artificial regeneration in this study, and it may be that a lack of these factors resulted in the *Carex* (sedge) dominated meadows that they found in the cut sites. Of the two naturally burned sites that these authors observed, one became a sedge meadow and the other regenerated to jack pine. They also found that plant species richness in three 4-year-old cut sites ranged between 10 and 22 species, while in two burned sites of the same age, species richness was higher at 21 and 44 species. An earlier study by Noble *et al.* (1977) in northwestern Ontario and Minnesota examined the vegetation of jack pine-black spruce forests before and after various disturbances. They discovered no clear differences between the two burned and six cut sites. Vegetation frequency and cover however, showed a greater change between pre-disturbance forest and burned and cut/rock-raked sites than was seen between the pre-disturbance and cut alone or cut/slash burned values. All of these authors note how important the individual character

of each stand is in determining the composition of the site after disturbance.

Some general conclusions can be drawn from the studies mentioned here, although many suffer from very small sample sizes. A forest resulting from a clear-cut can have a similar plant composition to a naturally burned forest, but this is not always the case. Fire probably leads to a greater variety of new forests, due to their variety in size and severity, than does clear-cutting. Also, one study with a much larger sample size than most, found strong evidence that when black spruce forests are disturbed, the 'average' forest regrowing after a clear-cut is not the same as the 'average' forest after fire (Carleton and MacLellan 1994). No similar large scale study has been done in jack pine forests.

Only three studies have compared animal diversity or behaviour following clear-cutting and fire. One study pertained to differences between small mammal diversity in pure versus mixed jack pine forests (Naylor & Bendell 1983), and included only one known cut site (pure jack pine) and one known burned site (jack pine-mixed). Diversity and abundance of shrews was greater in the burn site, whereas rodent abundance was greater in the cut site. Unfortunately differences in pre-disturbance forest composition and the existence of only one site of each type makes it difficult to draw conclusions from this study.

The remaining two studies focussed on invertebrates. McCullough and Kulman (1991) examined four young jack pine stands after wildfire or clear-cutting to determine whether disturbance was a factor in the quality of jack pine foliage and the survival of jack pine budworm. The levels of nitrogen, monoterpenes, needle weight and needle moisture were all higher on clear-cut sites than on burned areas. Their laboratory experiments strongly suggested that survival of jack pine budworm would be higher on stands that had been clear-cut, probably due to the higher nitrogen levels and despite higher levels of monoterpenes. This study shows how an inconspicuous difference in foliage may lead to apparent quantitative differences in a specific moth

population.

Lafreniere's (1994) study, which came closest to the present work, examined the effect of clear-cutting and wildfire on carabid beetle diversity in pure jack pine forests of different ages (5, 15, 25 and 40 years of age). For the most part, he found that the abundance and species richness of carabid beetles was not significantly affected by the type of disturbance, however, he did show that natural stands maintained peak levels of diversity for longer than the cut stands. Similarity in carabid abundance, as measured by Kendall's τ , was greater for one of two years within sites, for the planted stands than it was for the fire-originated stands. Lafreniere attributed this result to a greater patchiness of trees in the fire-originated sites than in the planted sites.

Lepidopteran Diversity in Forests

No studies comparing the effects of fire and clear-cutting on lepidoptera diversity were found. In their review of the effects of forestry on Scandinavian invertebrates, Heliövaara and Väisänen (1984) noted that there were very few papers presenting quantitative data outside of studies involving pest insects. Two papers address the question of logging effects on Lepidoptera in the boreal or temperate forests. Roberts (1996) suggests that in British high forest environments (where mature trees are grown for timber), an uneven-aged forest structure should be encouraged to 'conserve' moths. He further states that a greater diversity of tree species than presently exist and long rotation periods are recommended for coppice systems to promote moth diversity; for example, 8-year rotations for hazel (*Corylus avellana* L.), and 20-25 years for mixed firewood crops. Thomas *et al.* (1996) showed that the butterfly *Euphydryas editha* Boisduval in montane California used a new host plant in some clear-cuts until the plant died out after severe frosts.

There are numerous studies on the effects of various logging practices on the Lepidoptera

of tropical forests, however most of these concern butterflies, not moths (e.g. Kremen 1992, Hill *et al.* 1995, Intachat *et al.* 1997, Spitzer *et al.* 1997). Recent interest in tropical forests is probably due to the interest in biodiversity of tropical forests and concerns over deforestation. Two of the studies cited found somewhat contradictory results. Hill *et al.* (1995) showed that an unlogged lowland monsoon forest in Indonesia had higher richness, abundance and evenness of butterflies than did a selectively logged forest. On the other hand, Spitzer *et al.* (1997) found that gaps in a selectively logged montane cloud forest in Vietnam were more diverse and richer in butterflies than the surrounding forest. Different forest types and different approaches (one examining logged versus unlogged forest and another examining logged versus unlogged parts of the same forest) may account for these possibly contradictory results. Kremen's (1992) study dealt with the viability of tropical butterflies as a potential indicator group and a means of assessing other groups of organisms for potential as indicators. She found the butterflies of Madagascar of excellent use in indicating topographic/moisture gradients, of limited use for indicating heterogeneity due to anthropogenic disturbance and not good indicators of plant diversity. Intachat *et al.* (1997) looked at the diversity of geometrid moths in four differently disturbed Malaysian forest sites. Two differently clear-cut sites had lower alpha diversities than a selectively logged and a mixed dipterocarp plantation, although the most recently clear-cut site had a higher total abundance of moths than the other three sites.

Some studies concerning moths in temperate regions have been undertaken with the primary purpose of describing the moth diversity of mature undisturbed forests (Butler & Kondo 1991, Grimble *et al.* 1992,, Thomas 1996, Hammond & Miller 1998). Thomas (1996) found 304 macrolepidopteran moth species within and above the canopy of a balsam fir (*Abies balsamea* (L.)))-red maple (*Acer rubrum* L.) forest in New Brunswick, while Butler and Kondo (1991) found 395 macrolepidopteran moths in 55 year old mixed oak forest in West Virginia. Grimble *et al.*

(1992) found a similar number (331 species) in riparian zones within the coniferous forests of the Blue Mountains of eastern Oregon. All three studies found that about half of the species collected were in the family Noctuidae (between 48% and 56%) and a quarter were in the family Geometridae (between 24% and 28%). Hammond and Miller (1998) scrutinized the food plants of the moths found in the Virginian and eastern Oregon studies in addition to a third study in western Oregon. They found that at all three sites, hardwood feeders predominated (52-68% of moth species with known food plants), followed by herbaceous/grass feeders (22-33%) - this was despite the fact that both Oregon sites were in coniferous forest regions.

Together, the studies on moth diversity in mature forests, lepidopteran response to tropical logging and the response of non-lepidopteran organisms to wildfire and clear-cutting, can give some indication as to what might be expected when comparing the diversity of moths in clear-cut and burned forests. The moth diversity studies suggest that about 300-400 moth species, mostly noctuids, are likely to be found in mature temperate forests. Because this study is in young boreal forests, the numbers of species may not be the same, but still, several hundred species are likely to be found. The studies of lepidopteran response to tropical logging imply that some difference will be detected in moth diversity under different disturbance regimes, although what that difference will be is difficult to predict. The studies comparing fires and clear-cuts also suggest that differences will be noticed, although a few studies suggest that no difference is a possible outcome. The most consistent difference noticeable in previous research is the greater heterogeneity apparent amongst burned forests in contrast to the relatively homogeneous cut forest. One would expect a richer moth fauna among burned sites than among cut sites, based on these studies.

The present study was undertaken in order to provide more information on the consequences of silvicultural practices and wildfire on select insect assemblages, specifically

macrolepidopteran moths. Important environmental variables were also examined to provide possible explanations for any observed differences between the disturbance types.

MATERIALS & METHODS

Site Description

Field work was conducted during the summer of 1997 in the townships of Roberts and Rhodes, Sudbury District, Ontario (46° N, 81° W). Six sites were chosen in these areas; three in clear-cuts and three in naturally burned forests (two of the burned sites were situated 2.5 km apart within the same burned area). The shortest distance between any two sites was 1.5 km, while the furthest distance between any two sites was 22 km. All forests were formerly mature stands of jack pine, black spruce, white birch and trembling aspen (Table 1). The size, age, stocking and site class of the forest stand that existed prior to disturbance was recorded using Forest Resource Inventory (FRI) maps. Sites were assessed on the accuracy of FRI stand composition and any deviations were noted. Sites were paired so that each set of cut and burn sites had a similar percentage of each tree type prior to disturbance; 1) Rhodes Burn (RhB) and Rhodes Cut (RhC), 2) Roberts Burn South (RBS) and Roberts Cut East (RCE), and 3) Roberts Burn North (RBN) and Roberts Cut West (RCW). The first pair was 80 % jack pine, the second pair was 50 % jack pine, and the third pair was 40 % jack pine. When present, spruce, birch and poplar, made up between 10 to 30 % of the stand. The abbreviations for each site will be used throughout the thesis; note that each burn has a 'B' in its abbreviated name, and each cut site has a 'C'. Two burned sites (Rhodes Burn and Roberts Burn South) are shown in Figure 1, while two cut sites (Rhodes Cut and Roberts Cut West) are shown in Figure 2.

A soil pit was dug in each site to compare soil type and moisture regime between sites (Deholm and Scott 1993). Most sites had rapid drainage, coupled with a moderately fresh moisture regime. All sites had a humi-fibrimor humus form over shallow Ae and Bf mineral layers (Table 1). Bedrock was less than a metre below the surface at all sites.

Cutting or fire disturbance occurred four to eight years prior to the study. The size of the

Table 1. Location, pre-disturbance forest composition and soils of study sites and two mature forests (#1 and #2), used to sample adult moths in Sudbury Dist., Ontario, during 1997.

Site	Township Lat./Long.	Stand composition	Corrections to FRI? ^b	Stand size (ha)	Soil ^a		
					Moisture regime	Drainage	Humus form
Rhodes Burn (RhB)	Rhodes 46° 56' N, 81° 25' W	Pj6 Sb2 Bw2 ^c 117 yrs 0.6 st ^d S.C. 2 ^e	yes Pj8-9 Sb1 Bw1	100	moderately fresh (1)	rapid	humi- fibrimor
Roberts Burn South (RBS)	Roberts 46° 55' N, 81° 07' W	Pj5 Sb2 Bw2 Po1 108 yrs 0.6 st S.C.2	none	176	moderately dry (0)	rapid (to moderately well)	humi- fibrimor
Roberts Burn North (RBN)	Roberts Twp. 46° 56' N, 81° 09' W	Pj4 Sb2 Bw2 Po2 128 yrs 0.5 st S.C.2	yes Pj3-4 Sb2 Bw2 Mr2 Po0-1	108	moderately fresh (1)	rapid (to well)	humi- fibrimor
Rhodes Cut (RhC)	Rhodes 46° 53' N, 81° 23' W	Pj8 Sb1 Po1 75 yrs 0.9 st S.C.2	none	~100	moderately fresh (1)	rapid	humi- fibrimor
Roberts Cut East (RCE)	Roberts 46° 57' N, 81° 08' W	Pj5 Sb3 Bw2 129 yrs 0.3/0.6 st S.C.2	none	124	moderately fresh (1)	rapid	humi- fibrimor
Roberts Cut West (RCW)	Roberts 46° 55' N, 81° 06' W	Pj4 Sb3 Bw2 Po1 119 yrs 0.5 st S.C.2	none	68	moderately fresh (1)	rapid	?, (very shallow)
Mature forest #1	Roberts 46° 54' N, 81° 07' W	Pj6 Po2 Sw1Bw1 108 yrs 0.5 st S.C.X	none	66	-	-	-
Mature forest #2	Roberts 46° 56' N, 81° 05' W	Pj10 73 yrs 1.0 st S.C.2	none	236	-	-	-

^a Soil characteristics are based on Deholm and Scott (1993)

^b Corrections based on observations in the field

^c Pj = jack pine Sb = black spruce Bw = white birch Po = poplar (usually trembling aspen)
Mr = red maple Sw = white spruce 1 = 10%, 2 = 20% etc.

^d Stocking: stand density as a proportion of highest density that could grow on site,
as judged by Ontario Ministry of Natural Resources (range: 0.0 - 1.0)

^e Site class: an expression of forest site quality based on height of trees at a specified age
(PEDFC 1992) (range: X (richest), 1, 2, 3 (poorest))

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disturbance was recorded using E.B. Eddy Forest Products Ltd. harvest maps for the cut sites, and Ontario Ministry of Natural Resources (OMNR) East Fire Region fire records for the burned sites (Table 2). Details of the cutting methods, site preparation, tree regeneration techniques and herbicide treatments were also taken from E.B. Eddy silvicultural project records (Table 2). All cut sites had been cut with a chainsaw and delimbed and topped on site, and each was site prepared with either a skidder or with Young's teeth on a tractor. RhC was seeded 6 years prior to this study, while RCE and RCW were planted one year prior to this study.

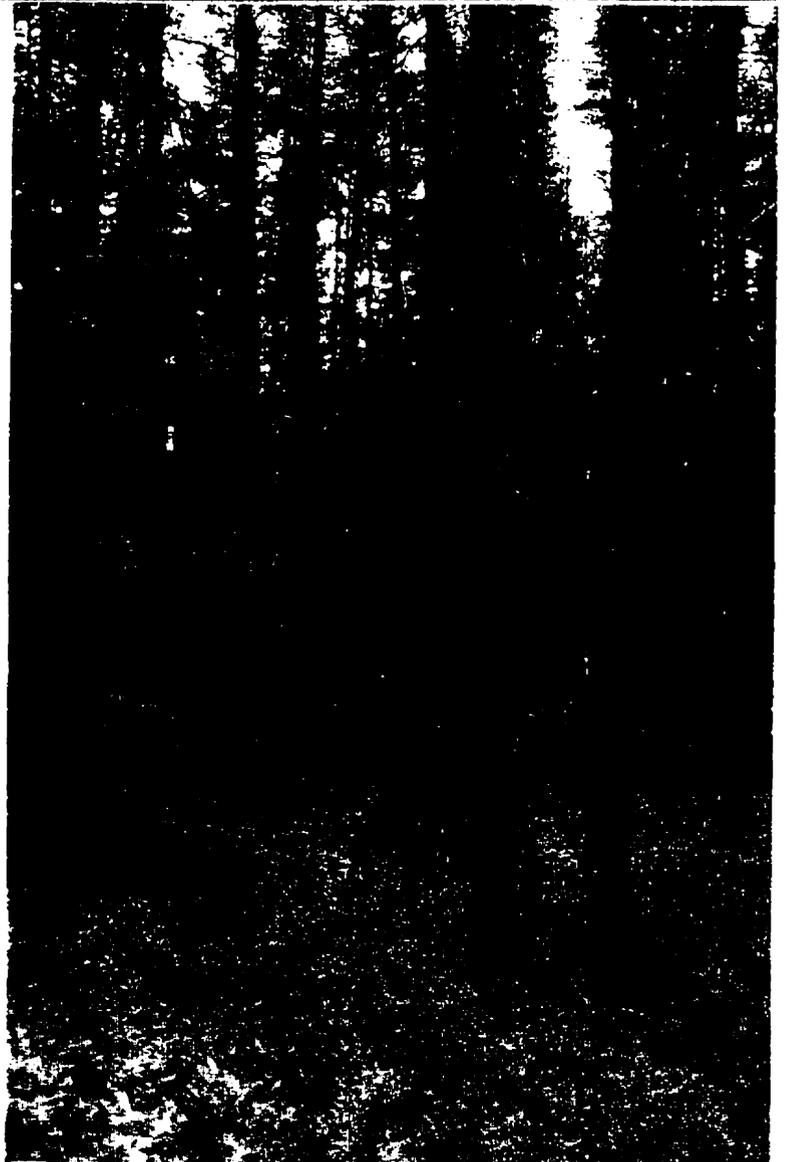
Two additional sites of mature forest in Roberts Township (Forest #1 and #2) were used as comparison sites (Fig. 3). Forest #1 was a 108-year-old forest of jack pine, poplar, spruce and white birch while Forest #2 was a 73-year-old pure jack pine forest (Table 1).

Table 2. Disturbance and landscape characteristics of study sites used to sample adult moths in Sudbury Dist., Ontario, during 1997.

Site	Disturbance						Landscape			
	Size (ha)	Age (years)	Type	Cutting method	Site preparation	Regeneration method	Herbicide	Aspect and Slope	Distance from trap to nearest forest (m)	Distance from trap to nearest water (m)
Rhodes Burn (RhB)	210	6	wildfire					W 8%	400	113 - 15 ha open water, sedge, rush, shrub
Roberts Burn South (RBS)	2000	5	wildfire					SW 10%	900	28 - tiny stream 350 - large open pond
Roberts Burn North (RBN)	2000	5	wildfire					NE 8%	300	85 - few ha swampy land with little standing water
Rhodes Cut (RhC)	1700	8	clear-cut	chainsaw, delimited & topped on site, skidded to roadside	7 yrs ago, Power TTS skidder (trencher)	6 yrs ago, seeded 50,000 seeds/ha	4 yrs ago, glyphosate, 34 l/ha (on border of spray area)	SW 9%	200	300 - river (Friday Crk)
Roberts Cut East (RCE)	48	4	clear-cut	chainsaw, delimited and topped on site, skidded to roadside	2 yrs ago, Young's teeth on tractor; windrowed	1 yr ago, planted	none	W 1%	200	180 - tiny pool 600 - small river (Beau Crk)
Roberts Cut West (RCW)	222	4	clear-cut	chainsaw, delimited and topped on site, skidded to roadside	2 yrs ago, Young's teeth on tractor; windrowed	1 yr ago, planted	none	SW 9%	205	105 - 2 ha Sb bog; little standing water



Figure 3. Mature Forest #1 (top) and Mature Forest #2 (bottom) study sites, Sudbury Dist., Ontario. Photographs taken July and August 1997 respectively.



Moth Sampling and Identification

Light traps were used to collect adult lepidopterans. It was necessary to sample sites several times within an approximately 2-week period because of the relatively short lifespan of adult Lepidoptera (Young 1997). Therefore, each of the three pairs of sites was visited every third day over a nine day period, during each of three separate periods through the summer (12 - 20 June, 1- 9 July and 29 July - 7 August, 4 August excepted). This ensured that different species groups were sampled. Throughout the remaining sections of the thesis, either 'monthly' or 'June', 'July', and 'August' will refer to these three 9-day periods during which moths were collected. Thus, each site was trapped three times each month, for a total of 18 samples per month and a grand total of 54 samples. Moths were collected in Forest #1 on 6 July and in Forest #2 on 2 August.

One light trap was placed on the ground at each site, in the same location throughout the summer. The locations were selected based on distance to the nearest mature forest (> 200 m), consistency of slope and aspect, distance to the original stand edge (> 100 m) and access. It was felt that if the light traps were at least 200 m away from the nearest forest that few moths of the forest would be caught. This was based on two studies. Baker and Sadovy (1978) found that two noctuid moth species did not actually respond to a light trap until three metres away from a 125 W mercury vapour light. However, the catch area would be expected to be larger than this since moths are not stationary. Nieminen (1996), in his study of moth movement between Finnish islands, found that over 80 % of marked moths travelled less than 200 m. Other studies that he reviews show that most species, except a few of the larger species, usually move less than 100 m. The slope and aspect of the light trap location were measured with a clinometer and compass (Table 2). All sites appeared to have a similarly undulating topography with frequent wet spots and ponds in low-lying areas. An effort was made to avoid placing traps close to the



Figure 4. Universal Black Light Trap (including transistor in plastic bag), photoelectric switch (also in plastic bag) and portable rechargeable battery, as used in the field to trap adult moths in Sudbury Dist., Ontario during 1997.

larger wet areas in order to sample terrestrial and not wetland Lepidoptera. Distance to the nearest mature forest and to the nearest wet area were measured for each site.

The light traps, 12 volt DC Universal Black Light Traps, utilized a 22 watt Circline BL ultraviolet tube (BioQuip, Gardena, California) and were powered by portable rechargeable batteries (Booster Pac International Corp., St-Jean-Sur-Richelieu, Quebec) (Fig. 4). A photoelectric switch (BioQuip) automatically turned the light on and off at dusk and dawn to conserve power. A 8 x 8 cm piece of Vapona ® (containing dichlorvos, a cholinesterase inhibitor) was placed in the bottom of each trap to kill the moths so that they could be identified at a later date.

The traps remained in one location for a single night. Each morning, two traps (one cut and one burn) were checked, emptied of specimens and then moved to the next pair of sites. Moths were placed in paper envelopes and then frozen until mounted or identified.

Insect collections were sorted in the laboratory and then identified. In order to have a manageable number of specimens to identify, some groups were excluded from the beginning. Specimens excluded from identification included: non-lepidopteran species, lepidopterans less than 13 mm in length from tip of head to forewing apex with wings folded over the body, and all pyralid species. Thus, all species from the macrolepidopteran families were identified, except a few of the smallest species of noctuids and geometrids. Samples were initially sorted according to 'morphospecies' with representative individuals pinned and spread on boards in the conventional manner (Covell 1984, Martin 1977). The spread specimens (approximately 600) were then used to identify most of the remaining individuals. Numerous literature sources were used to identify the specimens to species (Lafontaine 1969, McGuffin 1972, Rockburne & Lafontaine 1976, McGuffin 1977, Service d' Entomologie et de Pathologie, Gouvernement du Québec 1979, McGuffin 1981, Covell 1984, Ferguson 1985, Lafontaine 1987, McGuffin 1987, Lafontaine &

Poole 1991, Rings *et al.* 1992, Riotte 1992, Poole 1995, Handfield 1997).

Specimens that were difficult to identify were taken to the Royal Ontario Museum, Toronto for comparative identification and then to the Canadian National Collection at the Eastern Cereal and Oil Seed Research Centre, in Ottawa, Ontario. D. Lafontaine (Noctuids and other families) and K. Bolte (Geometrids) at the CNC provided final verification of these specimens (approximately 45 species). The nomenclature used follows the most current source (Handfield 1997).

Weather

A hydrothermograph (Enercorp Instruments Ltd., Toronto, Ontario) was placed at ground level in Roberts Burn North, to record temperature and relative humidity throughout each night. Nightly temperature was calculated as a mean of the hourly temperatures recorded between 20:00 and 5:00 E.S.T. inclusive (N = 10). Relative humidity was not used in any analyses because the nightly readings appeared consistent and dew point at the hydrothermograph level appeared to be reached earlier than that of the air one metre above the ground.

Rainfall was recorded by placing plastic containers in the sites each night. Little rain was observed and no record of its duration was available. Rainfall duration is a more important influence on moth flight than the amount of rain, because moths will rarely fly during rain (B. Lamond, Hamilton Naturalists Club, Hamilton, pers comm). Most rainfall seemed to be of short duration (thunderstorms of less than an hour) rather than the long-lasting rain such as found in low pressure systems. Thus, it was thought that rainfall had little effect on moth flight and hence was not used in the analyses.

Environmental Variables

At each site, five 75 m-long transects were sampled north, south, east, west and downhill from the light trap. Soil measurements were taken in 11 places along these transects with a soil auger 25 cm in length (Fig. 5). The depth of organic material, the Ae and Bf mineral layers, and depth to bedrock (if it was less than 25 cm) were recorded at each location. Depth of the organic layer was calculated as a mean of the 11 readings for each site.

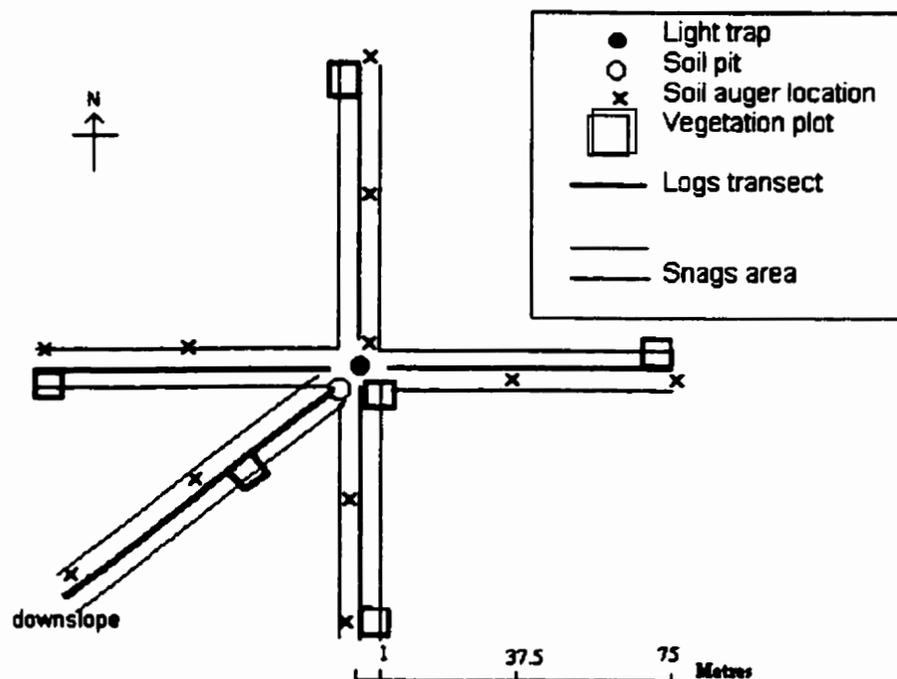


Figure 5. Sampling design used to measure vegetation cover, soils, and woody debris (logs and snags) at study sites in Sudbury Dist. Ontario during 1997.

Six 5-m² plots per site were used to measure vegetation (Fig. 5). All woody plants and herbaceous plants were identified to species, with the exception of grasses, which were identified to family (Graminae), and sedges, which were identified to genus (*Carex*). Mosses were

identified as *Polytrichum spp.*, *Sphagnum spp.*, or 'other mosses'. The percentage cover of each taxa was estimated visually for each plot. The percentage cover of all lichens was also recorded. The percentage of jack pine present prior to disturbance (from FRI maps) was used as an environmental variable to represent the pre-disturbance vegetation.

The number of logs (downed woody debris > 2.5 cm dbh) and snags (standing woody debris > 10 cm dbh) were recorded. The number of pieces of downed woody debris that crossed each of the five soil transects were counted which gave the mean number of logs per transect for each site. The number of snags per 100 m² was also recorded by noting the dbh and species of each snag in a corridor one metre on either side of the five transects.

Data Analysis

Moth Assemblages

Each of the 151 most common species were ranked chronologically to graphically show the seasonal change in species presence. Chronological rank was calculated for each species by: multiplying the nightly number of moths by a night number (eg. June 12 = 1, June 13 = 2,); adding each of these numbers together; and then dividing by the total number of individuals for that species. Species excluded from these calculations were those caught on only one or two nights and with a total of four or less individuals. The seasonal change in moth abundance for five moth families was also graphed. For both of these calculations, the burn and cut data was combined.

Temperature Effects

The numbers of adult moths caught per night were graphed against nightly temperature. A power equation was used to describe the trendline in order to avoid a line that went through the origin. This would suggest that moths are flying at the freezing point and although this is true for a few species (Metzler 1998, Philip 1998, Lindquist 1998) most do not fly until it is several degrees above freezing (Ryznar 1998, Kreigel 1998, Greatorex-Davies 1998, Kendrick 1998). To test the significance of this relationship, an ANOVA was used (SYSTAT, SYSTAT Inc., 1990). Before this was done, the line was transformed into a linear relationship using the log rule (the antilog of $(x + 1)$ and $(y + 1)$ was taken). The response to night temperature by the four most speciose moth families was then compared with ANCOVA (SAS 6.12, SAS Institute Inc. 1996) to test if these families were responding in a similar manner to night temperature. The ANCOVA was followed by a Least Squares Means test to assess which specific families were responding differently (SAS 6.12, SAS Institute Inc. 1996).

Trapping Effects

To assess whether light-trapping had a removal effect on local populations of moths, the number of moths caught at each site, on the first night that each site was trapped (in each month) was compared to the number caught on the second and third nights, using an ANOVA (Excel 97, Microsoft Corp. 1996). To confirm whether the first night was different than the second and third nights, a t-test was performed on these two nights (Excel 97, Microsoft Corp. 1996). The number of moths used in this calculation was first adjusted to the number expected if the temperature on all nights had been 19° C. This was done using the equation $y = 0.055x^{2.955}$ derived from the temperature trendline noted above. First, the temperature for each night (x) was put in the equation to derive the expected number for each night (y) at that temperature. The difference between the expected number and the actual number was then calculated. This difference was then added or subtracted to the expected number of moths at 19° C to get the adjusted number.

Burn-Cut Comparisons of Moth Diversity I - Richness, Abundance and Diversity Indices

Moth species richness and abundance of the two disturbance types was compared using t-tests (Excel 97, Microsoft Corp. 1996). The χ^2 test that was used to compare rank abundance curves was calculated manually (Magurran 1988). Shannon, Simpson and Alpha diversity indices were calculated for each site (Colwell 1997). A t-test was then used to assess differences between indices of each disturbance type (Excel 97, Microsoft Corp. 1996).

Burn-Cut Comparisons of Moth Diversity II - Ordinations and Species Rankings

A binomial Z test (Ostle & Mensing 1975) was used to assess whether moth species that were caught a total of two or three times in total, in only one disturbance type could have been

found there by chance alone. This was done by comparing the proportion of species caught twice or three times in only one disturbance type relative to the number of these species caught in both disturbance types, with the expected probability of finding two and three individuals in either one or two disturbance types. When seven and eight individuals were found in only one disturbance type, the probability of this happening by chance was calculated using the equations, $(.5)^7 \times 2$ and $(.5)^8 \times 2$ respectively.

The multi-species and multi-variable nature of the data led to the use of ordinations for further analysis. In this approach, both moth species and abundance information are used in making ordination diagrams (Ter Braak 1994). Each site is represented by a point; the closer a point is to other points in the diagram, the more similar are those sites' species composition. Thus, points (sites) at opposite ends of an ordination diagram are the most dissimilar of all sites shown. In ordinations, sites cannot be said to be significantly different from one another or not without further analysis, despite each axis of the ordination diagram having a 'percentage variance of the species data' assigned to it. The first axis is always more important than the second, and the second more important than the third, and so on (although usually only two axes are shown). In indirect ordinations, such as those done here, each axis represents an implied environmental gradient.

Each point on the ordination graphs in this thesis represented one nights' collection from one site. Thus, each site is represented by a number of points in all ordinations, both those covering the whole summer and those covering each month. Two nights (RhC August 5 and RCE August 6) were excluded from all August ordinations because they were extreme outliers. All Detrended Correspondence Analysis (DCA) and Correspondence Analysis (CA) ordinations were achieved using CANOCO 3.12 (ter Braak 1991, also 1988, 1990). The data were condensed using PC-ORD 2.0 (McCune & Mefford 1995) prior to use in CANOCO. DCA's

were used to avoid the distorting arch effect often found in CA's (Gauch 1982). All ordinations were done with nightly temperature as a covariable. This statistically removed the influence of temperature so that other variables of interest could be observed. The monthly ordinations were further analysed to look for differences in cut and burn disturbances by employing a MANOVA that used the first four DCA axes scores from each of the June, July and August ordinations as the dependent variables (SAS 6.12, SAS Institute Inc. 1996).

Comparison of Recently Disturbed Sites With Mature Forests

CA was used to compare the moths of two mature forest sites with the moths of burned and cut sites. DCA was not used because no arch effect was apparent.

Environmental Factors of Importance to Moths

Environmental variables were examined passively in DCA to determine which were most important in determining moth species and abundance. The environmental variables were: depth of the organic layer, a vegetation score, percentage of jack pine on the site prior to disturbance, logs, snags, disturbance size, disturbance age, distance of trap from forest edge, and distance of trap from water. Passive DCA ordination was used because direct ordinations (canonical correspondence analysis or redundancy analysis) require a larger sample size than mine, and because the collections were extremely variable at each site. The passive DCA ordination approach is the same as DCA ordination except that after ordinating the sites and species, the environmental variables are correlated with the DCA axes to examine which explain the distribution of the points on the diagram the best (ter Braak 1991). Vectors for each variable were calculated and those that were furthest from the centre are more important in influencing moth diversity than closer ones. This relative importance was quantified by calculating the degree

of correlation between the environmental variable for each site and the DCA axis score (of the axis that lies closest to the vector for the chosen variable) for each site (Excel 97, Microsoft Corp. 1996). A zero correlation value demonstrated that no relationship exists, whereas a large correlation value (up to 1.0) showed a strong positive correlation.

Food Plants of Moths Commonly Found in Young Jack Pine-Deciduous Forests

Literature sources were consulted to ascertain the host (food) plants of selected moth species, in order to ascertain which were the preferred host plants of the plants found in the study sites.

RESULTS

Over 27 sampling days, 7525 individual moths were caught and identified to 241 species (Appendix 1). Five of these 'species' actually consisted of two or more closely related species, considered together because they were too difficult to identify. A further five 'morphospecies' were not identified to the species level, because they were never fully identified. Fifty-one individuals from the burns and 57 individuals from the cuts were not identified because they were in very poor condition. These latter were omitted from all analysis. In the three burn sites, 4070 individuals of 204 species were found. In the three cut sites 3455 individuals of 211 species were recorded. About half of all species captured were from the family Noctuidae (52 % N, = 125) and a quarter were from the family Geometridae (26 %, N = 63).

Seventy-three individuals of 29 species were found in Forest #1 on July 6, and 143 individuals of 22 species were collected in Forest #2 on August 2 (Appendix 2).

Moth Assemblages

As expected, assemblages of macrolepidopteran species changed over the summer (Fig. 6). Most species were present for about four or five weeks, although even those found in two of the three collection periods were most abundant in only one period, with about a 2-week peak. Only 16 species out of 241 were found in all three months. For most of these 16 species, only one individual was caught in either June or August, suggesting that these individuals were either unusually long-lived or were phenologically different than others of their species. *Semiothisa neptaria* (Gn.) (Geometridae) was the one exception; 28 individuals were caught in June, four in July and 16 in August. This suggests that this species may have two broods a year (bivoltine).

The largest number of moth species (N = 159) were collected during early July, compared to 97 species in June and 94 species in August. A breakdown by month of the five most common families is similar; four of the five families were most abundant in July (Fig. 7). Members of the

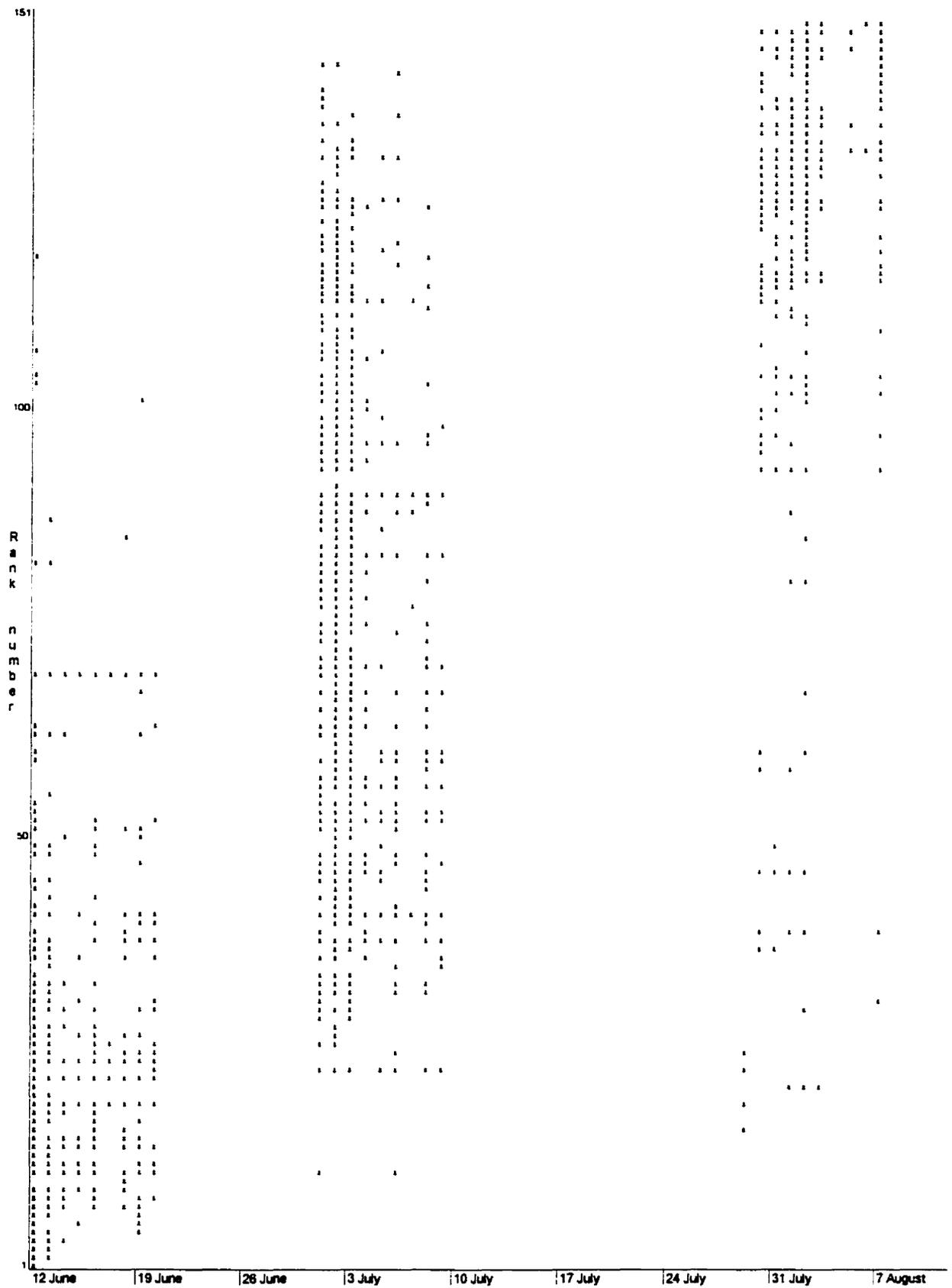


Figure 6. Presence of 151 most common adult moth species ranked according to date found in Sudbury Dist., Ontario during 1997. No collections made between 21 -30 June and 10 - 28 July.

Sphingidae and Notodontidae were found almost exclusively in this peak period of early July. Arctiidae were the only family which were most abundant in June with three *Spilosoma* species (tiger moths) comprising most of the individuals. In June, Geometridae were almost as common as Noctuidae, with geometrids such as *Homochlodes fritillaria* (Gn.), *Tacparia deterrentata* (Gn.) and *Petrophora subaequaria* Hbn. (all in the tribe Lithinini) being common, whereas in August the noctuids, comprised of many species, were clearly the predominant family.

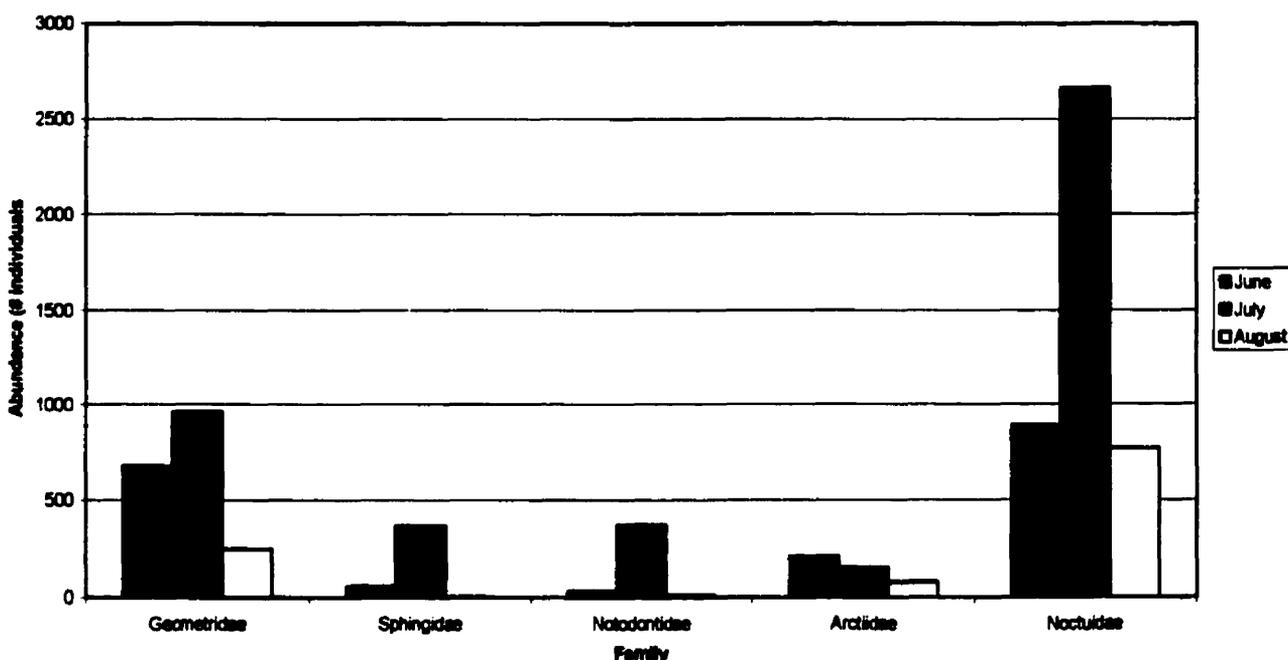


Figure 7. Abundance of adult moths from the five most common macrolepidopteran families found in Sudbury Dist., Ontario, during the summer of 1997 (June = 12-20 June, July = 1-9 July, and August = 29 July-7 August).

Temperature Effects

Nightly temperature had an obvious effect on the number of moths caught, in that the warmer the night, the more moths caught (Fig. 8) ($y = 0.055x^{2.955}$, $R^2 = 0.712$, $F_{1,32} = 124.5$, $P < 0.001$). On nights warmer than 16°C , from 400 to over a 1000 moths were caught in one light-trap. At temperatures a few degrees above freezing however, usually less than 10 individuals would be caught.

Trap catch in relation to night temperature was also examined at the family level for Geometridae, Noctuidae, Notodontidae and Sphingidae (Fig. 9). There was no difference between these families in the rate that species became active with increasingly warmer nights ($F = 1.70$, $df = 3$, $P > 0.17$). However, Sphingidae were active in greater numbers (percentage of species per family) at a given temperature than the other three families, while Notodontidae were active in smaller numbers under the same conditions ($F = 3.16$, $df = 3$, $P > 0.03$; L. S. Means: Probability of Sphingidae being different from the other 3 families: 0.002, 0.0003, 0.0001; Probability of Notodontidae being different from the other 3 families: 0.002, 0.01, 0.0001.). At warmer temperatures, towards the upper end of those recorded in this study, this effect would not be found because all species of each family would be active.

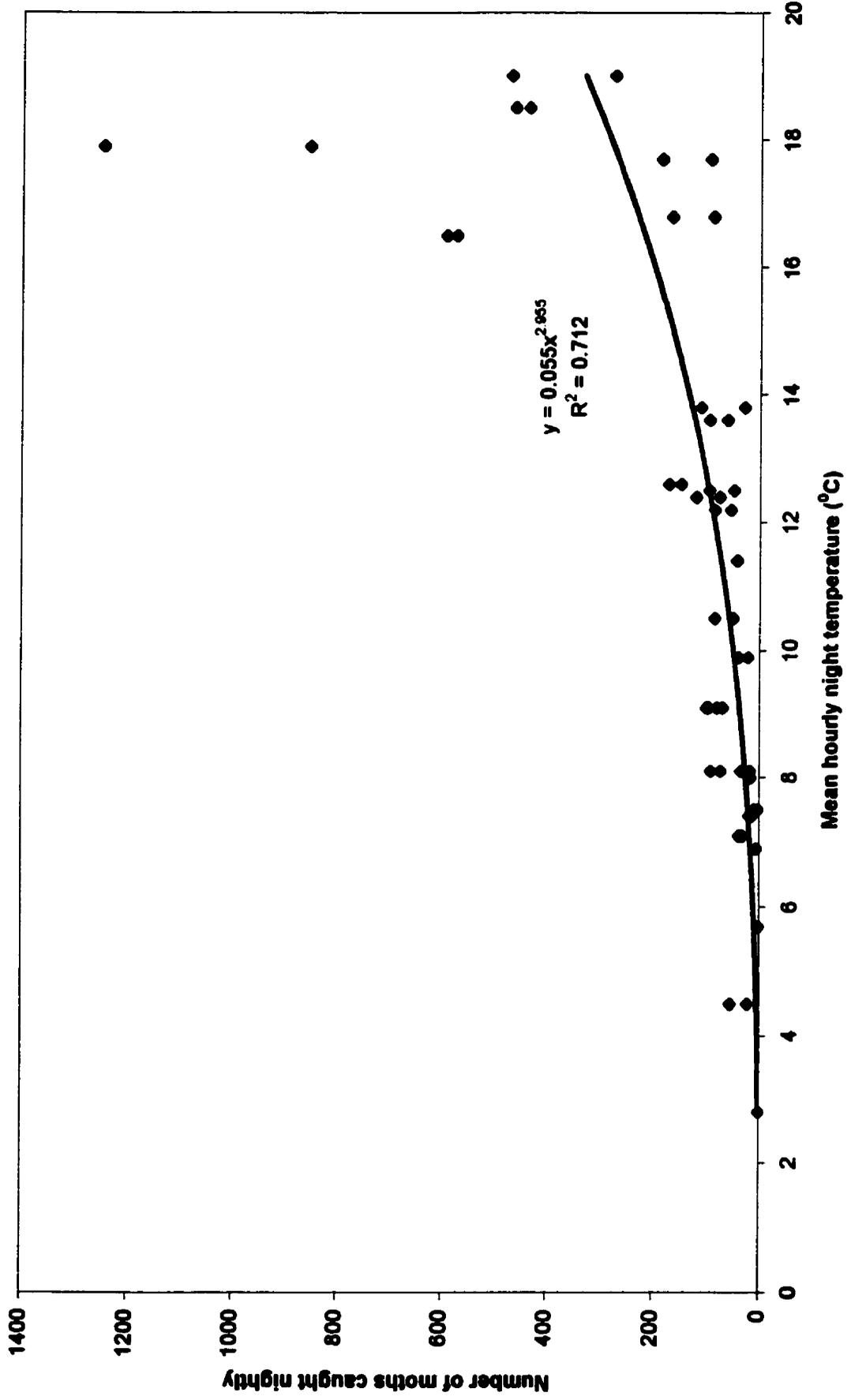


Figure 8. The number of adult moths caught per night at different nightly temperatures in light traps in Sudbury Dist., Ontario during 1997.

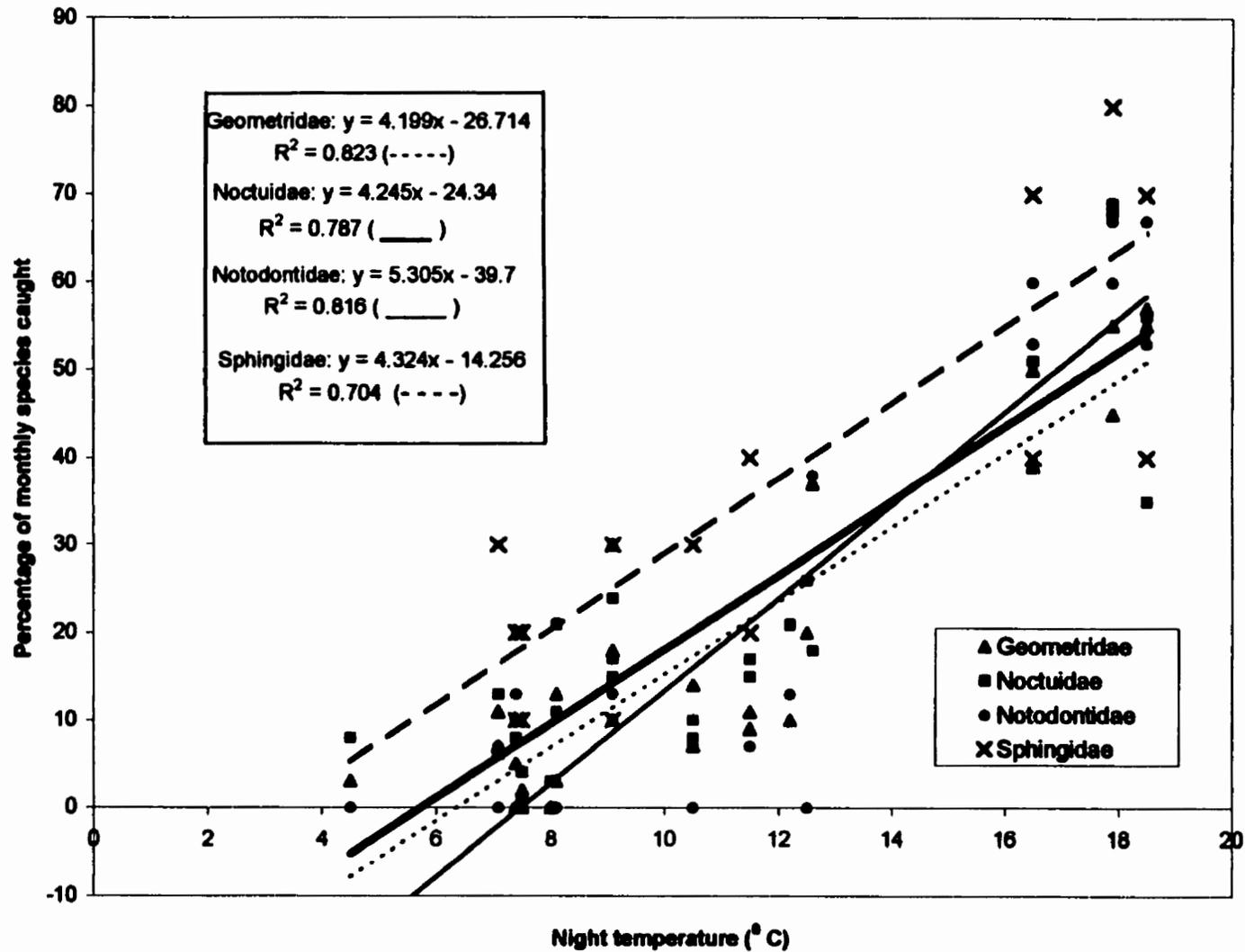


Figure 9. Percentage of adult moth species (of all species caught from each family within each month) caught nightly at different nightly temperatures, (Slopes of lines: $F = 1.70$, $df = 3$, $P > 1.70$ Elevations of lines: $F = 3.16$, $df = 3$, $P < 0.03$).

Trapping Effects

The number of moths caught on the first night of trapping at each site (for all three periods) was significantly larger than the numbers caught on either the second or third nights (within one nine-day period) even after adjusting for temperature differences (Fig. 10) ($F = 6.84$, $df = 2$, $P < 0.002$ and $t = 1.83$, $df = 34$, $P > 0.08$ for second and third nights).

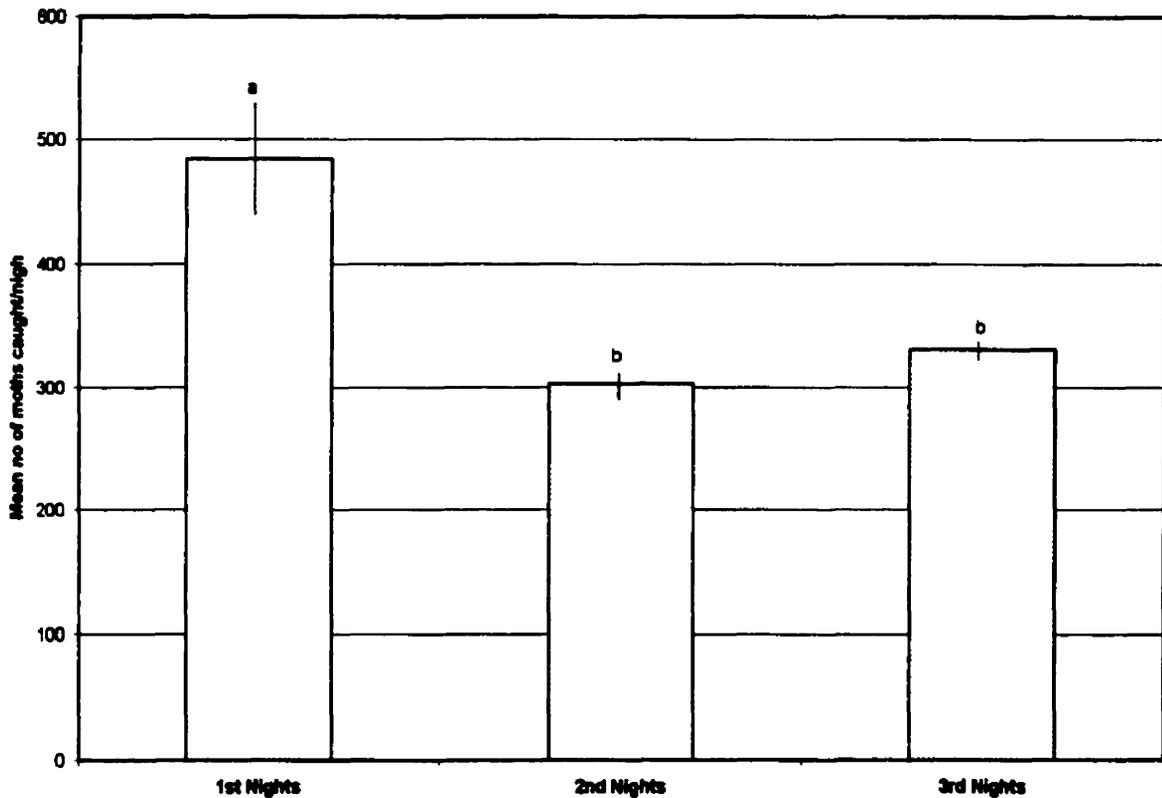


Figure 10. The mean number of adult moths caught per night, after adjusting to the number expected at 19°C, in either the first, second or third nights' trapping in each site (June, July and August combined). Lines on columns represent standard errors. ($F = 6.84$, $df = 2$, $P < 0.002$, and $t = 1.83$, $df = 34$, $P > 0.08$ for second and third nights (b))

Burn-Cut Comparisons of Moth Diversity I - Richness, Abundance and Diversity

Indices

No significant differences were observed in species richness and abundance of moths between the cut and burn sites (Fig. 11)(for six t-tests $P \geq 0.57 - 0.98$), although burned sites tended to have a greater abundance of moths than cut sites, and cut sites had slightly greater richness than burn sites.

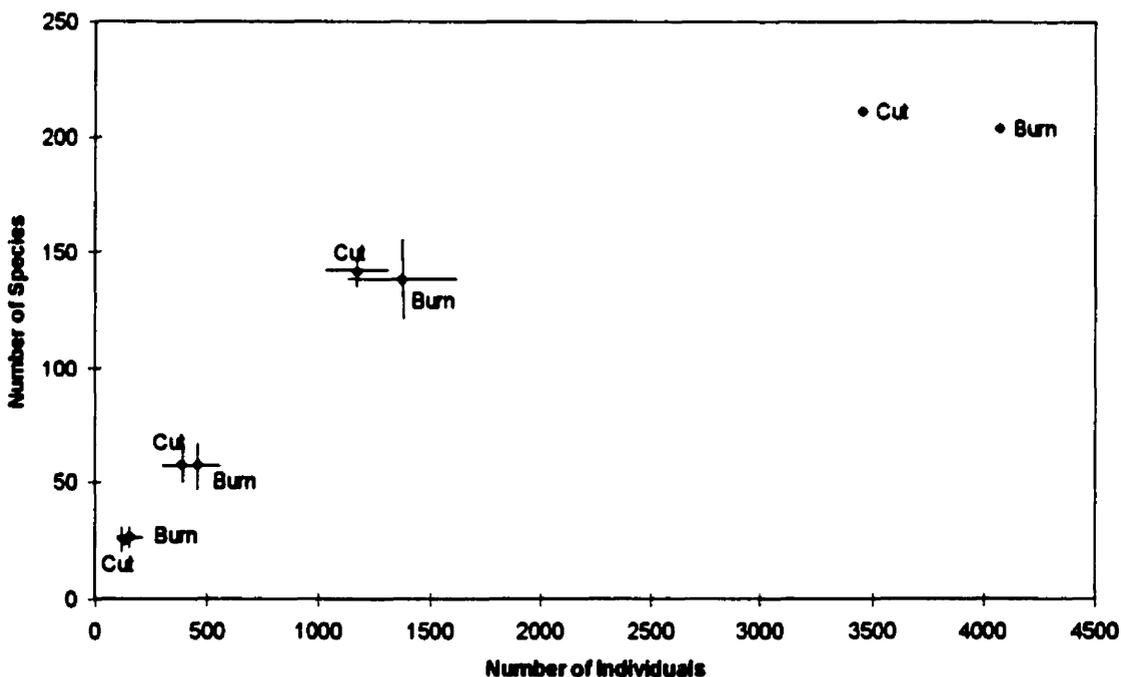


Figure 11. Adult moth diversity (number of species and individuals) in recently burned and cut jack pine-deciduous forests, within Sudbury Dist., Ontario during 1997. 1st pair of points = mean of all days (N = 27). 2nd pair of points = mean of sites, within each month (N = 9). 3rd pair of points = mean of sites (N = 3) 4th pair of points = total number of species and individuals in each treatment. Horizontal and vertical bars on first three pairs of points represent plus or minus 1 standard error of the mean. For six t-tests $P \geq 0.57 - 0.98$.

Moth communities in both cut and burn sites had a few, very abundant species, numerous moderately common species and many uncommon or rarely caught species. There was no

significant difference found between rank abundance plots for each disturbance type (Fig. 12)($X^2 = 11.998$, $df = 8$, $P > 0.10$). When the rank abundance curves were examined by month, there was again no significant difference (Figs. 13)(June: $X^2 = 14.067$, $df = 7$, $P > 0.50$; July: $X^2 = 9.587$, $df = 7$, $P > 0.20$; August: $X^2 = 12.592$, $df = 6$, $P > 0.30$). The slight (non-significant) difference in moth abundance between treatments noted in Figure 11, appears to be caused by differences in the middle-ranking species (those with abundances of about 20 to 50 individuals caught in total) because the rank abundance curves show the greatest divergence there (Figs. 12 and 13).

None of three diversity indices examined were significantly different between treatments (Table 3)(Alpha index: $t = 0.995$, $df = 4$, $P > 0.38$, Shannon index: $t = 0.098$, $df = 4$, $P > 0.92$, Simpson Index: $t = 0.416$, $df = 4$, $P > 0.70$).

Table 3. Alpha, Shannon and Simpson diversity indices for moth communities found in six recently burned or cut jack pine-deciduous forests, within Sudbury Dist., Ontario in 1997.

Treatment	Site	Alpha Index ^a	Shannon Index	Simpson Index
Burn	RhB	37.99	4.07	36.59
	RBS	45.34	4.12	29.80
	RBN	32.90	3.70	19.71
Cut	RhC	46.53	4.15	36.13
	RCE	42.11	3.79	17.15
	RCW	39.85	3.90	23.55

^aMean value for burn and cut sites were not significantly different for all indices (Alpha index: $t = 0.995$, $df = 4$, $P > 0.38$, Shannon index: $t = 0.098$, $df = 4$, $P > 0.92$, Simpson Index: $t = 0.416$, $df = 4$, $P > 0.70$)

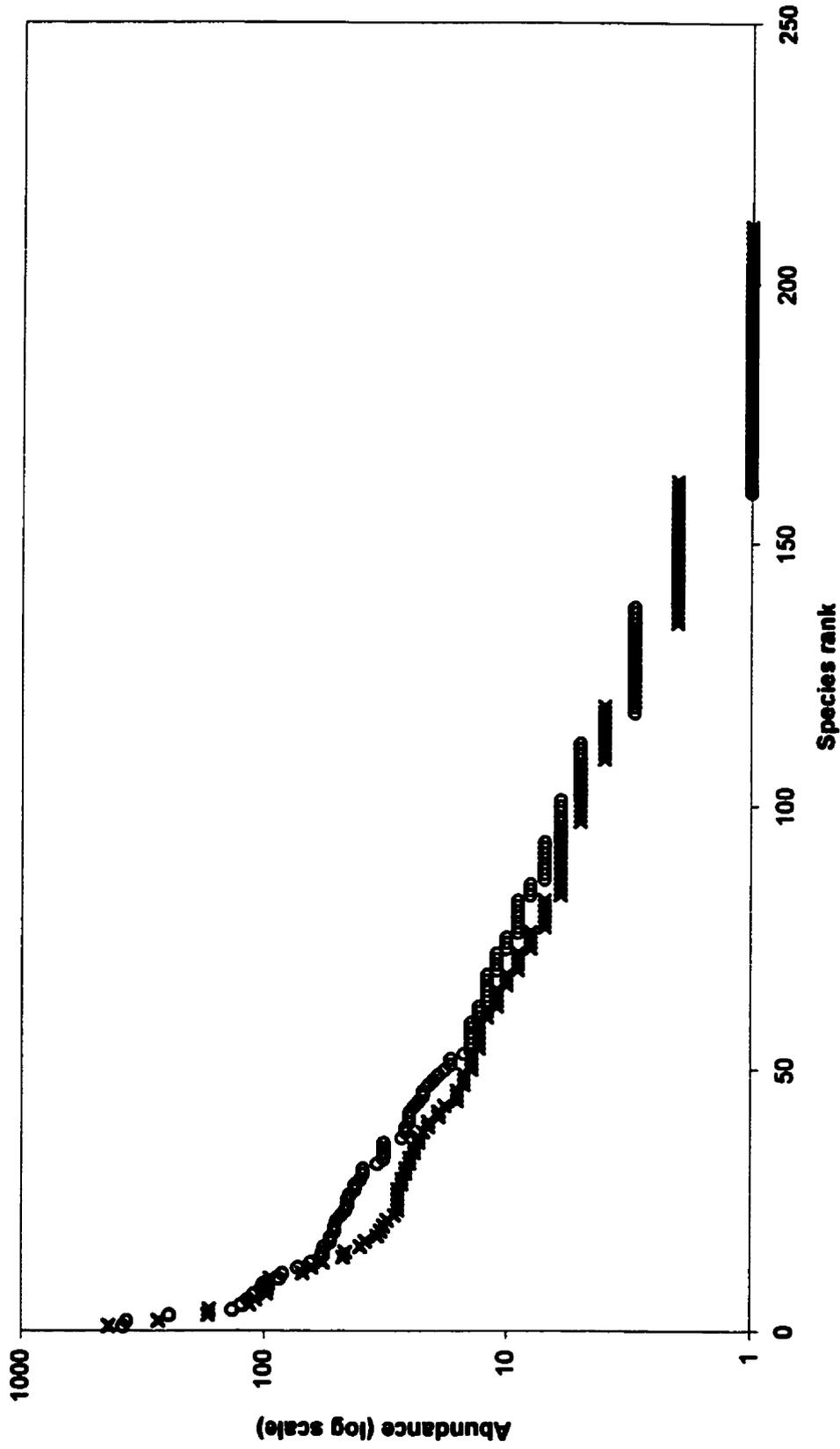


Figure 12. Rank abundance curves of adult moths collected in light traps throughout the summer of 1997 in recently burned or cut jack pine-deciduous forests within Sudbury Dist., Ontario. o = burn sites x = cut sites

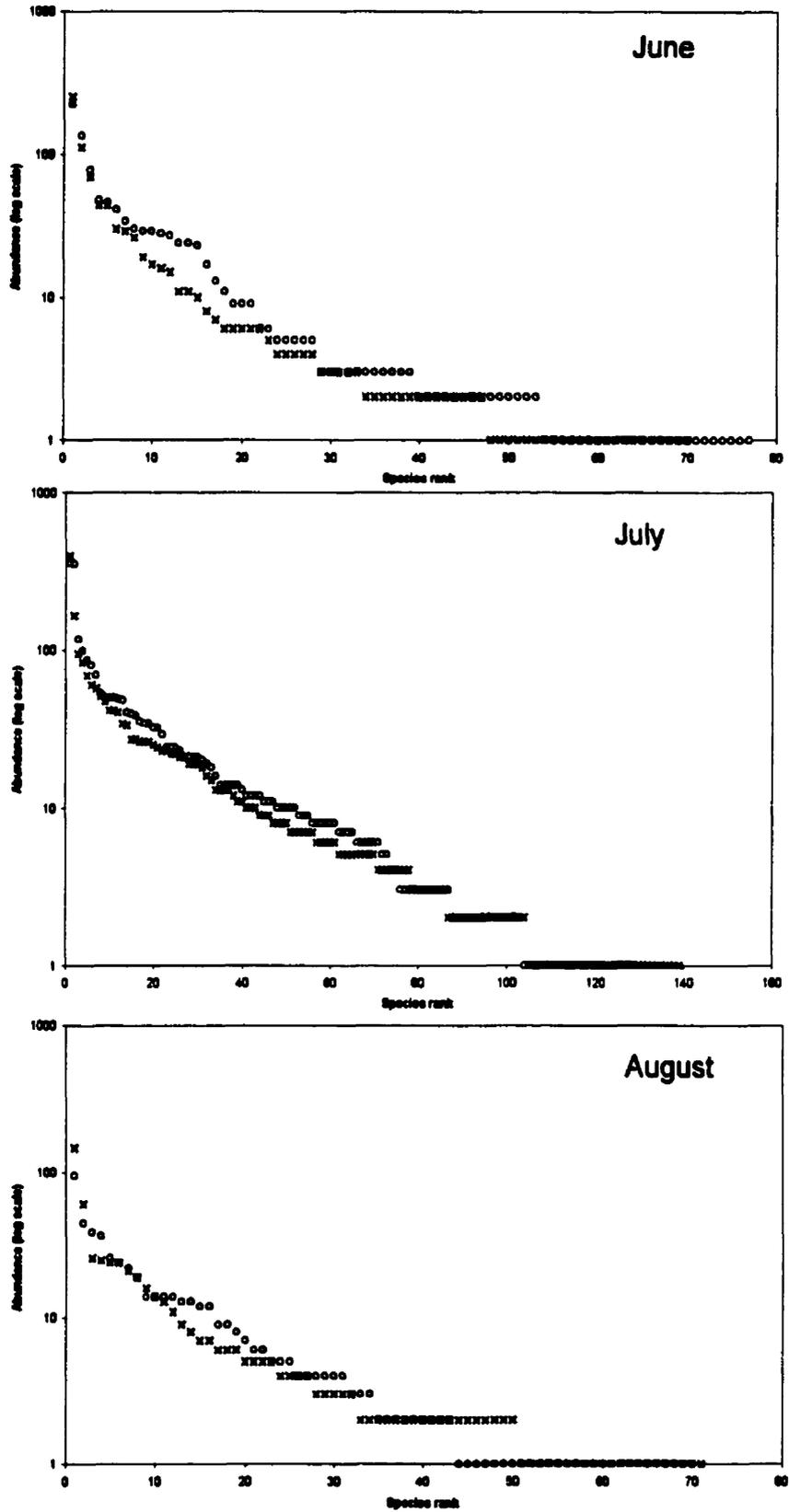


Figure 13. Rank abundance curves of adult moths collected in recently burned or recently clear-cut jack pine-deciduous forests, in Sudbury Dist., Ontario during 1997. o = burn sites, x = cut sites Note different scales.

Burn-Cut Comparisons of Moth Diversity II - Ordinations and Species Rankings

No differences in moth communities were found between burned and cut sites based upon DCA ordination (Fig. 14). The resulting matrix consisted of 52 samples and 241 species. The first two axes accounted for 22.3 % of the variance. Samples (points) clustered into three groups based upon collection period, indicating the importance of time as a correlate of the first axis.

When each of these monthly clusters was examined separately using DCA ordination, again no clustering of cut versus burn sites was apparent, further suggesting that moth species composition was not different for these two disturbance types (Fig. 15). No significant difference was found between cut and burn sites in any of the three months when the first four DCA axes were used as variables in a MANOVA (June: Wilks' Lambda = 0.685, $F_{4,13} = 1.498$, $P > 0.23$; July: Wilks' Lambda = 0.718, $F_{4,13} = 1.274$, $P > 0.33$; August: Wilks' Lambda = 0.925, $F_{4,11} = 0.224$, $P > 0.92$).

However, the DCA ordinations suggested that the moth community in June may have been structured slightly differently than moth communities of the rest of the summer. Figure 14 shows that the points representing June cluster more tightly than those of the following months. Also, the DCA ordination of the June data shows partial separation of the cut and burn centroids (representing each disturbance type) along DCA axis 1, whereas there is no separation of these centroids along axis 1 in July and August (Fig 15).

The five most abundant moth species found in each disturbance type were the same, with only a slight difference in ranking (Table 4). A similar situation is true for the five most abundant species of each month, although some species appear on the list of one disturbance type and not the other (Table 4). In June, *Drasteria adumbrata* (Behr.) was the fourth most common species

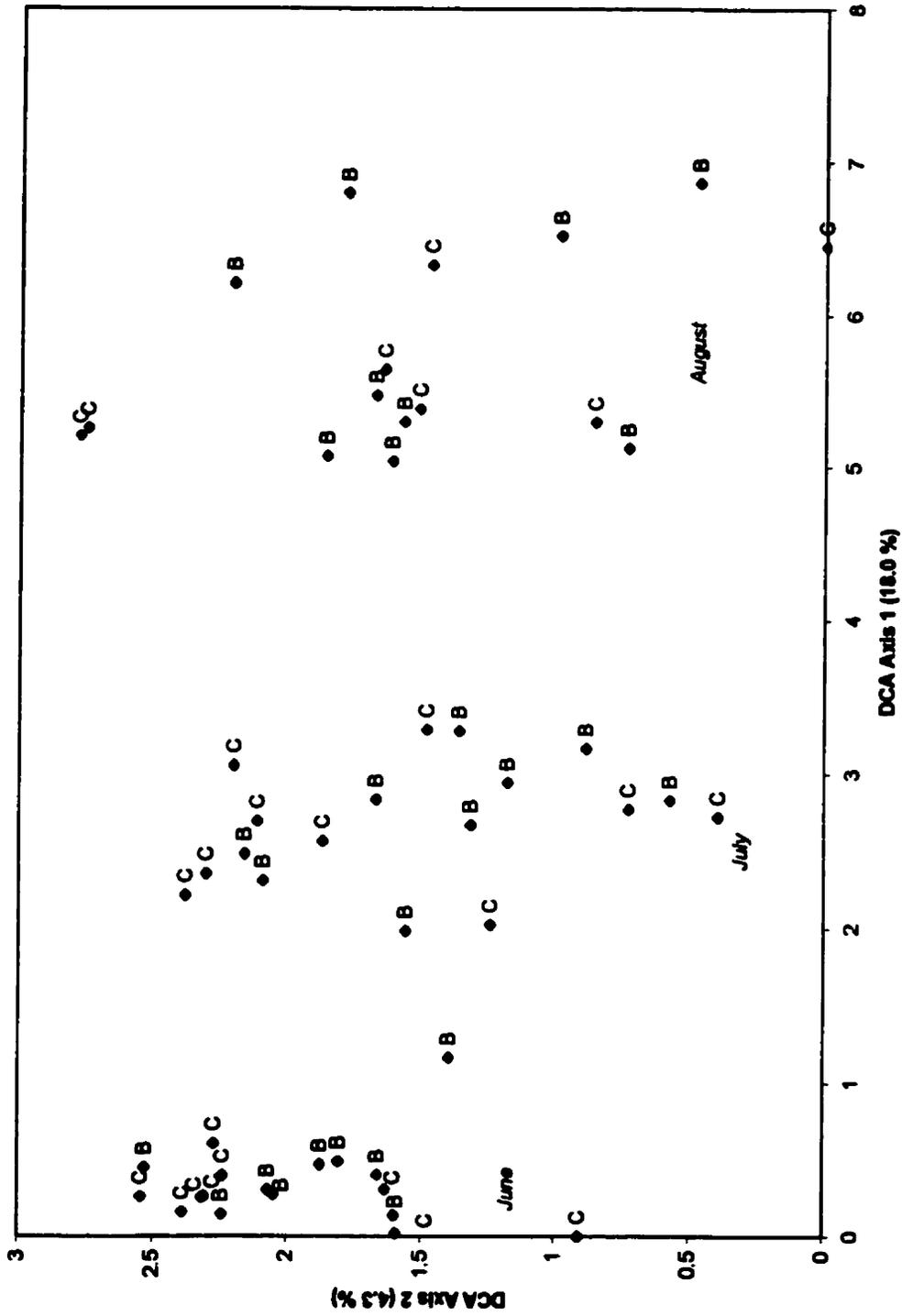


Figure 14. DCA ordination of all trap nights; each point representing adult moth species composition in either recently burned (B) or cut (C) jack pine-deciduous forest in Sudbury Dist., Ontario during 1997. Two nights in August were excluded because they were outliers. % = percent variance of species accounted for by the respective axis. First axis corresponds with time, thus June, July and August indicate which time period each cluster of points comes from.

in the cut sites, but was only the seventeenth most common species in the burn sites. In July, *Peridea ferruginea* (Pack.) appeared as the third most common species in cut sites, but was ninth in burn sites. During August, *Zanclognatha jacchusalis* (Wlk.) appeared as the second commonest species in the cut sites, but did not appear among the top five in the burn sites.

Table 4. The five most abundant adult moth species found throughout the summer, and within June, July and August in jack pine-deciduous forests burned by wildfire or clear-cut, in Sudbury Dist., Ontario during 1997. Data for each category are pooled from three sites.

Rank	Burns	Cuts
Overall 1	<i>Orthodes cynica</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
" 2	<i>Callopietra cordata</i> (Noctuidae)	<i>Protorthodes oviduca</i> (Noctuidae)
" 3	<i>Protorthodes oviduca</i> (Noctuidae)	<i>Callopietra cordata</i> (Noctuidae)
" 4	<i>Petrophora subaequaria</i> (Geometridae)	<i>Idia americalis</i> (Noctuidae)
" 5	<i>Idia americalis</i> (Noctuidae)	<i>Petrophora subaequaria</i> (Geometridae)
June 1	<i>Protorthodes oviduca</i> (Noctuidae)	<i>Protorthodes oviduca</i> (Noctuidae)
" 2	<i>Petrophora subaequaria</i> (Geometridae)	<i>Petrophora subaequaria</i> (Geometridae)
" 3	<i>Spilosoma congrua</i> (Arctiidae)	<i>Spilosoma congrua</i> (Arctiidae)
" 4	<i>Homochlodes fritillaria</i> (Geometridae)	<i>Drasteria adumbrata</i> (Noctuidae)
" 5	<i>Lasionycta albinuda</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
July 1	<i>Orthodes cynica</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
" 2	<i>Callopietra cordata</i> (Noctuidae)	<i>Callopietra cordata</i> (Noctuidae)
" 3	<i>Polia detracta</i> (Noctuidae)	<i>Peridea ferruginea</i> (Notodontidae)
" 4	<i>Sphinx gordius</i> (Sphingidae)	<i>Sphinx gordius</i> (Sphingidae)
" 5	<i>Scopula spp.</i> (Geometridae)	<i>Polia detracta</i> (Noctuidae)
August 1	<i>Idia americalis</i> (Noctuidae)	<i>Idia americalis</i> (Noctuidae)
" 2	<i>Polia purpurisata</i> (Noctuidae)	<i>Zanclognatha jacchusalis</i> (Noctuidae)
" 3	<i>Eurois astricta</i> (Noctuidae)	<i>Eueretagrotis attentata</i> (Noctuidae)
" 4	<i>Eueretagrotis attentata</i> (Noctuidae)	<i>Xestia normaniana</i> (Noctuidae)
" 5	<i>Xestia normaniana</i> (Noctuidae)	<i>Polia purpurisata</i> & <i>Eurois astricta</i> (both Noctuidae)

Twenty-six species of moths were collected exclusively in the burn sites and 37 exclusively in the cut sites (Table 5). Most of these unique species were collected once or in very small numbers. All of the species from this unique group that were collected twice or three times could have been there solely by chance ($Z = 0.416$, $P > 0.68$). On the other hand, three of the unique species were very unlikely to have been found only in one disturbance type by chance:

Table 5. Species and numbers of adult moths collected in only one of two disturbance types; either recently burned or clear-cut jack pine-deciduous forest in Sudbury Dist., Ontario during 1997. Bold type species are those that were not likely to be found solely by chance in one disturbance type.

Family	Burn sites		Cut sites	
	Species	Number	Species	Number
Geometridae	Cyclophora pendulinaria	8	<i>Scopula ancellata</i>	1
	<i>Anticlea multiferata</i>	4	<i>Epirrhoe alternata</i>	1
	<i>Eulithis serrataria</i>	1	<i>Besma quercivoraria</i>	1
	<i>Eulithis propulsata</i>	3	<i>Caripeta piniata</i>	1
	<i>Anagoga occiduaria</i>	1	<i>Cepphis decolorata</i>	1
	<i>Euchlaena johnsonaria</i>	2	<i>Eumacaria latiferrugata</i>	2
	<i>Itame loricaria</i>	1	<i>Iridopsis larvaria</i>	1
	<i>Metarranthis indeclinata</i>	2	<i>Protobarmia porcelaria</i>	1
Saturniidae			<i>Anisota virginiensis</i>	1
Notodontidae	<i>Notodonta simplaria</i>	1		
	<i>Odontosia elegans</i>	2		
	<i>Shizura unicornis</i>	1		
Artiidae			<i>Holomelina aurantiaca</i>	1
Lymantriidae			<i>Dasychira plagiata</i>	1
Noctuidae	<i>Phalaenophana pyramusalis</i>	1	<i>Zanclognatha sp 2</i>	1
	<i>Catocala ultra</i>	3	<i>Argyrostris anilis</i>	1
	<i>Zale lunata</i>	5	<i>Zale lunifera</i>	1
	<i>Anagrapha falcifera</i>	1	<i>Autographa ampla</i>	2
	<i>Acronicta fragilis</i>	1	<i>Autographa mappa</i>	2
	<i>Acronicta funeralis</i>	1	<i>Plusia putnami</i>	1
	<i>Acronicta haesitata</i>	2	<i>Syngrapha microgramma</i>	1
	<i>Acronicta tritona</i>	1	Acronicta innotata	8
	<i>Andropolia contracta</i>	4	<i>Harrisimemna trisignata</i>	1
	<i>Apamea verbascooides</i>	2	<i>Achatodes zea</i>	1
	Hyppa nr. xylinoides	7	<i>Apamea finitima</i>	1
	<i>Anaplectoides pressus</i>	2	<i>Apamea impulsa</i>	1
	<i>Peridroma saucia</i>	1	<i>Apamea remissa</i>	1
	<i>Rhynchagrotis brunneipennis</i>	1	<i>Aletia oxygala</i>	1
	<i>Xestia youngii</i>	1	<i>Polia nimbose</i>	3
			<i>Pseudaletia unipuncta</i>	1
			<i>Trichordestra tacoma</i>	2
			<i>Agrotis volubilis</i>	3
			<i>Euagrotis forbesi</i>	1
			<i>Euxoa comosa</i>	5
			<i>Euxoa mimallonis</i>	1
			<i>Euxoa quebecensis</i>	1
			<i>Euxoa scholastica</i>	2
			<i>Feltia herilis</i>	3
			<i>Trichosilisa geniculata</i>	4
			<i>Xestia praevia</i>	1

Cyclophora pendulinaria (Gn.) (8 individuals found, $P = 0.008$) and *Hyppa nr. xylinoides* (Gn.) (7 individuals found, $P = 0.02$) were both found in burns exclusively and *Acronicta innotata* Gn. (8 individuals found, $P = 0.008$) was only found in cuts. Also, four of a total of five *Euxoa* species were collected only in the cut sites.

Some species appeared to have a noticeably higher abundance in one of the two disturbance types (Table 6). Four geometrids and one noctuid were significantly more frequently caught in the burned than the cut sites, including the green geometrid, *Nemoria rubrifontaria* (Pack.) ($t = 2.179$, $df = 12$, $P < 0.02$). The other species, including the common species *Drasteria adumbrata*, *Peridea ferruginea* and *Zanclognatha jacchusalis* mentioned earlier, were not found in significantly larger numbers in one disturbance type than the other (Table 6).

Table 6. Overall abundance (total # of moths caught) of moth species found more frequently in one of two disturbance types - recently burned or clear-cut jack pine-deciduous forest in Sudbury Dist., Ontario during 1997.

	Family	Species	Burn sites	Cut sites	Significance		
					t ^a	DF ^b	
Burn > Cut	Geometridae	<i>Nemoria rubrifrontaria</i>	42	5	2.179**	12	
		<i>Lobophora nivigerata</i>	23	5	-	15	
		<i>Antepione thisoaria</i>	53	15	2.131*	15	
		<i>Cabera erythemaria</i>	22	4	-	15	
		<i>Cabera variolaria</i>	56	28	-	22	
		<i>Itame brunneata</i>	53	21	-	6	
		<i>Semiothisa neptaria</i>	39	9	2.056*	26	
		<i>Tacparia deterrenta</i>	51	26	2.262*	9	
		Notodontidae	<i>Pheosia rimosa</i>	20	5	-	24
			Noctuidae	<i>Callopietra cordata</i>	370	170	-
	<i>Polia detracta</i>	117		69	-	8	
	<i>Polia imbrifera</i>	40		16	-	5	
	<i>Polia purpurisata</i>	45		24	-	8	
	<i>Agrotis obliqua</i>	32		11	-	9	
	<i>Eueretagrotis attentata</i>	86		33	-	17	
	<i>Heptagrotis phyllophora</i>	44		13	2.131*	15	
	Cut > Burn	Sphingidae	<i>Xestia oblata</i>	25	6	-	13
<i>Paonis excaecatus</i>			12	25	-	15	
Notodontidae		<i>Heterocampa umbrata</i>	7	23	-	17	
		<i>Nadata gibbosa</i>	14	28	-	19	
Noctuidae		<i>Peridea ferruginea</i>	51	97	-	17	
		<i>Zanclognatha jacchusalis</i>	45	108	-	17	
		<i>Drasteria adumbrata</i>	27	95	-	16	

^a = Paired sample t test; ** P < 0.02, *P ≤ 0.05, - = not significant (t values not given)

^b = Df varied because the sample size was based on the number of days that each species was collected, from the earliest collection date to the last

Comparison of Recently Disturbed Sites With Mature Forests

In order to determine whether moth assemblages differed between mature forests and young, recently burned or cut forests, moths were collected on one night each in two mature forest sites (Forest #1 and #2). Ordination diagrams show that the moth composition of mature forest sites differed noticeably from the moth composition of young, recently disturbed sites (Fig. 16).

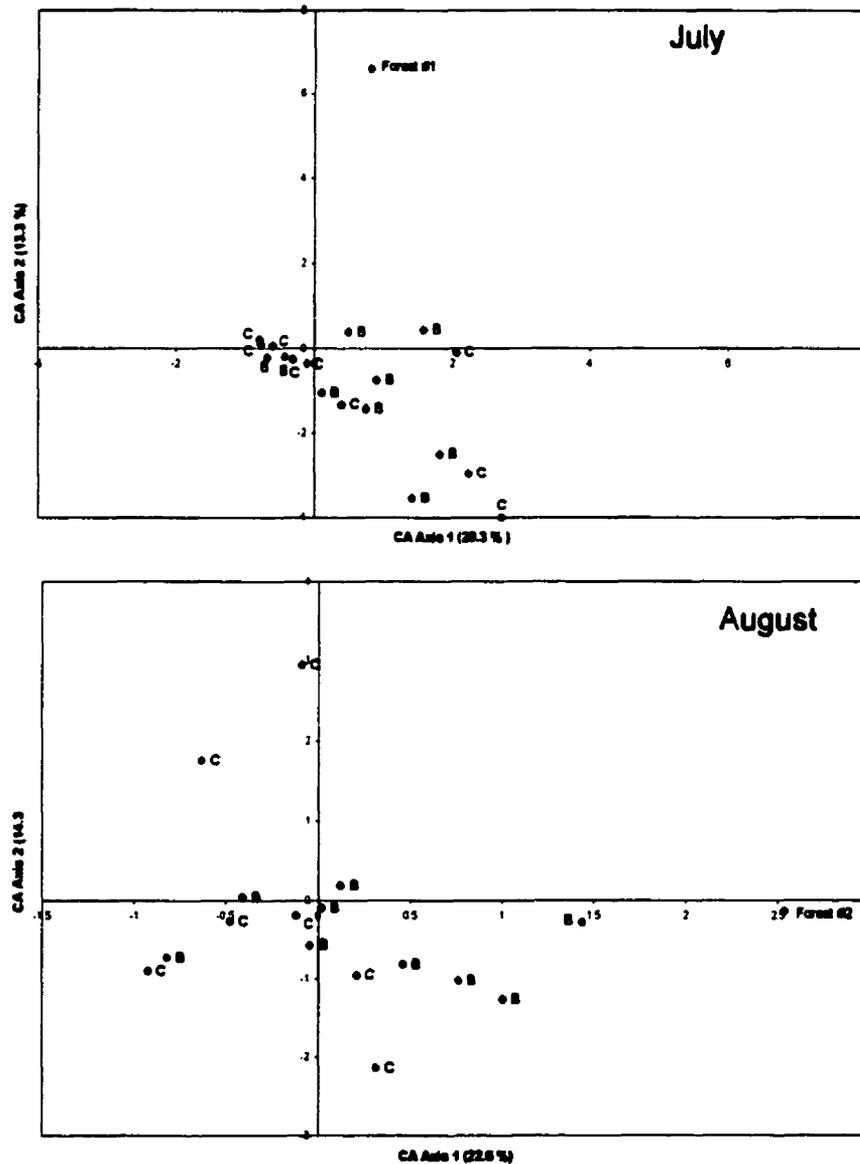


Figure 16. CA ordinations for adult moth species in recently disturbed jack pine-deciduous sites (B = burned, C = clear-cut) and two mature forests in Sudbury Dist., Ontario during 1997.

Environmental Factors

Twenty-six woody plant species and 29 herbaceous plant species (excluding grasses and sedges) were recorded in the study sites (Table 7). Common plants that had a mean coverage of greater than 10 % in at least one site were: red maple (*Acer rubrum* L.), sweetfern (*Comptonia peregrina* (L.)), bush honeysuckle (*Diervilla lonicera* Mill.), jack pine, low sweet blueberry (*Vaccinium angustifolium* Ait.), bunchberry (*Cornus canadensis* L.), bracken fern (*Pteridium aquilinum* L.) and *Polytrichum* mosses. Green alder (*Alnus viridis* (Villars)), white birch, beaked hazel (*Corylus cornuta* Marsh.), trembling aspen, pin cherry (*Prunus pensylvanica* L. fil) and velvet-leaf blueberry (*Vaccinium myrtilloides* Michx.) were also common and widespread.

A DCA ordination was performed on the vegetation data with each plot as a point (Figs. 17 and 18). There was considerable overlap in the clusters of points representing the plots from different sites, indicating that quite similar vegetation was present on all sites (Fig. 17). RhB was the exception; the plots from this site were in a small separate cluster, suggesting a less varied and slightly different flora. Most of the plant species with negative DCA axis 1 scores in Figure 18 were species typical of wet depressions that made up a minority of the landscape, thus these species (with the exception of *Salix humilis* Marsh.) represent plants that the moths would infrequently encounter. The remainder of the plant species shown in this diagram represent the most abundant plant species found on the sites, with for example, those species with a relatively high axis 1 score and low axis 2 to be most likely found in RBN, and those with a relatively low, but positive, axis 1 score to be most often found in RhB or RhC.

The average score of the six plots on the first ordination axis (of Fig. 17) was used to derive a single number that represented vegetation in further analyses. This meant that numerous vegetation variables, consisting of different species coverages, did not have to be used. Two plots were excluded from the average score because they were outliers in the ordination. This

Table 7. Mean percentage cover of plant species found in six plots within each study site, Sudbury Dist., Ontario during 1997. Those species present but with < 1% coverage were recorded as having .01% coverage, while those which were not found were recorded as '-'.
 .

Plant Groups	Species	BURNS			CUTS			
		RhB	RBS	RBN	RhC	RCE	RCW	
Woody Plants	<i>Abies balsamea</i>	-	-	-	-	1.33	0.52	
	<i>Acer rubrum</i>	0.17	0.52	14.17	-	2.52	2.67	
	<i>Alnus viridis</i>	2.83	0.83	-	-	1.50	5.83	
	<i>Amelanchier sp</i>	-	-	0.02	0.35	-	0.03	
	<i>Betula papyrifera</i>	1.50	0.85	0.68	0.36	2.83	7.52	
	<i>Comptonia peregrina</i>	24.83	2.18	0.33	0.17	0.02	0.03	
	<i>Corylus cornuta</i>	0.02	-	5.67	-	5.00	2.67	
	<i>Chaemodaphne corymbulata</i>	-	-	-	0.18	-	-	
	<i>Diervilla lonicera</i>	9.35	0.70	2.67	0.52	13.83	5.02	
	<i>Kalmia angustifolia</i>	-	2.33	0.02	-	-	0.33	
	<i>Ledum groenlandicum</i>	-	0.83	-	3.00	-	0.35	
	<i>Nemopanthus mucronata</i>	-	0.02	-	-	-	-	
	<i>Picea mariana</i>	0.08	0.20	0.02	6.03	-	0.03	
	<i>Pinus banksiana</i>	21.67	3.37	0.55	21.50	1.35	1.53	
	<i>Pinus strobus</i>	-	-	-	-	-	0.02	
	<i>Populus grandidentata</i>	1.17	-	1.17	-	-	-	
	<i>Populus tremuloides</i>	6.02	0.52	0.03	5.18	-	0.03	
	<i>Prunus pensylvanica</i>	0.20	1.70	1.38	3.00	5.68	3.52	
	<i>Ribes glandulosum</i>	-	0.17	-	0.50	-	0.03	
	<i>Rubus idaeus</i>	-	0.03	0.17	0.68	1.37	0.22	
	<i>Salix humilis</i>	0.07	0.50	0.02	2.70	1.03	0.52	
	<i>Sambucus sp</i>	-	-	-	-	-	0.02	
	<i>Sorbus americana</i>	-	-	0.02	0.02	-	0.03	
	<i>Vaccinium angustifolium</i>	0.67	14.68	16.83	1.68	0.72	8.02	
<i>Vaccinium myrtilloides</i>	0.02	7.85	2.35	6.00	1.38	0.70		
<i>Viburnum cassinoides</i>	-	-	1.00	-	-	-		
Herbaceous Plants	<i>Anaphalis margaritacea</i>	-	-	-	0.02	-	-	
	<i>Apocynum androsaemifolium</i>	0.17	-	-	-	0.03	-	
	<i>Aralia hispida</i>	0.22	0.52	0.17	0.20	-	0.17	
	<i>Aralia nudicaulis</i>	0.02	0.05	0.38	-	0.40	0.08	
	<i>Arenaria sp</i>	0.02	-	-	-	-	-	
	<i>Aster macrophyllus</i>	0.20	-	0.35	0.33	3.03	0.85	
	<i>Clintonia borealis</i>	-	0.20	1.20	-	-	0.38	
	<i>Coptis groenlandicum</i>	-	0.02	-	0.02	-	0.02	
	<i>Cornus canadensis</i>	2.33	8.52	9.18	30.00	3.87	4.52	
	<i>Corydalis sempervirens</i>	-	-	-	-	0.22	0.02	
	<i>Drosera rotundifolia</i>	-	-	-	0.02	-	-	
	<i>Dryopteris intermedia</i>	-	-	0.02	0.02	-	0.17	
	<i>Epigaea repens</i>	-	0.02	0.02	-	-	-	
	<i>Epilobium angustifolium</i>	0.25	0.05	0.37	0.20	0.17	-	
	<i>Equisetum sylvaticum</i>	-	-	-	1.67	-	-	
	<i>Gaultheria hispida</i>	-	0.02	-	0.05	-	-	
	<i>Linnaea borealis</i>	-	-	-	0.03	0.02	-	
	<i>Lycopodium clavatum</i>	0.02	0.05	0.02	0.03	-	-	
	<i>Lycopodium obscurum</i>	-	-	0.33	-	-	-	
	<i>Maianthemum canadense</i>	0.18	0.05	0.07	0.02	0.05	0.08	
	<i>Osmunda claytoniana</i>	0.02	-	-	-	-	-	
	<i>Polygonum callode</i>	0.02	0.17	0.18	-	4.17	2.22	
	<i>Pteridium aquilinum</i>	13.68	28.20	55.33	15.33	37.67	25.83	
	<i>Scirpus cyperinus</i>	0.17	4.50	-	0.67	-	-	
	<i>Solidago rugosa</i>	-	-	-	0.02	-	-	
	<i>Streptopus rosea</i>	-	-	0.02	-	-	0.02	
	<i>Teraxacum officinale</i>	-	-	-	-	0.02	-	
	<i>Trientalis borealis</i>	0.02	0.03	0.07	0.02	0.20	0.03	
	<i>Viola sp</i>	-	-	-	0.03	-	-	
	<i>Carex spp</i>	0.23	0.38	0.08	0.05	0.72	1.38	
	<i>Grass spp</i>	-	0.52	0.02	0.40	0.02	-	
	Mosses and Lichen	<i>Polytrichum</i>	68.67	4.68	6.00	19.33	0.90	0.37
		<i>Sphagnum</i>	-	8.33	0.02	3.68	-	-
<i>Other moss</i>		0.35	4.35	3.83	0.37	0.20	0.22	
<i>Lichen</i>		0.18	0.83	0.20	0.53	0.02	-	

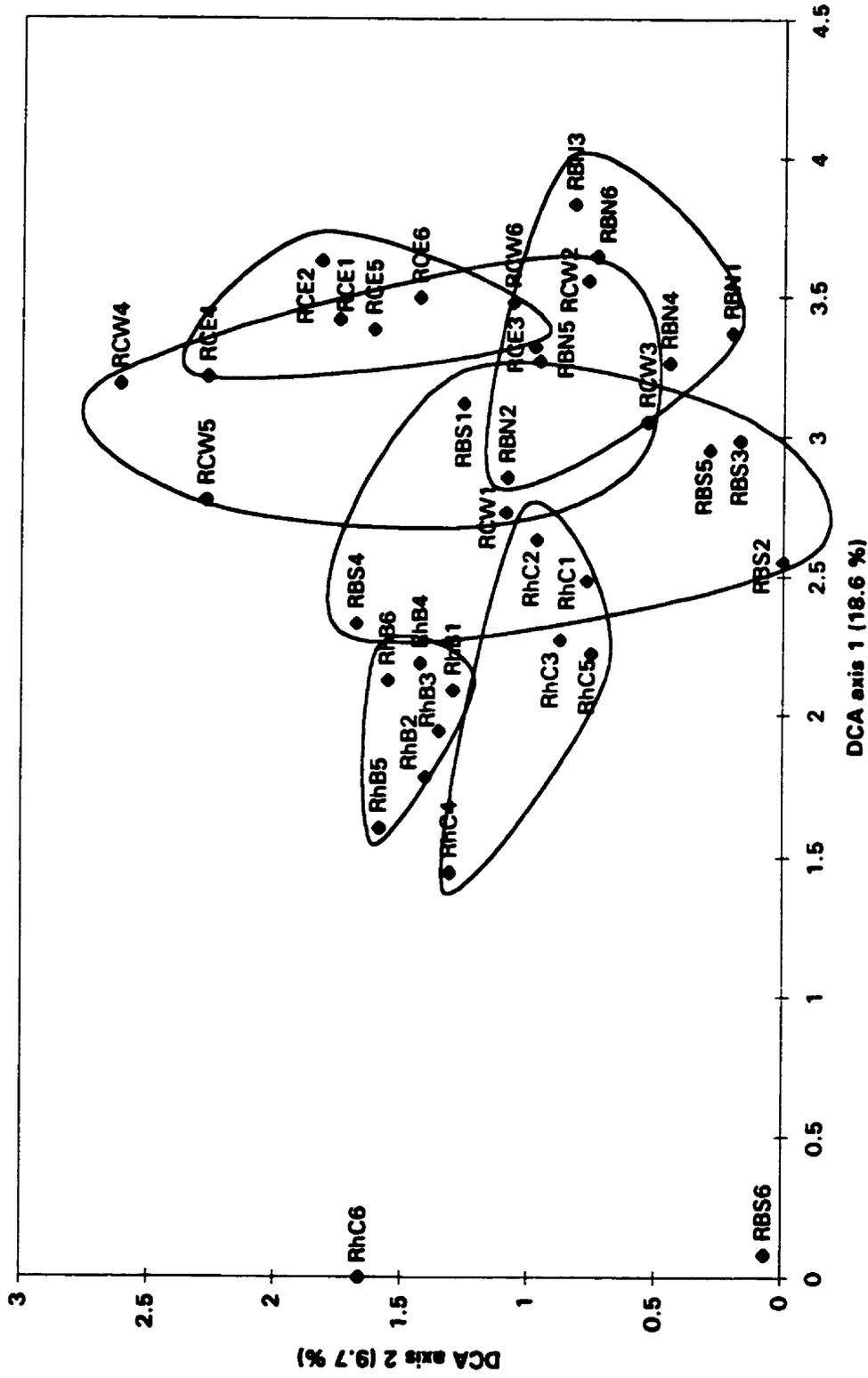


Figure 17. DCA of vegetation data from 36 plots for six study sites where adult moths were collected from Sudbury Dist., Ontario during 1997. Lines encircle six plots from each site, except RhC6 and RBS6. These two outliers were excluded from the mean axis 1 score, used to represent vegetation for each site in passive DCA ordinations of moth data. Codes with a 'B' are burn sites; those with a 'C' are cut sites. % = percent variance of species accounted for by the respective axis.

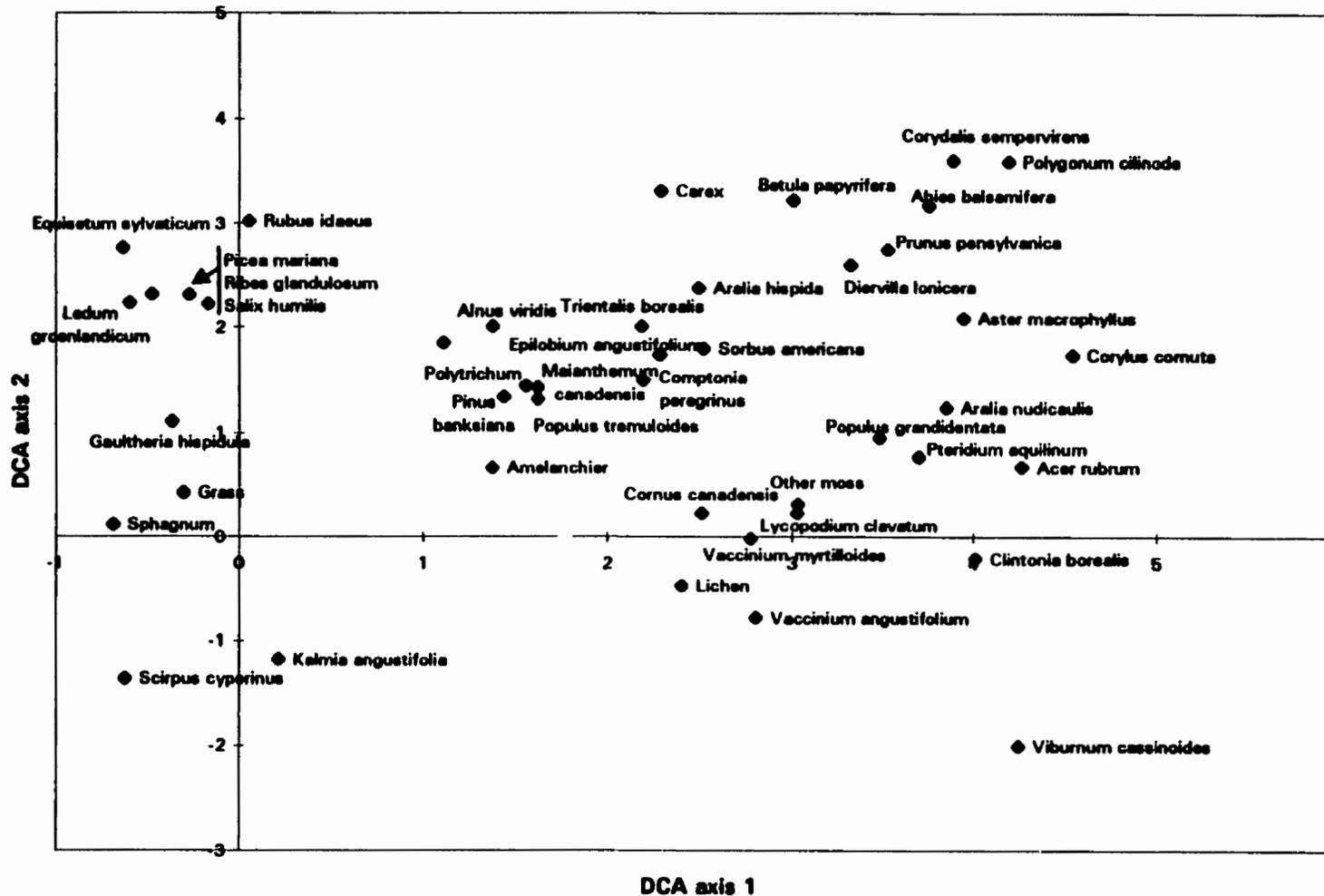


Figure 18. Species scores of DCA for vegetation data from 36 plots in six sites, where adult moths were collected in Sudbury Dist., Ontario during 1997. All species found were used in the ordination but those with ≤ 3 occurrences of $\leq 1\%$ cover are not shown in the diagram.

seemed logical because these plots were situated in locally wet areas, as noted above. Thus, if the vegetation score for a site was a relatively high number, this site would be relatively abundant in plants such as *Corylus cornuta* and *Aster macrophyllus* L., if the score was low the site would have relatively more *Pinus banksiana*, *Polytrichum*, *Maianthemum canadensis* Desf. and other species with a lower DCA axis 1 score. This vegetation score along with the other environmental variables were then used passively in DCA ordinations of the moth data.

Vegetation, disturbance age, percentage of jack pine pre-disturbance and logs (downed woody debris) were the four most important environmental correlates of moth community composition (Fig. 19). When each month's data was assessed in the same manner, these same environmental variables were again seen as the most important for moths (Fig. 20).

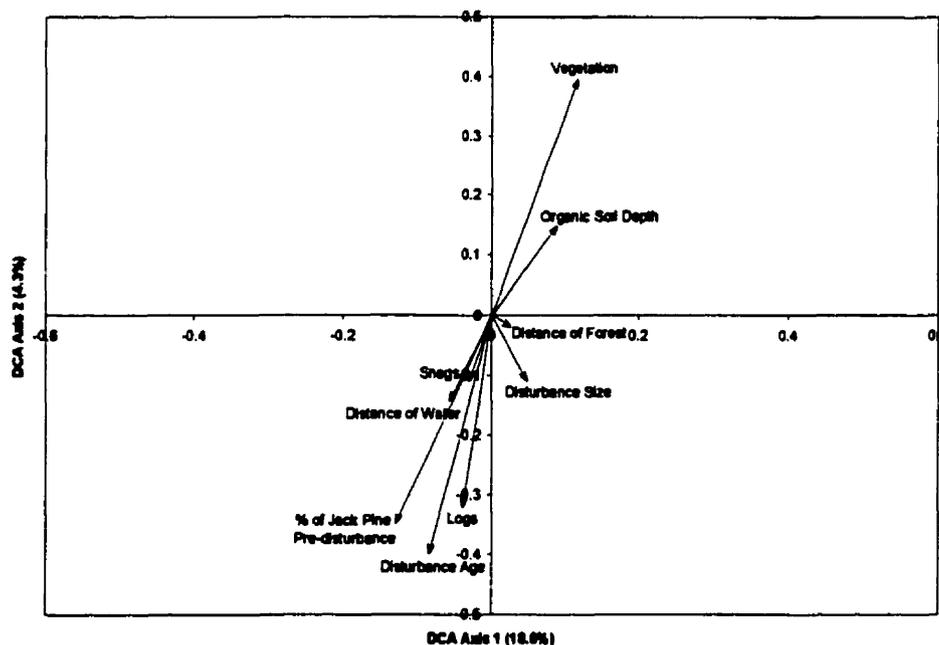


Figure 19. Environmental variable biplot scores of a passive DCA ordination of adult moth species collected in light-traps through the summer of 1997 in recently burned or clear-cut jack pine-deciduous sites in Sudbury Dist., Ontario. % = percent variance of species accounted for by the respective axis.

The relative importance of these four variables (vegetation, disturbance age, pre-

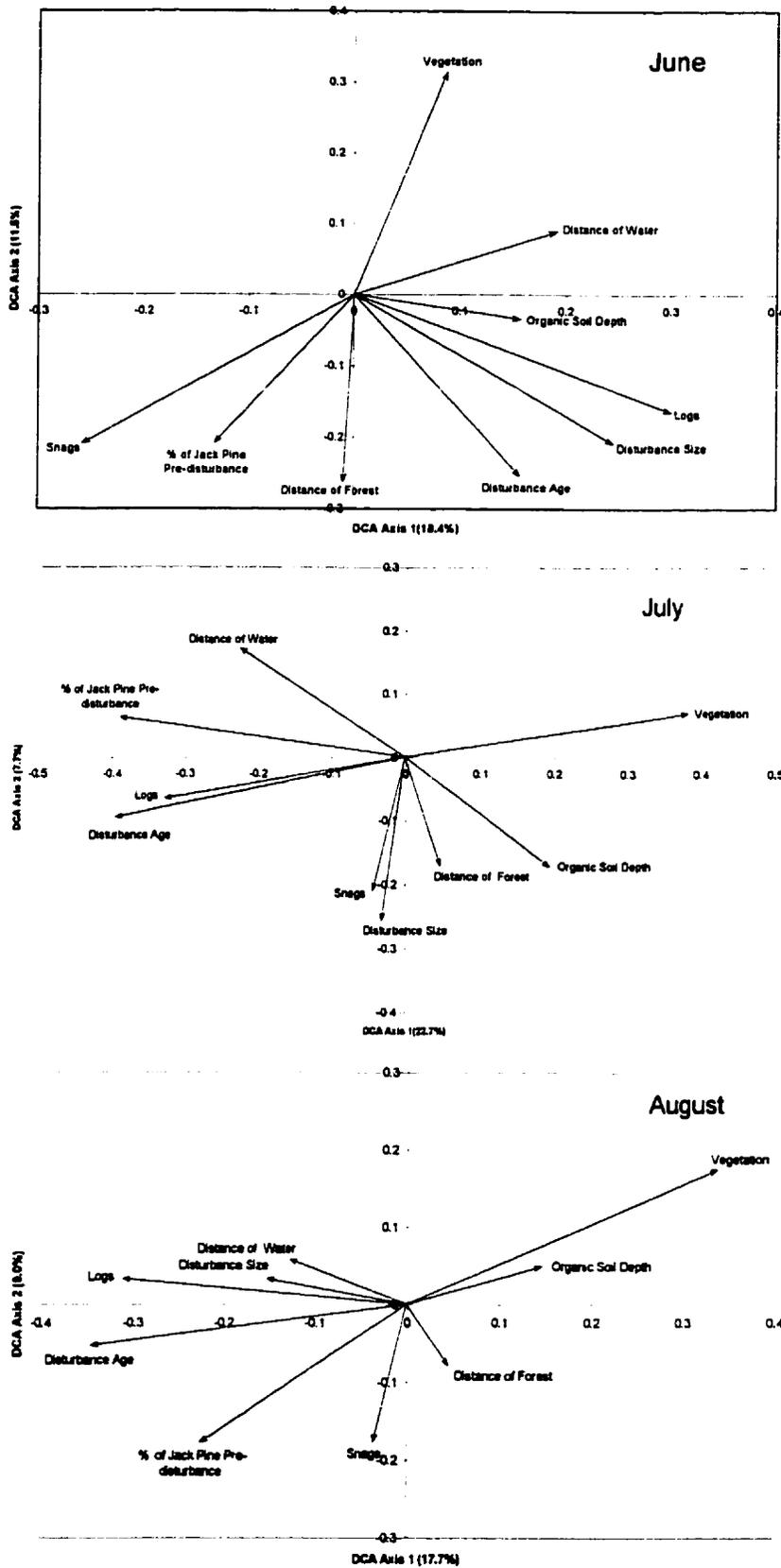


Figure 20. Environmental variable biplot scores for passive DCA ordinations (each month separate) of adult moths in young jack pine-deciduous forests, Sudbury Dist., Ontario, 1997. % = % = percent variance of species accounted for by the respective axis.

disturbance jack pine %, and logs) can be seen clearly when the correlations between the environmental variables and the site scores are examined. In all three months, the four variables consistently had the highest correlation values. These values ranged from -0.42 to -0.85. For example, in July the correlations were: disturbance age -0.85; vegetation 0.75; logs 0.72 and pre-disturbance jack pine composition -0.68. In comparison a relatively unimportant variable such as snag density had a correlation value of -0.13 in July.

In the output from CANOCO, the percentage of jack pine pre-disturbance always showed a strong negative correlation with vegetation suggesting a close inverse relationship. Thus, the amount of jack pine, and presumably other vegetation, present before the disturbances had an important influence on the plant community post-disturbance; more specifically, a greater amount of jack pine pre-disturbance is directly correlated with a lower vegetation score (lower DCA axis 1 score on Fig. 17).

The position of each study site relative to one another seemed to follow a consistent pattern in both the moth ordinations (Figs. 14 and 15) and the vegetation ordinations (Fig. 17). Usually, RhC was at one end of the gradient, followed by RhB, RBS, RCW and ending with RCE. This further emphasizes the important relationship between plant communities and moth assemblages.

Food Plants of Moths Commonly Found in Young Jack Pine-Deciduous Forests

A search of the literature for the larval food plants of the common moth species found in this study showed that blueberries and bracken appear to be the most frequently eaten larval food plants (Table 8). The three bracken-feeding species, *Callopietra cordata* (Ljungh), *Petrophora subaequaria* and *Homochlodes fritillaria* appear to be oligophagous (feeding on one or a few plants). On the other hand, while some blueberry feeders are probably oligophagous, others seem to be polyphagous (generalist). A third food group appears to be the deciduous trees and shrubs, such as white birch, pin cherry and green alder. No one deciduous woody species appeared as a principal food source. Dead plant material is the main food of two small common noctuids in the subfamily Hermininae (*Idia americalis* (Gn.) and *Zanclognatha jacchusalis*).

Orthodes cynica Gn. and *Protorthodes oviduca* (Gn.), two extremely abundant noctuids in the tribe Eriopygini, subfamily Hadeninae, have not been recorded feeding on any of the plants that were seen in the study sites (except grasses, which were present in very small numbers). These moth species may be polyphagous herbaceous plant feeders (given that they have been recorded as feeding on this plant group), or they may be oligophagous, feeding on an as yet unknown food source in this habitat.

Table 8. Food plants reported in the literature and likely eaten by moths commonly found in recently disturbed jack pine-deciduous forests within Sudbury Dist., Ontario during 1997.

Moth species name (Family)	Larval food plant(s) reported in literature ^a	Source ^b	Likely food plant(s) in study sites ^c
<i>Orthodes cynica</i> (Noctuidae)	reared on plantain, dandelion, collected on goldenrod	1,2	unknown
<i>Callopietra cordata</i> (Noctuidae)	ferns	3	bracken fern
<i>Protorthodes oviduca</i> (Noctuidae)	dandelion, plantain, grasses, and other low plants	1,3,4	unknown
<i>Petrophora subaequaria</i> (Geometridae)	ferns, bracken	3,4,5	bracken fern
<i>Idia americalis</i> (Noctuidae)	lichen, dead plant material especially in art mounds	1,2,3,4	lichen, dead plant material
<i>Spilosoma congrua</i> (Arctiidae)	herbaceous plants	3	herbaceous plant(s)
<i>Hornochlodes fritillaria</i> (Geometridae)	bracken and other ferns	3,4	bracken fern
<i>Lesionycta albinuda</i> (Noctuidae)	not known; probably blueberries	6	blueberries?
<i>Draeria edumbrata</i> (Noctuidae)	blueberries	4	blueberries
<i>Polia detracta</i> (Noctuidae)	blueberries, serviceberry, clover, hickory, oaks and others	1,2,3,4	blueberries, serviceberry
<i>Sphinx gordius</i> (Sphingidae)	larch, apple, blueberries, huckleberry, sweetfern, white spruce, ash, birch and others	3,4,7,8	blueberries, sweetfern, white birch
<i>Scopula</i> spp. (<i>S. junctaria</i> and <i>S. limboundata</i>) (Geometridae)	blueberries, wild cherry, apples, bedstraw, elm, clovers, meadow beauty, chickweed and others	3	blueberries, pin cherry, herbaceous plants
<i>Peridea ferruginea</i> (Notodontidae)	birches, including white birch	3,4	white birch
<i>Polia purpuriseta</i> (Noctuidae)	alders, blueberries, birches, willows, sweetfern, maples, strawberry, glechoma, poplar, rhododendron, spirea, viburnum; general woody plant feeder	1,2,3,4	green alder, blueberries, white birch, sweetfern, upland willow and other woody plants
<i>Eurois stricta</i> (Noctuidae)	trembling aspen, maple, alder, white birch, strawberry, pin cherry, spirea, blueberries, viburnum, helianthus	1,4	trembling aspen, green alder, white birch, pin cherry, blueberries
<i>Eueretrotis attentis</i> (Noctuidae)	not known (<i>E. parattentis</i> eats blueberry and fire cherry)	3	blueberries?, pin cherry?
<i>Xestia normaniensis</i> (Noctuidae)	blueberries, raspberries, black cherry, pin cherry, meadow sweet, sweetfern, plantains	2,3	blueberries, pin cherry, sweetfern
<i>Zanclognatha jacchusalis</i> (Noctuidae)	cottonwood or other dead leaves	2,3	dead leaves

^a Plant names in English, usually the language of source

^b Sources: 1) Rockburne and Lafontaine (1976); 2) Rings et al. (1992); 3) Covell (1984); 4) Tietz (1972); 5) McGuffin (1987); 6) D. Lafontaine, Canadian National Collection, Ottawa, pers. comm.; 7) McOgden (1958); 8) Hodges (1971)

^c Likely food plants are based on plants cited in the literature which were commonly found in the study sites

Latin names for plants likely eaten in study sites: bracken fern = *Pteridium aquilinum*; blueberries = *Vaccinium angustifolium* and *V. myrtilloides*; serviceberry = *Amelanchier* spp.; sweetfern = *Comptonia peregrina*; pin cherry = *Prunus pensylvanica*; green alder = *Alnus viridis*; upland willow = *Salix humilis*; trembling aspen = *Populus tremuloides*

DISCUSSION

Moth Behaviour and Phenology

Species Assemblages

A sequence of changing species through the warm months of the year is the expected pattern for insect life in boreal zones (Danks & Footitt 1989). In central Ontario, adult moths were found to follow this pattern. This seasonal segregation is believed to be due to the specialization of many herbivorous insects on a specific type of tissue of one or a few plant species (Strong *et al.* 1984, Schoonhoven *et al.* 1998). Thus, if one is interested in discovering the full diversity of adult moths in northern temperate or boreal forest environments, sampling should continue from spring through to fall. If sampling can only occur over a short period of time and maximum diversity of moths is desired, then collecting should probably occur around early July in southern boreal zones. A. Thomas (unpublished data, Canadian Forest Service, Fredericton, N.B.) found similar results in Fundy National Park, New Brunswick with extensive trapping that was carried out from March to November over four years. The rate of capture of new species peaked noticeably over an approximately six week period from the second week of June to the third week of July. My results also indicated that this is the time of the year when almost all Spingidae and Notodontidae are in flight, as well as many species of geometrids and noctuids. If the Arctiidae are the family of interest then trapping earlier in the summer will yield maximum diversity.

Fully half of the macrolepidopteran species caught were noctuids and a quarter were geometrids. These proportions appear to be consistent across habitats and regions within North America (Butler and Kondo 1991, Grimble *et al.* 1992, Thomas 1996).

All species that were caught appeared to be univoltine, with the exception of *Semiothisa neptaria*. McGuffin (1972) also noted that this species was bivoltine. Danks and Footitt (1989)

state that although most boreal insects are univoltine, a few south boreal species are known to have two generations of adults per year. Grimble *et al.* (1992) reported that a small minority of the species caught in their study were bivoltine. The bivoltine species found in both Grimble *et al.* (1992) and this study were: *Itame bitactata* (Wlk), *Phyllodesma americana* (Harr.), *Melanchra adjuncta* (Gn.), *Perodromia saucia* (Hbn.) and *Pseudaletia unipuncta* (Haw.). Failure to observe two adult generations of these species in my study was probably either due to the small numbers captured of these species or because the second generation was present outside of my trapping periods.

Increasing variation in moth communities as the summer progressed, as reflected in the increasing spread amongst points of each month in the ordination of all trap nights (Fig. 14) was an interesting observation with no clear cause. Limited adult food sources early in the year may cause moth communities early in the year to be more alike.

Another possible cause may relate to overwintering strategies. Typical hibernation states appeared to be different for the June species; for instance of the Ennominae captured in June, where hibernation stage is known, 89% (N=9) overwinter as a pupae (calculated from McGuffin 1972, 1977, 1981, 1987). In contrast, 26% of all Ontario butterflies (calculated from Holmes *et al.* 1991), 41% of British macrolepidopterans, and 43% of Finnish macrolepidopterans (both Young 1997) overwinter as pupae. Similar information is not readily available for other Canadian moths, therefore it is not possible to tell if the Ennominae are a typical group. If more early-flying moth species overwinter as pupae than do later flying moths, perhaps this somehow leads to a greater synchronicity in the emergence of the adults. Thus, although the typical overwintering mode may differ for early-flying species, it is not clear if this is the reason for increasing levels of heterogeneity seen in moth assemblages amongst sites as the summer progresses. A better understanding of adult moth behaviour is probably needed before this question can be answered.

Temperature Effects

This study clearly shows the influence of temperature on the activity of moths; on warmer nights, there are more active individuals, and thus is in agreement with numerous other works and reviews (eg. Hardwick 1972, Persson 1976, McGeachie 1989, Senapati *et al.* 1990, Thomas 1996, Young 1997). However, not all groups or species react to increasing temperature in the same way. My results show that when the percentage of species from each family is examined at different temperatures, not all families respond the same way. In all four families investigated, the rate that species became active was the same, but at a given temperature more sphingid species and less notodontid species were active. This also suggests that some sphingids become active at lower temperatures, about 3 °C, rather than about 6 °C for the noctuids and geometrids and 7 or 8 °C for the notodontids. This was somewhat contrary to expectations because during the coldest nights, the species most likely to be caught were noctuids. This can be seen by examining the individual points in Figure 9. Linear regression lines may be a weak way to illustrate this behaviour because at the lowest and highest temperatures observed one would not necessarily expect a straight line response.

No difference was found between the response of noctuids and geometrids to temperature in the present study, however other researchers have noted differences between these two families when examined by other methods (Casey & Joos 1983, Holyoak *et al.* 1997, Utrio 1995 in Nieminen & Hanski 1998). When 10 noctuid and 10 geometrid species trapped in the Czech Republic were examined for an increasing abundance with warmer temperatures, nine noctuids showed this response while only five geometrid species did, although this difference could not be tested statistically (Holyoak *et al.* 1997). Casey and Joos (1983) showed that the relatively slender-bodied geometrids did not sustain a body temperature much different than ambient temperature. Thus, although they were able to fly with little warm-up time, they were erratic and

slow fliers. The heavier bodied noctuids needed longer to warm up, but were more versatile fliers that could hover and manoeuvre more readily than geometrids. Nieminen and Hanski (1998) also classed most noctuids and sphingids as strong fliers, while geometrids and the small, thin-bodied noctuid subfamilies such as Herminiinae and Hypeninae were classed as weak fliers. Combining together the Herminiinae and Hypeninae with the more typical large-bodied noctuid in my study (Fig. 9) may have erased differences that might have been seen between geometrids and 'typical' noctuids.

It seems probable that each species has its own lower temperature limit, if increasing numbers of species are becoming active with increasing temperature. This idea is supported by numerous other studies. Lindquist (1998) collected two geometrid species at below freezing temperatures and a microlepidopteran species is known to fly below 0°C in Alaska (Philip 1998). Other researchers studying pest species have noted precise, but different, temperatures for the onset of activity of each species; for example, *Helicoverpa armigera* Hubn. did not fly until a temperature of 13°C was reached in India (Sinha & Jain 1992) whereas *Pyllocnistis citrella* Stainton initiates activity at 9°C in Japan (Ujiye 1990). It also seems possible that there is an upper temperature limit for each species; for example, Kendrick (1998) suggested that temperatures of 27°C initiated a decrease in moth activity in Hong Kong, and Korat and Lingappa (1995) found that maximum temperature had a negative rather than a positive relationship with the numbers of cotton bollworm moths (*Pectinophora gossypiella* (Saunders)) they caught in India.

Other researchers have noted that relative humidity (generally more moths caught with increasing humidity), wind speed (less moths) and moon illumination (less moths) frequently affect moth catch numbers, but that temperature is almost always found to be the most influential of all weather or lunar factors (Persson 1976, McGeachie 1979, Young 1997).

Trapping Effects

A comparison of numbers of moths collected on the first night in all locations as compared to the second and third nights in trapped locations, indicated that the use of light traps, and the associated killing of moths, affected the local population of moths by removing a significant portion of adults in the first night. This is in agreement with White (1989) and Thomas (1989). Most researchers using light traps are generally aware that this collection method assesses the relative abundance of moths, and therefore cannot be used in assessing actual populations of moths (Thomas 1989, Butler & Kondo 1991). The existence of this removal effect makes it especially important to treat different study sites in an identical manner and to be cautious in comparing a collection from one time period with one from a later period from the same location, when the effects of light-trapping on moth populations are not well known.

Moth Diversity in Burned and Clear-cut Forests

Moth diversity was similar in jack pine-deciduous forests that had been either burned by wildfire or clear-cut four to eight years earlier. This conclusion was based on several statistical analyses, including comparisons of rank abundance curves, diversity indices, DCA ordinations and examinations of species occurrence. In contrast with these results, most other comparison studies have found a difference in attributes between burn and cut sites. My results imply that either moths are not very sensitive to differences in habitat conditions that result from burning and clear-cutting, or that in this forest type, in young forests, silvicultural practices simulate natural disturbances. I believe that there are aspects of both of these ideas occurring.

Environmental Factors and Food Plants

It is necessary first of all, to discuss which environmental variables are of relative importance to moths. Out of nine environmental variables considered in my study, vegetation appeared as one of the four relatively important variables. The age of the disturbance was a second variable of relative importance, while the percentage of jack pine that was present prior to disturbance was a third. These two variables are directly related to vegetation. The percentage of jack pine present prior to disturbance is related to current vegetation, because the presence of jack pine will almost always affect how many jack pine and other tree species will grow on a site after fire. Disturbance age is probably related to vegetation in that in the early stages post-disturbance, a difference of four years, was probably long enough to see a successional change in plants. The youngest sites in the study were four year-old cut sites that had been planted the year before the study was conducted, whereas the oldest site was an eight year-old cut site that was seeded six years earlier (and therefore had some 2-3 m high pine) and had been sprayed four years prior with herbicide. Thus, although this was human-mediated succession (no jack pine following

harvesting, followed by planted or seeded pine, followed by herbicide-treated stands), it was still succession with a fairly rapid change in plant species.

'Disturbance age', 'pre-disturbance jack pine' and 'vegetation', as a group of correlated variables, suggest that plant composition is an influential factor in determining moth composition. This is not unexpected because the vast majority of moths (over 98 %) are herbivorous when in the larval stage (Strong *et al.* 1984, Young 1997). Presence of adult food sources is considerably less important because adults do not consume a large amount of food - only enough nectar or other liquid to sustain them for about a week, the approximate lifespan of one moth (Young 1997). Blueberries and bracken were two of the most important larval food plants in these young forests. Auerbach and Hendrix (1980) show that ferns are not as under-utilized a food plant as was previously thought. Bracken in particular, has more known associated Lepidoptera than any other fern species. Another important group of food plants in my study was the woody deciduous plant group. Many species caught were feeders of this plant group (McGuffin 1972, 1977, 1981, 1987, Covell 1984, Rings *et al.* 1992). My study is not unique in finding a dependence on deciduous trees and shrubs by numerous moth species. McGuffin (1987) in his series on Canadian Ennominae, noted that many of these geometrids appear to prefer the *Alnus-Betula-Populus-Salix* group of host plants, and Hammond and Miller (1988) found that the majority of moths fed upon hardwoods, regardless of the type of forest.

Jack pine, bush honeysuckle, bunchberry and *Polytrichum* moss were common plants in my study area, but they have not been recorded in the literature as food plants of many of the moth species I collected. The apparent lack of feeders on jack pine is probably an accurate reflection of a paucity of larval feeders of pine. A comparison of larval food groups of moths in three forested ecosystems, including two conifer-dominated forests, showed that conifers had a much lower percentage of larval moth species feeding on them (1-18% of all moth species), as

compared to other potential food groups, such as herbaceous plants and deciduous trees and shrubs (Hammond and Miller 1998). Thus, although a few species caught in my study such as; *Caripeta piniata* (Pack.), *C. angustiorata* Wlk., *Semiothisa bicolorata* (F.), *Macaria signaria* (Hbn.) and *Lapara bombycoides* Wlk., are known to feed on pines, they are in the minority (McGuffin 1972 and 1987, Covell 1984). Even in the pure jack pine forest of Forest #2, jack pine-feeders did not dominate; instead the dominant moth was *Eulithis explanata*, (Wlk.), another *Vaccinium*-feeder (Covell 1984). *Nematocampa resistaria* (H.-S.), also common there, is a generalist that often concentrates on conifers, thus it may be feeding on jack pine in Forest #2 (Entomologie et de Pathologie 1979, Covell 1984, McGuffin 1987, Grimbale *et al.* 1992). The small number of species that feed on conifers is perhaps due to the relatively tough foliage. The lack of larval feeding on bush honeysuckle, bunchberry and *Polytrichum* may either be a true reflection of a lack of lepidopteran herbivores using these plants, or it could be due to the incomplete nature of host plant knowledge.

The fourth variable that appeared to be of importance for moths (along with vegetation and the associated disturbance age and pre-disturbance jack pine) was the presence of logs. The reason for this is less clear than the reason for the importance of vegetation. Less than one percent of British Lepidoptera consume dead wood (Young 1997), thus wood is not likely an important food resource as it is for many beetles, nor does it seem likely that moths need the physical presences of logs for shelter or resting places, as do some animals (Fox 1983). The explanation could lie in one of two directions. The first possible explanation is that a relationship was found between the moths and amount of woody debris because it is correlated with one of the other variables, such as disturbance age, that its vector lies close to. A second possible explanation is that a significant number of moths do use downed woody debris in some way during their life, perhaps a substrate to rest on. A greater knowledge of adult moth behaviour is

needed before one of these explanations can be chosen.

Clear-cut - Wildfire Comparisons

Given that moth diversity appears to be strongly related to plant composition, one can argue that if the vegetation is similar in young burned and young clear-cut jack pine-deciduous forests, then the moths of these habitats are likely to be similar. The ordination of the vegetation data (Fig. 17) and the list of plants found at each site (Table 7) suggest that the vegetation is similar at all sites. Thus, in some ways, those relevant to moths, clear-cutting is emulating wildfire by providing for the environmental requirements of moths. At the same time, the differences, other than vegetation differences, that other researchers have noted between cut and burned areas, although they exist in other forest types as well as this forest type, are presumably not very relevant to moths.

Abundance of snags is an example of a feature that clearly differs between burned and clear-cut forests, yet appears to be of little importance to moths. This difference has been noted by Daust (1995) and was also found in my study, in which burned sites had a mean of 270 snags per hectare, while clear-cut sites had only 7 snags per hectare. While this did not appear to influence moth diversity, it probably does affect other organisms such as cavity-nesting birds and wood-eating insects. For instance, my observations of the breeding birds seen in the study sites suggest that cavity-nesting birds such as northern flicker, American kestrel, eastern bluebird and black-backed woodpecker might have been more successful breeders in the burn sites than in clear-cut sites (pers. obs.). Others have substantiated this idea; for instance, Drapeau (unpublished data, Département de sciences biologiques, Université du Québec à Montréal) found black-backed woodpeckers and some species in the cerambicid and buprestid beetle families to be strongly associated with early post-fire habitats and not any other habitat in northern Ontario and

Quebec. In recently burned coniferous forests of the Rocky Mountains, Hutto (1995) also found black-backed woodpeckers to be almost exclusive to burned habitat when compared to other terrestrial habitats of the region. Interestingly, when comparing the presence of cavity-nesting birds in his recently burned study sites with those in recently cut sites from other studies, only the black-backed woodpecker and three-toed woodpecker were found notably more frequently in the burned sites, whereas mountain bluebird, northern flicker, and American kestrel were found in approximately equal percentages. Thus, while there is little to suggest that the silvicultural practices used in jack pine forests affect moths in a different way than does wildfire, other organisms are clearly responding differently to the two disturbances.

In Scandinavia similar observations have been made. Almost total fire suppression has meant a lack of young forests regenerating after fire (Niemälä 1997). Ecologists in that part of Europe have noted a decline in some insects associated with this habitat (Heliövaara & Väisänen 1984, Ahnlund & Lindhe 1992, Niemälä 1997). None of the rare or declining species however are Lepidoptera; most are Coleoptera or Heteroptera (Heliövaara & Väisänen 1984, Ahnlund & Lindhe 1992, Muona and Rutanen 1994). The rarity of some of these species implies that for them, clear-cuts were not a suitable replacement for burns. It is of interest to note that in a Swedish study, although many endangered insects that were found in burns that were not found in clear-cuts, the clear-cuts had an approximately equal number of endangered insects (31 species) as did the burns (27) (Ahnlund & Lindhe 1992). Niemälä (1997) feels that the insect fauna of burned and clear-cut sites are 'quite different' based on Ahnlund and Lindhe's study.

This may be too strong a statement however, because my study and Lafrenière's (1994) suggest that the diversity of moths and carabids in jack pine dominated forests was not significantly different most of the time. Lafrenière's conclusion was based on the abundance, species richness and Shannon and Alpha diversity indices of carabid beetles assemblages in jack

pine forests at 5, 15, 25 and 40 years after fire or after clear-cutting. While most of his analyses found no difference between the treatments, a few differences were observed. Of two similarity indices, one in one of two sample years showed a significant difference. That meant that burned sites appeared to be slightly more heterogeneous than cut sites in terms of carabid diversity. This was attributed to the relatively heterogeneous nature of the burned stands, which had a mixture of relatively open and relatively close trees in contrast with the relatively homogenous nature of tree spacing found in the planted stands. The other difference observed was a significantly greater number of *Harpalus laticeps* Leconte in five-year-old burned stands relative to cut stands. The larger amounts of woody debris noticed in the burned sites than in the clear-cut sites, may have accounted for this. Notably, this difference in woody debris, and a difference in soil topography (cut sites having been somewhat levelled off during scarification) did not seem to influence other carabid beetles. Thus, Lafrenières' study and mine, while finding a few subtle differences between disturbance types, on the whole, found diversity of the insect groups studied to be the same in burned and cut jack pine forests.

Moths Typical of Young Jack Pine-Deciduous Forests

One can name the species that are characteristic of young jack pine-deciduous forests whether burned or cut, because the moth assemblages are roughly the same in these two disturbance types. The five most abundant species found were: *Orthodes cynica*, *Protorthodes oviduca*, *Callopistra cordata*, *subaequaria*, and *Idia americalis*. *Petrophora subaequaria* is of particular interest because it was not found in other moth diversity studies (Butler & Kondo 1991, Grimble *et al.* 1992, Thomas 1996). Nonetheless, it is unlikely to have very specific habitat needs because it feeds on bracken, an extremely widespread and common fern species. *Spilosoma congrua* and *Lasionycta albidula*, two species common in June, are also worth noting since they

too were not found in the three afore-mentioned studies. *Lasionycta albinuda* is recorded as rare by Rockburne and Lafontaine (1976), and Lafontaine (Canadian National Collection, Ottawa, pers. comm.) suspects that it is yet another blueberry feeder. If there are specialists of this habitat type, they are perhaps more likely to be found amongst the less common species.

The only previously recorded burn-specialist moth, *Actebia fennica* (Tauscher) (Noctuidae), a species that responds to the smoke of a fire, (J. McNeil, Biology, Laval University, pers. comm.), was not captured in any of the study sites. Although Phipps (1930) regarded this species as one of the important insect pests of blueberry crops in Maine, and might therefore be expected to be found in my study, its absence is perhaps not surprising since McNeil (Biology, Laval University, pers. comm.) states that the females are believed to move away when fresh ash is no longer detected.

Species Typical of Unique Disturbance Regimes

Despite overall results that show no difference in the moth assemblages of recently clear-cut or burned jack pine-deciduous forests, a very small portion of the species recorded were found more significantly in one disturbance type over another or were found solely in one disturbance type. Notably, all the species found significantly more frequently in one disturbance type were found in the burn sites. Most of the species that were found in only one disturbance type could have been there by chance, while only three species were probably not there by chance: *Cyclophora pendulinaria*, and *Hyppa* nr. *xylinoides* in burns, and *Acronicta innotata* in cuts.

The species which may be burn specialists are: *Nemoria rubrifrontaria*, *Antepione thisoaria* (Gn.), *Semiothisa neptaria*, *Tacparia deterrentata*, *Cyclophora pendulinaria*, *Hyppa* nr. *xylinoides* and *Heptagrotis phyllophora* (Grt.). There is little obvious similarity between these species - they do not have a common food plant nor do they fly at the same time of the year,

although all but the last two species are geometrids. Moth diversity studies carried out in various parts of North America record all but *Nemoria rubrifrontaria* as present in at least one of the study areas. These studies took place in areas as diverse as: balsam fir-red maple forests of New Brunswick (Thomas 1996), mixed oak forests of West Virginia (Butler & Kondo 1991), and riparian zones within coniferous forests of Oregon (Grimble *et al.* 1992), which suggests that these moth species are not likely burn specialists. There is no research that focuses solely on these species, thus it is difficult to confirm or disprove whether these species are burn specialists.

Nemoria rubrifrontaria emerges as a more likely burn specialist. According to Ferguson (1985), the two main food plants of *N. rubrifrontaria* are sweetfern and sweetgale (*Myrica gale* L). Sweetgale was not found in the study sites, but sweetfern was common in two of the three burn sites, and rare in the cut sites, thus possibly explaining the difference.

Acronicta innotata was found at all three cut sites, but in none of the burn sites. This is not easy to explain, especially because this moth is a member of the *Betula-Alnus-Populus-Salix* feeding group (Covell 1984, Rings *et al.* 1992). Also, four out of the five *Euxoa spp.* (Noctuidae) were found solely in the cut sites. This speciose genus, comprising 171 species north of Mexico, is characteristic of dry temperate habitats (Lafontaine 1987). Although the food plants are not known for many species, it is thought that they are generalist feeders, based upon those for which food plants are known, (Lafontaine 1987). *Euxoa* overwinter in the egg or sometimes the first instar larva stage, and eggs are placed in the soil just below the surface (Lafontaine 1987). Lafontaine (1987) thinks that soil conditions such as moisture, texture and exposure are probably more important in defining *Euxoa* range than food plants. Perhaps this relates to their habit of placing their eggs in the topsoil. Information collected from the soil augers in my study suggests that a greater amount of mineral soil was exposed and that the organic layer was marginally shallower in the cut sites than in the burn sites. This suggests that *Euxoa* prefer to lay their eggs

in the dryer, coarser mineral soil found more often in the cut sites, rather than in the organic layer. Munson *et al.*'s (1997) preliminary results suggest that the organic layer is thinner after fire than after 'careful logging' of black spruce, but they do not comment on the prevalence of organic versus mineral soil exposure. Careful logging (cut with protection of regeneration and vegetation) might be expected to retain more organic soil than the conventional clear-cutting and scarification that took place in my study sites.

Thus it appears that there are subtle differences in the way that different disturbances affect moths because a few moth species were significantly more abundant in burned forests than in clear-cut forests. Conversely, it is possible that differences seen in species composition may be a response to individual site differences and would disappear with a larger number of sampled sites.

CONCLUSIONS

Macrolepidopteran diversity was not significantly different between naturally burned and clear-cut jack pine-deciduous forests approximately five years after disturbance. Some characteristic species of this young forest type were four noctuids, *Orthodes cynica*, *Protorthodes oviduca*, *Callopistra cordata*, and *Idia americalis* and the geomtrid, *Petrophora subaequaria*. Only eight out of the 241 species caught between mid June and mid August showed a significant difference in abundance between the two disturbance types.

Nemoria rubrifrontaria, a larval feeder of sweetfern, was the only example of a species that was clearly associated with the burned areas. Four other species were found significantly more frequently in the burn sites than in cut sites, but are unlikely to be burn specialists. *Acrionicta innotata* and the noctuids in the *Euxoa* genus may be examples of species that are found more frequently in cuts than in burns. The *Euxoa* genus was the only moth group where the soil conditions might be more influential than plant composition in determining moth occurrence. In order to discover if this is correct, any future research should include a more detailed examination of the soil surface conditions. Also, because many *Euxoa* species fly in late summer (Lafontaine 1987), collection periods should occur in late August and into September if this genus is of interest .

Future research could take several directions. One direction for research would be to test whether burned forests, as a group, are more heterogeneous than cut forests, because my study was too small to determine this. A greater number of sites would be needed, northwestern Ontario would be an ideal location for this since fires are more frequent in that region than in Sudbury District and jack pine is widespread. If heterogeneity of moth communities was found to be greater amongst burned sites than cut, then it suggests that harvesting, scarification and regeneration techniques should be more varied (Hutto 1995 and Haila 1994 also) and that there is

not one single best way to log a given forest type. For instance, patches of trees could be left behind in some cuts but not in others, and a variety of scarification equipment could be used so that not all soils are similarly disturbed.

A survey similar to mine, conducted at 20 or 30 years post-disturbance, would answer a different question - does moth diversity in cuts and burns continue to be similar in older forests as it is in younger? At about 25 years post-disturbance, the percentage of conifer versus deciduous trees would probably remain the same for many decades. Perhaps clear-cut sites that are sprayed with herbicides will become forests with a lower deciduous component than prior to disturbance, or perhaps the herbicides will merely cause a temporary set-back to woody deciduous species. The percentage of deciduous trees may have an important impact on the diversity of moths, given the apparent importance of this plant group as a larval food. Hammond and Miller (1998) recommend the avoidance of herbicides so that this component of the forest is not completely lost as a moth resource.

Another research direction, and perhaps the most interesting, would be to conduct a similar study in a different forest type, perhaps boreal mixed-wood or boreal spruce. There is evidence that these commercially important spruce forests are not successfully regenerating back to spruce after harvesting. If moth communities are dependent on vegetation composition and plant communities are changing due to logging, then one could expect the lepidopteran community to be changing at the same time. Confirming the importance of vegetation as a determining factor in moth communities might also be possible if the latter two research proposals were carried out.

A final future research direction, unrelated to forestry, would be to collect further details on the host plants of forest moths - an area where knowledge is far from complete - by using a method described here. The method would entail a survey of many sites detailing moth and plant

species found and would be followed by analysis using CCA ordinations. Environmental variables would consist of individual plant species abundances. The resulting ordination should show a moth species adjacent to its host plant in an ordination diagram. This method was tried with the data collected in my study, but it was felt that a larger number of sites and a larger gradient in habitat type were needed to reveal the specific host plants for each moth species.

Trapping for all of the above suggestions for future research would ideally occur on and off at regular intervals from early spring through late fall. If funding was limited, trapping should occur in late June through early July when peak numbers of moths are flying. Also, both night temperature and relative humidity would preferably be recorded in order to compensate for these influential factors in analyses.

The use of indicator species or groups is a concept that forest managers have shown great interest in recently (McKenney *et al.* 1994, Naylor *et al.* 1996). Indicator species are those which theoretically represent a group of organisms and the presence of the indicator species is usually thought to indicate a healthy and diverse ecosystem. Regardless of whether or not this is a useful or valid concept, I would not recommend macromoths as a potential indicator species or group. As a group they are too numerous to easily inventory. While they can be caught readily in large numbers, the large number of species are time-consuming to identify and few people have the expertise. The variation in nightly catches caused by weather can be a further confounding factor. Furthermore, yearly variation on species abundance can be quite large and it is not fully understood what is causing this variation (Butler & Kondo 1991).

In summary, adult moth diversity is similar in recently burned and recently clear-cut jack pine-deciduous forests of the southern boreal forest of Ontario. This research begins to bring an understanding to how moths response to disturbance in this region. It leads to the ideas for further research as outlined in this conclusion. It also suggests that not all organisms are equally

sensitive to the differences between clear-cuts and burns. If moths are responding primarily to the vegetation composition found at these sites, then surveys of plants may be sufficient to account for the diversity of moths.

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Appendix 1. Number of adult moths collected in light traps throughout the summer of 1997 from study sites within Sudbury Dist., Ontario.
Subfamilies listed for Drepanidae, Geometridae and Noctuidae only.

Family	Subfamily	Species	BURNS			CUTS		
			RhB	RBS	RBN	RhC	RCE	RCW
Sesiidae - Clear-winged Moths		<i>Synanthedon acari</i> (Clem.)		1			4	
Drepanidae -	Drepaninae	<i>Drepane arcuata</i> Wlk.	3	3		1		3
Noctuid and Thyatirid Moths		<i>Drepane bilineata</i> (Pack.)	3	1	1	3		1
	Thyatirinae	<i>Habrosyne scripta</i> (Gosse)		1	1	1		
		<i>Pseudothyatira cymatophoroides</i> (Gn.)	2	1			1	
Geometridae -	Geometrinae	<i>Nemoria rubrifrontaria</i> (Pack.)	26	16		4	1	
Inchworm Moths	Stemmatinae	<i>Cyclophora pendularia</i> (Gn.)	5	2	1			
		<i>Scopula ancellata</i> (Hulst)						1
		<i>Scopula frigideria</i> (Mosch.)		3	3	3	1	
		<i>Scopula junctaria</i> (Wlk./Vimboundata (Haw.))	8	65	27	12	34	17
	Larentinae	<i>Anticlea multifera</i> (Wlk.)		3	1			
		<i>Dysstroma herziata</i> (Gn.)		1		4		3
		<i>Epirrhoe alternata</i> (Muller)					1	
		<i>Eulithis explanata</i> (Wlk.)		9	13	3	4	6
		<i>Eulithis serrataria</i> (B. & McD.)	1					
		<i>Eulithis propulsata</i> (Wlk.)		3				
		<i>Lobophora niverata</i> Wlk.	19	3	1	3	1	1
		<i>Rheumaptera undulata</i> (L.)		2	1		1	1
		<i>Spargania</i> spp. Gn.	2	6		4	2	3
	Ennominae	<i>Anacamptodes</i> spp. McD.	6	21	5	14	4	10
		<i>Anagoga occiduaris</i> (Wlk.)			1			
		<i>Antepione thisoaria</i> (Gn.)	31	17	5	10	5	
		<i>Basma quercivoraria</i> (Gn.)					1	
		<i>Biston betularis</i> (L.)		3				2
		<i>Cabera erythemeris</i> Gn.	13	4	5		1	3
		<i>Cabera variolaris</i> Gn.	40	10	6	11	13	4
		<i>Caripeta angustiorata</i> Wlk.	5	1		7		5
		<i>Caripeta piniata</i> (Pack.)				1		
		<i>Cepphis decolorata</i> (Hulst)				1		
		<i>Euchlaena irrorata</i> (B. & McD.)	6	16	10	4	12	10
		<i>Euchlaena johnsonaria</i> (Fitch)	1	1				
		<i>Euchlaena madusaria</i> (Wlk.)	3	5	2	9		
		<i>Euchlaena marginaria</i> (Minot)	6			2	1	
		<i>Euchlaena muzaria</i> (Wlk.)		6	5		2	8
		<i>Eufidonia convergens</i> (Wlk./notataria (Wlk.))	5	2		10	1	
		<i>Eumacaria latiferrugata</i> (Wlk.)				1	1	
		<i>Eutrapela clemataria</i> (J.E. Smith)	1			1		
		<i>Hesperumia sulphuraria</i> Pack.	4	7	3	7	3	4
		<i>Homochlodes frillaria</i> (Gn.)	38	5	5	10	16	5
		<i>Iridopsis larvaria</i> (Gn.)				1		
		<i>Itame bitactata</i> (Wlk.)	5	4	4	13	2	6
		<i>Itame brunneata</i> (Thunb.)	1	41	11	9	5	7
		<i>Itame ioncarea</i> (Evers.)		1				
		<i>Itame pustularia</i> (Gn.)	1	12	1		3	1
		<i>Macaria signaria</i> (Hbn.)	32	17	8	21	5	12
		<i>Metanema inatoma</i> Gn.	4	1			1	1
		<i>Metanema determinata</i> Wlk.	22	24	4	17	7	10
		<i>Metarranthis duaria</i> (Gn./warmerae (Harv.))	18	6	2	9	3	4
		<i>Metarranthis indeclinata</i> (Wlk.)	2					
		<i>Nematocampa resistaria</i> (H.-S.)	3	9		1	3	2
		<i>Orthofidonia</i> sp. Pack.	2		1	1		
		<i>Orthofidonia</i> sp. Pack.	1	1				
		<i>Pero honestaria</i> (Wlk.)	9	22	11	8	19	19
		<i>Petrophora subaequaria</i> (Wlk.)	75	21	39	23	62	29
		<i>Probole emicaria</i> (H.-S.)	2	8		5	1	2
		<i>Prochoerodes transversata</i> (Drury)		3	4	1	7	
		<i>Protoboarmia porcelaria</i> (Gn.)				1		
		<i>Semiothisa bicolorata</i> (F.)	21	3		6		1
		<i>Semiothisa neptaria</i> (Gn.)	28	7	4	7	2	
		<i>Semiothisa ulsterata</i> (Pears.)		1			1	1
		<i>Semiothisa</i> Hbn. 'grey'		1				
		<i>Sicya macularis</i> (Harr.)	4	3	2		1	1
		<i>Tecperia atropunctata</i> (Pack.)	4	1		2	1	
		<i>Tecperia detersata</i> (Gn.)	31	18	2	17	9	
		<i>Tetracis cacheuxata</i> Gn.	38	16	10	10	11	8
		<i>Tetracis crocalleata</i> Gn.	2	1		1	1	
		<i>Xanthotype urticaria</i> Swett	2	3	4	2	3	1
		Unknown Geometrid	1	1		1		
Lasiocampidae		<i>Phylodesma americana</i> (Harr.)			1	1	2	2
Tent Caterpillar & Lappet Moths		<i>Malacosoma americanum</i> (F.)	1					
Saturniidae		<i>Actias luna</i> (L.)	1	1			1	
Giant Silkworm Moths		<i>Anisota virginensis</i> (Drury)					1	
		<i>Antheraea polyphemus</i> (Cram.)		1			2	
		<i>Dryocampa rubicunda</i> (F.)	1	2	1		4	2
Sphingidae		<i>Derapsa pholus</i> (Cram.)		12		7	4	2
Hawk Moths		<i>Hyles gallii</i> (Rottemburg)			1		1	2
		<i>Lapara bombycoides</i> Wlk.	1	5		3	5	1
		<i>Pachysphinx modesta</i> (Harr.)	3	3	3	4	8	2
		<i>Paonis excaecatus</i> (J.E. Smith)	3	5	4	6	15	4
		<i>Paonis myops</i> (J.E. Smith)		2			2	
		<i>Smerinthus cersisy</i> W. Kby.	1			1	1	
		<i>Smerinthus jamaicensis</i> (Drury)	37	18	3	22	19	6
		<i>Sphinx kalmiae</i> J.E. Smith		3		3		1

Appendix I cont'd.

Family	Subfamily	Species	BURNS			CUTS		
			RhB	RBS	RBN	RhC	RCE	RCW
Sphingidae cont'd		<i>Sphinx gordius</i> Cram.	12	71	19	49	29	16
Notodontidae		<i>Clostera albosigma</i> Fitch.	2	1		1		
Prominenta		<i>Clostera inclusa</i> (Hbn.)	3				1	1
		<i>Datana ministra</i> (Drury)	3	7	1	1	6	3
		<i>Furcula cinerea</i> (Wlk.)	1			1		
		<i>Gluphisia septentrionis</i> Wlk.	5	5	3	2	2	2
		<i>Heterocampa biundata</i> Wlk.			2		6	5
		<i>Heterocampa umbrata</i> Wlk.	3	2	2	1	8	14
		<i>Nedata gibbosa</i> (J.E. Smith)	6	4	4	4	14	10
		<i>Notodonta simplex</i> Graef		1				
		<i>Odontosis elegans</i> Stur	1		1			
		<i>Oligocentria lignicolor</i> (Wlk.)		1			1	1
		<i>Peridea ferruginea</i> (Pack.)	6	34	11	2	49	46
		<i>Pheosia rimosa</i> Pack.	17	3		3		2
		<i>Shizura apicalis</i> (G. & R.)	2	7		5	2	
		<i>Shizura ipomeeae</i> Doubleday	3	15	3		14	9
		<i>Shizura leptinoides</i> (Grt.)	2	14	2	1	11	6
		<i>Shizura unicomis</i> (J.E. Smith)	1					
Arctidae		<i>Ctenucha virginica</i> (Charpentier)	4	4		2	1	2
Tiger, Lichen & Wasp Moths		<i>Ellema bicolor</i> (Grt.)	2	9	1	11	1	7
		<i>Grammia parthenica</i> (W. Kby.)	1	10	3	5	5	6
		<i>Grammia williamsii</i> (Dodge)		2	1	2		
		<i>Holomelina aurantiaca</i> (Hbn.)				1		
		<i>Holomelina ferruginosa</i> (Wlk.)	2	2	1	3		2
		<i>Holomelina laeta</i> (Guer.)		14			2	3
		<i>Lophocampa maculata</i> Harr.	4	4	5	1	5	7
		<i>Phragmatobia assimilians</i> Wlk.	4	2		5	1	
		<i>Platactia parthenos</i> (Harr.)	2	1		2	2	1
		<i>Spilosoma congrua</i> Wlk.	51	34	25	22	52	22
		<i>Spilosoma dubia</i> (Wlk.)	2	3		6	5	4
		<i>Spilosoma virginica</i> (F.)	4	9	2	4	18	5
Lymantriidae		<i>Dasychira plagiata</i> (Wlk.)				1		
Tussock Moths		<i>Dasychira vagans</i> (B. & McD.)	1	1	1		2	4
Noctuidae- Hemminiinae		<i>Bleptina caradrinalis</i> Gn.		5		1	10	
Owlet Moths or Cutworms		<i>Chyloita petraealis</i> Grt.		1				1
		<i>Idia aemula</i> Hbn.		2			4	3
		<i>Idia americalis</i> (Gn.)	8	76	40	81	25	62
		<i>Idia lubricalis</i> (Gey.)	2	2	1	1	5	7
		<i>Phalaenophana pyramusalis</i> (Wlk.)			1			
		<i>Zanclognatha jecchusalis</i> (Wlk.)	5	22	18	5	87	16
		<i>Zanclognatha</i> Led. sp.					1	
Hyperinae		<i>Bomolocha baftimoralis</i> (Gn.)			2		3	1
		<i>Sparganoma sexpunctata</i> Grt.	6	2	3	1	7	6
Catocalinae		<i>Argyrostris anilis</i> (Drury)					1	
		<i>Catocola sordida</i> Grt.		2			1	1
		<i>Catocola ultronia</i> (Hbn.)			3			
		<i>Drasteria adumbrata</i> (Behr.)	10	13	4	69	17	9
		<i>Pangrapta decoralis</i> Hbn.		6	3	1		
		<i>Perellela bistriens</i> Hbn.		2	5		1	
		<i>Scoliopteryx libatrix</i> (L.)		1				
		<i>Zale aeruginosa</i> (Gn.)	5			7		
		<i>Zale lunata</i> (Drury)	4	1				
		<i>Zale lunifera</i> (Hbn.)				1		
		<i>Zale unilineata</i> (Grt.)	1			3		
Plusiinae		<i>Anagrapha faicifera</i> (W. Kby.)		1				
		<i>Autographa ampla</i> (Wlk.)					2	
		<i>Autographa meppe</i> (G. & R.)				1		1
		<i>Chrysenympha formosa</i> (Grt.)	1	1	1		2	1
		<i>Plusia putnami</i> Grt.				1		
		<i>Syngrapha epigeae</i> (Grt.)		1		2		1
		<i>Syngrapha octoscripta</i> (Grt.)			1		1	
		<i>Syngrapha microgramma</i> (Hbn.)				1		
		<i>Syngrapha viridisigma</i> (Grt.)	1					1
Serotripinae		<i>Baileya ophthalmica</i> (Gn.)	1			1	1	
Pantheinae		<i>Panthea pallescens</i> McD.		1				1
		<i>Raphia frater</i> Grt.	11	4	2	8	4	2
Acronictinae		<i>Acronicta americana</i> (Harr.)		1	1		2	2
		<i>Acronicta dactylina</i> Grt.	5	17	3	5	9	14
		<i>Acronicta fragilis</i> (Gn.)			1			
		<i>Acronicta funeralis</i> G. & R.	1					
		<i>Acronicta hesta</i> Gn.	2			1	2	
		<i>Acronicta grisea</i> Wlk.	1	8	5	3	6	4
		<i>Acronicta haesitata</i> (Grt.)	1	1				
		<i>Acronicta impressa</i> Wlk.	1	6		2	1	
		<i>Acronicta innotata</i> Gn.				1	4	3
		<i>Acronicta quadrata</i> Grt.		1		2		
		<i>Acronicta sperata</i> Grt.		1		3		
		<i>Acronicta superans</i> Gn.		3	3		1	
		<i>Acronicta tritona</i> (Hbn.)		1				
		<i>Agripodes fallax</i> (H.-S.)			1			1
		<i>Hemisemna trisignata</i> (Wlk.)					1	
Amphipyriinae		<i>Achatodes zeeae</i> (Harr.)					1	

Appendix 1 cont'd.

Family	Subfamily	Species	BURNS			CUTS				
			RhB	RBS	RBN	RhC	RCE	RCW		
Amphipyrtinae cont'd		<i>Andropolia contracta</i> (Wlk.)	4							
		<i>Apamea commoda</i> (Wlk.)		1		5				
		<i>Apamea dubitans</i> (Wlk.)		1			1	1		
		<i>Apamea sordens</i> (Hufn.)						1		
		<i>Apamea impulsa</i> (Gr.)				1				
		<i>Apamea remissa</i> (Hbn.)						1		
		<i>Apamea verbascoides</i> (Gn.)		2						
		<i>Bellura obliqua</i> (Wlk.)		1		2				
		<i>Callopietra cordata</i> (Ljungh)	21	217	132	4	72	94		
		<i>Chytonix palliatricula</i> (Gn.)	18	42	23	12	21	24		
		<i>Dypterygia rozmani</i> Berio		2		1	3	2		
		<i>Euplexia benesimilis</i> McD.		6	4		3	3		
		<i>Hyppa nr. xylinoides</i> (Gn.) ^a	1	5	1					
		<i>Phlogophora iris</i> Gn.	1	9	2	1	12	6		
		<i>Phlogophora periculosa</i> Gn.	1	2	1	1		6		
		<i>Proxenus miranda</i> (Gr.)	18	22	32	22	8	10		
		Cucullinae		<i>Apharetra dentata</i> (Gr.)		3	3	2		1
				<i>Cucullia florea</i> Gn.		2	1		1	
		Hadeninae		<i>Aletia oxygala</i> (Gr.)				1		
<i>Crocigrapta normani</i> (Gr.)	2					1				
<i>Lacanobia radix</i> (Wlk.)				3		1				
<i>Lacanobia subjuncta</i> (G. & R.)				1			1			
<i>Lacinipolia anguina</i> (Gr.)	14			16	2	24	2	1		
<i>Lacinipolia lorea</i> (Gn.)	1			6	5	3	10	2		
<i>Lacinipolia lustralis</i> (Gr.)	11			9	14	16	3	3		
<i>Lacinipolia olivacea</i> (Morr.)				3		1	1	1		
<i>Lasionycta albinuda</i> (Sm.)	14			25	7	26		6		
<i>Leucania probably multilinea</i> Wlk.	1			1		2				
<i>Melanchnra adjuncta</i> (Gn.)				7	4		6	4		
<i>Melanchnra assimilis</i> (Morr.)				7		1	4			
<i>Orthodes cynica</i> Gn.	84			169	128	27	282	129		
<i>Orthosia revicta</i> (Morr.)	1				1	1		1		
<i>Papestra quadrata</i> (Sm.)	2			1		4	2			
<i>Polia detracta</i> (Wlk.)	10			71	36	32	24	13		
<i>Polia imbrifera</i> (Gn.)				34	6		10	6		
<i>Polia nimbose</i> (Gn.)							3			
<i>Polia purpurissata</i> (Gr.)	14			23	8	6	7	11		
<i>Protorthodes oviduca</i> (Gn.)	78			95	74	61	112	100		
<i>Pseudeletia unipuncta</i> (Haw.)								1		
<i>Sideridis meryx</i> (Gn.)				14	3	1	4	1		
<i>Sideridis rosea</i> (Harv.)	2			1		2	6	4		
<i>Spiramater lutra</i> (Gn.)	2			13	4		3	2		
<i>Spiramater grandis</i> (Gn.)	9			11	5	5	19	4		
<i>Trichordestra tacoma</i> (Stkr.)						1		1		
<i>Ulolonche modesta</i> (Morr.)				1		2				
Noctuinae		<i>Agrotis obliqua</i> (Sm.)	23	3	6	2	8	1		
		<i>Agrotis volubilis</i> Harv.				1	2			
		<i>Anaplectoides prasina</i> ((D. & S.))		7			6			
		<i>Anaplectoides pressus</i> (Gr.)		1	1					
		<i>Aplectoides condita</i> (Gn.)		3	2			2		
		<i>Coenophila opacifrons</i> (Gr.)		1				2		
		<i>Cryptocala acadensis</i> (Bethune)	1			2				
		<i>Darsia rubifera</i> (Gr.)	1	1	1	1	1	1		
		<i>Euagrotis forbesi</i> Franc.						1		
		<i>Eueretagrotis attenta</i> (Gr.)	6	52	28	2	8	23		
		<i>Eueretagrotis perattenta</i> (Gr.)		4	5		1			
		<i>Eurois astricta</i> Morr.	8	25	6	3	6	15		
		<i>Eurois occulta</i> (L.)		3			1			
		<i>Euxoa comosa</i> (Morr.)					2	3		
		<i>Euxoa divergens</i> (Wlk.)	1	1			1			
		<i>Euxoa mimallonis</i> (Gr.)					1			
		<i>Euxoa quebecensis</i> (Sm.)				1				
		<i>Euxoa scholastica</i> McD.					1	1		
		<i>Feltia henili</i> (Gr.)					2	1		
		<i>Heptagrotis phyllophora</i> (Gr.)	4	26	14	4	5	4		
		<i>Ochropleura plecta</i> (L.)	1	4			2	4		
		<i>Peridroma saucia</i> (Hbn.)			1					
		<i>Protolampra rufpectus</i> (Morr.)	1	3			1	3		
<i>Rhynchagrotis brunneipennis</i> (Gr.)		1								
<i>Trichosilia geniculata</i> (G. & R.)				4						
<i>Xestia nr. bedcolli</i> (Gr.) ^b				1						
<i>Xestia normani</i> (Gr.)	5	6	15	3	8	14				
<i>Xestia obliata</i> (Morr.)	1	17	7	1	3	2				
<i>Xestia smithii</i> (Snell.)	2	3	4		1	5				
<i>Xestia youngii</i> (Sm.)			1							
Heiothinae		<i>Pyrrhia experimentis</i> (Wlk.)		1		4	4			
Number of species			131	171	113	143	150	132		
Number of individuals			1157	1925	968	959	1442	1054		

^a *Hyppa near xylinoides* is an as yet un-named species similar to *Hyppa xylinoides* (D. Lafontaine, Canadian National Collection, Ottawa, pers. comm.)

^b *Xestia near bedcolli* will be named *X. praevia* (D. Lafontaine, Canadian National Collection, Ottawa, pers. comm.)

Appendix 2. Number of adult moth species found in two different mature forests on one night each in Sudbury Dist., Ontario during 1997. Forest #1 is jack pine-deciduous; trapped July 6. Forest #2 is pure jack pine; August 2. Bold type species were those found only in mature forest and not in recently disturbed forests.

Forest # 1			Forest # 2			
Family	Species	Number	Family	Species	Number	
Geometridae	<i>Cyclophora pendulinaria</i>	1	Geometridae	<i>Scopula frigidaria</i>	3	
	<i>Scopula frigidaria</i>	2		<i>Scopula junctaria</i>	5	
	<i>Spargania</i> spp.	4		<i>Scopula limboundata</i>	1	
	<i>Cabera variolaria</i>	2		<i>Eulithis explanata</i>	69	
	<i>Caripeta divisata</i>	2		<i>Eulithis serrataria</i>	2	
	<i>Euchlaena johnsonaria</i>	1		<i>Hydria undulata</i>	1	
	<i>Euchlaena madusaria</i>	2		<i>Anacamptodes humaria</i>	8	
	<i>Euchlaena obtusaria</i>	1		<i>Campaea perlata</i>	2	
	<i>Itame brunneata</i>	1		<i>Itame pustularia</i>	2	
	<i>Macaria signaria</i>	2		<i>Macaria signaria</i>	4	
	<i>Metanema determinata</i>	1		<i>Nematocampa resistaria</i>	18	
	<i>Pero honestaria</i>	6		Noctuidae	<i>Idia americalis</i>	3
	<i>Probole amicaria</i>	1		<i>Zanclognatha jacchusalis</i>	3	
	<i>Xanthotype sospeta</i>	1		<i>Chrysanympa formosa</i>	1	
	<i>Xanthotype urticaria</i>	1		<i>Panthea pallescens</i>	1	
	Sphingidae	<i>Smerinthus jamaicensis</i>		1	<i>Apharetra purpurea</i>	3
		<i>Sphinx gordius</i>		7	<i>Leucania prob. multilinea</i>	2
Notodontidae	<i>Heterocampa biundata</i>	1	<i>Aplectoides pressus</i>	1		
	<i>Nadata gibbosa</i>	4	<i>Eueretagrotis attenta</i>	11		
Arctiidae	<i>Spilosoma congrua</i>	4	<i>Heptagrotis phyllophora</i>	1		
Noctuidae	<i>Idia americalis</i>	5	<i>Xestia normaniana</i>	1		
	<i>Bomolocha baltimoralis</i>	1	<i>Xestia nr. badicollis</i> *	1		
	<i>Pangrapta decoralis</i>	1				
	<i>Autographa mappa</i>	1				
	<i>Panthea acronyctoides</i>	1				
	<i>Orthodes cynica</i>	10				
	<i>Diarsia jucunda</i>	1				
	<i>Heptagrotis phyllophora</i>	8				

* *Xestia nr. badicollis* to be named *X. praevia* (D. Lafontaine, Canadian National Collection, Ottawa, pers. comm.)