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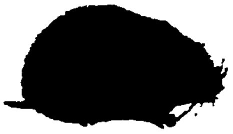
THE IMPACT OF ALTERNATIVE HARVESTING PRACTICES ON THE SMALL MAMMAL COMMUNITY IN AN ONTARIO BOREAL MIXEDWOOD FOREST

By : Carrie-Lee Hutchison



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ABSTRACT

Hutchison, C. 1997. The Impact of Alternative Harvesting Practices on the Small Mammal Community in an Ontario Boreal Mixedwood Forest. 142 pp. Advisor: Dr. A.R. Rodgers.

Key Words: biodiversity, boreal mixedwoods, ecosystem management, forest edge, integrated resource management, silvicultural systems, small mammal community, timber harvest methods, wildlife.

During the current project four studies were conducted to determine the effect of alternative silvicultural systems, and harvesting methods on the small mammal community of a boreal mixedwood forest in northern Ontario. In the first study (Chapter 1) pitfall and livetrapping were used to monitor the small mammal community in uncut forest, on lands harvested under the clearcut and shelterwood silvicultural systems, and at the edge of these harvest treatments. Livetrapping was used during the second study (Chapter 2) to monitor the effect of different harvesting methods on the small mammal edge community of clearcut and shelterwood cut areas. The third study (Chapter 3) investigated how small mammals used the treated and untreated side of livetrapping grids at the edge of all six timber harvest treatments, and in uncut forest. Finally, during the fourth study (Chapter 4) radio-telemetry was used to investigate the response of *Peromyscus maniculatus* (deer mice) to several timber harvest treatments.

Differences in the small mammal communities associated with the harvest treatments were noted during all four studies. For instance, the first study revealed that the number of *Clethrionomys gapperi* (southern red-backed voles) was lower, and the number of *Glaucomys sabrinus* (northern flying squirrel) captures was higher at clearcut edges than at shelterwood edges and in controls by the second year after timber harvest. The second study found a higher number of *G. sabrinus* captures at the edge of full-tree clearcuts than at tree-length clearcuts and on controls in the second post-harvest year. The third study revealed that *C. gapperi* and *P. maniculatus* utilized harvested edges differently. And the fourth study revealed differences in the way habitat was used by *P. maniculatus* on clearcut, shelterwood, and control treatments.

These studies revealed that applying different silvicultural systems and harvesting methods can influence the small mammal community. Since small mammal species responded to the harvest treatments differently, it follows that foresters will need to implement a variety of silvicultural systems and harvest methods within boreal mixedwood forests if conservation of small mammal species diversity in these areas is of concern. Some species, such as *Phenacomys intermedius* (heather voles), *Sorex hoyi* (pygmy shrews), and *Glaucomys sabrinus*, were more common in this mixedwood forest than expected so they could be of particular importance in boreal mixedwood management.

The variability in species abundance observed among the replicates used during this work demonstrates the importance of replicating the timber harvest treatments being investigated during such projects. The conclusions from this research could have been much different if treatments had not been replicated. Also demonstrated was the importance of using several different trapping methods when assessing the abundance, richness, diversity and composition of small mammal species in a community as some species were captured by only one trapping method during this project.

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ACKNOWLEDGEMENTS

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Dr. A.R. Rodgers, my supervisor, has had the most substantial influence on my work since that time. I thank him for having the faith to take me as his graduate student and for always finding time for me when I felt I needed instruction or assistance. I also thank him for his patience, and friendship. He has spent many hours proof reading earlier drafts of this document and his suggestions have greatly improved its quality.

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INTRODUCTION

In recent years wildlife management strategies have shifted from a single species to a multiple species, or ecosystem approach. This has resulted largely from increased public awareness about the importance of biodiversity on ecological, economical, cultural, ethical, and aesthetic grounds (Noss 1990; McMinn 1991; Olsson 1991; Boyle 1992). Non-timber oriented forest uses have also emerged as an important consideration in forest resource management (Anonymous 1992; OFPP 1993). As a result, forest managers must now consider the recreational, wildlife, and spiritual demands on a forest, as well as forest biodiversity, while developing timber management plans. This process, known as integrated resource management, has been recommended by many recent Canadian government advisory and policy documents where it is often strongly associated with the concept of sustainable resource use, or sustainable development (WMCC 1990; OWWG 1991; Anonymous 1992; OFPP 1993; BCO 1995).

Although the exact wording for the definition of biodiversity given in government policy and advisory documents varies, the word is generally defined, either directly or indirectly, as a term representing ecosystem variability at the genetic, species, and landscape levels (WMCC 1990; OWWG 1991; Anonymous 1992; OFPP 1993; BCO 1995). In this definition, the term ecosystem is paramount to understanding biodiversity. Ecosystems can be divided into three components: their composition, structure, and function (Noss 1990). Ecosystem composition refers to the variety of genes, species, or landscapes within an area of concern. Ecosystem structure includes horizontal and vertical spatial patterns of organization at the genetic, species and landscape levels. Finally, ecosystem function encompasses the processes and mechanisms by which an ecosystem operates and can include evolution, gene flow, colonisation, and nutrient and hydrological cycling (Noss 1990; Fleming and Aagaard 1993; BCO 1995).

Considering the wide breadth of concepts encompassed in the term biodiversity, it is easy to understand why there is no single measure capable of describing all aspects of biodiversity at once. In fact, scientists in different regions and countries often measure biodiversity differently, making comparisons among studies and through time extremely difficult if not impossible (Fleming and Aagaard 1993). It is also evident that measuring all the components of biodiversity requires expertise and techniques from many scientific disciplines. Since it is difficult to organize scientists from so many disciplines in any particular study, biodiversity is usually investigated by different scientists, one component at a time, and at one level at a time.

The compositional component of biodiversity at the species level, species diversity, is probably the easiest part of biodiversity to understand. Begon *et al.* (1990) and Boyle (1992) define species diversity as the number and relative frequency of different species in a community and this definition has been adopted throughout the current document. Species diversity is often described by a diversity index (Magurran 1988). Numerous diversity indices are available and they vary in their sensitivity to changes in species richness, and species evenness (Ludwig and Reynolds 1988; Magurran 1988). Species richness is the total number of species in the community, and species evenness describes how evenly distributed abundance data, or the number of individuals, are among those species (Ludwig and Reynolds 1988). The choice of diversity index used may depend on certain functions and criteria such as the ability to discriminate between study sites, dependence on sample size, what component of diversity is measured, and whether the index is widely used, understood, and accepted (Magurran 1988).

Caution is advised when comparing communities by their species richness and diversity indices alone because the species composition, or the actual species in a community, can change without changes in these two measures. This occurs when eliminated species are replaced by new species such that the new species compose the same percentage of the community as the eliminated species once did. As a result of this complication, comparing lists of species present in the areas being compared is worthwhile and should complement community comparisons made with species richness and diversity measures (Kirkland 1990).

Measurements of species similarity as outlined in Krebs (1989) may also assist researchers in detection of communities that have different species compositions. However, like species richness and diversity indices, species similarity measurements do not indicate which species were absent, or less common, in one community than in another. As such, comparison of species composition lists for each community is still advisable when similarity indices are used to compare communities.

Loss of habitat quality, which is the ability of a habitat to contribute to the reproduction and survival of a species (Krohn 1992), is presently considered the main reason for decreases in species richness and diversity (Morrison *et al.* 1992; Noss 1991). Relating species density to habitat survey data is one method used to determine which habitat features are important for conservation of habitat quality for any particular species. This method assumes that higher densities signify better habitat quality, but this assumption has been severely criticized by those who believe realized population densities are more closely related to the ability of animals to disperse and detect new habitats than to habitat structure characteristics (Hobbs and Hanley 1990). Forest fragmentation is one example of a process that can prevent a species from discovering or using prime habitat areas. The term "forest fragmentation" refers to the break-up of large continuous mature forests into smaller isolated or semi-isolated remnants that are separated by habitat types which are either temporarily, or constantly inhospitable for interior forest species (Bennett 1990; van Apeldoorn *et al.* 1992; Rajska-Jurgiel 1992; Kozakiewicz 1993; Diffendorfer *et al.* 1995). Of the processes that can affect habitat quality, forest fragmentation has been cited by several scientists as the most serious (Harris and Scheck 1991; Noss 1991; Morrison *et al.* 1992; Kozakiewicz 1993).

Forest fragmentation can degrade habitat quality for interior forest species by changing the distribution and type of food and shelter available, the number as well as the hunting success or infection rate of predators and parasites, and the microclimate of the area. As a result, these species may be deprived of the opportunity for safe movement between important areas, such as winter and summer ranges, of the previously un-fragmented forest (Harris and Scheck 1991; Kozakiewicz 1993). Harvest operations may also remove critical features needed by a species for successful breeding and the rearing of offspring such as courtship display logs used by grouse, mineral licks used by ungulates, and nesting trees used by many birds. Finally, forest fragmentation can decrease the rate of gene flow between metapopulations, which are subpopulations occupying partially isolated remnant forest patches, resulting in less genetic variability and reduced long term viability for interior forest species (Bennett 1990; van Apeldoorn *et al.* 1992; Rajska-Jurgiel 1992; Kozakiewicz 1993; Diffendorfer *et al.* 1995).

Unlike interior forest species, forest fragmentation enhances habitat quality for species which are disturbance tolerant (Kirkland 1990; Harris and Scheck 1991; Kozakiewicz 1993). These species may be adapted to open areas, or to the forest edge. In 1933, Aldo Leopold introduced the concept of "edge effects" in his textbook on wildlife management by noting an increase in the density and species diversity of animals at habitat boundaries. He attributed this phenomenon to the simultaneous access species in edge habitats have to more than one environment. Since then, the concept of edge effects has become widely accepted (Sekgororoane and Dilworth 1995). Unfortunately this concept overlooks the disastrous outcome creation of edge habitats can have for internal forest species (Harris and Scheck 1991; Kozakiewicz 1993). A paradox exists when species diversity and edge habitat are examined because introducing edge habitat initially increases species diversity of an area once covered by mature forest, but decreases species diversity of the region if internal forest species are subsequently eliminated (Harris and Scheck 1991). The most successful conservation strategy will satisfy the requirements of both internal forest and disturbance tolerant species. In areas of recent timber harvest it is often easier to satisfy the needs of disturbance tolerant species than of internal forest species, so foresters and wildlife managers must find ways to make timber harvest less intrusive for the latter during the process of ecosystem management.

There are several strategies forest managers can use to alter harvesting practices in order to alleviate the associated problems faced by interior forest species. One option is to decrease the differences found in habitat between clearcut and uncut forest, the "hard edge", so interior forest species can use more of the harvested land. Creation of softer, or more permeable, edges can be accomplished by decreasing cut intensity on the sides of the harvested area, also known as "feathering", or on the entire cut stand (Stamps *et al.* 1987). Changing harvest intensity is not the only option available to forest managers. They can also alter the time, shape, size or position of clearcuts in accordance with the requirements of the internal forest species concerned. This may require harvesting at a specific time of year to avoid the breeding season, leaving features of importance to the species in cut areas by altering cut size, shape, position, and the equipment or harvesting method used during timber extraction (Anonymous 1988).

Uncut strips of land, or "corridors", have been used by forest managers in an attempt to maintain the diversity and movement patterns of "featured species" within clearcut areas (Anonymous 1988; OWWG 1991; Anonymous 1992; Ruefenacht and Knight 1995). A corridor is any linear feature of vegetation that differs from surrounding vegetation and which connects at least two habitat patches that were once continuous habitat (Hobbs 1992). When placed around lakes, streams, roadways and on ridges or hilltops, corridors have the added benefit of reducing soil erosion, contributing to aesthetic beauty, and consequently to the recreational opportunities in or around a harvested area (Bacon 1995; O'Laughlin and Belt 1995).

Research into the effect of corridors on wildlife has been largely focused on "featured species" such as the commercially valuable moose, deer, and bear (Harris and Atkins 1991; Anonymous 1988; Corn *et al.* 1988; Gibbons 1988; Szaro 1988). These species tend to be disturbance tolerant because they often find their food in cleared areas, however, they also require the shelter that corridors can provide (Anonymous 1988). Although this aspect of corridor use is important, understanding the effect corridors have on non-commercial species is also essential to ecosystem management (Beier and Loe 1992).

During the era of featured species management it was often argued that addressing the needs of the larger "featured species" would in itself ensure that the needs of most smaller, non-commercially important species were met, however, this is not the case because larger animals can traverse a corridor more quickly than smaller animals (Merriam 1991). The difference in the time required for a large and a small animal species to traverse a corridor can be substantial ranging from several hours for the large animal, to several days or even generations for the smaller animal species. As a result of this difference, fewer life history requirements for large animals must be met by corridors in order to ensure their survival during the traverse than for the smaller animal species (Merriam 1991; Beier and Loe 1992).

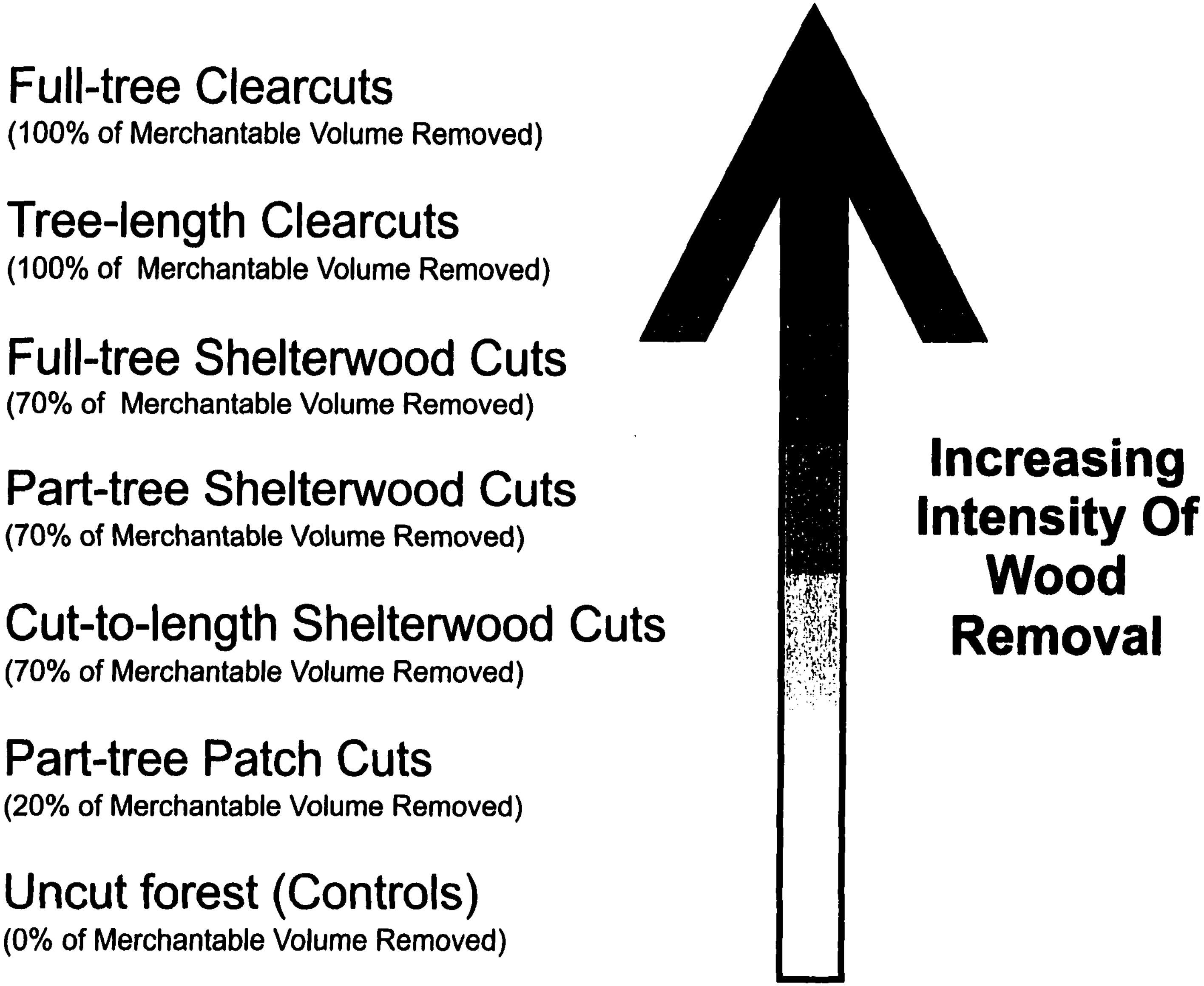
Small mammals such as *Peromyscus leucopus* (white-footed mice) and *Tamias striatus* (eastern chipmunk) have been shown to preferentially move along corridors in fragmented habitat (Hobbs 1992). It is also evident that some small mammal species such as *Clethrionomys gapperi* (southern red-backed vole), are most successful in mature forest interiors (Raphael 1988a; Mills 1995). Understanding how small mammal species react to the habitats created by timber harvest, and the associated wildlife conservation measures would undoubtedly be beneficial for ecosystem based management planning.

Small mammals are important to the forest ecosystem because they disperse seeds and mycorrhizae, contribute to soil mixing and aeration processes, ingest insects, seeds, and plants, and are a food source for many other wildlife species (Martell and Macaulay 1981; Kirkland

1985; Jenson and Nielson 1986; Bergeron and Jodoin 1994; Cazares and Trappe 1994; North and Trappe 1994). Despite their obvious importance to the forest ecosystem, the reaction of small mammals to timber harvest and wildlife conservation practices remain largely unknown and unstudied (Martell 1983; Gibbons 1988; Beier and Loe 1992; LeMay *et al.* 1992). Research that focuses on how small mammal species react to the edge habitat created by forested corridors is of particular importance since corridor use is currently a widespread means of incorporating the needs of wildlife species on recently harvested land (Beier and Loe 1992).

Managers of Ontario boreal mixedwood forests in particular are encouraged to use corridors to incorporate the needs of a multitude of forest users in their management plans (Anonymous 1988; Scarratt 1996). This is largely because boreal mixedwood forests generally occupy the most fertile forested land in the boreal forest region and cover approximately 50% of the productive forest land in Ontario (Scarratt 1996). As such, these forests have the potential to be the most productive for both timber and wildlife resources. Also, the remoteness and aesthetic beauty of boreal mixedwoods encourages recreational uses such as fishing, camping, and hiking (Scarratt 1996).

Despite the ecological, and economical importance of mixedwood forests, few studies have investigated the effects of timber extraction on them and their small mammal communities (Martell and Radvanyi 1977; Martell 1983). As part of the Black Sturgeon Boreal Mixedwood Research Project, the present study involved monitoring small mammals at the edges of seven harvest treatments, which represent a gradient of timber removal, from two similar mixedwood stands in northern Ontario (Figure 1; Appendix 1). The edge habitats associated with these treatments covered a range of edge permeability from the hard edges found at the full-tree clearcut/forest interface, to any soft edges that may be found within uncut forests. Small mammals were monitored by livetrapping, pitfall trapping, and radio-telemetry.



Full-tree Clearcuts
(100% of Merchantable Volume Removed)

Tree-length Clearcuts
(100% of Merchantable Volume Removed)

Full-tree Shelterwood Cuts
(70% of Merchantable Volume Removed)

Part-tree Shelterwood Cuts
(70% of Merchantable Volume Removed)

Cut-to-length Shelterwood Cuts
(70% of Merchantable Volume Removed)

Part-tree Patch Cuts
(20% of Merchantable Volume Removed)

Uncut forest (Controls)
(0% of Merchantable Volume Removed)

Figure 1. Diagrammatic representation of wood removal intensities associated with the harvest treatments applied in 1993 at the Black Sturgeon Boreal Mixedwood Research Project.

Specifically, this study investigates four questions: 1) Are small mammal species abundance, diversity, richness, and composition in edge habitats affected by the intensity of timber extraction? 2) Are small mammal species abundance, diversity, richness and composition in edge habitats affected by the method used for timber extraction?, 3) Does the abruptness of the interface between harvested and un-harvested land influence how the small mammal edge community uses this habitat? 4) Are there differences in the movement patterns of *Peromyscus maniculatus* (deer mice) amongst the harvest treatments examined in this study, and do they suggest adequate dispersal for detection of areas with good habitat quality? Answers to these questions will assist both forest and wildlife managers with integrated resource management by enhancing their knowledge about the reactions of various small mammal species to a wide variety of harvest edge habitats. This will assist with timber management planning as it relates to ecosystem based management in boreal mixedwood forests.

SITE DESCRIPTION

The study area is composed of two stands situated on the Black Sturgeon Forest Management Agreement licence area (F.M.A.), (49°10'N, 88°45'W), of Avenor Incorporated, approximately 120 km northeast of Thunder Bay, Ontario (Figures 2 and 3). The closest long term weather station is at Cameron Falls, approximately 50 km east of the study site. This station reports an annual total precipitation of 826.3 mm, 599.1 mm of this falling as rain and the rest as snow, sleet, and hail (Environment Canada 1992). Average monthly temperature extremes occur in January and July and are -22.9°C and 24.9°C respectively (Environment Canada 1992).

The Black Sturgeon site has an average elevation of 290 m above mean sea level and is predominately a flat, till plain comprised of coarse to fine sands containing various amounts of cobbles and silt (Anonymous 1994). Erratics, which are large boulders set on the ground by glaciers, also occur in the area. Soils are generally slightly moist, well-drained and fertile (Scarratt 1996).

Before timber harvest in 1993, the area was covered with a second growth mixedwood forest overstorey dominated by *Populus tremuloides* Michx. (trembling aspen) and *Abies balsamea* (L.)Mill. (balsam fir). Other tree species present in the overstorey included *Picea mariana* (Mill.)B.S.P. (black spruce), *Picea glauca* (Moench) Voss (white spruce), *Betula papyrifera* Marsh. (white birch), *Pinus strobus* L. (eastern white pine) and *Pinus banksiana* Lamb. (jack pine). A previous harvest operation occurred between 1939 and 1942 which removed many of the larger pine from the area. As a result, both pine species were probably less extensive in 1993 than they were in the original forest (Scarratt 1996). Many large stumps left from the 1939-1942 harvest still cover the forest floor.

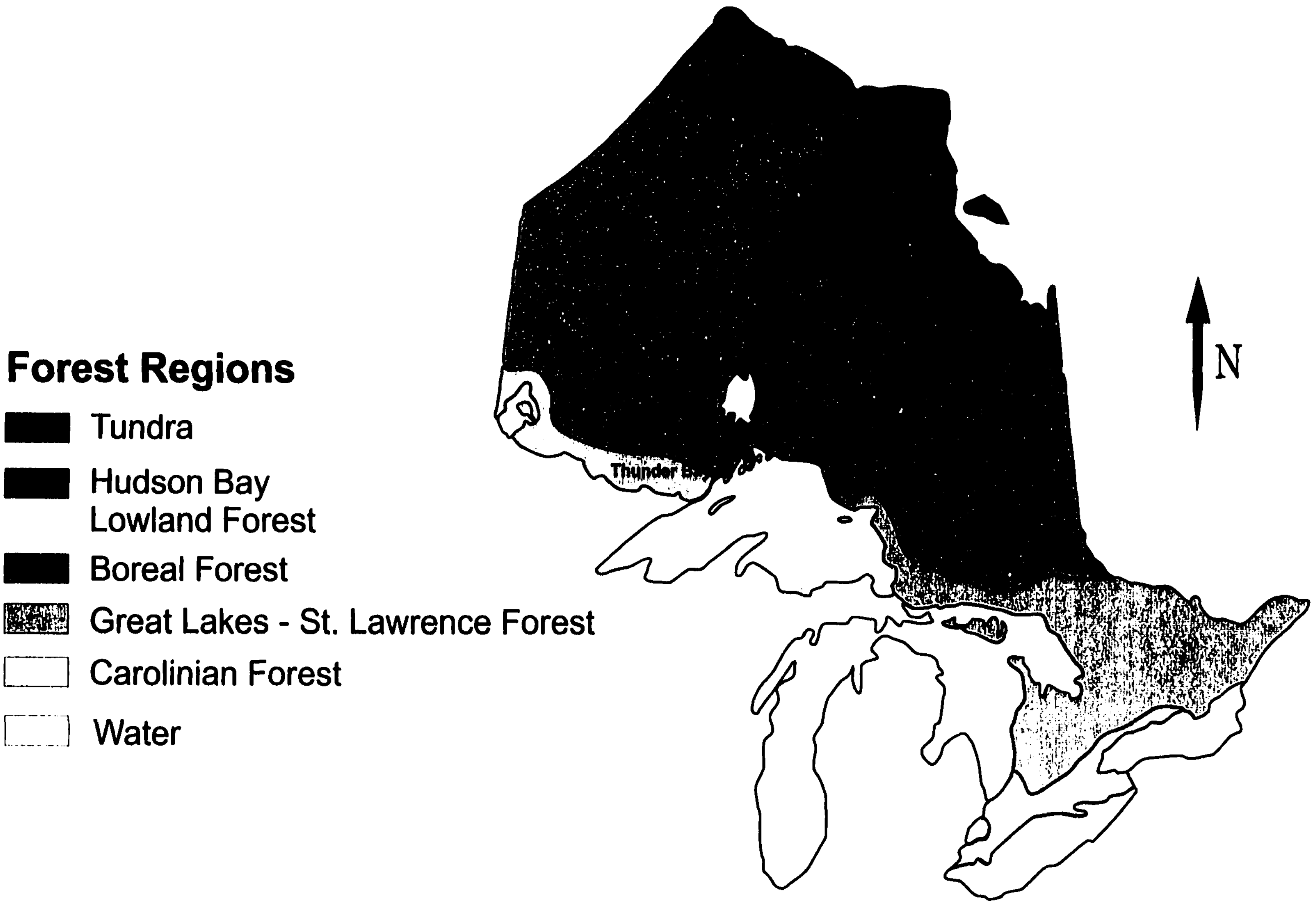


Figure 2. Map of Ontario showing the forest regions (Hosie 1990), Thunder Bay, and the Black Sturgeon Boreal Mixedwood Research site.

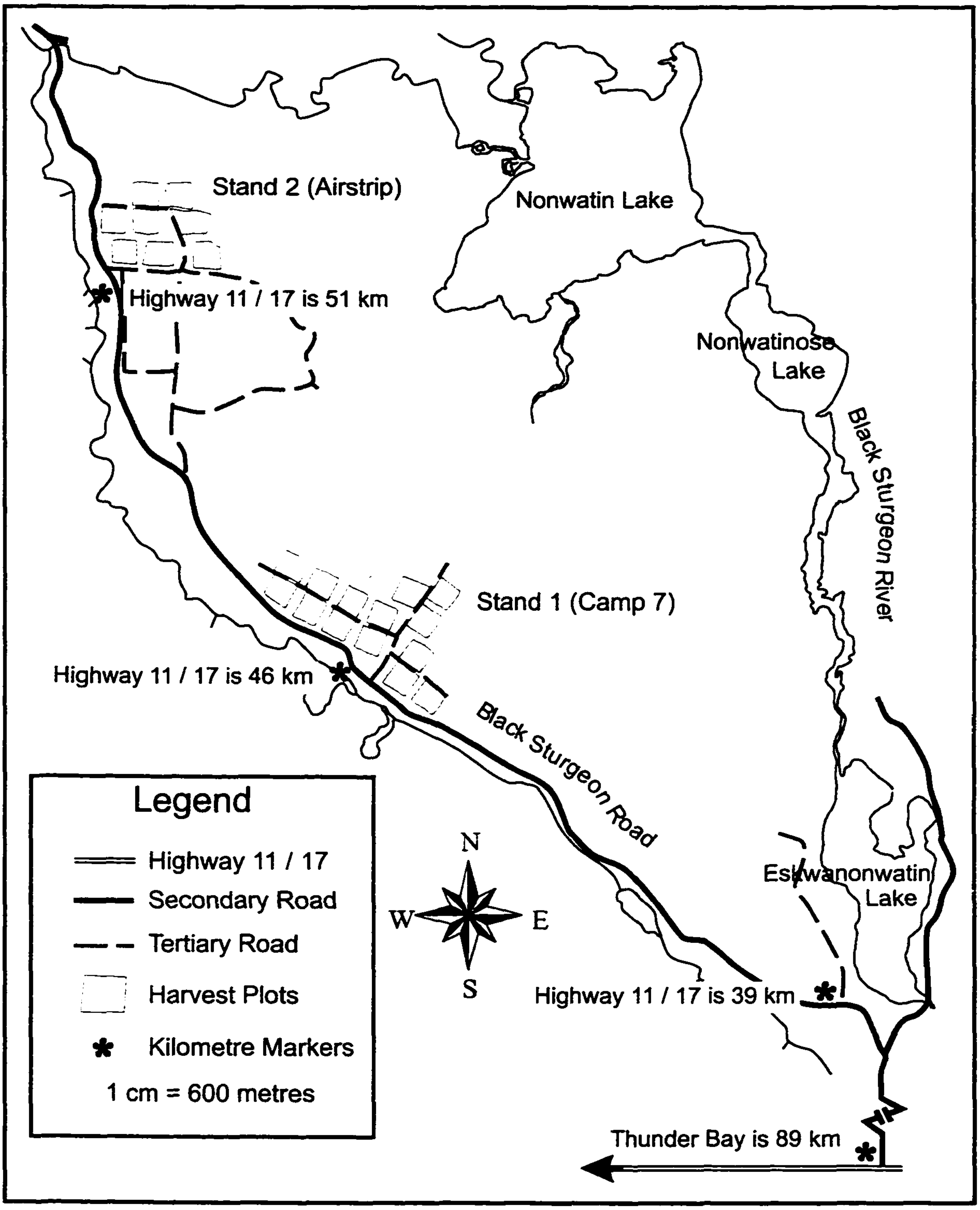


Figure 3. Positioning of the two harvest stands utilized for the Black Sturgeon Boreal Mixedwood Research Project relative to each other and to highway 11/17 to Thunder Bay, Ontario.

Severe *Choristoneura fumiferana* (Clem.) (spruce budworm) infestations have occurred on this study site three times since the beginning of the 1900's (Bichon 1996; Scarratt 1996; Blair 1985). The most recent outbreak occurred during the last 10 years and has largely prevented flower or seed production of *Picea glauca* and *Abies balsamea* during that time (Scarratt 1996). As a result of these *C. fumiferana* budworm infestations most of the overstorey coniferous trees are either dead or dying. As a consequence of the deteriorated overstorey, blow-down of single, or large groups of trees was common throughout this forest before the 1993 harvest. Subsequently the forest floor was log covered in many areas. Canopy openings have occurred as a result of these blow-downs and may have contributed to the vibrant shrub and herb growth evident in these stands.

In uncut areas, and before timber harvest, dominant shrub species included *Acer spicatum* Lam. (mountain maple), *Corylus cornuta* Marsh. (beaked hazel), *Cornus canadensis* L. (bunch berry), *Rubus* sp. (dwarf and wild red raspberry) and various species of *Lonicera* sp. (honeysuckle). Regeneration of canopy level species, mainly of *Abies balsamea*, was also evident in some areas. Ground cover consists largely of leaf litter and moss but some herb species such as *Linnaea borealis* L. (twinflower), *Pyrola* sp. (wintergreen), *Maianthemum canadense* Desf. (wild lily-of-the-valley), and *Clintonia borealis* (Ait.) Raf. (blue-beaded lily) were also present.

Regenerating vegetation present in cut areas was dependent on the cut treatment applied. Clearcuts began as predominantly bare land the first spring after harvest but were well covered with vegetation, mainly *Populus tremuloides* suckers, by the second post-harvest year. Shelterwood and patch cut areas retained more of the shrub component present in the original forest throughout both post-harvest years. However, *P. tremuloides* suckers were dominant as well by the second year after timber harvest in these areas.

FIELD PROCEDURES

Harvesting Techniques

Timber harvesting was conducted as part of the Black Sturgeon Boreal Mixedwood Research Project and occurred between September and December of 1993. Four harvesting methods were employed: full-tree, tree-length, part-tree and cut-to-length extraction (Appendix 1). One or several of these methods were used to remove either 0, 20, 70, or 100 percent of the merchantable timber volume from the twenty-one treatment areas of the study. The combination of these harvest methods and intensities created seven harvesting treatments which together represent a gradient of woody material removal (Figure 1).

Treatment areas were approximately square in shape and each one covered 10 ha (Figure 4). A 100 m wide strip of uncut forest was left between each harvest area to allow for separation of treatment effects. Each of the seven harvest treatments were randomly assigned to three of the twenty-one treatment areas (two in stand 1 and one in stand 2). Although the assignment of treatments in this project allows for stand 1 and stand 2 to be treated statistically as separate blocks, this was not done in the following analysis due to their similarity in habitat structure, and climate characteristics, as well as their close proximity. They were approximately 4 km apart (Figure 3). Although the part-tree shelterwood treatment was assigned to three treatment areas, it was replicated only twice due to the high cost of manual felling. Harvesting with all the other harvest treatments was completed as planned so that each was successfully replicated three times.

Mammal Trapping

General

Non-collapsible Sherman live traps, 7.6 cm X 7.6 cm X 25.4 cm, and Longworth live traps, 6.5 cm X 8.5 cm X 14.0 cm were used in this study. Both have been shown to capture many small mammal species including shrews, mice, voles, chipmunks, squirrels, and weasels

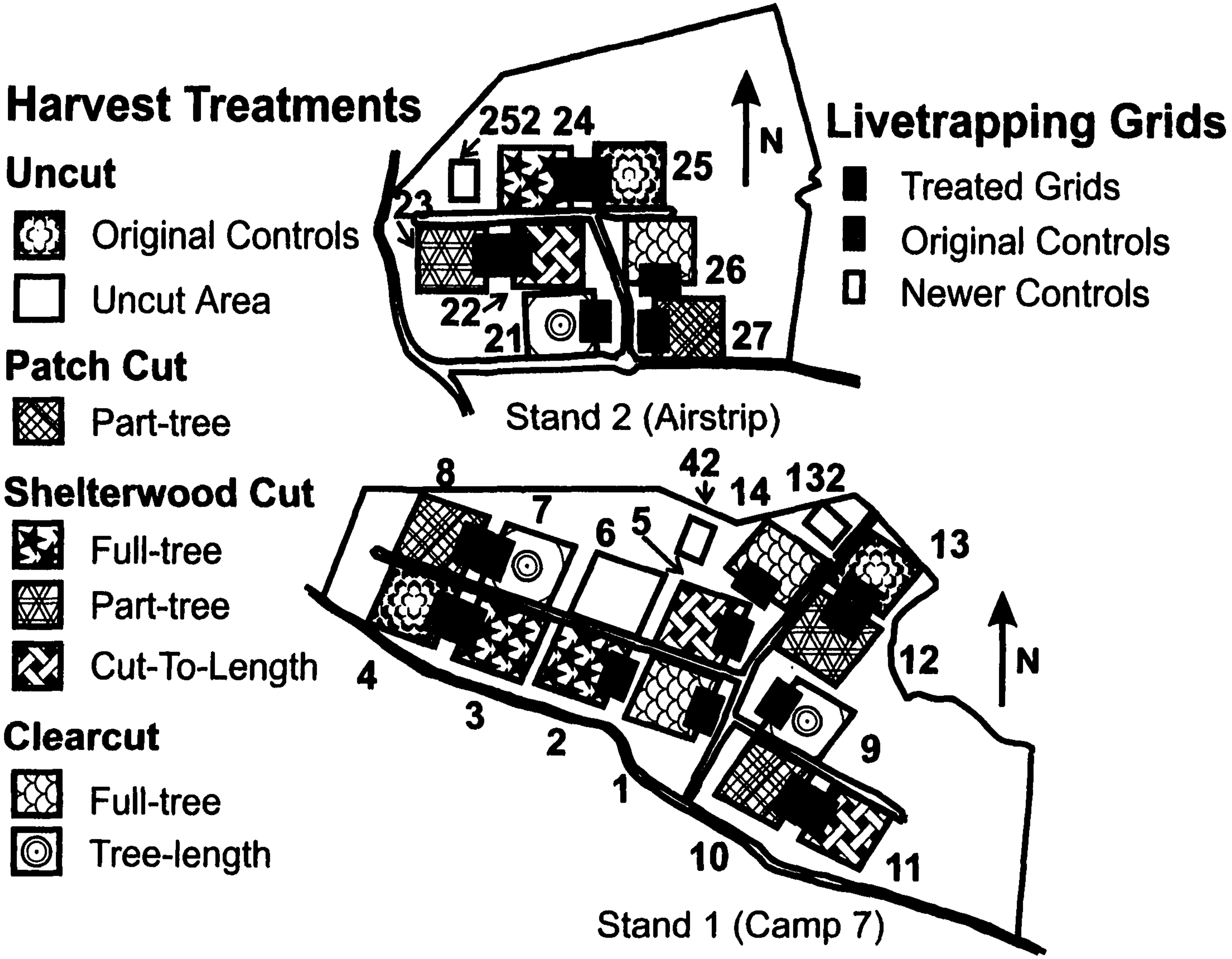


Figure 4. Positioning of the seven harvest treatments applied to the twenty-one 10 ha treatment areas in 1993 as well as the location and number assigned to livetrapping grids used to monitor small mammals during the pre-harvest (1993) and two post-harvest (1994 and 1995) years at the Black Sturgeon Boreal Mixedwood Research site.

(Morris 1968; Wiener and Smith 1972; Williams and Braun 1983; Slade *et al.* 1993). Small mammal specimens captured accidentally in pitfall traps used for a separate invertebrate study by Kevin Barber and Jan Addison of the Canadian Forest Service, were also made available for the current work. Although pitfall trapping occurred on only a subset of the treatment areas, this information was valuable because pitfall traps capture small mammal species that weigh <20 g more effectively than the live traps used in this study. Therefore, use of pitfall trapping data in the current study counteracts biases that are present when only livetrapping data are used (Block *et al.* 1988; Szaro *et al.* 1988).

Livetrapping

All livetrapping grids were 100 m wide and 200 m long, containing a total of 45 trapping stations with 25 m spacing. These grids covered 2 ha and were established at the edge of treatment areas in 1993 such that the centre of five columns was on the interface between the treated area and uncut forest (Figure 5). This resulted in the placement of two columns of each grid in the uncut forest and two other columns on the treatment area. Three control grids of the same shape and size were established in 1994 and located in the same forest stands, not less than 100 m from cut edges (Figure 4).

There were a total of twenty-three livetrapping grids in this study. These grids can be split into three groups: the treatment grids, the original control grids, and the newer control grids (Figure 4). One trap was located at each station and once in position was not moved until the trapping season of that year ended. The treatment grids, and the original control grids, were trapped with Longworth traps for one session in the fall of 1993 (Table 1). To determine if natural annual fluctuations in the small mammal community existed, the original controls continued to be trapped with the same methods and on approximately the same dates in 1994 and 1995. However, the treatment areas and the newer controls were each trapped for three sessions between the beginning of June and the end of August in 1994 and 1995.

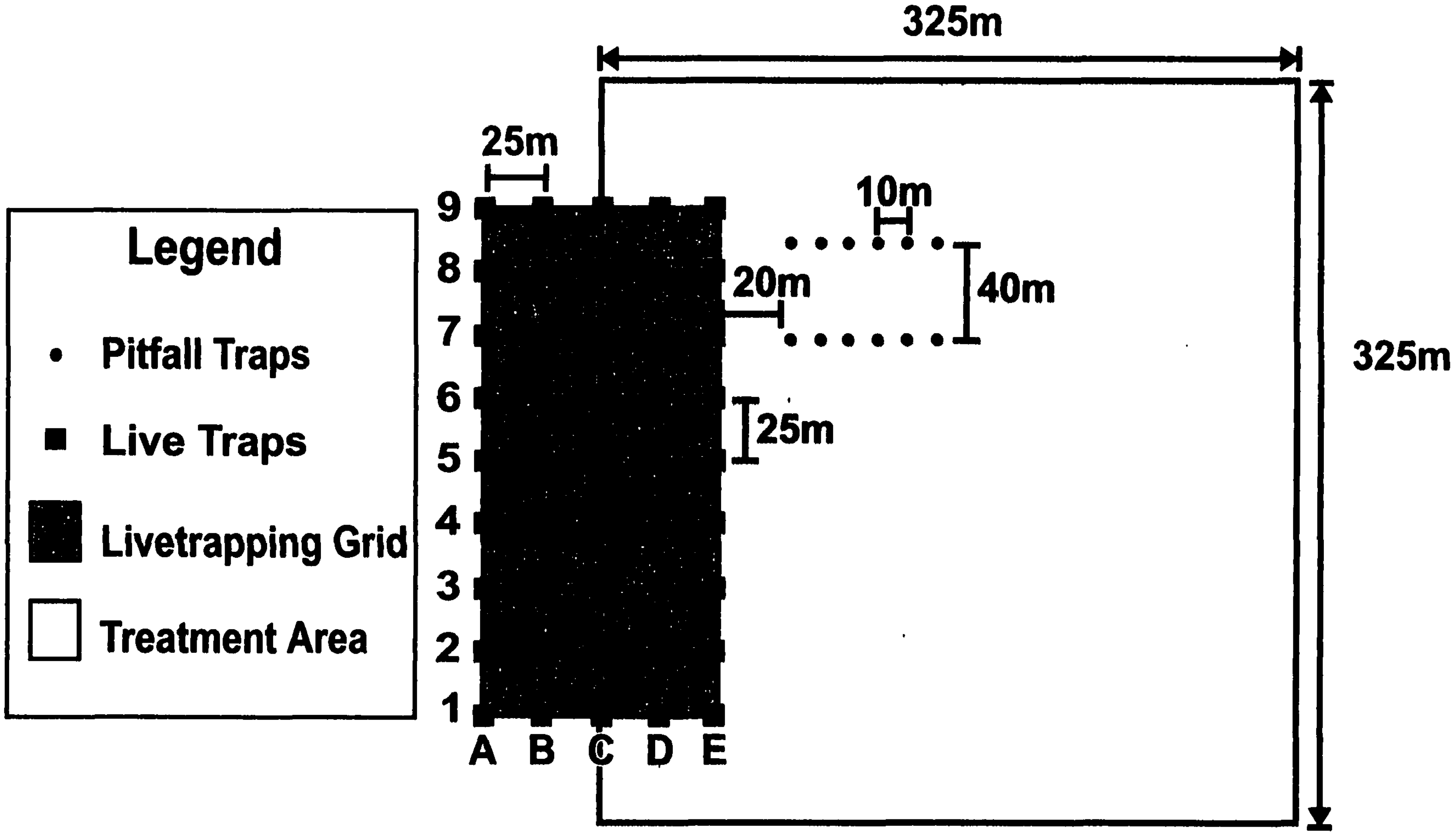


Figure 5. Placement of the livetrapping grids and the pitfall traps in relation to treatment areas and uncut forest during the three years (1993, 1994, and 1995) of small mammal monitoring at the Black Sturgeon Boreal Mixedwood Research site.

Table 1. Seasons and live trap types used to monitor the small mammal community on the three treatment grid groups during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) of research at the Black Sturgeon Boreal Mixedwood Research site.

Year	Trapping Time	Trap Type Used	Treatment Grid Groups		
			Original Control Grids	Harvested Grids	Newer Control Grids
1993	Fall	Longworth	●	●	
1994	Summer and Fall	Sherman		●	●
1994	Fall	Longworth	●		
1995	Summer and Fall	Sherman		●	●
1995	Fall	Longworth	●		

Each trapping session involved three days of pre-baiting, with whole oats and sunflower seeds, followed by three or four nights of trapping. If more than 40% of the animals caught on the third night of trapping had not been captured previously in that trapping session, then trapping was conducted on a fourth night. Two exceptions to this procedure occurred in 1993 when area 2 was trapped for a fifth night due to low recapture rates, and area 24 was trapped for only two nights due to commencement of timber harvest.

In addition to food, each trap was supplied with cotton bedding during trapping nights. Traps were locked open during the day for pre-baiting, and between trapping sessions, to avoid animal death from starvation, dehydration, or overheating. Upon capture, animals were marked with #1 National band ear-tags for later identification. The location, tag numbers, species, sex, sexual condition, and weight of each animal were recorded before release at the site of capture.

Pitfall Trapping

Invertebrate pitfall traps were placed on areas harvested with full-tree extraction (stand 1 areas 1, 2, 3, 14; stand 2 areas 24, 26), and controls (stand 1 areas 13, 4; stand 2 area 25) (Figure 6). Each trap line consisted of 12 pitfall traps arranged in two parallel rows of six. Trap lines were separated from each other by 40 m and traps within a line were spaced 10 m apart (Figure 5). Pitfall trap lines that accidentally caught the small mammals analysed in this study were located on treatment areas starting approximately 20 m from the small mammal livetrapping grids and ran perpendicular to them.

Each pitfall trap was set into the ground so that the top of the trap was even with ground level. Traps were covered with a plate to prevent large amounts of rain from entering and were filled with ethylene glycol to ensure a humane death to any organisms captured. In 1993 all traps were set for 14 days in the fall and examined once before timber harvest. In 1994 and 1995, all traps were examined seven times throughout the summer, once approximately every

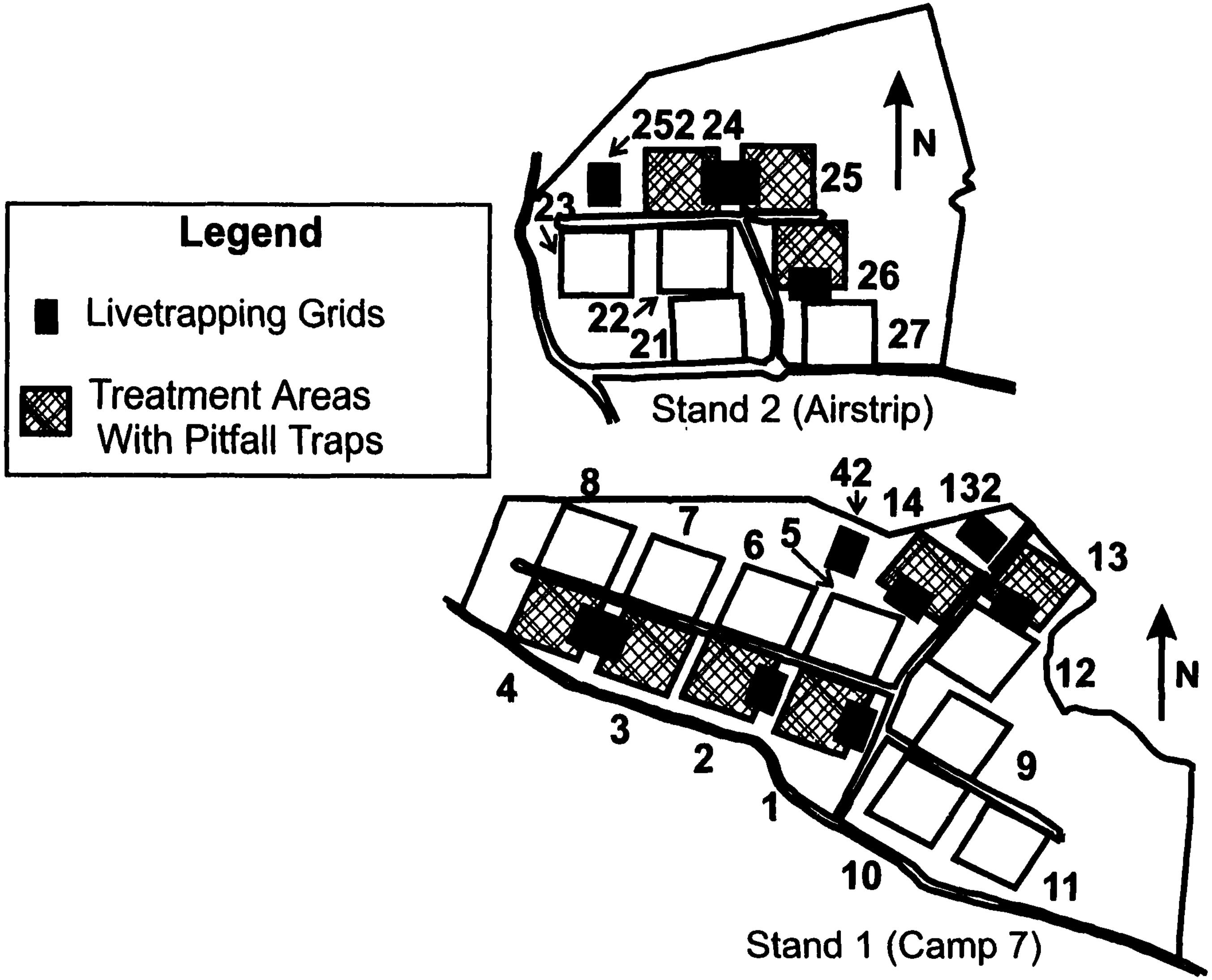


Figure 6. The treatment areas where pitfall trapping was conducted and the livetrapping grids used to monitor small mammals during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) of research at the Black Sturgeon Boreal Mixedwood Research site.

14 days between June and September. Any small mammals captured by these traps were recorded and preserved. Identification of these specimens was later conducted following van Zyll de Jong (1983), and Kurta (1995).

Mammal Tracking

Radio-collars (model MD-2C by Holohil Systems Limited, Woodlawn, Ontario, Canada) transmitting at individual frequencies between 164-168 MHz, were attached to adult *Peromyscus maniculatus* weighing 16 g or more in the summers of 1994 and 1995. In each year these collars were attached between early and mid July and were tracked, when weather permitted, during the next 11-36 days. Radio-telemetry receivers (model SRX-400 by Lotek Engineering Incorporated or model TR-4 by Telonics) in combination with either a three or four element hand held antenna, were used to locate the position of radio-collared mice during radio tracking. In 1995 radios were located in daylight hours only, however, in 1994 some telemetry work was also accomplished at night.

Twelve radio-collared mice were tracked in 1994 while in 1995 thirteen were tracked (Table 2). Radio attachment was conducted from July 8th to July 16th in 1994, and from June 30th to July 16th in 1995. Mice on grids of clearcut areas 1 and 14, shelterwood cut area 5, and control area 42 were radio-collared in both years. In addition, mice from control grid 132 were radio-collared in 1994 while in 1995 mice were radio-collared on shelterwood grid 2. Although both male and female mice were radio-collared in post harvest years, a much higher proportion of females were collared in 1995. This was in part a result of fewer captures of adult male mice during the radio attachment period of 1995. In 1994, six mice were tracked on harvested treatment areas, and on controls. In 1995, eight mice were tracked on harvested treatment areas, while five were tracked on controls.

Mouse positions were flagged immediately after they were located with radio-telemetry equipment. The habitat features associated with that location (Table 3), and the position of the location with respect to harvest treatments were also noted. The distance and direction of these

Table 2. Numbers of radio-collars attached to female and male *Peromyscus maniculatus* on each grid in each treatment during the two post-harvest years (1994 and 1995) of research at the Black Sturgeon Boreal Mixedwood Research site.

		Treatments						
		Controls		Shelterwood Cuts		Clearcuts		Totals
Year	Sex	Grid 42	Grid 132	Grid 2	Grid 5	Grid 1	Grid 14	
1994	Females	1	2		2	1	1	7
	Males		3		2			5
	Combined Totals	1	5		4	1	1	12
1995	Females	4		2	1	1	3	11
	Males	1			1			2
	Combined Totals	5		2	2	1	3	13

Table 3. Definitions of the habitat features associated with the day refuges of *Peromyscus maniculatus* located by radio-telemetry during the two post-harvest years (1994 and 1995) of research at the Black Sturgeon Boreal Mixedwood Research site.

HABITAT FEATURES	DEFINITIONS
Ground	An area of land with a diameter of at least 1.5 m having no obvious above ground features (such as logs, stumps, shrubs, and rocks). These could have exposed soil, moss, or a leaf litter covering.
Logs (decay class 1-2)*	These logs consisted of strong wood on the outside layers but could have wood rot well within the log. Logs were at least 1.5 m long and ≥ 5 cm in diameter and had to be resting directly on the ground at or above the position where the mouse was located with radio-telemetry.
Logs (decay class 3-5)	These logs consisted mainly of decayed wood material, even on the outside layers of the log. Logs were at least 1.5 m long and ≥ 5 cm in diameter and had to be resting directly on the ground at or above the position where the mouse was located with radio-telemetry.
Trees/snags (decay class 1-2)	These trees/snags were alive and healthy, to declining in health, or almost dead. Trees and snags were any woody vegetation ≥ 5.0 m in height and ≥ 5 cm in diameter at breast height (DBH)**.
Snags (decay class 3-5)	These snags were dead and decayed woody material, ≥ 5.0 m in height and ≥ 5 cm in diameter at breast height (DBH).
Stumps (decay class 1-2)	These stumps consisted of strong wood on the outside layers but occasionally had wood rot at the centre of the stump. Stumps were ≤ 2.0 m high and ≥ 5 cm in diameter at the top of the stump, or at breast height if the stump was equal to or above 1.3 m high.
Stumps (decay class 3-5)	These stumps consisted of decayed wood throughout most of the stump. Stumps were ≤ 2.0 m high and ≥ 5 cm in diameter at the top of the stump, or at breast height if the stump was equal to or above 1.3 m high
Root-balls (decay class 1-2)	These root-balls were still strong and were not moss covered. They were the roots of trees which had fallen over and were now above ground level.
Root-balls (decay class 3-5)	These root-balls were composed of decayed wood and were usually at least partially moss covered. They were the roots of trees which had fallen over and were now above ground level.
Large rock	This was a rock located mostly underground which was too large to be moved without heavy equipment.
Erratic	This was a rock located mostly above ground which was too large to be moved without heavy equipment.
Slash-pile	This was a pile of harvesting debris (twigs, branches, tree tops) each piece having a diameter of < 5 cm at its widest point.
Under shrub	This habitat designation was used when an animal was located in the ground less than 0.75 m from a shrub. Shrubs were defined as woody vegetation > 0.40 m and ≤ 2.0 m in height.
Camper trailer	A portable human built shelter for protection from inclement weather.

*Decay class definitions are based on the description of gradual decay in logs adapted by Maser *et al.* (1979) and Thomas *et al.* (1979) from Fogel *et al.* (1973 as cited by Hunter 1990). In general class 1-2 woody habitat features were comprised of intact to partially soft wood, and held their living shape. Class 3-5 woody habitat features were comprised of decay levels characterized by large or small pieces of wood, or a powdery substance, and usually did not hold the shape they had when the tree was alive.

**DBH is approximately 1.3 m above the ground.

points from trapping stations was then measured. Finally, all day refuge positions were assigned to one of two categories depending on their height. All day refuges located 2 m or more above the ground were included in the "elevated" category while day refuges below 2 m in height were categorized as "ground" positions.

In the fall, mouse radio-telemetry locations were more accurately determined with the global positioning system (GPS). A Trimble Pathfinder™ Basic+ receiver and external antenna were used for this purpose. Trimble Pathfinder™ software version 2.3 was then used for differential correction of the raw pseudo-range data. Other researchers have tested the accuracy of differentially corrected GPS data and found their positions were accurate to 3-7 m (Deckert and Bolstad 1996; Rempel and Rodgers 1997). Because these researchers monitored GPS position accuracy in forests, and open canopy areas, it is probable that the differentially corrected positions, collected from clearcut and uncut forest during the current study, are also within this range of accuracy.

CHAPTER 1: The Effect of Timber Harvest Intensity on the Small Mammal Community in a Northern Ontario Boreal Mixedwood Forest

Most published studies addressing the effects of timber extraction on small mammal communities have begun trapping experimental areas only after timber harvest (Tevis 1956; Kirkland 1977; Martell and Radvanyi 1977; Martell 1983; Scrivner and Smith 1984; Swan *et al.* 1984; Kirkland 1985; Monthey and Soutiere 1985; Clough 1987; Parker 1989; Walters 1991; Sekgororoane and Dilworth 1995). Without access to pre-harvest data it is impossible for these studies to ensure that the small mammal communities present in the different treatment areas were similar prior to timber extraction. In these cases, comparing the differences among sites and then attributing any differences found to the harvest treatments may be invalid. Unfortunately, this practice is so prevalent in published literature that only one small mammal study reviewed during this project, (Sullivan and Krebs 1981) included pre-harvest data. Readers must consider this limitation when results of other studies are discussed throughout the following work.

Several researchers have investigated the effect of clearcut timber harvesting on the small mammal community inside cut areas (Tevis 1956; Kirkland 1977; Martell and Radvanyi 1977; Martell 1983; Scrivner and Smith 1984; Swan *et al.* 1984; Monthey and Soutiere 1985; Clough 1987; Parker 1989; Walters 1991). Kirkland (1990) compared twenty-two of these studies, all conducted in North America, and found the response of small mammal communities to clearcut harvesting was similar in deciduous and coniferous forests during the first six years after disturbance. Two Ontario studies, Martell and Radvanyi (1977) and Martell (1983), were included in this comparison but their results deviated from the trends of increased total small mammal numbers, species richness, and species diversity which were generally observed by Kirkland (1990). These Ontario researchers also noted a difference in how the small mammal communities in boreal black spruce, and mixedwood forests respond to timber extraction.

Unfortunately there are some difficulties in interpreting the results of Martell and Radvanyi (1977) and Martell (1983) as they relate to harvest intensity. In both studies, each harvest intensity investigated was administered to a different forest type so that clearcuts occurred only in pure black spruce stands, and selective cuts occurred only in mixedwood stands. As a result, their work cannot differentiate between the effects of timber harvest intensity and forest type. Since Martell and Radvanyi (1977) and Martell (1983) are the only published papers which study the relationship between small mammal communities and timber harvest in the boreal forests of Ontario, it is obvious that current understanding of this topic is limited. A study which investigates the effect of different harvest intensities on the small mammal community in the same forest type within Ontario is required for further enhancement of forest management planning strategies.

When assessing the effect of harvest intensity on small mammal communities, researchers in North America have traditionally located sampling plots well within cut and adjacent uncut forest areas. As a result of this practice, the relationship between small mammal communities and harvest edges is poorly understood (Kirkland 1985; Sekgororoane and Dilworth 1995). Studies which have investigated small mammal communities at the harvest edge have been conducted in the northern hardwood forest of Pennsylvania (Kirkland 1985), the sub-alpine mountain hemlock forest of British Columbia (Walters 1991), and the red spruce-pine forest of New Brunswick (Sekgororoane and Dilworth 1995). In all of these studies only two harvest intensities, clearcutting and no cutting, were investigated. No study in North America has been published which examines the effect of more than two harvest intensities on the small mammal edge community.

In contrast, two studies in northeastern North America have investigated the effect of timber harvest intensity on small mammal communities within harvested areas. The first study, by Swan *et al.* (1984), also investigated the effect of harvest system (strip cut vs shelterwood cut) on the small mammal community in a hardwood forest of central Nova Scotia. This study was conducted entirely within the same forest type and compared uncut controls to clearcut (100% removal), strip-cut (38% and 45% removal), and shelterwood cut (45% removal) treatments (Freedman *et al.* 1981). However, the 2-5 ha harvested areas used by Swan *et al.* (1984) were exceptionally small in relation to operational scale cutting in Ontario. Cut size is probably an important factor in determining how small mammal communities react to timber harvest (Buckner and Shure 1985), so it is difficult to extend the observations made by Swan *et al.* (1984) to the scale of commercial harvesting operations in Ontario. Also, the small mammal sampling plots used by Swan *et al.* (1984) were as close as 30 m, and sometimes only 10 m from the cut edge. Because edge effects have been demonstrated in the small mammal community at 50 m and up to 90 m from a cut edge (Walters 1991; Mills 1995), it is difficult to determine how strongly the results of Swan *et al.* (1984) were influenced by this phenomenon.

The second study, by Monthey and Soutiere (1985), was conducted in northern Maine. In this study small mammal communities in clearcut, partially cut, and uncut softwood forests were compared. A comparison between partially cut and uncut hardwood forests was also conducted. The size of treatment areas used for both comparisons was not revealed by Monthey and Soutiere (1985), but judging from published photographs it seems that the size of areas used were much larger than those of Swan *et al.* (1984). Although no minimum distance between small mammal sample plots and treatment edges was given by Monthey and Soutiere (1985), plots were located with the intention of restricting immigration from the neighbouring uncut forest. As a result, it is probable that this second study successfully compares small mammal communities found within multiple intensities of timber extraction in the softwood forest. However, since specifics on cut size and the proximity of small mammal sample plots to forest edges were not given, it is possible that they change with each sample plot. In such a case it would be difficult to attribute any differences observed to the harvest treatments, as opposed to cut size, or the distance of sample plots from cut edges.

Design of the current study addresses many of the difficulties previous researchers have had when investigating the effect of timber harvest intensity on small mammal communities. Small mammal trapping was conducted both before and after timber harvest, at harvest edges, and within treatment areas. All treatments were the same size with each covering 10 ha, the same shape, and within the same forest type. This allowed for comparison of different harvest intensities without complications which develop when cuts are of different sizes, shapes, and in different forest types. Although the harvested areas studied in the current work were smaller than the size of normal operational scale cuts in Ontario, they are much more appropriate for determining the effect of such harvesting on the small mammal community than smaller harvested areas. Two specific questions were investigated in this study: 1) Are there differences in the small mammal communities on the treatment areas as a result of the different timber harvest intensities applied? 2) Are there differences in the small mammal edge communities associated with different intensities of timber extraction? This research will assist wildlife and forest managers in understanding the implications of using alternative harvest intensities for small mammal communities within, and at the edges of harvested land.

Method of Data Analysis

Trapping data collected only from areas harvested with full-tree extraction and controls were used to ascertain the effects of harvest intensity on the small mammal community. As a result, three clearcut, three shelterwood cut, and six control grids were involved in this analysis (Figures 4 and 6). Exclusion of areas which were harvested at these intensities but with other methods reduced difficulties of interpretation because harvest method was known to be consistent throughout the treatments compared and was not a secondary factor in the analysis.

The number of individuals of each small mammal species, captured on each treatment area, by each trapping method, in each year was then determined. Then pre-harvest data from all treatments were used to assess the ability of live traps and pitfall traps to capture small mammal species. Use of only the pre-harvest data for this comparison was beneficial because it eliminated consideration of the differences in grid placement with respect to the harvest edge which occurred after timber harvest. Finally, the abundance of both the common and the rare species on each treatment during each year of this study were examined. Rare species were defined as those captured less than five times by a particular trapping method, within a particular year. After this, rare species were excluded from further data analysis for that trapping method, in that year. This was done due to the difficulty in attributing any differences observed to biological, as opposed to random events when so few animals were involved in the comparison.

After elimination of rare species, the total small mammal abundance, species richness, and species diversity for each trapping method, on each treatment area, in each year were determined. Hill's diversity indices, N0, N1, and N2, were also calculated (Magurran 1988). These diversity indices were chosen for three reasons. First they can easily be converted to other widely used diversity indices; N0 represents species richness, N1 is the exponent of the Shannon diversity index, and N2 is the reciprocal of Simpson's diversity index (Ludwig and Reynolds 1988; Magurran 1988; Krebs 1989). This property is important for comparison to other studies that have used the other diversity indices. Secondly, Hill's diversity indices, N1 and N2, can have more power to discriminate between sites with similar communities than the Shannon or Simpson diversity index (Magurran 1988). Since the treatment grids in this study were all located within the same mixedwood forest, it was reasonable to expect species composition on the sites to be similar. As a result, the ability of diversity indices to discriminate between sites with similar communities was important. Finally, Hill's diversity indices are generally easier to interpret and understand than other diversity indices used in ecological studies (Ludwig and Reynolds 1988).

Species abundance, Hill's diversity indices N0, N1, and N2, and the total number of animals captured on each area were used for all comparisons among the years, and treatments of this study. First, the Friedman test was used to investigate the similarity between the two mixedwood stands monitored during this research. This comparison was conducted for pitfall and livetrapping data separately, and in each case small mammal community characteristics collected over the three years of this study on each original control area were combined. Then inter-year comparisons completed with Friedman tests for both pitfall and livetrapping data collected on the original control areas were completed. These tests were conducted to assess the natural population fluctuations of the small mammal community in the area of this study during the three years of research. Finally, Kruskal-Wallis tests were used to compare how small mammal communities were affected by the harvest intensity within each of the three years of this study. For livetrapping data, the inter-treatment comparison included data from the original control areas in 1993, and the newer control areas in 1994 and 1995.

Results

General

There was a large difference in the species captured by pitfall and livetrapping methods. Family Soricidae (shrews) were captured more often by pitfall traps while various species of order Rodentia (rodents) were more prevalent in live traps. The difference between these trapping methods was evident during visual examination of the species captured by each method before timber harvest in 1993 (Tables 4 and 5). In that year, four Soricidae were captured by live traps while 61 were captured by pitfall traps. Also, only live traps captured *Peromyscus maniculatus*, *Napaeozapus insignis* (woodland jumping mice), *Phenacomys intermedius* (heather voles), and *Microtus chrotorrhinus* (yellow-nosed voles) in that year. The only species captured by both trap types in 1993 was *Clethrionomys gapperi*.

Table 4. Numbers of small mammals livetrapped on grids associated with the control, shelterwood, and clearcut treatments during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	SILVICULTURAL SYSTEM (later implemented)									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	Species Totals
LIVETRAPPING GRID NUMBER	4	13	25	2	3	24	1	14	26	
Clethrionomys gapperi	20	32	67	20	15	35	37	59	76	361
Peromyscus maniculatus	9	9	23	10	4	12	6	12	5	90
Microtus chrotorrhinus			2					3	9	14
Phenacomys intermedius								1	1	2
Napaeozapus insignis	1									1
Soricidae							2	1	1	4
EFFORT (# Trap Nights)	180	180	180	225	135	90	135	180	180	
							TOTAL CAPTURES (# individuals)			468
							TOTAL EFFORT (# trap nights)			1485
1994 (post-harvest)	SILVICULTURAL SYSTEM									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	2	3	24	1	14	26	
Clethrionomys gapperi	68	78	61	59	37	65	56	60	82	566
Peromyscus maniculatus	12	13	3	9	8	7	10	18	8	88
Microtus chrotorrhinus	8	11	17	5	2	3	1	12	5	64
Glaucomys sabrinus				2			3	3		8
Microtus pennsylvanicus		2	2		1			2	1	8
Napaeozapus insignis	1		1			4	1	1		8
Synaptomys cooperi	3	2	1					1	1	8
Phenacomys intermedius	2	1						1		4
Tamias minimus							1			1
Mustela sp.								1		1
Soricidae		1								1
EFFORT (# Trap Nights)	540	450	450	495	540	450	495	540	450	
							TOTAL CAPTURES (# individuals)			757
							TOTAL EFFORT (# trap nights)			4410
1995 (post-harvest)	SILVICULTURAL SYSTEM									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	2	3	24	1	14	26	
Clethrionomys gapperi	44	49	44	51	45	44	26	38	40	381
Peromyscus maniculatus	17	28	5	12	10	11	20	21	3	127
Microtus chrotorrhinus	8				2			5		15
Glaucomys sabrinus				2			5	2	2	11
Phenacomys intermedius	3	1			1			4		9
Tamias minimus				1			4			5
Napaeozapus insignis		1	1			2		1		5
Synaptomys cooperi	3				1			1		5
Mustela sp.						1		1		2
Soricidae					1					1
EFFORT (# Trap Nights)	450	540	450	405	405	495	450	405	495	
							TOTAL CAPTURES (# individuals)			561
							TOTAL EFFORT (# trap nights)			4095

Table 5. Numbers of small mammals pitfall trapped on the control, shelterwood, and clearcut treatment areas during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	SILVICULTURAL SYSTEM (later implemented)									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	Species Totals
TREATMENT AREA NUMBER	4	13	25	2	3	24	1	14	26	
Sorex cinereus	15	4	3	4	5	3	12	2	3	51
Clethrionomys gapperi				4	1	4			2	11
Sorex fumeus	3	1			2			1	1	8
Blarina brevicauda		1								1
Sorex arcticus						1				1
EFFORT (# Trap Nights)	168	168	168	168	168	168	168	168	168	
							TOTAL CAPTURES (# individuals)			72
							TOTAL EFFORT (# trap nights)			1512

1994 (post-harvest)	SILVICULTURAL SYSTEM									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	SPECIES TOTALS
TREATMENT AREA NUMBER	4	13	25	2	3	24	1	14	26	
Sorex cinerous	11	7	25	12	9	10	7	17	9	107
Clethrionomys gapperi	4	8	15	10	9	12	12	13	7	90
Sorex hoyi	1	5	4	6	2	3	6	4		31
Phenacomys intermedius			3	1		8		1		13
Microtus chrotorrhinus	1		3	2		4			1	11
Synaptomys cooperi			1	1		2	1			5
Sorex fumeus	1		1			1		1		4
Microtus pennsylvanicus	1									1
Sorex arcticus				1						1
EFFORT (# Trap Nights)	1200	1200	1200	1200	1200	1200	1200	1200	1200	
							TOTAL CAPTURES (# individuals)			173
							TOTAL EFFORT (# trap nights)			10800

1995 (post-harvest)	SILVICULTURAL SYSTEM									
	Control	Control	Control	Shelterwood	Shelterwood	Shelterwood	Clearcut	Clearcut	Clearcut	SPECIES TOTALS
TREATMENT AREA NUMBER	4	13	25	2	3	24	1	14	26	
Sorex cinereus	10	21	25	24	18	15	20	24	18	175
Clethrionomys gapperi	10	8	21	13	14	8	2	8	7	91
Sorex hoyi	2	1	2	6	3	6	2	12	2	36
Phenacomys intermedius				2	4	5	2		1	14
Peromyscus maniculatus					1	1	5	1		8
Sorex arcticus		1	1		1	1				4
Sorex fumeus	2			1	1					4
Synaptomys cooperi	3						1			4
Microtus chrotorrhinus			1	1				1		3
Blarina brevicauda						1				1
EFFORT (# Trap Nights)	1200	1200	1200	1200	1200	1200	1200	1200	1200	
							TOTAL CAPTURES (# individuals)			340
							TOTAL EFFORT (# trap nights)			10800

Edge Habitat Comparisons (based on livetrapping)

Clethrionomys gapperi, *Peromyscus maniculatus*, and *Microtus chrotorrhinus*, were the three species most commonly captured by live traps during each of the three years of this study (Table 4). *Glaucomys sabrinus* (northern flying squirrels), *Microtus pennsylvanicus* (meadow voles), *Synaptomys cooperi* (southern bog lemmings), *Tamias minimus* (least chipmunks), and *Mustela erminea* or *Mustela nivalis* (shorttail or least weasels) were captured only after timber harvest. There were no species captured by live traps only before harvest so overall species richness was higher in post-harvest years.

Comparison among the original control grids revealed that, in general, a larger number of small mammals were captured on grids 13 and 25, than on grid 4 during the three years of this research (Table 6). Also, *Clethrionomys gapperi* abundance was lowest on grid 4, moderate on grid 13, and highest on grid 25 during every year of this study (Tables 6 and 7). Inter-year comparison of the original controls revealed that *Peromyscus maniculatus* abundance, and Hill's diversity number N2 were higher in 1993 and 1995, than in 1994 (Table 8).

Investigating data from the treatment areas before timber harvest in 1993, revealed that one rare group of species, family Soricidae, had four individuals captured in live traps only on grids that were assigned to be clearcut (Table 4). Since all other rare species occurred only once or twice in live traps during this year, their occurrence in areas later assigned to the same treatment type could be more easily associated with random, than with biological events. Statistical testing indicated that the distribution of common species amongst the three harvest intensity treatments were even when livetrapping data were assessed (Table 9). Species richness and diversity indices also showed no statistically significant differences amongst the treatment areas when they were compared before harvest.

Table 6. Friedman tests (based on ranks regardless of year) comparing the small mammal community on original control areas are displayed along with the minimum and maximum values for the indicator variables determined by live and pitfall trapping both before (1993), and after (1994 and 1995) timber harvest at the Black Sturgeon Boreal Mixedwood Research site.

LONGWORTH TRAPPING DATA	Treatments				PITFALL TRAPPING DATA	Treatments			
	Area 4	Area 13	Area 25	P-value		Area 4	Area 13	Area 25	P-value
Clethrionomys gapperi	18-40 (a)	28-54 (b)	55-67 (c)	0.000*	*Sorex cinereus*	10-15	4-21	3-25	0.790
Peromyscus maniculatus	0-9	6-26	5-23	0.180	*Clethrionomys gapperi*	0-10	0-8	0-21	0.250
Microtus chrotorrhinus	0-3	0-2	0-2	0.588	*Sorex hoyi*	0-2	0-5	0-4	0.907
Synaptomys cooperi	0-2	0-1	0-0	0.145	*Microtus chrotorrhinus*	0-1	0-0	0-3	0.145
Capture (# individuals)	25-45 (d)	41-63 (e)	60-92 (e)	0.049	*Sorex fumeus*	1-3	0-1	0-1	0.134
Species Richness (N0)	2-4	2-4	2-3	0.934	Capture (# individuals)	18-24	5-30	3-49	0.790
Species Diversity (N1)	1.53-2.45	1.69-2.00	1.33-1.94	0.790	Species Richness (N0)	2-5	2-3	1-5	0.444
Species Diversity (N2)	1.26-1.83	1.34-2.00	1.18-1.69	0.444	Species Diversity (N1)	1.57-3.14	1.65-2.95	1.00-3.20	0.790
					Species Diversity (N2)	1.38-2.77	1.47-2.90	1.00-2.63	0.790

*Where $P < 0.05$ different letters indicate that treatment areas were significantly different

Table 7. Numbers of small mammals livetrapped on the original control grids during the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

YEAR	1994			1995			Species Totals
Original Control Grid Numbers	4	13	25	4	13	25	
Clethrionomys gapperi	40	54	55	18	28	59	254
Peromyscus maniculatus	0	6	5	2	26	15	54
Microtus chrotorrhinus	3	2	0	3	0	0	8
Synaptomys cooperi	2	1	0	2	0	0	5
Phenacomys intermedius	0	0	0	1	0	0	1
Soricidae	0	0	0	0	0	1	1
EFFORT (# Trap Nights)	135	180	135	135	135	135	

Table 8. Friedman tests (based on ranks regardless of area) comparing the small mammal communities on original controls through time are displayed along with the minimum and maximum values for the indicator variables determined by live and pitfall trapping both before (1993), and after (1994 and 1995) timber harvest at the Black Sturgeon Boreal Mixedwood Research site.

LONGWORTH TRAPPING DATA	YEAR				PITFALL TRAPPING DATA	YEAR			
	1993	1994	1995	P-value		1993	1994	1995	P-value
Clethrionomys gapperi	20-67	40-55	18-59	0.444	*Sorex cinereus*	3-15	7-25	10-25	0.826
Peromyscus maniculatus	9-23 (a)	0-6 (b)	2-26 (a)	0.049*	*Clethrionomys gapperi*	0-0 (e)	4-15 (f)	8-21 (g)	0.004
Microtus chrotorrhinus	0-2	0-3	0-3	0.790	*Sorex hoyi*	0-0 (h)	1-5 (i)	1-2 (i)	0.049
Synaptomys cooperi	0-0	0-2	0-2	0.250	*Microtus chrotorrhinus*	0-0	0-3	0-1	0.145
Capture (# individuals)	29-92	45-63	25-74	0.790	*Sorex fumeus*	0-3	0-1	0-2	0.588
Species Richness (N0)	2-3	2-4	2-4	0.934	Capture (# individuals)	3-18 (j)	18-48 (k)	24-49 (l)	0.004
Species Diversity (N1)	1.69-1.94	1.33-1.70	1.66-2.45	0.309	Species Richness (N0)	1-2 (m)	3-5 (n)	3-4 (o)	0.004
Species Diversity (N2)	1.52-1.75 (c)	1.18-1.34 (d)	1.48-2.00 (c)	0.049	Species Diversity (N1)	1.00-1.65 (p)	2.95-3.20 (q)	2.05-3.14 (q)	0.049
					Species Diversity (N2)	1.00-1.47 (r)	2.31-2.90 (s)	1.78-2.77 (s)	0.049

* Where P < 0.05 different letters indicate that years were significantly different

Table 9. Kruskal-Wallis tests (based on ranks) comparing the small mammal communities of harvest treatment area edges (livetrapping) and on harvest treatment areas (pitfall trapping) are displayed along with the minimum and maximum values of the indicator variables for the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 Livetrapping Data (pre-harvest)	SILVICULTURAL SYSTEM (later implemented)			
	Control	Shelterwood	Clearcut	P-value
Clethrionomys gapperi	20-67	15-35	37-76	0.129
Peromyscus maniculatus	9-23	4-12	5-12	0.102
Microtus chrotorrhinus	0-2	0-0	0-9	0.199
Capture (# individuals)	29-92	19-47	43-90	0.329
Species Richness (N0)	2-3	2-2	2-3	0.264
Species Diversity (N1)	1.69-1.94	1.67-1.89	1.50-1.83	0.491
Species Diversity (N2)	1.52-1.75	1.50-1.80	1.32-1.51	0.113

1993 Pitfall Trapping Data (pre-harvest)	SILVICULTURAL SYSTEM (later implemented)			
	Control	Shelterwood	Clearcut	P-value
Sorex cinereus	3-15	3-5	2-12	0.698
Clethrionomys gapperi	0-0	1-4	0-2	0.061
Sorex fumeus	0-3	0-2	0-1	0.768
Capture (# individuals)	3-18	7-8	3-12	0.737
Species Richness (N0)	1-2	2-3	1-3	0.513
Species Diversity (N1)	1.00-1.65	1.98-2.46	1.00-2.75	0.172
Species Diversity (N2)	1.00-1.47	1.96-2.13	1.00-2.57	0.172

1994 Livetrapping Data (post-harvest)	SILVICULTURAL SYSTEM			
	Control	Shelterwood	Clearcut	P-value
Clethrionomys gapperi	61-78	37-65	56-82	0.329
Peromyscus maniculatus	3-13	7-9	8-18	0.472
Microtus chrotorrhinus	8-17	2-5	1-12	0.161
Glaucomys sabrinus	0-0	0-2	0-3	0.195
Microtus pennsylvanicus	0-2	0-1	0-2	0.427
Napaeozapus insignis	0-1	0-4	0-1	0.961
Synaptomys cooperi	1-3 (a)	0-0 (b)	0-1 (ab)	0.048*
Capture (# individuals)	85-106	48-79	71-97	0.174
Species Richness (N0)	5-6 (c)	4-4 (d)	5-7 (c)	0.047
Species Diversity (N1)	2.37-2.39	1.92-2.06	1.81-3.16	0.252
Species Diversity (N2)	1.75-1.80	1.45-1.60	1.38-2.30	0.288

1994 Pitfall Trapping Data (post-harvest)	SILVICULTURAL SYSTEM			
	Control	Shelterwood	Clearcut	P-value
Sorex cinereus	7-25	9-12	7-17	0.863
Clethrionomys gapperi	4-15	9-12	7-13	0.865
Sorex hoyi	1-5	2-6	0-6	0.989
Phenacomys intermedius	0-3	0-8	0-1	0.591
Microtus chrotorrhinus	0-3	0-4	0-1	0.441
Synaptomys cooperi	0-1	0-2	0-1	0.513
Capture (# individuals)	17-51	20-39	17-35	0.807
Species Richness (N0)	3-6	3-6	3-4	0.641
Species Diversity (N1)	2.60-3.74	2.58-5.05	2.38-3.23	0.491
Species Diversity (N2)	2.08-2.94	2.41-4.51	2.21-2.94	0.430

1995 Livetrapping Data (post-harvest)	SILVICULTURAL SYSTEM			
	Control	Shelterwood	Clearcut	P-value
Clethrionomys gapperi	44-49	44-51	26-40	0.055
Peromyscus maniculatus	5-28	10-12	3-21	0.733
Microtus chrotorrhinus	0-8	0-2	0-5	0.939
Glaucomys sabrinus	0-0	0-2	2-5	0.056
Phenacomys intermedius	0-3	0-1	0-4	0.714
Tamias minimus	0-0	0-1	0-4	0.558
Napaeozapus insignis	0-1	0-2	0-1	0.801
Synaptomys cooperi	0-3	0-1	0-1	0.954
Capture (# individuals)	50-79	57-66	45-72	0.491
Species Richness (N0)	3-5	3-5	3-7	0.965
Species Diversity (N1)	1.52-3.14	1.89-2.14	1.53-3.53	0.670
Species Diversity (N2)	1.27-2.44	1.58-1.63	1.26-2.71	0.670

1995 Pitfall Trapping Data (post-harvest)	SILVICULTURAL SYSTEM			
	Control	Shelterwood	Clearcut	P-value
Sorex cinereus	10-25	15-24	18-24	0.873
Clethrionomys gapperi	8-21	8-14	2-8	0.110
Sorex hoyi	1-2	3-6	2-12	0.122
Phenacomys intermedius	0-0 (e)	2-5 (f)	0-2 (e)	0.042
Peromyscus maniculatus	0-0	0-1	0-5	0.211
Capture (# individuals)	22-48	35-45	28-45	0.661
Species Richness (N0)	3-3 (g)	4-5 (h)	4-5 (h)	0.045
Species Diversity (N1)	2.05-2.55 (i)	3.01-3.98 (j)	2.56-3.03 (j)	0.039
Species Diversity (N2)	1.78-2.37	2.58-3.49	2.07-2.58	0.077

* Where $P < 0.05$ different letters indicate that treatments were significantly different

In 1994, evaluation of Hill's species richness, N0, revealed a significant difference among the treatments with lower values at the edge of the shelterwood cuts, than on controls and clearcut edges (Table 9). Also, *Synaptomys cooperi* were more prevalent on controls than on other treatments. All other commonly captured species showed no statistically significant differences amongst the harvest treatments during this first post-harvest year.

In 1995 no significant differences were found for Hill's species richness or diversity (Table 9). However, the abundance of two common species, *Clethrionomys gapperi* and *Glaucomys sabrinus*, showed differences amongst treatments which approached statistical significance ($P<0.100$). *C. gapperi* were less prevalent at clearcut edges than at shelterwood edges and in controls, while *G. sabrinus* were captured predominately on grids associated with clearcut edges.

Within Treatment Area Comparisons (based on pitfall trapping)

The three species most commonly captured in pitfall traps before timber harvest were *Sorex cinereus* (masked shrews), *Clethrionomys gapperi*, and *Sorex fumeus* (smoky shrews) (Table 5). After harvest *Sorex hoyi* (pygmy shrews) replaced *S. fumeus* as the third most common species captured. *Sorex hoyi* was the only Soricidae species detected exclusively during post-harvest years. Other species which appeared in pitfalls only after harvest were *Phenacomys intermedius*, *Microtus chrotorrhinus*, *Synaptomys cooperi*, and *Microtus pennsylvanicus*. As with livetrapping, no species was captured in pitfall traps only before timber harvest. Subsequently overall species richness was higher during post-harvest years.

In contrast to livetrapping data, pitfall data revealed that control areas were similar with respect to all the small mammal community characteristics measured over the time of this study. Inter-year comparison on control areas showed that over time the total number of small mammals captured and the abundance of *Clethrionomys gapperi* increased (Table 8). These comparisons also demonstrated that *Sorex hoyi* abundance, and Hill's diversity numbers, N1 and N2, were higher in 1994 and 1995, than in 1993. Hill's species richness, N0, was lowest in 1993, highest in 1994, and moderate in 1995.

Comparison of the number of *Clethrionomys gapperi* captured with pitfall traps on each treatment before timber harvest in 1993 revealed differences that approached statistical significance (Table 9). For all other common species statistical tests failed to show any differences among the treatments during this pre-harvest year. Also, Hill's species richness and diversity numbers did not differ significantly with harvest treatment before timber extraction.

In 1994 no statistically significant differences were observed when treatments were compared with respect to small mammal abundance, species abundance, and Hill's species richness and diversity measures (Table 9). However, by 1995, pitfall data showed that *Phenacomys intermedius* abundance was higher on shelterwood areas than on clearcut and control areas. Also in 1995, Hill's diversity numbers N0 and N1 were lower in controls than on cut areas (Table 9). In addition, Hill's diversity number N2 approached statistical significance when treatments were compared in 1995.

Discussion

General

Mouse, vole, lemming, and squirrel captures were more common in live traps than in pitfall traps during the current study, while for shrews the opposite occurred. This agrees with the findings of other researchers who have investigated the effectiveness of pitfall and live traps (Briese and Smith 1974; Block *et al.* 1988; Szaro *et al.* 1988). It is likely that trap size, design, and placement all have a substantial effect on the number of small mammals captured by each of these trap types (Morris 1968; Williams and Braun 1983; Slade *et al.* 1993; O'Farrell *et al.* 1994). Use of both these traps in the same study is advantageous since together they produce a better assessment of small mammal community composition than either trap type can when used independently. This difference in trap effectiveness does have a disadvantage because it hinders comparison among studies, or locations, in which different types of traps have been employed. As a result, direct comparisons between small mammal communities livetrapped at cut edges and pitfall trapped within treatment areas were not made during the current work.

Comparisons Conducted With Original Control Data Only

Homogeneity Between Stands

Pitfall trapping data failed to show any significant differences among the original control grids, throughout the three years of this study. However, with livetrapping data, differences among these grids were observed when the total number of small mammals, and the abundance of *Clethrionomys gapperi* were assessed. The higher number of small mammals livetrapped on grids 13 and 25 could be related to differences in the pre-harvest vegetative structure on these two grids because Simpson (in litt., 27 Jan 1994) found control grids 13 and 25 more similar to each other than to control grid 4 before harvest when conducting cluster analysis of combined vegetation, overstorey, understorey, and shrub species abundance. Because *C. gapperi* represent between 68 and 77 percent of the individuals captured in each year of this study, it is understandable that their distribution could influence the total number of small mammal captures on study grids. The inability of pitfall traps to uncover the same trends as live traps could be related to their lower *C. gapperi* capture success.

The variation among the original control grids of this study revealed some differences in the number of small mammals, and the number of *Clethrionomys gapperi* supported by certain areas of the studied boreal mixedwood forest. Some variation within a studied forest is normal and unavoidable at the scale of the current work. There may be some concern that much of the variance is related to differences between the two stands investigated during this study. However, since the total number of species captured on control grid 25 in stand 2 and on control grid 13 in stand 1 are more similar to each other than to control grid 4 in stand 1, the choice of not treating these two stands as separate blocks during statistical analysis in the current study is supported.

Population Changes Revealed On Original Control Grids

Throughout the three years of this study both live and pitfall trapping methods uncovered changes in the small mammal communities on original control areas. Notable is the lower *Peromyscus maniculatus* abundance measured by livetrapping on these grids in 1994. The reason for low *P. maniculatus* abundance in these areas immediately after harvest is unknown. However, it follows the pattern of Hill's second diversity index, N2, in the same year. The similarity of the patterns for *P. maniculatus* abundance and Hill's second diversity index is understandable because *P. maniculatus* were the second most abundant species in this study and N2 diversity is affected more strongly by common, than by rare species.

Pitfall trapping uncovered more changes in the original controls over the three years of this study than livetrapping. However, the results of pitfall trapping were complicated by the increased effort, and earlier trapping season used during post-harvest years. All of the variables that changed when measured with pitfall traps (*Clethrionomys gapperi* abundance, *Sorex hoyi* abundance, species richness, Hill's diversity indices N1 and N2, and the total number of small mammals captured) were higher during the two years after timber harvest. Because these pitfall control grids were approximately 170 m from the edge of the nearest cut area, the adjacent harvest treatments should have had minimal impact on them. It is likely that the different trapping efforts, and trapping seasons, used during collection of pitfall data before and after timber harvest were responsible for the differences noted in these four variables when pre- and post-harvest data were compared. Two variables, *C. gapperi* abundance and the total number of small mammal captures, increased with time over the three years of this study. This could be related to natural population fluctuations in the *C. gapperi* community. However, since the same trend was not observed with live traps it is unlikely that this is the case.

Comparisons Amongst Treatments

Study Area Homogeneity Before Harvest

Before considering the effect of timber harvest on the small mammal community, it is important to investigate the similarity of treatment grids before harvest was conducted. All but two variables measured in the current study were evenly distributed among the treatment grids before timber harvest. The two which showed an uneven distribution at this time were pitfall trapped *Clethrionomys gapperi*, and livetrapped Soricidae. In both cases, these taxa were captured more successfully by the alternative trapping method. That is to say, more *C. gapperi* were captured in live traps than in pitfall traps, and more Soricidae were captured in pitfall traps than in live traps. As a result of these higher capture rates, the more successful trap type probably gave a better approximation of the distribution for these taxa than could the typically less successful trapping method. Because analysis of the data collected by the more successful trapping methods did not result in any significant differences when the pre-harvest distributions for these taxa were evaluated, both distributions were considered homogenous throughout the study area before timber extraction. This example demonstrates that it is important to consider the efficacy of each trapping method employed, for each species investigated during a small mammal study, because captures of a particular species, by a particular trap, may not necessarily be a good indicator of the relative abundance of the species in a study area.

The Small Mammal Edge Community

Species Richness, Diversity and Total Captures

In 1994 species richness was higher at clearcut edges and in controls than at shelterwood edges. Since no other researchers have compared clearcut and shelterwood edges to uncut forest, results of the current study cannot be directly compared to other edge studies. However, if compared to studies that monitored small mammals within clearcuts, the current work disagrees with the majority of studies reviewed by Kirkland (1990) that found higher species richness values on clearcuts than in uncut forest. Results of Martell (1983) also disagree with the current work because lower species richness was observed on clearcuts than in adjacent uncut black spruce forests. Lending support to the current findings are Martell and Radvanyi (1977) who observed no change in species richness between clearcut and uncut black spruce forest in Ontario. In Maine, results of Monthey and Soutiere (1985) partially agree with the current work because their work revealed higher species richness on controls than in shelterwoods. However, Monthey and Soutiere (1985) also found lower species richness in clearcuts than in uncut forest.

Although species richness changed with harvest intensity on livetrapping grids in the current study, Hill's diversity numbers, N1 and N2, did not. These results conflict with both Martell and Radvanyi (1977) and Martell (1983) as these researchers noted lower diversity values on clearcuts when compared with adjacent uncut black spruce forest. Kirkland (1990) noted considerable variation in the response of species diversity to clearcut harvesting in small mammal studies throughout North America. Subsequently, the disagreement between the current study and others conducted in Ontario may not be an extraordinary occurrence.

The similarity in the total number of small mammals captured on the intensity treatments of this study agrees with the results of Swan *et al.* (1984). However, this observation contrasts with many other North American studies (Kirkland 1990). Monthey and Soutiere (1985) noted higher small mammal abundance in partially cut forests than in clearcut and uncut forests in northern Maine. In Ontario, both Martell and Radvanyi (1977) and Martell (1983) found a difference in total small mammal abundance when clearcut and uncut forests were compared. However, the observations of these two Ontario researchers differed. Martell and Radvanyi (1977) noted substantially lower captures on recent unscarified clearcuts, while Martell (1983) noted the opposite response.

There is no solid explanation for the conflicting responses researchers have noted when using the total number of small mammal captures to monitor the effect of timber harvest on small mammal communities. Perhaps the close proximity of the trapping girds used by Swan *et al.* (1984), and the current work, to uncut forest edges accounts for the similar small mammal response observed in these studies. Grid position could also be responsible for the difference observed in species richness, and diversity when the livetrapping data of the current study are compared with Martell and Radvanyi (1977), Martell (1983), and Monthey and Soutiere (1985). It is also possible that the different responses observed by these researchers are related to forest structure, composition, location, and trap type. More research which can differentiate between these possibilities is recommended.

Overall species richness was lower before than it was after timber harvest. This could be attributed to the effect of harvest intensity on predation rates, interspecific (between species) and intraspecific (between individuals of the same species) competition, and on habitat quality. Timber harvest could affect predation rates by changing the number of predators hunting in the area, or by either increasing or decreasing the availability of shelter for small mammals, and hiding places for ambush predators. Interspecific competition can change with the addition or loss of species from an area. Intraspecific competition can change the number of individuals of a species in an area. And finally, habitat quality for small mammals can be altered by changes in the type and amount of food and shelter, as well as changes in the microclimate of an area.

There are other factors in the current study which could also have caused the higher overall species richness evident after timber harvest. These other factors include live trap design, trapping effort, and trapping season. In the current study, live trap design is important because both Longworth and Sherman live traps were used. These live trap designs have been shown to influence capture rate for several small mammal species in studies where both were used together on the same grid (Morris 1968). Reasons for this include differences in the size of trap openings, in trap door design, and in the ability of small mammals to see through traps (Slade *et al.* 1993; O'Farrell 1994). However, it is questionable if there is a significant difference in the species captured when Sherman or Longworth traps are used independently (Morris 1968). The greater trapping effort used in post-harvest years of the current study could have influenced overall species richness because greater trapping effort increases the likelihood of capturing rare species (Ludwig and Reynolds 1988; Magurran 1988: Krebs 1989). Finally, the earlier trapping season used in post-harvest years could alter the chances of capturing certain species, especially those which hibernate or go into torpor in the fall and winter. In the region of this study only family Zapodidae (jumping mice) and *Peromyscus maniculatus* would be affected in this way (Kurta 1995). It is assumed that the influence of all these factors on small mammals is species dependent.

Selected Species

Synaptomys cooperi

Because *Synaptomys cooperi* were the principle reason for significantly higher species richness values on control areas in 1994, it is of interest to investigate their distribution in that year. Changed habitat structure could have been responsible since many other researchers have found more abundant *S. cooperi* populations in mature forest habitat than in clearcuts (Martell and Radvanyi 1977; Monthey and Soutiere 1985; Parker 1989) and partial cuts (Monthey and Soutiere 1985). In contrast, Martell (1983) captured slightly more *S. cooperi* in recent unscarified clearcuts, than in mature black spruce forests, but did not monitor partially cut black spruce forests. As a result, the effect of partial cutting on *S. cooperi* in that forest type remains unknown. The observations of Kirkland (1977) also differ from the current work because in the deciduous and coniferous forests of Pennsylvania, *S. cooperi* were captured on recent clearcuts but not in uncut forest. It is evident that neither forest type or timber harvest intensity affect *S. cooperi* in a consistent way throughout eastern North America. Perhaps the general low abundance, or patchy distribution of this species on forested sites restricts the ability of scientists to determine the effect timber harvest has on its abundance.

Clethrionomys gapperi

Clethrionomys gapperi were the most common species captured during the current study and displayed lower abundance on clearcut edges than on shelterwood edges and control grids. This agrees with the results of some researchers who have studied mature coniferous forests of eastern (Martell and Radvanyi 1977; Martell 1983) and western (Corn *et al.* 1988; Nordyke and Buskirk 1988; Rachael 1988b) North America. In contrast, studies in coniferous forests of northern Maine (Monthey and Soutiere 1985), New Brunswick (Parker 1989), and Pennsylvania (Kirkland 1977) found more abundant *C. gapperi* populations on recent clearcuts than in uncut forests. In at least one study, the cause of this difference could be related to use of alternative timber harvesting methods because Monthey and Soutiere (1985) noted large amounts of slash on cut areas at their research site. However, in Chapter 2 of the current work, (which compares the small mammal communities on clearcuts harvested with two alternative timber extraction methods, Appendix 1) there was no significant difference in *C. gapperi* abundance noted for the two monitored clearcut treatments.

Clethrionomys gapperi often prefer interior forests to recently clearcut areas (Raphael 1988a; Kurta 1995; Mills 1995). As a result, many researchers suggest that the species might be useful as an indicator of old-growth conditions in western North American forests (Corn *et al.* 1988; Raphael 1988b; Wywialowski and Smith 1988). It is possible that the different forest types, composition, and climate in western North America would preclude use of the same old-growth indicator species in eastern North America. However, the distribution of *C. gapperi* in the current study suggests that the species might also be a useful old-growth indicator for boreal mixedwood forests in Ontario.

Sciuridae

Tamias minimus is an edge species which prefers forest bordering open habitat to continuous mature stands (Kurta 1995). This description is supported by both Martell and Radvanyi (1977) and Martell (1983) as they found *T. minimus* to be more prevalent in recent clearcuts, less than six years of age, than in uncut forests. It is therefore likely that appearance of *T. minimus* at cut edges after harvest in the current study resulted from improved habitat quality.

Unlike *Tamias minimus*, *Glaucomys sabrinus* generally prefers uncut forest habitat (Raphael 1988a; Kurta 1995; Waters and Zagel 1995). Although some studies, such as Kirkland (1977) and the current one, have captured more *G. sabrinus* on recent clearcuts than in uncut forest, it is unlikely that this indicates higher *G. sabrinus* abundance on cut land. It is more likely that clearcutting changes *G. sabrinus* activity patterns in harvested areas, increasing the probability of their capture on the ground.

There are two reasons *Glaucomys sabrinus* are more likely to travel on the ground at cut edges than in uncut areas. First, the lack of trees in cut areas can result in squirrels landing on the ground where the distance between forested lands is greater than approximately 50 m (Mowrey and Zasada 1984). In these situations *G. sabrinus* which crossed into a cut area by gliding would need to land and travel on the ground for a distance before continuing through the uncut forest. The results of Chapter 3 however, indicate that most *G. sabrinus* captures occurred on the uncut side of clearcut grids. Perhaps *G. sabrinus* are more likely to miss their target tree when gliding along clearcut edges. When landing on the ground perhaps they can smell live trap bait which then encourages them to enter the traps and be captured.

The second reason *Glaucomys sabrinus* may travel on the ground at the edge of clearcut areas is to collect lichen of *Bryoroa* species. This hair lichen, which grows on tree limbs, is often abundant in the slash piles of recent clearcuts. Because these lichen are commonly used by *G. sabrinus* as food and nesting material (Mowrey and Zasada 1982; Hayward and Rosentreter 1994; Waters and Zabel 1995), it is possible that their captures on the ground at the edge of recent clearcuts is related to the distribution of *Bryoroa* lichen.

Microtus pennsylvanicus

Microtus pennsylvanicus exploit clearcuts and other disturbances because they prefer areas of open habitat to uncut forest (Kirkland 1975; Kurta 1995). This observation is supported by the current study because *M. pennsylvanicus* were captured only during 1994 when cut areas were largely devoid of vegetative cover (Simpson, in litt., 27 Jan, 1994). As with the current study. Martell and Radvanyi (1977) found *M. pennsylvanicus* within clearcuts for only a short time after harvest. Martell (1983) found *M. pennsylvanicus* only in scarified clearcuts which ranged between 3 and 6 years of age. Since scarified clearcuts generally contain less vegetative cover than unscarified clearcuts of the same age, the 3 and 6 year old cuts surveyed by Martell (1983) could be quite similar to those of the current study, and of Martell and Radvanyi (1977). Occurrence of *M. pennsylvanicus* during the first post-harvest year of the current study probably resulted from improved habitat quality after timber harvest followed by loss of habitat quality in the second post-harvest year.

The Small Mammal Community Within Cut Areas

Species Richness, Diversity and Total Captures

In 1995, pitfall data showed higher species richness, N0, and Hill's N1 diversity values on treatment areas which had been cut. This agrees with the results of many researchers reviewed by Kirkland (1990), yet it disagrees with others (Martell and Radvanyi 1977; Martell

1983; Monthey and Soutiere 1985). In contrast, Hill's N2 diversity does not show as strong a difference between the cut and uncut treatments as do species richness and Hill's N1 diversity. This resulted largely from the abundance of two species rarely captured in pitfall traps. *Phenacomys intermedius* and *Peromyscus maniculatus*, and the greater sensitivity of Hill's species richness, N0, and N1 diversity index, to changes in rare species numbers when compared to the sensitivity of Hill's N2 species diversity. Since the difference between cut and uncut areas measured by Hill's N2 diversity approached significance, common species were affected somewhat by the harvest treatments.

As with the livetrapped small mammal edge community, there were no differences among treatments when the total number of small mammals pitfall trapped in any year were compared. This agrees with the results obtained by Swan *et al.* (1984) in Nova Scotia, but it differs from the results of many other researchers who sampled further from cut edges (Martell and Radvanyi 1977; Martell 1983; Monthey and Soutiere 1985). In the current study, pitfall grids were located within the cut areas and at least 60 m from the cut edge. As a result, edge effects probably had minimal impact on the number of small mammal captures in the current work. It is more likely that forest structure, composition, or location were responsible for the differences noted in the current study, and those of other small mammal researchers who sampled well within cut areas.

Overall species richness was again higher in post-harvest years than in the pre-harvest year. However, unlike livetrapping, the design of invertebrate pitfall traps did not change after timber harvest. Therefore, the higher overall species richness observed with pitfall traps after timber harvest cannot be related to trap design. Factors which could be related include predation, competition (within and between species), trapping effort, trapping season, and timber harvest itself. Predation and competition could affect species within cut areas by the same means as earlier discussed for the small mammal edge community. Since none of the species usually captured by pitfall traps in this region hibernate, it is unlikely that trapping season had a direct effect on evaluation of species richness. However, seasonal changes in the relative abundance of some species could affect diversity measurements. It is likely that trapping season had less influence on small mammal numbers in the current work than did trapping effort, timber harvest, predation, and competition.

Selected Species

Phenacomys intermedius

Occurrence of *Phenacomys intermedius* only on grids associated with timber extraction during the second post-harvest year of this study is consistent with the results of other Ontario small mammal community studies (Martell and Radvanyi 1977; Martell 1983). Kurta (1995) states that although these mammals prefer dry coniferous stands with a dense understorey, they are still captured in other forest types, probably as a result of juvenile dispersal into suboptimal habitats. Naylor *et al.* (1985) found that disturbed and mixedwood forests acted as dispersal sinks for this species and represented suboptimal habitat. This judgment was based on the low number of captures in combination with the high relative proportion of juveniles found in mixedwood forests by Naylor *et al.* (1985). These researchers suggested that habitat quality for *P. intermedius* was good in dry *Pinus banksiana* plantations due to the dense shrub understorey found in these stands. Because recently harvested boreal mixedwood forests in Ontario also have profuse vegetative cover, comprised of shrubs and saplings, the quality of habitat for *P. intermedius* could be very good there. This topic is worth considering during future research on *P. intermedius* within recently harvested boreal mixedwood forests.

Sorex hoyi and *Sorex fumeus*

Sorex hoyi was not captured before timber harvest, but by the first post-harvest summer it overtook *Sorex fumeus* as the third most common species captured in pitfall traps. The decrease in *S. fumeus* abundance after timber harvest is consistent with the results of other researchers who have found *S. fumeus* are often rare when *S. hoyi* are present (Martell 1983; Clough 1987; Parker 1989; Yahner 1992; and Sekgororoane and Dilworth 1995). However, when *S. hoyi* are absent, *S. fumeus* are often found to be among the most abundant species (Kirkland 1977; and Kirkland and Schmidt 1982). In communities where both species are present, *S. hoyi* can be the most abundant of the two (Martell 1983; Parker 1989). This was the case in the current study after timber harvest. However, in at least one study, *S. fumeus* have been more abundant than *S. hoyi* when both species were present (Sekgororoane and Dilworth 1995).

Kurta (1995) suggests that *Sorex fumeus* prefers wooded habitat. As such they may be an interior forest species. In contrast, *Sorex hoyi* have been abundant in highly fragmented forests of Pennsylvania, (Yahner 1992), selectively cut mixedwood forests in Ontario (Martell and Radvanyi 1977) and three-year-old clearcuts of Ontario (Martell 1983). The sites monitored by these researchers did not consist of the same forest type, but what they did have in common is an abundance of young forest re-growth on the harvested areas. This regeneration likely satisfies the preference of *S. hoyi* for habitats with low vegetative cover (Kurta 1995). The different habitat preferences exhibited by *S. fumeus* and *S. hoyi* could explain the dramatic change in their relative abundance in the current study after timber harvest. However, the different trapping effort, and trapping season used before and after timber harvest in the current study could also be a factor, as discussed previously.

van Zyll de Jong (1983) notes that *Sorex hoyi* are usually less than one tenth as common as the most common Soricidae species in an area, this usually being *Sorex cinereus*. This comment is supported by several North American small mammal studies (Martell 1983; Yahner 1992;) but not by others (Nagorsen and Peterson 1981; Parker 1989). One of these studies, Nagorsen and Peterson (1981), found approximately one *S. hoyi* for every five *S. cinereus* in uncut upland boreal mixedwood forests similar to those of the current study. Thus Nagorsen and Peterson (1981), and the current study indicate that upland boreal mixedwood forests support high densities of *S. hoyi* and therefore could be good quality habitat for the species. It has been suggested that *S. hoyi* may avoid live traps and snap traps more than pitfall traps (Kurta 1995). However, since Nagorsen and Peterson (1981) monitored with snap traps, and the current study used pitfall traps, it is unlikely that trap type is responsible for the relatively high *S. hoyi* abundance noted by both studies in upland mixedwood forest.

CHAPTER 2: The Effect of Timber Harvest Method on the Small Mammal Edge Community in a Northern Ontario Boreal Mixedwood Forest

A silvicultural system is the process by which a stand is harvested, regenerated, and tended in order to produce a crop of timber (Smith 1962; Matthews 1992; Sauvageau 1995). In general, a silvicultural system is named after the reproductive method which is used to establish regeneration on the site. Examples include the clearcut, shelterwood, strip, and selection silvicultural systems (Smith 1962; Matthews 1992; Sauvageau 1995).

The name of a harvest method describes the form of the wood that is delivered to the roadside. This is dependent on the amount of processing that occurs in the harvested area. Examples of harvest methods include full-tree, tree-length, part-tree (tree-section), and cut-to-length (shortwood) extraction (Grammel 1984; Silversides and Sundberg 1989; Pulkki 1996).

A harvest system is the actual equipment used to carry out a particular harvest method (Pulkki 1996). Several harvest systems could be employed to carry out any particular harvest method. For example, tree-length extraction can be completed with a single-grip harvester and grapple skidder, or by motor manual (chainsaw) felling, topping, and delimbing followed by cable skidding (Pulkki 1996).

Within any particular silvicultural system, different harvest methods can have notable effects on the habitat left for wildlife after timber extraction (Scarratt *et al.*. 1996). For instance, full-tree extraction removes much more unmerchantable woody debris, or slash, from the harvested area than does cut-to-length extraction (see Appendix 1). Some other factors which change with different harvesting methods are the amount of soil compaction, soil erosion, and residual tree damage to a stand (Deslauriers 1996; Pulkki 1996). Of the harvest methods employed at the Black Sturgeon Boreal Mixedwoods Research Project, cut-to-length extraction leaves the least soil compaction, soil erosion, residual tree damage, and the most slash on the harvested stand (Deslauriers 1996; Gingras 1996; Pulkki 1996).

Each of these factors could have effects on the small mammal community of a harvested site. Soil compaction and erosion can determine the health and vigour of vegetative re-growth after timber extraction (Hausenbuiller 1985). The severity and amount of residual tree damage can affect the health of the remaining trees in the new forest. This in turn can influence the number of seeds, insects and the regeneration success in the stand. Since seeds, insects, and vegetative re-growth are important food sources for small mammals, their populations on harvested stands could also be influenced by residual tree damage. Finally, the amount and distribution of slash in an area can affect the habitat of small mammals by influencing the availability of shelter, herbaceous vegetation, insects, and moisture at the soil surface (Kirkland 1975; Wywialowski and Smith 1988; Deslauriers 1996). Since tree tops and limbs often carry seeds, leaving slash on the harvested area can also influence the availability of seeds which are used as a food source by many small mammals (Kirkland 1990; Deslauriers 1996).

No published field research has investigated the effect of harvesting method on small mammal communities. Kirkland (1975) gives a summary of many of the possible effects that could occur with a switch from conventional (full-tree or topped full-tree) clearcutting in Northern Hardwood Forests of the eastern United States to harvest methods that would remove more woody material from the area. Many of the conclusions of Kirkland (1975) are based on studies which have researched habitat features, such as soil moisture, log density, and vegetative cover, and found them to influence the abundance of small mammals in uncut forest habitat. Small mammal studies on surface mines, which are devoid of slash and most vegetation, were also examined in this summary in order to gain insight into the effect of removing all slash from cut areas. Although the review of Kirkland (1975) is of interest to the current work, it fails to include any studies which directly compare different harvest methods. It also concentrates on comparing methods that remove more woody debris from harvested areas to full-tree harvesting and does not consider the effect of alternative harvesting methods that leave more slash on the site. These latter methods of timber extraction are currently gaining more attention from forest managers of boreal forests in North America because they may assist with ecosystem management more adequately than the more commonly used method of full-tree timber extraction.

The current study investigates the effect of alternative harvesting methods on the small mammal community in a boreal mixedwood forest of Ontario. Two questions are addressed: 1) Is there a difference in the small mammal edge community associated with alternative harvesting methods in the clearcut silvicultural system implemented at the Black Sturgeon Boreal Mixedwood Research Project?, and 2) Is there a difference in the small mammal edge community associated with alternative harvesting methods in the shelterwood silvicultural system implemented at the Black Sturgeon Boreal Mixedwood Research Project? The results of this study will increase understanding of how small mammals react to different methods of timber harvest at the edges of shelterwood cuts and clearcuts. This should aid forest managers in choosing between the various methods available for harvesting within clearcut and shelterwood silvicultural systems during the process of integrated resource management.

Method of Data Analysis

The effect of different methods of timber harvest on small mammal edge communities associated with the clearcut, and shelterwood silvicultural systems were analysed separately. With clearcutting, the harvest methods included were full-tree extraction (areas 1, 14, and 26), and tree-length extraction (areas 7, 9, and 21) (Figure 7). Three harvest methods were involved in the shelterwood system comparison. These were full-tree extraction (areas 2,3, and 24), part-tree extraction (areas 12 and 23), and cut-to-length extraction (areas 5, 11, 22). Control areas were included in each comparison. In 1993 the original controls (areas 4, 13,

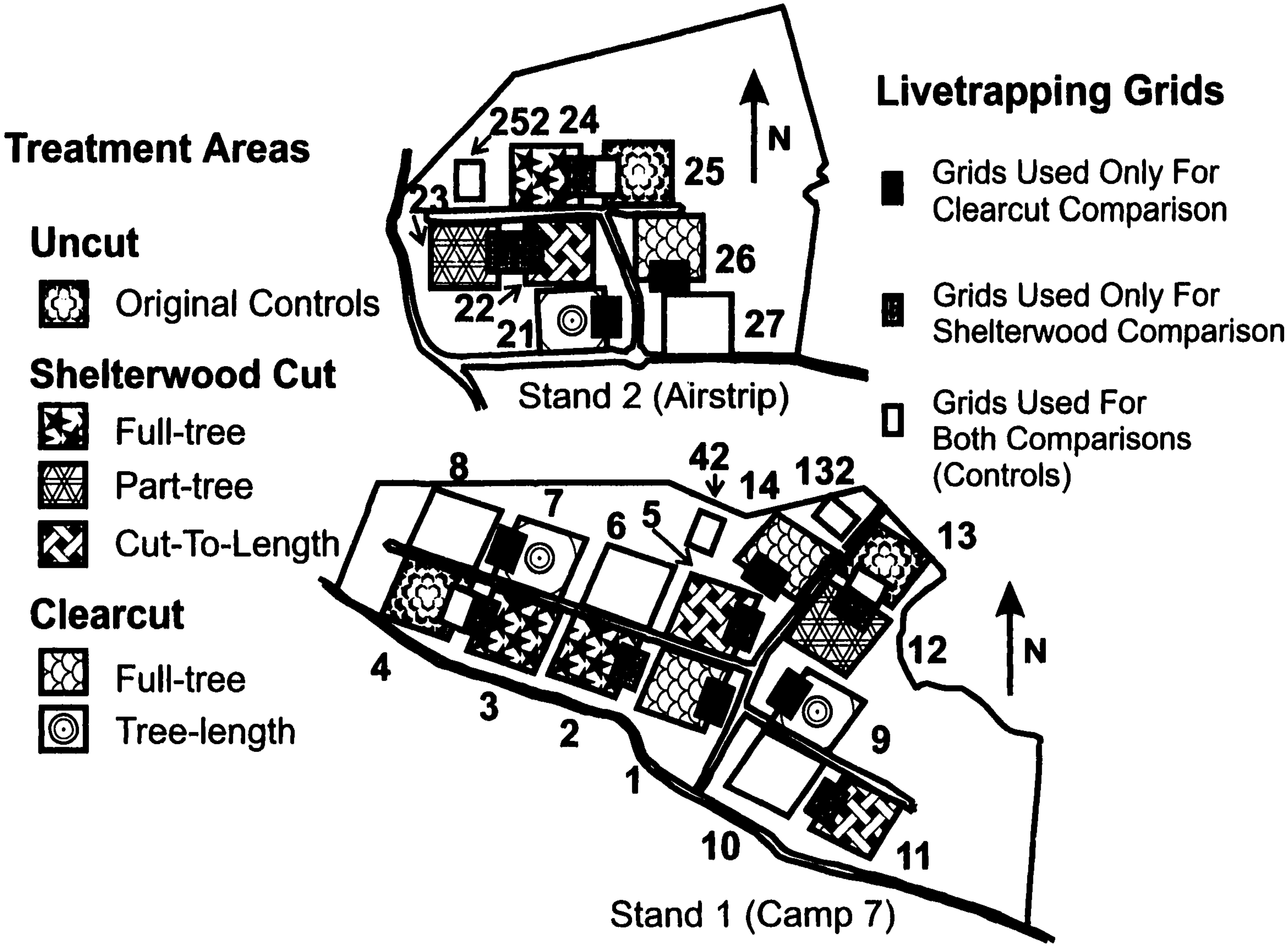


Figure 7. Locations of small mammal livetrapping grids used to compare effects of clearcut and shelterwood harvest methods during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

and 25) were included in both comparisons while in 1994 and 1995 the newer controls (areas 42, 132, and 252) were used. Analysis of data from the clearcut and shelterwood systems separately was required because the effect of timber harvest intensity was significant (Chapter 1) and needed to be controlled during comparison of timber harvesting methods.

Only livetrapping data, from the edges of treatment areas, were used during this investigation. Otherwise the methods of the current study follow those employed for the study of harvest intensity in Chapter 1. First, Kruskal-Wallis tests were used to determine how similar the treatment areas used for comparisons within each of the clearcut and shelterwood silvicultural systems were before timber harvest. Inter-year and inter-grid comparisons of the original controls were not repeated in this analysis because the results were presented and discussed in Chapter 1 (Tables 6 and 8). Finally, Kruskal-Wallis tests were conducted to compare the alternative harvest methods used within the clearcut, and shelterwood silvicultural systems.

Results

During the three years of this study, *Clethrionomys gapperi*, *Peromyscus maniculatus*, and *Microtus chrotorrhinus* were the three most commonly captured species on the treatment grids used for the harvest method comparisons within both the clearcut and shelterwood systems (Tables 10 and 11). Less commonly captured species which appeared in both data sets during all years were the *Phenacomys intermedius*, and *Napaeozapus insignis*. Species which appeared in both data sets only after harvest were *Microtus pennsylvanicus*, *Glaucomys sabrinus*, *Tamias minimus*, and *Mustela sp.* Of these, *G. sabrinus*, *T. minimus*, and *Mustela sp.* appeared only on harvested grids, and not in controls.

Table 10. Numbers of small mammals livetrapped on grids associated with the controls, tree-length clearcuts, and full-tree clearcuts during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	TREATMENTS (later implemented)									
CLEARCUTS	Control	Control	Control	Tree-length	Tree-length	Tree-length	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	4	13	25	7	9	21	1	14	26	
Clethrionomys gapperi	20	32	67	36	62	65	37	59	76	454
Peromyscus maniculatus	9	9	23	3	9	16	6	12	5	92
Microtus chrotorrhinus			2	1	1	5		3	9	21
Phenacomys intermedius				1		1		1	1	4
Synaptomys cooperi				1	1	2				4
Napaeozapus insignis	1									1
Soricidae						1	2	1	1	5
EFFORT (# Trap Nights)	180	180	180	180	180	225	135	180	180	
							TOTAL CAPTURES (# individuals)			581
							TOTAL EFFORT (# trap nights)			1620

1994 (post-harvest)	TREATMENTS APPLIED									
CLEARCUTS	Control	Control	Control	Tree-length	Tree-length	Tree-length	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	7	9	21	1	14	26	
Clethrionomys gapperi	68	78	61	73	63	60	56	60	82	601
Peromyscus maniculatus	12	13	3	12	20	12	10	18	8	108
Microtus chrotorrhinus	8	11	17	6	9		1	12	5	69
Glaucomys sabrinus						5	3	3		11
Microtus pennsylvanicus		2	2	1	1	1		2	1	10
Synaptomys cooperi	3	2	1	1				1	1	9
Napaeozapus insignis	1		1				1	1		4
Phenacomys intermedius	2	1						1		4
Tamias minimus						2	1			3
Zapus hudsonius				1						1
Mustela sp.						1		1		2
Soricidae		1		1						2
EFFORT (# Trap Nights)	540	450	450	540	540	495	495	540	450	
							TOTAL CAPTURES (# individuals)			824
							TOTAL EFFORT (# trap nights)			4500

1995 (post-harvest)	TREATMENTS APPLIED									
CLEARCUTS	Control	Control	Control	Tree-length	Tree-length	Tree-length	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	7	9	21	1	14	26	
Clethrionomys gapperi	44	49	44	62	42	26	26	38	40	371
Peromyscus maniculatus	17	28	5	21	14	11	20	21	3	140
Microtus chrotorrhinus	8							5		13
Glaucomys sabrinus				1		1	5	2	2	11
Phenacomys intermedius	3	1		3				4		11
Tamias minimus							4			4
Synaptomys cooperi	3			2				1		6
Napaeozapus insignis		1	1					1		3
Mustela sp.								1		1
EFFORT (# Trap Nights)	450	540	450	405	405	405	450	405	495	
							TOTAL CAPTURES (# individuals)			560
							TOTAL EFFORT (# trap nights)			4005

Table 11. Numbers of small mammals livetrapped on grids associated with the controls, cut-to-length shelterwoods, part-tree shelterwoods, and full-tree shelterwoods during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	TREATMENTS (later implemented)											
SHELTERWOODS	Control	Control	Control	Cut-to-length	Cut-to-length	Cut-to-length	Part-tree	Part-tree	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	4	13	25	5	11	22	12	23	2	3	24	
Clethrionomys gapperi	20	32	67	54	27	56	30	45	20	15	35	401
Peromyscus maniculatus	9	9	23	7	6	13	8	13	10	4	12	114
Microtus chrotorrhinus			2			2	1	7				12
Phenacomys intermedius							1					1
Napaeozapus insignis	1											1
Soricidae					1							1
EFFORT (# Trap Nights)	180	180	180	180	180	180	180	180	225	135	90	
									TOTAL CAPTURES (# individuals)			530
									TOTAL EFFORT (# trap nights)			1890
1994 (post-harvest)	TREATMENTS APPLIED											
SHELTERWOODS	Control	Control	Control	Cut-to-length	Cut-to-length	Cut-to-length	Part-tree	Part-tree	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	5	11	22	12	23	2	3	24	
Clethrionomys gapperi	68	78	61	102	86	65	55	76	59	37	65	752
Peromyscus maniculatus	12	13	3	9	7		12	8	9	8	7	88
Microtus chrotorrhinus	8	11	17	14		8			5	2	3	68
Phenacomys intermedius	2	1										3
Microtus pennsylvanicus		2	2	1			2			1		8
Synaptomys cooperi	3	2	1	2								8
Napaeozapus insignis	1		1								4	6
Glaucomys sabrinus									2			2
Tamias minimus				2								2
Mustela sp.					1							1
Soricidae		1		2								3
EFFORT (# Trap Nights)	540	450	450	540	540	540	450	495	495	540	450	
									TOTAL CAPTURES (# individuals)			941
									TOTAL EFFORT (# trap nights)			5490
1995 (post-harvest)	TREATMENTS APPLIED											
SHELTERWOODS	Control	Control	Control	Cut-to-length	Cut-to-length	Cut-to-length	Part-tree	Part-tree	Full-tree	Full-tree	Full-tree	Species Totals
LIVETRAPPING GRID NUMBER	42	132	252	5	11	22	12	23	2	3	24	
Clethrionomys gapperi	44	49	44	69	42	49	28	48	51	45	44	513
Peromyscus maniculatus	17	28	5	15	19	4	11	5	12	10	11	137
Microtus chrotorrhinus	8			5		10		7		2		32
Phenacomys intermedius	3	1		4		5		2		1		16
Synaptomys cooperi	3									1		4
Napaeozapus insignis		1	1								2	4
Glaucomys sabrinus				1	1		1		2			5
Tamias minimus				1	1	1			1			4
Mustela sp.					1	1	1				1	4
Soricidae					1					1		2
EFFORT (# Trap Nights)	450	540	450	450	450	495	405	450	405	405	495	
									TOTAL CAPTURES (# individuals)			721
									TOTAL EFFORT (# trap nights)			4995

Harvest Methods and the Clearcut Silvicultural System

Before timber harvest, in 1993, Soricidae were more abundant on trapping grids later designated to the full-tree clearcut treatment than to grids later designated to the tree-length clearcut and control treatments (Table 12). The biological significance of this event is questionable though because only five Soricidae were involved in the comparison and livetrapping is not the most effective means of measuring Soricidae abundance (see Chapter 1). All other small mammal community measurements, including species richness and diversity measures, failed to show significant differences among the future treatment sites during this pre-harvest year.

In 1995 *Glaucomys sabrinus* were more prevalent in full-tree extraction clearcuts than in tree-length extraction clearcuts and controls (Table 12). However none of the other measures, including species richness and diversity, showed differences among the treatments during the two post-harvest years of this study. This is not to state that there were no changes in the species composition of the treatments during those years. Some species were absent from some treatments during some of the years. Soricidae were absent from controls in 1993, *G. sabrinus* did not appear on controls in 1994, or 1995 (none were captured on any grid in 1993), and *Microtus chrotorrhinus* were absent from tree-length extraction grids in 1995.

Microtus chrotorrhinus are of special interest since they were the third most commonly captured species during all years of this study (Table 10). In 1995 their numbers were lower than in 1993, and substantially lower than in 1994. Not only was the abundance of *M. chrotorrhinus* lower in 1995, but they were also present on fewer grids during this year than in 1993 and 1994.

Overall species richness was higher after timber harvest than before harvest in 1993 (Table 10). Several species appeared in 1994 which had not previously been captured on the grids used for the current comparison. These were the *Microtus pennsylvanicus*, *Zapus hudsonius* (meadow jumping mouse), *Tamias minimus*, *Glaucomys sabrinus*, and *Mustela*

Table 12. Kruskal-Wallis tests (based on ranks)comparing the small mammal edge communities livetrapped on tree-length clearcuts, full-tree clearcuts, and on controls are displayed along with the minimum and maximum values of the indicator variables for the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	Treatments			
CLEARCUTS	Control	Tree-length	Full-tree	P-value
Clethrionomys gapperi	20-67	36-65	37-76	0.561
Peromyscus maniculatus	9-23	3-16	5-12	0.550
Microtus chrotorrhinus	0-2	1-5	0-9	0.414
Soricidae	0-0	0-1	1-2	0.056
Capture (# individuals)	29-92	40-87	45-91	0.733
Species Richness (N0)	2-3	3-4	3-4	0.100
Species Diversity (N1)	1.69-1.94	1.46-2.11	1.76-1.95	0.733
Species Diversity (N2)	1.52-1.75	1.23-1.68	1.41-1.55	0.177

1994 (post-harvest)	Treatments			
CLEARCUTS	Control	Tree-length	Full-tree	P-value
Clethrionomys gapperi	61-78	60-73	56-82	0.707
Peromyscus maniculatus	3-13	12-20	8-18	0.576
Microtus chrotorrhinus	8-17	0-9	1-12	0.288
Glaucomys sabrinus	0-0	0-5	0-3	0.345
Microtus pennsylvanicus	0-2	1-1	0-2	0.786
Synaptomys cooperi	1-3	0-1	0-1	0.103
Capture (# individuals)	84-106	78-93	70-97	0.874
Species Richness (N0)	4-5	4-5	4-6	0.564
Species Diversity (N1)	2.25-2.38	2.06-2.38	1.81-3.02	0.670
Species Diversity (N2)	1.71-1.76	1.57-1.94	1.38-2.26	0.670

1995 (post-harvest)	Treatments			
CLEARCUTS	Control	Tree-length	Full-tree	P-value
Clethrionomys gapperi	44-49	26-62	26-40	0.170
Peromyscus maniculatus	5-28	11-21	3-21	0.967
Microtus chrotorrhinus	0-8	0-0	0-5	0.558
Glaucomys sabrinus	0-0 (a)	0-1 (a)	2-5 (b)	0.032*
Phenacomys intermedius	0-3	0-3	0-4	0.886
Synaptomys cooperi	0-3	0-2	0-1	0.939
Capture (# individuals)	49-78	38-89	45-71	0.670
Species Richness (N0)	2-5	2-5	3-6	0.717
Species Diversity (N1)	1.39-3.14	1.75-2.32	1.53-3.33	0.733
Species Diversity (N2)	1.22-2.44	1.60-1.84	1.26-2.61	0.670

* Where $P < 0.05$ different letters indicate that treatments were significantly different

species. By 1995 *M. pennsylvanicus*, *Z. hudsonius*, and Soricidae no longer appeared on the treatment grids. No new species were evident in that year, so overall species richness was higher in 1995 than in 1993, and slightly higher in 1994 than in 1995.

Harvest Methods and the Shelterwood Silvicultural System

There were no significant differences in the small mammal community on the future shelterwood treatment sites before timber harvest in 1993 (Table 13). During the first year after timber harvest three variables, *Synaptomys cooperi* abundance, and Hill's diversity indices N1, and N2, showed differences which approached statistical significance ($P < 0.100$). All of these variables had higher values in the controls than on the shelterwood treatment grids. In 1994, two *S. cooperi* were present on area 5, which was harvested with the cut-to-length method (Table 11). Otherwise, this species was absent from areas harvested with the shelterwood system regardless of the harvest method used. Both Hill's diversity indices, N1 and N2, were higher on full-tree extraction shelterwood grids than on grids associated with the other harvested shelterwood treatments in 1994 (Table 13). By 1995 there were no longer any differences among the harvest treatments that were suggested by any of the variables measured during the current work.

As with the clearcut comparison, there were some species which were absent from at least one treatment during at least one year of this study (Table 13). *Microtus chrotorrhinus* were absent from the full-tree harvest grids before treatments were applied. However they were present on this treatment edge by the first post-harvest year, when they were absent from the edge of part-tree shelterwood areas. *Napaeozapus insignis* were absent from the cut-to-length and part-tree shelterwood grids and present on the control and full-tree grids in 1994. *Glaucomys sabrinus* abundance was generally low on shelterwood grids so no meaningful tests could be conducted on this species until the second post-harvest year. In 1995 *G. sabrinus* were always absent from the control areas but were captured on at least one grid in all of the shelterwood treatments.

Table 13. Kruskal-Wallis tests (based on ranks) comparing the small mammal edge communities livetrapped on cut-to-length shelterwoods, part-tree shelterwoods, full-tree shelterwoods, and on controls are displayed along with the minimum and maximum values of the indicator variables for the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

1993 (pre-harvest)	Treatments				
SHELTERWOOD CUTS	Control	Cut-to-length	Part-tree	Full-tree	P-value
Clethrionomys gapperi	20-67	27-56	30-45	15-35	0.460
Peromyscus maniculatus	9-23	6-13	8-13	4-12	0.780
Microtus chrotorrhinus	0-2	0-2	1-7	0-0	0.212
Capture (# individuals)	29-92	33-71	39-65	19-47	0.536
Species Richness (N0)	2-3	2-3	3-3	2-2	0.190
Species Diversity (N1)	1.69-1.94	1.43-1.82	1.86-2.26	1.67-1.89	0.173
Species Diversity (N2)	1.52-1.75	1.25-1.52	1.58-1.88	1.50-1.80	0.207

1994 (post-harvest)	Treatments				
SHELTERWOOD CUTS	Control	Cut-to-length	Part-tree	Full-tree	P-value
Clethrionomys gapperi	61-78	65-102	55-76	37-65	0.195
Peromyscus maniculatus	3-13	0-9	8-12	7-9	0.528
Microtus chrotorrhinus	8-17	0-14	0-0	2-5	0.106
Microtus pennsylvanicus	0-2	0-1	0-2	0-1	0.541
Synaptomys cooperi	1-3	0-2	0-0	0-0	0.073
Napaeozapus insignis	0-1	0-0	0-0	0-4	0.340
Capture (# individuals)	85-106	73-128	69-84	48-79	0.148
Species Richness (N0)	5-6	2-5	2-3	3-4	0.108
Species Diversity (N1)	2.36-2.39	1.31-2.04	1.37-1.80	1.85-2.04	0.069
Species Diversity (N2)	1.75-1.80	1.16-1.53	1.21-1.50	1.45-1.60	0.086

1995 (post-harvest)	Treatments				
SHELTERWOOD CUTS	Control	Cut-to-length	Part-tree	Full-tree	P-value
Clethrionomys gapperi	44-49	42-69	28-48	44-51	0.725
Peromyscus maniculatus	5-28	4-19	5-11	10-12	0.693
Microtus chrotorrhinus	0-8	0-10	0-7	0-2	0.716
Phenacomys intermedius	0-3	0-5	0-2	0-1	0.517
Glaucomys sabrinus	0-0	0-1	0-1	0-2	0.518
Capture (# individuals)	49-78	62-94	40-62	55-65	0.330
Species Richness (N0)	2-4	3-5	3-4	2-4	0.557
Species Diversity (N1)	1.39-2.77	2.00-2.40	2.01-2.13	1.65-1.99	0.289
Species Diversity (N2)	1.22-2.26	1.76-1.82	1.16-1.77	1.47-1.58	0.296

Overall species richness was higher after timber harvest than it was in 1993 (Table 11). Species which appeared on these grids in 1994 were *Microtus pennsylvanicus*, *Synaptomys cooperi*, *Glaucomys sabrinus*, *Tamias minimus*, and *Mustela* species. By 1995 *M. pennsylvanicus* were no longer captured. Since no new species appeared in 1995, overall species richness was lower in this second post-harvest year than in 1994, but it was still higher than the pre-harvest levels displayed in 1993.

Discussion

Clearcut Comparison

Comparisons Among Years

Species Composition Through Time

The occurrence of *Microtus pennsylvanicus* only during the first post-harvest year coincides with the results of other researchers who have found that they are effective invaders of disturbed habitat (Kirkland 1975). The single *Zapus hudsonius* captured on a tree-length harvest area in 1994 could have been a dispersing individual. Both *M. pennsylvanicus* and *Z. hudsonius* have similar habitat requirements, as they both prefer areas covered with grass, forbs, and sedges. However, they have very different diets with *M. pennsylvanicus* preferring herbaceous material and *Z. hudsonius* preferring seeds (particularly grass seeds), fruits, and insects (Kurta 1995). *Z. hudsonius* also tend to prefer more moist habitats than *M. pennsylvanicus*. The difference in habitat requirements for these two species could explain the much lower number of *Z. hudsonius* in the relatively dry upland mixedwood forest of the current study. Disappearance of both these species by the second post-harvest year could be related to a greater abundance of tree sapling growth in the cuts during that time, which in turn could have substantially decreased grass abundance in the area.

Soricidae had disappeared from live trap captures by the second year after harvest. However, Soricidae live trap captures were low on these grids during all years of this study. It is likely that the low Soricidae abundance detected on these grids is an artifact of livetrapping, and does not accurately reflect the abundance of this group on the treatment areas (see Chapter 1).

Comparisons Among Treatments

Species Richness, and Diversity

Differentiation among the clearcut and control treatments was not possible with Hill's species diversity numbers N0, N1, and N2 during any of the three years of this study. This does not indicate that there are no differences among the treatments, because the particular species present in a treatment can vary without changing its species richness, or diversity. Therefore analysis of the species composition of each treatment was appropriate.

Generally the species composition of each treatment was close to that of the others during each year of the current study. However, there are four instances were a species was absent from at least one treatment in the same year it was captured in the others. In 1993 and 1994 this occurred with only one species so the species richness and diversity indices would have accurately displayed this difference when treatments were compared. However, in 1995 two different species were absent from two different treatment areas. As a result the absence of *Glaucomys sabrinus* from control areas, and *Microtus chrotorrhinus* from tree-length extraction clearcuts would not be obvious when comparing these two treatments with species richness and the diversity indices alone.

Selected Species

Glaucomys sabrinus

The prominence of *Glaucomys sabrinus* on grids associated with clearcut edges is probably explained by a modification of their movement patterns in association with this harvest treatment as discussed in Chapter 1. In that chapter, two hypotheses were discussed which could explain the more frequent occurrence of *G. sabrinus* in traps set on grids associated with timber harvest: *Glaucomys sabrinus* could purposely travel on the ground at cut edges to harvest hair fungi (*Bryoroa* sp.) or they could accidentally glide past trees at the edge of harvested areas and then smell trap bait while on the ground, increasing the chances of capture.

Since tree-length extraction clearcuts generally have more slash left on site after harvest than full-tree extraction clearcuts, it follows that the former would contain higher amounts of hair fungi, which grows on tree limbs, on the ground at cut edges. If *Glaucomys sabrinus* were travelling on the ground at clearcut edges to harvest the hair fungi, their captures should be higher on tree-length extraction clearcuts. However, cuts with more slash on the ground would give opportunities for *G. sabrinus* to climb slash instead of walking directly on the ground. This action would reduce their likelihood of capture because in the current study, traps were placed on the ground, often under slash piles, to ensure captures of small mammals which do not normally climb. It is therefore not possible to differentiate between these two explanations for the higher capture rate for *G. sabrinus* on full-tree extraction clearcuts with this study. For the purposes of integrated resource management, it would be beneficial to conduct studies which investigate *G. sabrinus* activity patterns to determine why ground traps capture these animals more successfully at full-tree extraction clearcut edges than at the edges of tree-length extraction clearcuts and in uncut areas.

Microtus chrotorrhinus

Microtus chrotorrhinus abundance was variable through time and space over the course of the current study. Lack of a significant difference in *M. chrotorrhinus* abundance on the treatments of this study demonstrates that the abundance of this species was not directly related to the treatments applied. Instead it is likely that the high number of *M. chrotorrhinus* on certain grids of this study demonstrates the patchy distribution noted for this species by other authors (Kurta 1995). It would be worthwhile to investigate the habitat requirements of this species in detail to determine the reason for its patchy distribution and the changes in its distribution through time.

Tamias minimus

Generally the *Tamias minimus* avoids forest interiors and prefers to live in more open forests, or at forest edges (Kurta 1995). Capture of this species only after timber harvest on grids associated with timber extraction treatments, supports this generalization. Assuming that most of the *T. minimus* population was captured, it seems that their population density was much lower in the current study than their typical density of 1-6 animals/hectare (Kurta 1995). There are two possible explanations for this occurrence. First, the *T. minimus* is active only during the day, so night-time trapping, as occurred during the current study, could have failed to capture most individuals and subsequently underestimated the abundance of this species. Secondly, since the harvested stands of this study were recently changed from forest interior to disturbed habitats, perhaps *T. minimus* have not yet reached their normal population density for this habitat. The slight increase in the *T. minimus* population observed between the first and second post-harvest years of this study lends some support to this second explanation.

Mustela species

Mustela erminea and *Mustela nivalis* are said to be habitat generalists. Kurta (1995) states that these species prefer open forests, riparian woodlands, and shrubby fence rows to mature forests. Occurrence of *Mustela sp.* only on grids associated with the edge of harvested areas in the current study accurately reflects that description.

Shelterwood Cut Comparison

Comparisons Among Years

Species composition through time

While clearcut grids lost *Microtus pennsylvanicus*, *Zapus hudsonius*, and Soricidae between the first and second post-harvest years of this research, shelterwood areas lost only *M. pennsylvanicus* during this time. This is in part because *Z. hudsonius* never appeared on these treatment grids. As with the clearcut treatment, *M. pennsylvanicus* occurrence during the first post-harvest year was probably related to an abundance of grass immediately after harvest, followed by a decrease in grass abundance by the second post-harvest year. The more prevalent occurrence of Soricidae on shelterwood grids than on clearcut grids during the post-harvest years of this study could be related to a difference in the ground level moisture on these two treatments. However, as mentioned earlier, livetrapping does not necessarily reflect Soricidae abundance accurately, so conclusions based on Soricidae abundance in live traps are of limited value.

Species absent from some treatments

Microtus chrotorrhinus, which disappeared from the part-tree shelterwood treatment in 1994, were re-established on this treatment by 1995. This suggests that *M. chrotorrhinus* populations can effectively re-colonize edge habitats over the temporal and spatial scales involved in the current study. It would be beneficial to monitor the survival and establishment of these species within cut areas of various sizes so that forest managers could consider them during the process of integrated resource management.

Two less prevalent species were absent from particular shelterwood treatments during both the post-harvest years of this study. These were *Synaptomys cooperi*, from part-tree shelterwood grids, and *Napaeozapus insignis*, from cut-to-length and part-tree shelterwood grids. These species were not present in large numbers in the pre-harvest forest so their absence from some treatments during both post-harvest years is not necessarily of biological importance.

Comparisons Among Treatments

Species Richness, and Diversity

There were no significant differences observed in the species richness and diversity indices for the shelterwood treatments observed during the three years of this study. However, differences which approached significance were found when Hill's species diversity measures N1 and N2 were used to compare the treatments in 1994. Both of these indices were highest on control grids. This resulted from the cumulative impact of higher species abundance values for all species on control grids in 1994 as well as the occurrence of each species on at least one control grid when one to three species were missing from the shelterwood grids at that time.

The occurrence of higher species diversity in uncut forests than at shelterwood edges after harvest should be of concern to forest managers who need to conserve forest biodiversity yet still harvest timber. Also, the absence of some species from the edge of certain shelterwood treatments could demonstrate a problem for maintenance of species richness and diversity when these harvest methods are applied to the shelterwood system. At the edge of cut areas this absence is of special importance because these are probably the source of individuals which could re-establish lost species within the cut area after harvest. Studies which investigate the cause of lower species diversity measures, and the absence of some species, at shelterwood edges would assist with development of harvesting strategies that maintain these species in such areas.

Selected Species

Synaptomys cooperi

Although *Synaptomys cooperi* were not captured on control or shelterwood areas before harvest, they did occur on these grids during both post-harvest years. In 1994 differences which approached significance were found when the abundance of *S. cooperi* on the different treatments were compared. In that year *S. cooperi* were captured on every control, and on one cut-to-length area but were absent from all other treatment grids. Because the cut-to-length treatment displayed the least disturbance of all the shelterwood treatments in this project (Gingras 1996), and since controls were not touched with harvesting equipment, these data suggest that *S. cooperi* may be sensitive to disturbance caused by timber harvesting operations.

Synaptomys cooperi occurrence was too low for biologically meaningful statistical tests in 1995. However, the distribution of *S. cooperi* in that year shows that they were still most prominent on controls. Occurrence of one *S. cooperi* on a full-tree extraction shelterwood cut suggests that the species may be able to re-invade cut land a few years after timber harvest. However, since only one individual was involved, it is also possible that it was dispersing and was captured by chance as it passed through the full-tree harvest grid. If this occurred, then presence of this one individual in association with the full-tree shelterwood treatment does not indicate that this habitat is able to sustain *S. cooperi* populations during the second post-harvest year.

Although other studies researching the consequences of timber harvesting on small mammals have been conducted, the number of *Synaptomys cooperi* captured has been low in relation to the other small mammal species (Martell 1983; Monthey and Soutiere 1985). In fact, most studies in northern Ontario have not captured this species in uncut, or partially cut upland boreal mixedwood forests (Martell and Radvanyi 1977; Nagorsen and Peterson 1981; Martell 1983; Pasitschniak-Arts and Gibson 1989). The low number of *S. cooperi* in upland mixedwood forests makes it difficult to determine which habitat features are important to its survival. Without this knowledge it will be difficult for forest managers to develop strategies to conserve this species in harvested boreal mixedwood forests.

CHAPTER 3: The Effect of Harvesting Practices on Small Mammal Edge Community use of the Interface Between Uncut Forest and Harvested Land

Researchers studying the effects of harvesting on the small mammal community have traditionally located grids well within clearcuts and adjacent forested areas to ensure that discrete forest and clearcut communities were being sampled in each case (Kirkland *et al.* 1985). As a result, very little is known about small mammal use of the forest/clearcut interface (Kirkland *et al.* 1985; Walters 1991; Heske 1995; Mills 1995; Sekgororoane and Dilworth 1995). Small mammal communities at the forest edge of areas harvested with other silvicultural systems (ie. shelterwood) have not been studied so there are no published papers which deal with these edges.

Studies investigating small mammal use of agricultural land/forest edges, fence rows, and other long term edges are much more abundant (Merriam and Lanoue 1990; Apeldoorn *et al.* 1992; Cummings and Vessey 1994; Bollinger and Peak 1995; Demers *et al.* 1995; Diffendorfer *et al.* 1995; Heske 1995; Nupp and Swihart 1996). However, these edges are different from timber harvest/forest edges in a variety of ways (Cummings and Vessey 1994). The most obvious difference is the dramatic change in vegetative cover which occurs annually with row crops at the time of harvest (Cummings and Vessey 1994; Nupp and Swihart 1996). Also of importance are the different species composition of most wooded areas in agricultural lands (Nupp and Swihart 1996), the plant species available as food in agricultural fields (Cummings and Vessey 1995), and occurrence of well-established field species on the farmland next to forest/field edges. As a result of these differences it is dangerous to assume that the requirements for the preservation of woodland small mammals at the forest/field interface would be similar to those of small mammals at the forest/harvested area interface.

Understanding the response of the small mammal forest edge community to timber harvesting is important for conservation of biological diversity in lands which produce wood material for the forest industry. This edge habitat represents the area from which species will be able to re-invade cuts after timber harvest as the forest regenerates, re-establishing its ability to support their life cycles (Sullivan 1979a; Bennett 1990; Hobbs 1992). If the harvest edge and the adjacent forest cannot support the original small mammal community then the time required for re-establishment of pre-harvest biodiversity could be greatly extended. In areas which become further fragmented this could result in loss of interior forest species (Yahner 1992; Heske 1995).

Corridors, which are currently used to facilitate large mammal movement across harvested areas (Anonymous 1988; Ruefenacht and Knight 1995), could counteract the effects of timber harvesting on internal small mammal species by leaving areas of un-harvested lands dispersed within harvested areas. If these corridors are properly designed they may support internal forest small mammal species and provide a source population for re-establishment of such species in harvested areas (Hobbs 1992). However, little is known about the structural requirements, such as the width, length, and composition (Ruefenacht and Knight 1995) of corridors needed to meet this objective.

Also of importance for re-establishment of small mammal species in harvested lands is the willingness of each species to move across the forest/harvest area interface. This is referred to as the "hardness" or "permeability" of the edge for that species (Stamps *et al.* 1987; Morrison *et al.* 1992). Only species that will cross the habitat edge will be able to re-establish populations in the harvested area. The willingness of a species to cross the forest/harvest area interface can be related to the "abruptness" of the edge as it is viewed by that species (Yahner 1988; Linzey 1989). Areas harvested with the shelterwood system, could have "softer" edges for a species than those areas which are clearcut. Since the current study included clearcut, shelterwood, and patch cuts, an opportunity was available to investigate the differences these systems have on both the movement of small mammals across the forest edge, and small mammal species abundance on each side of these forest/harvest edges.

There are two specific questions addressed by the current study: 1) Is there a difference in the small mammal species composition, abundance, richness, or diversity associated with the treated, and buffer zone (uncut) sides of the grids which represent the seven harvest treatments in the Black Sturgeon Boreal Mixedwoods Research Project?, 2) If there was movement of individuals between the treated and buffer zone sides of these grids was it related to either species, or harvest treatment type? This work will assist forest managers with conservation of small mammal species by advancing knowledge about how these species use various forest/harvest area edges. Subsequently this work will assist forest and wildlife managers in maintaining biodiversity in the boreal mixedwood forests of Ontario.

Method of Data Analysis

Livetrapping data collected from all the harvest and control grids of the current study were analysed to determine small mammal abundance and movement patterns at the edge of each treatment area representing the seven timber harvest treatments of the Black Sturgeon Boreal Mixedwood Research Study. For each small mammal trapping grid, the number of individuals of each species captured on the treated and buffer zone sides of the grid, (Figure 8), was determined separately for each year of the study. Also, Hill's diversity values N0, N1, and N2 and the total number of small mammals captured were calculated for each side of each small mammal grid during each of the three years of this study. After calculation of the small mammal variables, the Mann-Whitney test was used to compare small mammal abundance, species richness and diversity, and the total number of small mammals captured on the two sides of each

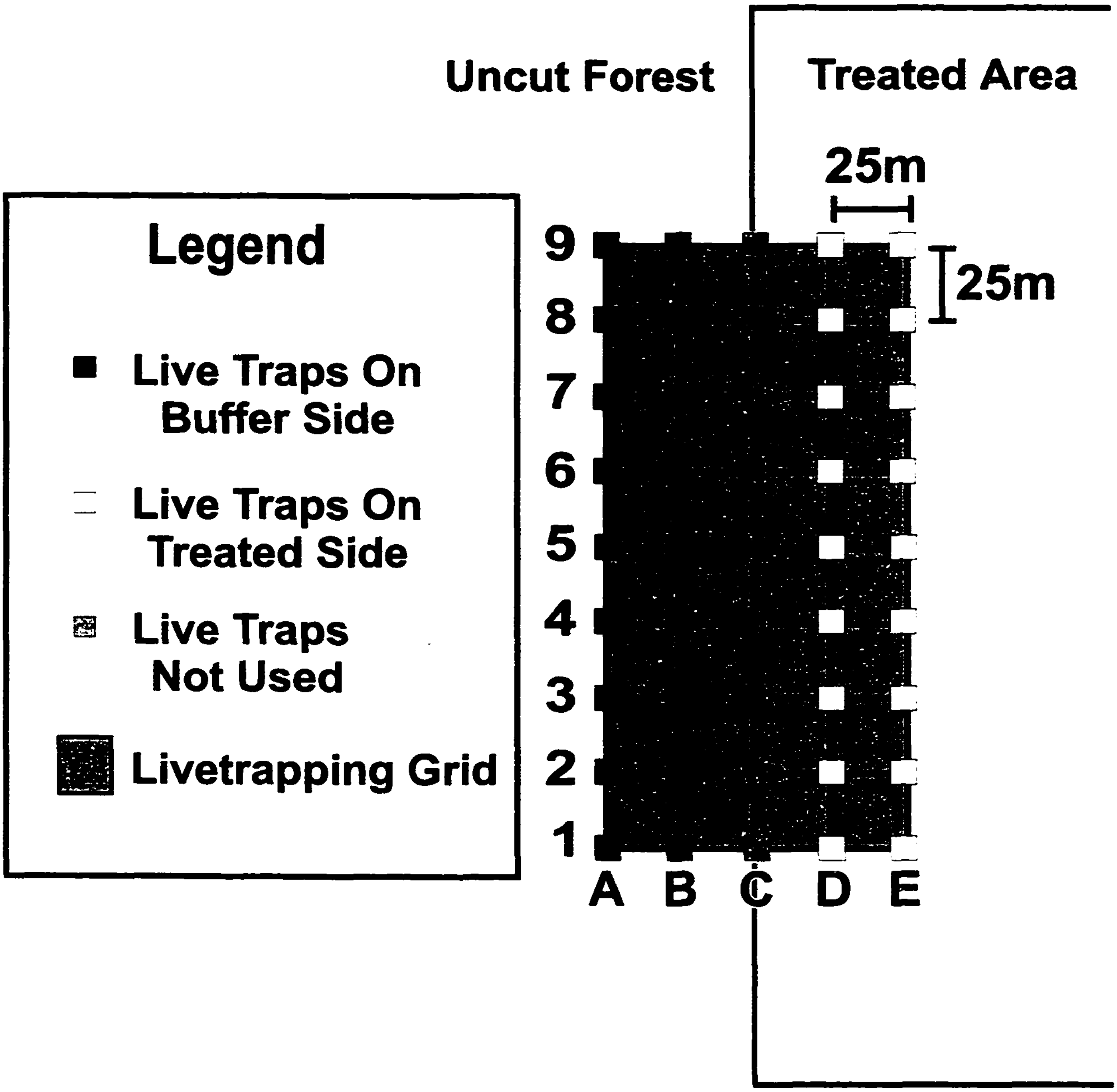


Figure 8. Locations of live traps used to collect data from the buffer and treated sides of the forest/harvested area interfaces during the pre-harvest year (1993) and the two post-harvest years (1994 and 1995) of research at the Black Sturgeon Boreal Mixedwood Research Project site.

grid, of each treatment, during each year of this study. During post-harvest years, the original and newer controls were considered separate treatments for the purposes of this comparison because trapping on these grids occurred in different seasons.

In cases where an individual small mammal was captured on both sides of a grid, it was included in the calculations for the treatment and buffer zone sides of that grid. Although this may inflate the number of small mammals captured on the entire treatment grid, it gives a more accurate portrayal of small mammal use of both sides of the harvest edge than would occur if these individuals were removed from the data. Also, since these individuals are included on both sides of the grid, their presence does not change the ranks of these two areas relative to each other, so comparison of the sides of each grid remains valid.

The number of individuals which crossed the harvest edge during this study was also determined for each species on each treatment. The percent of animals which crossed the edge in relation to the total number of individuals of that species which were captured on each treatment was determined. Comparison of the species which moved and the frequency of their movements was conducted by direct observation of these data.

Results

Side Comparisons

In 1993, comparison of the treated and buffer zone halves of the grids in each treatment revealed no differences in small mammal species abundance before timber harvest (Table 14). There were also no significant differences found when the total number of small mammals captured, or Hill's diversity numbers N0 and N1 were used for this comparison. However, when Hill's diversity number N2 was used, the halves of the grids later designated full-tree extraction clearcuts had significantly higher diversity numbers than the buffer zone halves of these grids (Table 14). The magnitude of these differences were quite variable. For areas 1

Table 14. Numbers of small mammals livetrapped on the treated and buffer zone sides of the grids before timber harvest in 1993 at the Black Sturgeon Boreal Mixedwood Research site.

SILVICULTURAL SYSTEM		Patch Cut			Shelterwood Cut		Shelterwood Cut			Shelterwood Cut			Clearcut			Clearcut			Original Control		
HARVEST METHOD		Part-tree			Part-tree		Full-tree			Cut-to-length			Full-tree			Tree-length			Uncut		
LIVETRAPPING GRIDS		8	10	27	12	23	2	3	24	5	11	22	1	14	26	7	9	21	4	13	25
SPECIES	SIDE																				
Clethrionomys gapperi	treated	18	2	31	15	25	9	1	17	20	18	30	17	23	33	21	30	29	13	18	34
	buffer	8	14	36	12	13	9	7	13	26	4	18	18	29	36	10	22	27	5	10	28
Peromyscus maniculatus	treated	.	1	3	5	9	6	6	4	3	2	6	2	7	1	2	3	6	6	6	6
	buffer	1	1	5	2	2	5	3	7	5	2	8	3	3	3	1	5	9	4	.	15
Microtus chrotorrhinus	treated	.	.	1	1	1	.	.	.	.	.	.	1	3	6	1	.	2	.	.	2
	buffer	.	1	2	.	4	.	.	.	.	.	1	.	.	2	.	.	2	.	.	.
Phenacomys intermedius	treated	.	.	2	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.
Synaptomys cooperi	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Microtus pennsylvanicus	treated	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Napaeozapus insignis	treated	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Soricidae	treated	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.
Captures (# individuals)	treated	18	4	37	22	35	15	7	21	24	20	36	20	35	40	24	34	38	19	24	42
	buffer	9	16	43	14	19	14	10	20	31	6	27	21	32	42	12	27	41	9	10	43
Species Richness (N0)	treated	1	3	4	4	3	2	2	2	3	2	2	3	5	3	3	3	4	2	2	3
	buffer	2	3	3	2	3	2	2	2	2	2	3	2	2	4	3	2	6	2	1	2
Species Diversity (N1)	treated	1.00	2.83	1.84	2.41	2.00	1.96	1.51	1.63	1.72	1.38	1.57	1.68	2.75	1.71	1.58	1.53	2.11	1.87	1.75	1.81
	buffer	1.42	1.59	1.72	1.51	2.28	1.92	1.84	1.91	1.56	1.89	2.12	1.51	1.36	1.74	1.76	1.61	2.79	1.99	1.00	1.91
Species Diversity (N2)	treated	1.00	2.67	1.40	1.92	1.73	1.92	1.32	1.45	1.40	1.22	1.38	■	■	■	1.29	1.27	1.64	1.76	1.60	1.47
	buffer	1.25	1.29	1.40	1.32	1.91	1.85	1.72	1.83	1.37	1.80	1.87	■	■	■	1.41	1.43	2.06	1.98	1.00	1.83

Significantly different at $P < 0.05$ ■

and 26 these differences were 0.04 and 0.07 respectively while area 14 showed a difference of 0.88. Since Hill's diversity measure N2 ranged between 1.00 and 2.67, a difference of 1.67, during this entire study, the difference of 0.88 on area 14 is considerable.

In 1994, the first year after harvest, differences in the abundance of *Clethrionomys gapperi* and *Peromyscus maniculatus* were observed (Table 15). For *C. gapperi* this difference was evident on both clearcut treatments. In each case the abundance of *C. gapperi* was higher on the uncut side of these grids. The magnitude of the differences noted were quite large. On full-tree extraction clearcuts these differences were 33, 17, and 29, while on tree-length extraction clearcuts they were 14, 18, and 12. For *P. maniculatus*, a significant difference between the two sides was observed only in clearcuts harvested with full-tree extraction. In contrast to *C. gapperi*, *P. maniculatus* were more abundant on the harvested side of the grids clearcut with full-tree harvesting. The magnitude of these differences were 10, 15, and 2. The different response these species have to full-tree extraction clearcut edges is more obvious when the percent of captures for each species, on each side of the grids are determined. This work reveals that 88% of the *P. maniculatus* captures on the full-tree extraction clearcuts occurred on the harvested side while 72% of *C. gapperi* captures on the same grids occurred on the buffer zone side of the grids.

As with *Clethrionomys gapperi* abundance, the total number of small mammals captured on grids for both clearcut treatments was higher on the uncut side of the grids (Table 15). For the clearcut areas harvested with full-tree extraction the magnitudes of these differences were 24, 11, and 29 while for the tree-length extraction clearcuts the differences were 10, 18, and 15. The differences in small mammal abundance, and *C. gapperi* abundance on the tree-length extraction clearcuts were more similar than on the full-tree extraction clearcuts. This was largely due to the higher *Peromyscus maniculatus* abundance on the treatment side of the full-tree extraction clearcut areas.

Table 15. Numbers of small mammals livetrapped on the treated and buffer zone sides of the grids during the first year after timber harvest (1994) at the Black Sturgeon Boreal Mixedwood Research site.

SILVICULTURAL SYSTEM		Newer Control			Patch Cut			Shelterwood Cut		Shelterwood Cut			Shelterwood Cut			Clearcut			Clearcut			Original Controls		
HARVEST METHOD		Uncut			Part-tree			Part-tree		Full-tree			Cut-to-length			Full-tree			Tree-length			Uncut		
TREATMENT AREA		42	132	252	8	10	27	12	23	2	3	24	5	11	22	1	14	26	7	9	21	4	13	25
SPECIES	SIDE																							
Clethrionomys gapperi	treated	32	32	28	16	24	43	21	23	25	17	27	46	36	16	■	■	■	■	■	■	12	19	20
	buffer	33	34	28	26	24	48	30	46	25	18	37	48	36	42	■	■	■	■	■	■	18	27	28
Peromyscus maniculatus	treated	9	6	1	.	6	3	7	3	4	5	3	4	1	.	■	■	■	10	12	5	.	5	4
	buffer	2	4	2	.	2	5	4	4	2	2	5	5	4	.	■	■	■	2	10	5	.	2	.
Microtus chrotorrhimus	treated	4	7	9	4	.	3	.	.	1	.	.	7	.	.	.	.	1	.	3	.	.	.	.
	buffer	4	3	6	1	.	3	.	.	3	.	.	5	.	5	.	9	2	3	6	.	.	.	.
Phenacomys intermedius	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Synaptomys cooperi	treated	.	1	1	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	1	.
	buffer	1	.	.	1	.	.	.	.	.	.	.	2	.	.	.	.	1	1	.	.	.	.	.
Microtus pennsylvanicus	treated	.	1	2	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	1	.	.	.	.
	buffer	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.
Napaeozapus insignis	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.
Tamias minimus	treated	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	2	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.
Glaucomys sabrinus	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.
Zapus hudsonius	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Mustela sp.	treated	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.
Soricidae	treated	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	.
	buffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Captures (# individuals)	treated	45	47	41	20	32	49	29	26	30	23	30	60	37	16	■	■	■	■	■	■	13	25	24
	buffer	41	43	36	28	27	56	34	50	30	20	46	61	41	47	■	■	■	■	■	■	18	29	28
Species Richness (N0)	treated	3	5	5	2	4	3	3	2	3	3	2	5	2	1	2	4	3	3	4	4	■	■	■
	buffer	5	5	3	3	3	3	2	2	3	2	3	5	3	2	2	5	4	5	3	5	■	■	■
Species Diversity (N1)	treated	■	■	■	1.65	2.11	1.58	2.00	1.43	1.71	2.00	1.38	2.26	1.13	1.00	2.00	2.49	1.85	2.09	2.87	2.31	■	■	■
	buffer	■	■	■	1.36	1.52	1.66	1.44	1.32	1.76	1.38	1.88	2.18	1.54	1.40	1.12	2.21	1.56	1.92	2.33	2.35	■	■	■
Species Diversity (N2)	treated	■	■	■	1.47	1.67	1.29	1.71	1.26	1.40	1.68	1.22	1.65	1.06	1.00	1.99	2.24	1.54	1.86	2.54	1.79	■	■	■
	buffer	■	■	■	1.16	1.25	1.34	1.26	1.17	1.41	1.22	1.50	1.58	1.28	1.23	1.05	1.71	1.24	1.41	1.96	1.71	■	■	■

Significantly different at $P < 0.05$ ■

Significantly different at $P < 0.100$ ■

So far, only differences which occurred on clearcut grids in 1994 have been discussed, however, differences in the small mammal community on the original and newer control areas existed in that year as well. Hill's diversity numbers, N1 and N2, were both higher on the treated side of these girds in 1994 even though neither side of the controls were touched by timber harvesting equipment (Table 15). The magnitudes of these differences on the newer control areas were 0.10, 0.49, and 0.59 for N1, and 0.30, 0.43, and 0.36 for N2. On the original control areas these differences were 0.31, 0.64, and 0.57 for N1, and 0.17, 0.46, and 0.38 for N2. Even though the differences noted for Hill's diversity number N2 were not as large as occurred on the full-tree clearcut grid 14 in 1993, they were still of considerable size. There was also less variation in Hill's N2 species diversity on areas within each control treatment in 1994 than occurred on the full-tree clearcut treatment areas before harvest.

In contrast to species diversity, higher values of Hill's number N0 occurred on the treatment side of each original control grid in 1994. Although species richness was higher on the treated side in each case, the difference between the treated and buffer sides overall, only approached statistical significance ($P<0.100$). This resulted because a value of "2" for species richness occurred on both the treated and buffer zone sides of different original control grids during 1994 (Table 15). The distribution of *Peromyscus maniculatus*, and *Synaptomys cooperi* on the original controls in 1994 were responsible for this difference because the only other species present, *Clethrionomys gapperi*, occurred on each side of each original control grid during this first post-harvest year.

Unlike the other harvest methods, both the clearcut and shelterwood full-tree extraction treatments had differences in the abundance of at least one species in 1995 (Table 16). During the second post-harvest year the abundance of *Clethrionomys gapperi* and *Glaucomys sabrinus* showed significant differences between the two sides of these clearcut grids. As in 1994, *C. gapperi* abundance was higher on the buffer zone side of these clearcuts however, the magnitude of this difference had decreased from the 1994 levels to 5, 15, and 15. *Glaucomys*

Table 16. Numbers of small mammals livetrapped on the treated and buffer zone sides of the grids during the second year after timber harvest (1995) at the Black Sturgeon Boreal Mixedwood Research site.

SILVICULTURAL SYSTEM		Newer Control			Patch Cut			Shelterwood Cut		Shelterwood Cut			Shelterwood Cut			Clearcut			Clearcut			Original Controls		
HARVEST METHOD		Uncut			Part-tree			Part-tree		Full-tree			Cut-to-length			Full-tree			Tree-length			Uncut		
TREATMENT AREA		42	132	252	8	10	27	12	23	2	3	24	5	11	22	1	14	26	7	9	21	4	13	25
SPECIES	SIDE																							
Clethrionomys gapperi	treated	■	■	■	27	14	20	16	28	25	24	20	36	18	22	■	■	■	23	19	11	13	10	23
	buffer	■	■	■	28	22	17	8	19	21	15	18	33	19	27	■	■	■	31	18	15	5	14	23
Peromyscus maniculatus	treated	8	10	1	6	3	5	5	3	■	■	■	9	9	4	14	10	3	14	9	2	1	13	7
	buffer	7	14	4	3	6	5	5	1	■	■	■	6	10	.	3	8	.	6	3	9	1	16	7
Microtus chrotorrhimus	treated	6	.	.	3	.	1	.	.	.	.	.	4	.	3	.	.	.	.	.	.	.	.	.
	buffer	3	.	.	2	.	.	.	5	.	2	.	.	.	6	.	5	.	.	.	.	2	.	.
Phenacomys intermedius	treated	.	1	.	1	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	1	.	.
	buffer	2	1	.	1	.	.	.	2	.	1	.	2	.	2	.	4	.	3	.	.	.	.	.
Synaptomys cooperi	treated	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
	buffer	2	.	.	1	.	.	.	.	.	1	.	.	.	.	.	1	.	2	.	.	1	.	.
Napaeozapus insignis	treated	.	1	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
	buffer	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Tamias minimus	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	1	.	.	1	.	.	1	2	.	1	.	.	.	.	.	.	.	.
Glaucomys sabrinus	treated	.	.	.	.	1	1	.	.	.	.	.	.	.	.	■	■	■	.	.	1	.	.	.
	buffer	.	.	.	.	1	1	1	.	1	.	.	1	1	.	■	■	■	1	.	1	.	.	.
Mustela sp.	treated	.	.	.	.	.	.	1	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	1	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Soricidae	treated	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
	buffer	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Captures (# individuals)	treated	■	■	■	37	18	27	22	31	■	■	■	50	27	32	25	19	15	37	28	14	16	23	30
	buffer	■	■	■	35	30	25	15	27	■	■	■	43	33	35	19	44	28	43	21	25	9	30	33
Species Richness (N0)	treated	4	4	2	■	■	■	3	2	2	2	4	4	2	6	4	2	2	2	2	3	4	2	2
	buffer	5	3	3	■	■	■	4	4	4	5	2	5	5	3	4	7	2	5	2	3	4	2	4
Species Diversity (N1)	treated	2.85	2.37	1.51	2.28	1.92	2.18	2.03	1.37	1.78	1.71	2.51	2.28	1.89	2.90	2.59	2.00	1.65	1.94	1.87	1.93	■	■	■
	buffer	3.09	2.15	1.59	2.13	2.17	2.64	2.89	2.40	1.96	2.81	1.51	2.22	2.89	1.95	2.29	3.91	1.17	2.53	1.51	2.23	■	■	■
Species Diversity (N2)	treated	2.39	2.01	1.32	1.77	1.57	1.71	1.72	1.21	1.64	1.54	2.05	1.79	1.80	2.00	2.24	1.99	1.47	1.89	1.77	1.56	1.49	1.97	1.56
	buffer	2.30	1.99	1.32	1.53	1.72	1.97	2.47	1.86	1.50	2.02	1.32	1.63	2.33	1.59	1.74	2.83	1.07	1.83	1.32	2.04	2.61	1.99	1.87

Significantly different at $P < 0.05$ ■

Significantly different at $P < 0.100$ ■

sabrinus abundance was higher on the buffer zone side of full-tree extraction clearcuts because one individual was captured on the buffer zone side of each of these grids in 1995. For the tree-length extraction clearcuts there was no longer any significant difference between the two sides of the grids, for any variable used to compare them during 1995.

Peromyscus maniculatus abundance, and the total number of small mammals captured on the full-tree shelterwood grids in 1995 were higher on the harvested than on the buffer zone side (Table 16). For *P. maniculatus* the magnitude of these differences were 6, 4, and 5. For the total number of small mammals captured, 8, 9, and 10 more individuals were trapped on the harvested side of these grids.

During 1995 the only other treatment with results that suggested differences between the treated and buffer zone sides of the grids was the patch cut treatment conducted with manual felling and cable skidding (Table 16). On these grids the difference between the species richness on the cut and uncut sides of each grid approached statistical significance. In each case the number of species captured on the uncut side of the grids was one higher than on the buffer zone side. Small mammals which occurred only on the buffer zone side of these grids were *Synaptomys cooperi*, *Mustela sp.*, and Soricidae species.

As in 1994, both the newer and original control treatments showed differences in small mammal captures on the two sides of these completely forested trapping grids. The newer control areas had higher *Clethrionomys gapperi*, and total small mammal abundance values on the buffer zone side of the grids (Table 16). For *C. gapperi* the magnitude of these differences were 2, 2, and 26 while the differences in the total number of small mammals captured were 1, 5, and 30 individuals. The original control areas also had higher values on the buffer zone side of the grids but in this case it was Hill's diversity number N1 that showed significant differences. The magnitude of these differences were 1.17, 0.02, and 0.63.

Throughout all the years of this study, part-tree, and cut-to-length shelterwood treatments never showed any statistically significant differences (P<0.05) when the two sides of the associated grids were compared. In addition, only in one case was a difference which approached statistical significance found on the part-tree patch cut treatment. The part-tree, and cut-to-length harvesting methods were not used at the clearcut intensity during this study. However the full-tree extraction method was, and differences in the two sides of the trapping grids in this case were found on both the shelterwood and clearcut grids.

Small Mammal Movement

Of all the species captured during the current study only five crossed the centre of trapping grids. These five were *Clethrionomys gapperi*, *Peromyscus maniculatus*, *Phenacomys intermedius*, *Microtus chrotorrhinus*, and *Tamias minimus* (Table 17). Of these the most common species to move were *C. gapperi* and *P. maniculatus*. *Clethrionomys gapperi* crossed the grid centre on more treatments than *P. maniculatus*, however, a larger percentage of *P. maniculatus* moved across the centre of treatment grids than *C. gapperi*. For both species, the highest rate of movement occurred on the full-tree extraction shelterwood areas before timber harvest. During the first year after timber harvest *P. maniculatus* movement was higher on the newer and original controls than at the other treatment edges. By 1995 this pattern no longer existed because more *P. maniculatus* moved across the centre of patch cut grids than control grids in that year. For *C. gapperi* no obvious differences among the treatments were noted when the number of individuals captured on each side of the grids was investigated. For the other three species, only one individual crossed the grid centres during this entire study.

Table 17. For species that crossed grid centres, the number that moved, the number captured, and the percentage that crossed during the pre-harvest (1993) and post-harvest (1994 and 1995) years of research at the Black Sturgeon Boreal Mixedwood Research site are shown.

Year		Newer Control Uncut	Patch Cut Part-tree	Shelterwood Cut Part-tree	Shelterwood Cut Full-tree	Shelterwood Cut Cut-to-length	Clearcut Full-tree	Clearcut Tree-length	Original Controls Uncut	Species Totals
1993	***Peromyscus maniculatus***									
	Number Moved (# individuals)	NA	0	0	5	3	0	0	1	9
	Captures (# individuals)	NA	11	17	24	22	19	26	35	154
	Percent Moved (%)	NA	0.00	0.00	20.83	13.63	0.00	0.00	2.86	5.84
	Clethrionomys gapperi									
	Number Moved (# individuals)	NA	2	0	3	5	1	1	1	13
	Captures (# individuals)	NA	107	64	59	112	153	137	105	737
	Percent Moved (%)	NA	1.87	0.00	5.08	4.46	0.65	0.73	0.95	1.76
1994	***Peromyscus maniculatus***									
	Number Moved (# individuals)	2	1	1	1	0	2	2	1	10
	Captures (# individuals)	21	17	14	20	14	33	34	10	163
	Percent Moved (%)	9.52	5.88	7.14	5.00	0.00	6.06	5.88	10.00	6.13
	Clethrionomys gapperi									
	Number Moved (# individuals)	5	5	2	4	4	3	3	1	27
	Captures (# individuals)	184	165	95	142	201	174	156	113	1230
	Percent Moved (%)	2.72	3.03	2.11	2.82	1.99	1.72	1.92	0.88	2.20
	Tamias minimus									
	Number Moved (# individuals)	0	0	0	0	1	0	0	0	1
	Captures (# individuals)	0	0	0	0	2	0	2	0	4
	Percent Moved (%)	NA	NA	NA	NA	50.00	NA	0.00	NA	25.00
1995	***Peromyscus maniculatus***									
	Number Moved (# individuals)	2	3	0	2	1	0	0	4	12
	Captures (# individuals)	39	23	13	28	28	36	41	38	246
	Percent Moved (%)	5.13	13.04	0.00	7.14	3.57	0.00	0.00	10.53	4.88
	Clethrionomys gapperi									
	Number Moved (# individuals)	2	2	1	3	3	2	1	1	15
	Captures (# individuals)	121	106	61	114	134	90	108	87	821
	Percent Moved (%)	1.65	1.89	1.64	2.63	2.24	2.22	0.93	1.15	1.83
	Microtus chrotorrhinus									
	Number Moved (# individuals)	1	0	0	0	0	0	0	0	1
	Captures (# individuals)	8	6	4	0	12	4	0	2	36
	Percent Moved (%)	12.50	0.00	0.00	NA	0.00	0.00	NA	0.00	2.78
	Phenacomys intermedius									
	Number Moved (# individuals)	0	0	0	0	1	0	0	0	1
	Captures (# individuals)	3	2	0	1	4	3	2	1	16
	Percent Moved (%)	0.00	0.00	NA	0.00	25.00	0.00	0.00	0.00	6.25

Discussion

Side Comparisons

Comparison of the small mammal communities on the treated and buffer zone sides of grids representing each treatment of this study before timber harvest showed a significant difference only on the full-tree extraction clearcuts when Hill's N2 species diversity was used. For two of the grids in this treatment the magnitude of this difference was small but on grid 14 this difference was considerable. Higher Hill's N2 diversity on the treated side of grid 14 resulted from the lower *Clethrionomys gapperi* abundance, in combination with higher *Peromyscus maniculatus*, *Microtus chrotorrhinus*, and *Phenacomys intermedius* abundance on the treated, in comparison to the buffer zone side, of this grid. Hill's N1 species diversity did not reveal this difference probably due to its greater sensitivity to changes in the less common species (Magurran 1988). The cause of the large difference in Hill's N2 species diversity on the treated and buffer zone side of grid 14 could be related to particular habitat features on the grid. Regardless of the cause, this difference should be taken into consideration when interpreting post-harvest results for N2 diversity on grid 14 of this study. For the other treatment grids it appears that small mammal use of the two sides was not significantly different when all grids within each treatment were considered before timber harvest.

During the first post-harvest year only the two clearcut treatments showed differences in species abundance values on the cut and uncut sides of the sampling grids. Higher *Clethrionomys gapperi* abundance on the uncut side of these grids corresponds with observations of researchers who have found this species to avoid disturbed habitat (Mills 1995; Sekgororoane and Dilworth 1995). However, this does not agree with the results of other researchers such as Kirkland (1985), who observed the opposite response, and Walters (1991) who found *C. gapperi* activity similar on each side of the forest/clearcut interface. In contrast to *C. gapperi*, *Peromyscus maniculatus* abundance was higher on the harvested side of the full-tree extraction clearcut grids of the current study. This observation supports the work of researchers who have found higher *P. maniculatus* abundance on recently clearcut lands than in adjacent uncut forests (Walters 1991), but not with Sekgororoane and Dilworth (1995) who found very little difference between the harvested and un-harvested sides of their forest/clearcut interface.

The occurrence of higher total small mammal, and *Clethrionomys gapperi* abundance on the uncut side of the clearcut treatments in 1994 resulted largely because the latter are the most common species in this region. Other researchers who have studied small mammal communities at habitat edges not older than 5 years of age have found small mammal abundance to be higher on both the harvested (Kirkland 1985) and the uncut (Sekgororoane and Dilworth 1995) side of the forest edge. Because the forest studied by Sekgororoane and Dilworth (1995) in New Brunswick was probably more similar to that of the current work than the forest studied by Kirkland (1985), it is possible that forest type was responsible for the different responses noted by Kirkland (1985).

The only other treatments to show statistically significant differences between the two sides of the trapping grids in 1994 were the original and newer controls. In both cases Hill's diversity numbers N1 and N2 were higher on the treated side of the grids. For the newer controls the cause of this difference is not obvious. However, on the original controls this difference results largely from a combination of lower *Clethrionomys gapperi* abundance, higher *Peromyscus maniculatus* abundance, and higher species richness values on the treated side. The reason for these responses on original controls could be related to higher levels of human activity just off of the treated side of the trapping grid, where other researchers conducted studies. This cannot be the case with the newer controls because there were no studies being conducted by other researchers nearby. The order in which sides of the grids were set and later checked during trapping sessions varied during this research so trap opening and checking time were also unlikely to have caused these results. As with grid 14 in 1993, these differences could be due to specific habitat features on the grid, however, loss of this pattern from newer control girds in 1995 does not support this option. Unfortunately, the true reason for these differences is likely to remain unknown.

During the second post harvest year, clearcuts harvested with full-tree extraction had higher *Clethrionomys gapperi* and *Glaucomys sabrinus* abundance on the uncut side of the sampling grids. For *C. gapperi* this was consistent with results from this treatment in 1994. However, for *G. sabrinus* this was a new occurrence. Appearance of these squirrels only on the forested side of the full-tree extraction clearcuts, and predominantly on the forested side of harvested areas overall, suggests that these squirrels use the ground of forests near (25 m from) habitat edges more intensely than in continuous forest. One reason for this could be that *G. sabrinus* accidentally glide and miss their target tree more often near forest edges than in continuous forest. They could also be entering clearcuts to forage for food and nesting material (see chapters 1 and 2 for further discussion) by means of ground travel and thus encounter the live traps. Finally, ground trapping data for *G. sabrinus* could accurately indicate areas of high use for the species, in which case these animals may be using habitat edges as corridors for travel.

In addition to the full-tree clearcut treatment, the full-tree shelterwood treatment also showed differences in species abundance during this second post-harvest year. In this case *Peromyscus maniculatus* were more abundant on the treated side of the grids. Although no other studies have investigated *P. maniculatus* abundance at the edge of shelterwood cuts, two in northeastern North America have studied their abundance inside partially cut areas. (Swan *et al.* 1984; Monthey and Soutiere 1985). The results of both researchers coincide with the current study because both studies found *P. maniculatus* abundance was higher in the partially cut than in the uncut forests.

Patch cuts were the only other treatment in which differences in the small mammal community on the treated and buffer zone sides of the grids were found during 1995. In this case species richness was consistently higher on the buffer zone side. Occurrence of Soricidae, *Mustela sp.*, and *Synaptomys cooperi* only on the uncut side of these plots was responsible for the difference found. The forests studied by Swan *et al.* (1984) had narrow strip cuts which were similar in design to the patch cuts of the current study. These researchers also captured more Soricidae on control than on strip cut areas. However, no *Mustela sp.* or *S. cooperi* were captured during that study. Understanding of how patch and strip cut harvesting affects small mammals is still very limited since no other published research is available on this topic. Further study of the response small mammals display in relation to these silvicultural systems is advised for the purposes of ecosystem management in areas where these harvesting systems will be used.

As in 1994, differences in the small mammal community located on the two sides of both the original and newer control grids were found in 1995. The newer control grids had higher *Clethrionomys gapperi*, and total small mammal abundance on the buffer zone side. Although the relationship between these two variables is understood, (see above) the cause for this difference on control grids is unknown. The original controls had higher N1 diversity values on the buffer zone side. The reason for this higher diversity was related to lower *C. gapperi* abundance on the buffer zone side for grid 4, and to higher Soricidae abundance on the uncut side of grid 25. For grid 13 the difference between the two sides was extremely small and for that reason, possibly not of biological importance.

There were two treatments, part-tree shelterwoods and cut-to-length shelterwoods, in which significant differences between the two sides of the grids were not observed during any of the three years of this study. These two harvesting methods would have left more slash on the cut area than any of the others used during this project. Unfortunately neither of these harvesting methods were used with clearcut harvesting so it is not possible to determine if they would moderate the differences between the sides of forest/clearcut edges. However, tree-length extraction clearcuts, which like the part-tree and cut-to-length methods have more remaining slash than full-tree extraction, did not display any significant differences by the second post-harvest year. It is therefore possible that use of the part-tree and cut-to-length methods could also have moderated the effects of timber extraction at the forest/clearcut edge. With the latter methods this may have even occurred during the first post-harvest year due to the higher concentration of slash which would have been left on those sites than on the areas clearcut with full-tree harvesting. More work on the effects of these two harvesting methods on small mammal communities in areas which have been clearcut with part-tree or cut-to-length extraction would be worthwhile if foresters decide to use them with this silvicultural system in the future.

Small Mammal Movement

When considering the hardness and softness of the habitat edge represented by the harvest treatments of the current study it may be expected that small mammal movement across the centre of control grids would be most common because any boundary at the centre of these grids would probably be softer than with the other treatments. For *Peromyscus maniculatus* this prediction was generally correct because movement was higher on both the newer and original controls than on the harvested area edges during the first post-harvest year. The change in this pattern by 1995 may have occurred due to an increase in ground cover provided by the regenerating forest in harvested areas which could have made these forest/harvested area edges softer than in 1994.

For *Clethrionomys gapperi* there seemed to be little variation among the treatments in the amount of movement that occurred between the treated and buffer zone sides of grids. Thus the response of *C. gapperi* at the edge of harvested areas was very different than for *Peromyscus maniculatus*. The different responses displayed at the edge of harvested land by these species suggests that the habitat characteristics which control edge permeability for *P.*

maniculatus and *C. gapperi* are different. Examination of pre-harvest movement data demonstrates that in the fall, movement of *P. maniculatus* was more patchy and inconsistent than movement of *C. gapperi*.

Kirkland (1985) observed low amounts of movement by *Clethrionomys gapperi* across a forest/clearcut interface. A similar edge response for *C. gapperi* was also found by Walters (1991) who failed to find any *C. gapperi* movement across edges of forest/clearcut interfaces. Observations made by these two studies corresponds to the current work because only a small portion, if any, of the *C. gapperi* crossed habitat edges in all cases.

Such agreement cannot be found in relation to *Peromyscus maniculatus* movement across the forest/harvested area interface because no other studies have reported movement of this species across forest/harvested area edges. However, movements of *Peromyscus leucopus* across the forest/harvested edge interface has been reported by some researchers (Kirkland 1985; Linzey 1989). For Kirkland (1985) the closest trapping stations were 7.5 m from the cut edge, while for Linzey (1989) this distance was only 5 m. Since the current work had trapping stations at more than twice this distance (25 m) from the cut edge, direct comparison of mouse movement across the forest/harvested area interfaces in these different studies is not appropriate. However, the general observations from these studies could assist with interpreting the current work.

Kirkland (1985) found many *Peromyscus leucopus* moved freely across the forest/harvested area interface, while Linzey (1989) did not. The explanation given for this difference by Linzey (1989) was that the forest/harvested area interface studied by Kirkland (1985) had continuous ground-level vegetation while the area studied by Linzey (1989) did not. Following this reasoning, the current work should have less *Peromyscus maniculatus* movement across the more intensively harvested edges than in the controls during the first post-harvest year, before vegetation was re-established in the harvested areas. This was indeed the case, so to this point the current work supports the suggestion of Linzey (1989). If loss of this pattern by the second post-harvest year of the current study was related to the increased abundance of ground-level vegetative re-growth on the harvested areas by that time, then the suggestion of Linzey (1989) is also supported by data from the second post-harvest year of the current study.

CHAPTER 4: The Effect of Timber Harvest on the Activity Patterns of *Peromyscus maniculatus* in an Ontario Boreal Mixedwood Forest

The range of *Peromyscus maniculatus* is one of the most extensive of any North American mammal, reaching from the northern Yukon Territory of Canada southwards into central Mexico, and from the west, almost to the east coast of the continent (Hooper 1968; Burt and Grossenheider 1980; Kurta 1995). Throughout this range *P. maniculatus* are known to occupy a diverse array of habitats including agricultural fields, sand dunes, recent burns, regenerating clearcuts, shrubby areas, and mature forests (Ahlgren 1966; Burt and Grossenheider 1980; Sullivan 1980; Gilbert and Krebs 1981; Martell 1983; Probst and Rakstad 1987; Kurta 1995). It is primarily a nocturnal species and spends the day inside one of several refuge sites, or nests, which it maintains throughout its home range (Blair 1940; Stickel 1968; Van Horne 1981; Wolff and Hurlbutt 1982; Sharpe and Millar 1990; Seabloom *et al.* 1994).

Day refuges may be located in burrows underground, inside or under stumps, logs, rock piles, woody debris piles, and within hollow trees or tree cavities (Wolff and Hurlbutt 1982; Sharpe and Millar 1990; Kurta 1995). As with most mice, *Peromyscus* species have been shown to make numerous short trips outside of their day refuge at night to obtain food and other requirements (Stickel 1968). These mice also switch day refuge locations periodically (Blair 1940; Stickel 1968; Wolff and Hurlbutt 1982; Sharpe and Millar 1990). As a result of these behaviours, *P. maniculatus* utilize different portions of their home ranges to different extents, at different times (Stickel 1968). Therefore, measures that can evaluate specific activity areas are beneficial in assessing habitat use by this species.

The harmonic mean method of home range estimation is one such measure (Dixon and Chapman 1980). With this method, isopleths that are calculated with less than all of the locations for a mouse can outline specific areas of high use for that individual. Another method of home range estimation called the minimum convex polygon (White and Garrott 1990) has been used to evaluate the home range of *Peromyscus* species in other studies (Krohne 1986; Wolff 1985). Unlike harmonic mean estimation, the minimum convex polygon method cannot be easily used to identify multiple areas of high activity within a home range.

Peromyscus maniculatus generally occupy a home range with an area between 500 m^2 (0.05 ha) and 3000 m2 (0.3 ha) (Wolff 1985). Differences in the home range size used by these mice could be a function of the availability of food, shelter, vegetative cover, and water. However, population density, and past or present interspecific and intraspecific competition have also been cited as factors which could affect home range size (Bowers and Smith 1979; Wolff 1985; Harney and Dueser 1987). In addition to these causes, the procedures used to collect data points and the method of home range estimation employed by researchers also affects the size of home range estimates (Wolff 1985).

Many researchers have suggested that mice with small home ranges are in habitat of higher quality than mice with large home ranges (Stickel 1968; Millar and Getz 1977; Bowers and Smith 1979). Van Horne (1982) found open areas of forest with vegetative cover in the form of forbs, shrubs, and trees to be of high habitat quality as measured by over-winter survival of mice. Other researchers using radio-telemetry (Douglass 1989) and trapping data (Martell 1983; Swan *et al.* 1984) have also found that *Peromyscus maniculatus* intensely utilize such habitat. As a result, it is believed that forests in their early successional stages provide high quality habitat for this species.

Harvesting of mature forests is one method of converting them to an earlier successional stage. Subsequently, timber harvest may influence *Peromyscus maniculatus* populations. High numbers of this species on seeded clearcuts attracted the interest of foresters during the early 1900s due to the presumed deleterious effect their presence had on forest regeneration (Sullivan 1979b). Since that time, *P. maniculatus* have been shown to provide many benefits to regenerating forests by assisting with control of insect pests, dispersal of mycorrhizal fungi, and aeration of forest soils (Maser *et al.* 1978; Martell and Macaulay 1981; Kurta 1995). Also of importance to foresters is the current trend towards ecosystem management that requires consideration of all wildlife during forest management planning.

The current study addresses these concerns by investigating three questions: 1) What is the effect of timber harvesting on the movement patterns of *Peromyscus maniculatus*?, 2) What habitat features are commonly used by *P. maniculatus* as day refuges or nest sites?, 3) Are there differences in the activity patterns, or the habitat features used by male and female *P. maniculatus*? Knowing which habitat features are important to *P. maniculatus* and understanding the effect of forest harvesting on the species will assist forest managers with ecosystem management.

Method of Data Analysis

After radio-telemetry field work, and differential correction of the locations where *Peromyscus maniculatus* were found (see Mammal Tracking in Field Procedures, this document), a home range analysis program, (Tracker 1994: version 1.1, Camponotus AB and Radio Location Systems AB, Sweden) was used to assess the data. This work determined the duration of radio attachment for each mouse (duration), the number of times each mouse was located (locations), the number of unique positions where each mouse was found (day refuges), and the distance mice travelled for every day refuge they used (distance/day refuge).

Several home range calculations were also performed. These were the 90% minimum convex polygon estimate, and the area within the 90%, 80% and 50% isopleths based on the harmonic mean home range estimate (Dixon and Chapman 1980; White and Garrott 1990). For female *Peromyscus maniculatus* a grid spacing of 4.9 was used for the latter method of home range estimation while for males a grid spacing of 11.0 was employed. To attain these grid spacings, first the grid spacing recommended for each animal by Tracker was determined.

Then the average recommended grid spacing for male and female mice was calculated. Finally, an iterative process was used to modify the average recommended grid spacing for each sex so that this number was within the limits allowed by Tracker for as many mice of that sex as possible.

The number of separate active areas associated with the 90%, 80%, and 50% harmonic mean home range estimates was also determined. For the purposes of this work an active area was defined to be a section of a home range within a completely enclosed isopleth that was separate from other enclosed isopleth areas. Because the same grid spacing was used during harmonic mean home range estimation for *Peromyscus maniculatus* within each sex, this count of active areas is another method of assessing, and comparing, the dispersion of radio-telemetry locations of female or male *P. maniculatus*.

Peromyscus maniculatus locations obtained outside daylight hours, between 22:00 and 05:00, were not used in this study even though some radio-telemetry was conducted on *P. maniculatus* at night in 1994. This was done because only a small number of night-time locations could be obtained. There are two reasons why these data could not be collected. First, walking over the slash covered harvested areas, and the piles of blown down trees in uncut forest, was very difficult and time consuming at night. And secondly, it was not possible to walk discretely through the forest at night as the flashlights, when they were on, or the logs cracking, when flashlights were off, probably disturbed mice from their normal activities as they attempted to either investigate or escape the commotion.

Because the duration of radio attachment varied among *Peromyscus maniculatus*, variables which could be closely related to duration, such as the total distance travelled, and the number of day refuges, could not be directly compared. For this reason, the ratios of distance/ duration, and the number of day refuges/duration were used for comparing the activities of *P. maniculatus* on different treatments. The ratio of distance/number day refuges was also calculated. As with the home range estimates, this variable described the degree of day refuge dispersion. It had some advantages over the home range estimation methods because unlike them, values for this measure could be determined for every *P. maniculatus* in this study.

After elimination of night radio-telemetry locations, and calculation of variables which described mouse activity, the scale at which *Peromyscus maniculatus* were using their environment was investigated. All *P. maniculatus* were included in this work with two females that had entered more than one treatment each being assigned to the treatment where they were originally radio-collared. The proximity of day refuges, daytime radio-telemetry locations, to uncut forest, timber harvest treatments, and the border between these environments was determined for each *P. maniculatus*, on each treatment of this study. For the purposes of this work, borders were defined to stretch 5 m on either side of the transition between cut and uncut forest. Finally, the percent of day refuges, and radio-telemetry locations, within and outside of the treatments associated with the grids on which *P. maniculatus* were radio-collared was determined. All of this was completed separately for female, male, and both sexes of *P. maniculatus* in combination.

The relative importance of specific habitat features (for definitions see field procedures) used as day refuges for female, male, and both sexes of *Peromyscus maniculatus* were also summarized. Then the ratio of "elevated" day refuges (those 2 m above the ground) to "ground" day refuges (those <2 m above the ground) was determined for each sex of *P. maniculatus* on each treatment of this study. Results were presented separately for each sex of *P. maniculatus* on each treatment, and for all *P. maniculatus* on each treatment. Finally this ratio was determined for all *P. maniculatus* in this study regardless of their sex or treatment designation. As with the investigation into the scale of habitat use, all radio-collared *P. maniculatus* were included in this work with the females that had entered more than one treatment assigned to the treatment where they were originally radio-collared. The percent of day refuges in each habitat feature, regardless of the harvest treatment in which they occurred, was then calculated. Finally the five habitat features most commonly used by each sex, and for both sexes in combination were determined.

After these summaries, several statistical comparisons were conducted. First the Mann-Whitney test was used to compare the weights of female and male *Peromyscus maniculatus* radio-collared during this study. For this comparison all *P. maniculatus* were included regardless of the treatments with which they were associated. The activities of male and female *P. maniculatus* on the shelterwood and control treatments were also compared using the Mann-Whitney test. For this comparison two female *P. maniculatus* radio-collared in 1995 had to be eliminated because each had entered two harvesting treatments and could not be assigned exclusively to one treatment. Also, variables associated with the harmonic mean home range estimates could not be used to compare between the sexes because this method is sensitive to changes in the grid spacing used for its calculation (White and Garrott 1990; Kie *et al.* 1996). Therefore, the variables which were used for this latter comparison were distance/duration, number of day refuges/duration, distance/number of day refuges, and the 90% minimum convex polygon home range estimate.

The differences observed while investigating the activity patterns of male and female *Peromyscus maniculatus* (see results), indicated that data from the two sexes should be analysed separately for all other comparisons. For each sex, data from the two years of collection and from the multiple grids associated with each treatment were combined after Mann-Whitney tests failed to find any statistically significant effect for grids or year in these data. Then the activity patterns of male and female *P. maniculatus* in relation to harvest intensity were compared. For female *P. maniculatus* the clearcut, shelterwood, and control treatments were compared with Kruskal-Wallis tests. For male *P. maniculatus* the shelterwood and control treatments were compared with the Mann-Whitney test. For both of these comparisons *P.*

maniculatus were assigned to the treatment associated with the grid on which they were radio-collared and *P. maniculatus* that entered more than one harvest treatment were eliminated from the comparison.

Results

When investigating the scale at which *Peromyscus maniculatus* used habitat, it was found that the median distance/duration for female *P. maniculatus* in this study was 4.3 m while for males this value was 23.2 m (Table 18). Large differences in the home range size for these two sexes were also observed with females having a median 90% minimum convex polygon home range of 8.19×10^{-4} ha (8.19 m^2) and males with an average home range of 6.099×10^{-3} ha (60.99 m^2). In addition, most of the day refuges, and radio-telemetry locations were within the treatment area associated with the grid on which *P. maniculatus* had been radio-collared (Table 19). This occurred even though several *P. maniculatus* were collared inside the uncut buffer zone associated with the shelterwood and clearcut treatments. When female *P. maniculatus* were examined alone the same trend was observed although the proportion of day refuges, and radio-telemetry locations on the treated areas had decreased. Data from male *P. maniculatus* displayed the highest portion of day refuges, and radio-telemetry locations, within the treatment associated with the grid where *P. maniculatus* were radio-collared. In all cases, use of boundary habitat was lower than for the forested, shelterwood, and clearcut environments.

The most common habitat features used by these *Peromyscus maniculatus*, when results of male and female mice were combined, were decay class 3-5 root-balls, tree/snags, and logs, slash-piles, and areas of ground not associated with any above ground features (Table 20). Four of these habitat features remained important when the most common habitat features used only by female *P. maniculatus* were examined (Table 20). These were decay class 3-5 root-balls, and logs, slash-piles, and ground not associated with any obvious above ground

Table 18. Characteristics of *Peromyscus maniculatus* and their movement patterns as measured by radio-telemetry during the first and second post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

Frequency	Year	Grid	Treatment	Sex	Weight	Duration	Distance / Duration	Locations	Day Refuges	Distance / Day Refuge	Day Refuges/ Duration	90% Minimum Convex Polygon	Harmonic Mean Home Range And Active Area Estimates					
													90%	90%	80%	80%	50%	50%
(MHz)					(g)	(days)	(m/day)			(m/day refuge)	(day refuge/day)	(m^2)	(m^2)	(# areas)	(m^2)	(# areas)	(m^2)	(# areas)
165.736	1994	132	control	male	18.0	30	1.9	19	3	19.0	0.10	8.19	250.73	2	250.73	2	11.68	1
165.813	1994	132	control	male	17.5	21	7.7	20	4	40.6	0.19	0.78	58.98	1	58.98	1	58.98	1
166.220	1994	132	control	male	17.0	19	26.7	10	4	126.7	0.21	740.98	1434.73	2	930.00	2	15.09	1
165.716	1995	42 and 132	control	male	20.5	25	23.2	13	5	116.2	0.20	2.01	171.82	1	171.82	1	66.99	1
165.754	1994	5	shelterwood	male	17.0	20	33.3	14	4	166.7	0.20	1242.15	3864.34	2	2571.03	2	18.35	1
166.145	1994	5	shelterwood	male	19.5	16	19.9	13	3	106.2	0.19	0.00	278.02	2	278.02	2	18.77	1
166.065	1995	5	shelterwood	male	17.5	17	46.1	14	5	156.8	0.29	11426.70	3760.79	4	2032.45	3	209.70	2
166.342	1994	42	control	female	21.5	36	2.6	25	3	31.2	0.08	163.27	187.76	2	187.76	2	0.50	1
165.946	1994	132	control	female	26.0	34	2.4	19	2	41.5	0.06	0.00	6.38	1	6.38	1	6.38	1
166.305	1994	132	control	female	19.0	27	2.5	15	3	22.2	0.11	59.00	245.80	2	245.80	2	12.51	1
165.635	1995	42	control	female	19.0	19	8.7	17	5	33.1	0.26	81.37	505.44	2	102.81	2	4.02	1
165.923	1995	42	control	female	16.5	18	0.0	16	1	0.0	0.06	NA*	NA	NA	NA	NA	NA	NA
165.946	1995	42	control	female	20.0	30	2.3	25	3	23.0	0.10	0.00	9.45	1	9.45	1	9.45	1
165.654	1995	42 and 5	control	female	22.0	11	21.6	9	4	59.4	0.36	1554.36	1388.73	3	1047.88	2	1.40	1
165.675	1995	2	shelterwood	female	22.0	20	1.4	17	4	7.2	0.20	26.26	113.76	2	113.76	2	8.03	1
166.266	1995	2	shelterwood	female	22.0	20	0.1	17	2	1.2	0.10	NA	NA	NA	NA	NA	NA	NA
165.607	1994	5	shelterwood	female	25.0	31	0.3	17	3	3.3	0.10	0.11	NA	NA	NA	NA	NA	NA
166.464	1994	5	shelterwood	female	18.0	17	4.8	11	2	40.7	0.12	0.00	35.70	2	35.70	2	2.61	1
165.984	1995	5 and 1	shelterwood	female	16.0	15	6.3	11	3	31.3	0.20	114.75	228.05	1	228.05	1	0.41	1
165.694	1994	14	clearcut	female	26.7	27	27.7	14	6	124.5	0.22	6275.03	NA	NA	NA	NA	NA	NA
166.184	1994	1	clearcut	female	18.5	29	8.2	18	3	79.4	0.10	0.00	3272.21	2	0.37	1	0.37	1
165.854	1995	14	clearcut	female	17.5	22	3.8	19	5	16.9	0.23	559.44	333.65	2	280.45	2	40.88	2
165.795	1995	14	clearcut	female	18.0	19	11.6	17	6	36.6	0.32	1126.58	172.62	3	125.51	3	89.03	2
165.896	1995	14	clearcut	female	20.0	18	12.3	16	4	55.4	0.22	34.50	183.07	1	183.07	1	34.43	1
166.184	1995	1	clearcut	female	21.5	25	4.8	15	3	40.3	0.12	62.98	45.79	2	44.58	2	10.11	1
Median for males regardless of treatment					17.5	20	23.2	14	4	116.2	0.20	8.19	278.02	2	278.02	2	18.77	1
Median for females regardless of treatment					20.0	21	4.3	17	3	32.2	0.12	60.99	185.41	2	119.63	2	7.20	1

*NA indicates the value could not be determined.

Table 19. Affinity of radio-tracked *Peromyscus maniculatus* (18 females and 7 males) for the harvest treatment areas associated with the grid where they were radio-collared during the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site displayed as the percent of day refuge positions, and locations situated within, outside, and at the boundary of these treatment areas.

	SEXES COMBINED (DAY REFUGES)			SEXES COMBINED (LOCATIONS)		
Treatments where *P. maniculatus* Were Radio-Collared:	Control	Shelterwood	Clearcut	Control	Shelterwood	Clearcut
On treated area associated with the grid where mice were radio-collared (%)	91.89	69.23	77.78	95.74	70.18	85.86
Outside of areas like the treated part of the grid where mice were radio-collared (%)	2.70	23.08	22.22	1.60	28.95	14.14
In boundary areas (%)	5.41	7.69	0.00	2.66	0.88	0.00
Total number of day refuges or locations	37	26	27	188	114	99
Total number of mice radio-collared	11	8	6	11	8	6
	FEMALES (DAY REFUGES)			FEMALES (LOCATIONS)		
Treatments where *P. maniculatus* Were Radio-Collared:	Control	Shelterwood	Clearcut	Control	Shelterwood	Clearcut
On treated area associated with the grid where mice were radio-collared (%)	85.71	57.14	77.78	93.65	61.64	85.86
Outside of areas like the treated part of the grid where mice were radio-collared (%)	4.76	28.57	22.22	2.38	36.99	14.14
In boundary areas (%)	9.52	14.29	0.00	3.97	1.37	0.00
Total number of day refuges or locations	21	14	27	126	73	99
Total number of mice radio-collared	7	5	6	7	5	6
	MALES (DAY REFUGES)			MALES (LOCATIONS)		
Treatments where *P. maniculatus* Were Radio-Collared:	Control	Shelterwood	Clearcut	Control	Shelterwood	Clearcut
On treated area associated with the grid where mice were radio-collared (%)	100.00	83.33	NA*	100.00	85.37	NA
Outside of areas like the treated part of the grid where mice were radio-collared (%)	0.00	16.67	NA	0.00	14.63	NA
In boundary areas (%)	0.00	0.00	NA	0.00	0.00	NA
Total number of day refuges or locations	16	12	NA	62	41	NA
Total number of mice radio-collared	4	3	NA	4	3	NA

*NA indicates that no mice were radio-collared on that treatment

Table 20. Location and description of day refuges discovered during radio-telemetry of *Peromyscus maniculatus* in clearcut, shelterwood and uncut control treatment areas during the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

SEXES COMBINED (based on 25 radio-collared deer mice)

HABITAT FEATURES	Class	Control	Shelterwood	Clearcut	Total	Percent
Root-balls (decay class 3-5)*	ground	8	5	1	14	**15.56**
Snags (decay class 3-5)	elevated	10	1	1	12	**13.33**
Ground	ground	2	2	7	11	**12.22**
Logs (decay class 3-5)	ground	3	5	3	11	**12.22**
Slashpile (under or inside)	ground	4	2	2	8	**8.89**
Trees/Snags (decay class 1-2)	elevated	6	0	0	6	6.67
Stumps (decay class 1-2)	ground	0	1	5	6	6.67
Stumps (decay class 3-5)	ground	1	3	2	6	6.67
Erratics	elevated	0	4	1	5	5.56
Logs (decay class 1-2)	ground	0	1	2	3	3.33
Base of Tree/Snags (decay class 1-2)	ground	2	0	1	3	3.33
Shrubs (under)	ground	1	0	1	2	2.22
Base of Tree/Snags (decay class 3-5)	ground	0	1	0	1	1.11
Rock (under)	ground	0	0	1	1	1.11
Trailer	elevated	0	1	0	1	1.11
Root-balls (decay class 1-2)	ground	0	0	0	0	0.00
Total Day Refuge Sites		37	26	27	90	100.00
Day Refuge Location Ratio (elevated:ground)		1:1	1:3	1:12	1:3	
Percent of Day Refuges in Treatment		41.11	28.89	30.00	100.00	

FEMALES (based on 18 radio-collared female deer mice)

HABITAT FEATURES	Class	Control	Shelterwood	Clearcut	Total	Percent
Root-balls (decay class 3-5)	ground	5	3	1	9	**14.52**
Snags (decay class 3-5)	elevated	2	1	1	4	6.45
Ground	ground	1	0	7	8	**12.90**
Logs (decay class 3-5)	ground	3	5	3	11	**17.74**
Slashpile (under or inside)	ground	4	0	2	6	**9.68**
Trees/Snags (decay class 1-2)	elevated	2	0	0	2	3.23
Stumps (decay class 1-2)	ground	0	0	5	5	8.06
Stumps (decay class 3-5)	ground	1	2	2	5	8.06
Erratics	elevated	0	1	1	2	3.23
Logs (decay class 1-2)	ground	0	1	2	3	4.84
Base of Tree/Snags (decay class 1-2)	ground	2	0	1	3	4.84
Shrubs (under)	ground	1	0	1	2	3.23
Base of Tree/Snags (decay class 3-5)	ground	0	0	0	0	0.00
Rock (under)	ground	0	0	1	1	1.61
Trailer	elevated	0	1	0	1	1.61
Root-balls (decay class 1-2)	ground	0	0	0	0	0.00
Total Day Refuge Sites		21	14	27	62	100.00
Day Refuge Location Ratio (elevated:ground)		1:6	1:4	1:13	1:6	
Percent of Day Refuges in Treatment		33.87	22.58	43.55	100.00	

MALES (based on 7 radio-collared male deer mice)

HABITAT FEATURES	Class	Control	Shelterwood	Clearcut	Total	Percent
Root-balls (decay class 3-5)	ground	3	2	NA**	5	**17.86**
Snags (decay class 3-5)	elevated	8	0	NA	8	**28.57**
Ground	ground	1	2	NA	3	**10.71**
Logs (decay class 3-5)	ground	0	0	NA	0	0.00
Slashpile (under or inside)	ground	0	2	NA	2	7.14
Trees/Snags (decay class 1-2)	elevated	4	0	NA	4	**14.29**
Stumps (decay class 1-2)	ground	0	1	NA	1	3.57
Stumps (decay class 3-5)	ground	0	1	NA	1	3.57
Erratics	elevated	0	3	NA	3	**10.71**
Logs (decay class 1-2)	ground	0	0	NA	0	0.00
Base of Tree/Snags (decay class 1-2)	ground	0	0	NA	0	0.00
Shrubs (under)	ground	0	0	NA	0	0.00
Base of Tree/Snags (decay class 3-5)	ground	0	1	NA	1	3.57
Rock (under)	ground	0	0	NA	0	0.00
Trailer	elevated	0	0	NA	0	0.00
Root-balls (decay class 1-2)	ground	0	0	NA	0	0.00
Total Day Refuge Sites		16	12	NA	28	100.00
Day Refuge Location Ratio (elevated:ground)		3:1	1:3	NA	1:1	
Percent of Day Refuges in Treatment		57.14	42.86	NA	100.00	

***Bold** - habitat features and percentages that were considered important for *P. maniculatus*

**NA - indicates that no *P. maniculatus* were radio-collared in that category features. However, stumps of all decay classes were also important for female *P. maniculatus*. When the results from male *P. maniculatus* were examined separately, three habitat features important when data from the two sexes were combined were still commonly utilized (Table 20). These were decay class 3-5 root-balls, and tree/snags, and areas of ground not covered by any obvious above ground habitat features. In addition, decay class 1-2 tree/snags and erratics were also commonly use by male *P. maniculatus*. Of the five habitat features most commonly used by male *P. maniculatus*, decay class 3-5 tree/snags were by far the most heavily used.

Examining the elevation of day refuge positions for all *Peromyscus maniculatus* combined showed that use of ground level day refuges was most common among the *P. maniculatus* radio-collared during this study. However, when the ratio of elevated to ground day refuges was considered for each sex separately, some important differences were noted. For *P. maniculatus* in controls, females tended to use ground day refuges six times as often as elevated refuges while males used elevated refuges three times more often than ground day refuges (Table 20). In addition to this, the elevated to ground level day refuge ratio changed with harvest treatment for both sexes. This difference was particularly noticeable for male *P. maniculatus* in the shelterwood treatment because the direction of the elevated to ground day refuge ratio was the reverse of that observed in controls. For females however, the effect of harvest treatment on this ratio was only notable on the clearcut treatment where the ground/elevated day refuge ratio was substantially higher than in the other treatments.

When the activity patterns of male and female *P. maniculatus* were compared on shelterwood and control treatments, statistically significant differences between the sexes were found only for *P. maniculatus* in the shelterwood treatment (Table 21). In shelterwoods, both the distance/duration, and distance/number of day refuges were higher for male than for female

Table 21. Mann-Whitney tests (based on ranks) comparing the movement patterns of male and female *Peromyscus maniculatus* on the shelterwoods and uncut controls are displayed with the minimum and maximum values for each variable determined from radio-telemetry during the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

SILVICULTURAL SYSTEM	CONTROL			SHELTERWOOD		
	Females	Males	P-value	Females	Males	P-value
Day refuges/Duration (day refuge/day)	0.06-0.26 n = 6	0.10-0.21 n = 4	0.165	0.10-0.20 n = 4	0.19-0.29 n =3	0.108
Distance/Duration (m/day)	0.0-8.7 n = 6	1.9-26.7 n = 4	0.201	0.1-4.8 n = 4	19.9-46.1 n =3	0.034
Distance/Day refuges (m/day refuge)	0.0-41.5 n = 6	19.0-126.7 n = 4	0.201	1.2-40.7 n = 4	106.2-166.7 n =3	0.034
90% minimum convex polygon (m^2)	0.00-163.27 n =5	0.78-740.98 n = 4	0.806	0.00-26.26 n =3	0.00-11426.70 n =3	0.376

P. maniculatus. As a result, comparison of the activity patterns for male and female *P. maniculatus* associated with the different timber harvest intensities of this study were conducted separately.

Comparison of the activity patterns for female *P. maniculatus* associated with clearcut, shelterwood, and control treatments revealed a statistically significant difference when distance/ duration was examined (Table 22). In this case females associated with clearcuts travelled further for each day they were radio-collared than females associated with shelterwood and control treatments. Variables that showed differences which approached statistical significance ($P<0.100$) were the number of day positions/duration, and the distance between day positions. In each case the values of these variables seemed to be higher for females associated with the clearcut treatment.

For male *P. maniculatus*, comparison of activity patterns on the shelterwood and control treatments failed to find any statistically significant differences (Table 22). However, the 90% and the 80% harmonic mean estimations of home range showed differences which approached statistical significance. In both cases the data suggested values were higher on the shelterwood treatment than on the uncut controls.

Discussion

Before interpreting the effect of timber harvest on *Peromyscus maniculatus* it is important to understand whether these mice considered the treatment areas in the current study at the microhabitat or macrohabitat level. Macrohabitats have a size no smaller than the home range of an animal and thus are large enough to satisfy all the biological needs of that animal during a typical activity cycle (Morris 1987). Microhabitats are smaller than the home range of an animal and can influence the pattern of home range use by that individual (Morris 1987). Therefore, if *P. maniculatus* interpreted treatment areas as microhabitats it is more likely that

Table 22. Kruskal-Wallis tests (for females) and Mann-Whitney tests (for males) comparing the movement patterns of *Peromyscus maniculatus* associated with the clearcut (females only), shelterwood, and uncut control treatment areas are displayed with the minimum and maximum values for each variable determined from radio-telemetry during the two post-harvest years (1994 and 1995) at the Black Sturgeon Boreal Mixedwood Research site.

MOUSE MOVEMENTS	FEMALES					MALES			
	Sample Size	Controls	Shelterwoods	Clearcuts	P-values	Sample Size	Controls	Shelterwoods	P-values
Day Refuges/Duration (day refuge/day)	16	0.06-0.26 n = 6	0.10-0.20 n = 4	0.10-0.32 n = 6	0.064	7	0.10-0.21 n = 4	0.19-0.29 n = 3	0.593
Distance/Duration (m/day)	16	0.0-8.7 (a) n = 6	0.1-4.8 (a) n = 4	3.8-27.7 (b) n = 6	0.015*	7	1.9-26.7 n = 4	19.9-46.1 n = 3	0.517
Distance/ Day Refuges (m/day refuge)	16	0.0-41.5 n = 6	1.2-40.7 n = 4	16.9-124.5 n = 6	0.076	7	19.0-126.7 n = 4	106.2-166.7 n = 3	0.157
90% Minimum Convex Polygon (m^2)	14	0.00-163.27 n =5	0.00-26.26 n =3	0.00-6275.03 n = 6	0.198	7	0.78-740.98 n = 4	0.00-11426.70 n = 3	0.480
90% Harmonic Mean (m^2)	12	6.38-505.44 n =5	35.70-113.76 n =2	45.79-3272.21 n =5	0.439	7	58.98-1434.73 n = 4	278.02-3864.34 n = 3	0.077
90% Harmonic Mean (# areas)	12	1-2 n =5	2-2 n =2	1-3 n =5	0.502	7	1-2 n = 4	2-4 n = 3	0.115
80% Harmonic Mean (m^2)	12	6.38-245.80 n =5	35.70-113.76 n =2	0.37-280.45 n =5	0.881	7	58.98-930.00 n = 4	278.02-2571.03 n = 3	0.077
80% Harmonic Mean (# areas)	12	1-2 n =5	2-2 n =2	1-3 n =5	0.705	7	1-2 n = 4	2-3 n = 3	0.115
50% Harmonic Mean (m^2)	12	0.50-12.51 n =5	2.61-8.03 n =2	0.37-89.03 n =5	0.291	7	15.09-66.99 n = 4	18.35-209.70 n = 3	0.480
50% Harmonic Mean (# areas)	12	1-1 n =5	1-1 n =2	1-2 n =5	0.214	7	1-1 n = 4	1-2 n = 3	0.248

* Where $P < 0.05$ different letters indicate that treatments were significantly different.

they would encounter several different treatments during daily activities than if they considered treatment areas at the macrohabitat level. Subsequently, any differences in the activity patterns of such *P. maniculatus* could not be directly attributed to any one particular harvest treatment but would be the combined effects of several treatments.

In the current study the question of scale was addressed by investigating the distance *Peromyscus maniculatus* travelled in relation to the number of day refuge positions they had. and the home range sizes estimated for these mice from day refuge data. Because only day locations were used in these home range calculations the estimates do not represent the total area used by each individual mouse but instead are used as a measure of day refuge dispersion. Since the majority of distance/day refuge values were smaller than the distance between any two treatment areas, and home range estimates were smaller than the areas treated in this study, it seems that treatment area selection by *P. maniculatus* occurred at the macrohabitat level.

In addition to this evidence, the affinity *Peromyscus maniculatus* displayed for the treatment areas associated with the grids where they were radio-collared also suggests that selection of these areas was at the macrohabitat level. The fact that two female *P. maniculatus* entered more than one harvest treatment does not change this conclusion because many researchers have observed that *P. maniculatus* occasionally explore areas outside of their home ranges (Stickel 1968). Therefore, these two mice could have encountered the different treatments on exploration trips and subsequently needed to choose between the old and newly found treatment areas as home range habitats.

After investigating the scale of habitat use it was meaningful to determine if male and female *Peromyscus maniculatus* utilized their environments differently because if they did not then data from both sexes could be combined during further analysis. Inspecting the movement patterns of male and female *P. maniculatus* revealed that in the shelterwood treatment males travelled further for each day they were radio-collared, and in relation to the number of day refuges they had, than female *P. maniculatus*. Also, although the differences were not statistically significant, the movement variables were higher for males than for female *P. maniculatus* on both the control and shelterwood treatments. This information suggested that males had larger home ranges than females during the current study.

Many other researchers have found that male *Peromyscus maniculatus* have larger home ranges than females (Stickel 1968; Bowers and Smith 1979; Van Horne 1981; Wolff 1985). However, there have been some exceptions to this trend (Blair 1940; Stickel 1968; Bowers and Smith 1979; Ormiston 1985). In the current study there was a notable weight difference (P=0.05) between the sexes with females outweighing the male *P. maniculatus* (Table 18). Other researchers have noted that heavier mice have an advantage in aggressive encounters so it is possible that female *P. maniculatus* on average secure the higher quality habitat through territorial behaviour so that males must on average settle for habitat of lesser quality (Bowers and Smith 1979). This in turn may have translated into larger home range sizes for the male *P. maniculatus* in the current study.

Another possibility would be that female *Peromyscus maniculatus* are genetically more aggressive than their male counterparts. This could enable them to attain better quality habitats and subsequently to grow larger than male *P. maniculatus* (Bowers and Smith 1979). This second possibility would seem to be more strongly supported by the research of Bowers and Smith (1979) because they found that *P. maniculatus* in habitats homogeneous with respect to habitat quality did not display sexually related differences in their weights, or home range sizes. The current study seems to support this suggestion as well because the magnitude of the differences between the movement patterns of male and female *P. maniculatus* on the more heterogeneous shelterwood areas were much larger than those in the more homogeneous controls.

This difference in habitat utilization could also be explained by another theory. It is possible that during the breeding season, male and female *Peromyscus maniculatus* have different reproductive strategies (Galindo and Krebs 1987). Females may distribute themselves in relation to the resources required for raising of their young, while males may distribute themselves in relation to female *P. maniculatus* in order to ensure access to mates. It may be worthy to note that the work of other researchers studying polygamous microtine rodents corroborate this theory (Boonstra 1977; Ostfeld 1985; Ostfeld *et al.* 1985; Ostfeld 1986; Ostfeld *et al.* 1988). However, one should be cautious when using information collected from one species to support theories about the habitat use patterns, and spatial distribution of other species (Ostfeld 1986).

Regardless of the mechanism which has caused female *Peromyscus maniculatus* to have smaller home ranges than the males in the current study, separation of habitat quality by *P. maniculatus* in this way would be advantageous to their offspring. Areas of higher habitat quality generally have thick vegetative cover which would be useful in protecting the young from predators (Bowers and Smith 1979; Douglas 1989; Van Horne 1982). Also, if females and young are in areas of higher habitat quality they would not need to travel as far to attain their life requirements in any given day as they would if located in an area of lower habitat quality. Because travelling could easily expose *P. maniculatus* to a higher risk of predation than remaining in refuges, it would seem that less travelling could also reduce risks to the survival of female P. *maniculatus* and their offspring.

The greater distances travelled by female *Peromyscus maniculatus* associated with 1-2 year old clearcuts in the current study may indicate that young clearcuts are of lower habitat quality than the shelterwood and uncut forest areas. This, in combination with the suggestion of more day refuges, and the longer distances travelled in relation to the number of day refuges for these *P. maniculatus*, all indicate that females on clearcuts were using larger home ranges than those in the other treatments. In fact, although the differences were not statistically significant, the average home range size for female *P. maniculatus* on clearcuts was much larger than on any other treatment.

Investigation of the number of captures for *Peromyscus maniculatus* on uncut and clearcut livetrapping grids in Chapter 1 of the current work failed to find differences in the number of *P. maniculatus* captured on these grids. In addition, Chapter 3 of this study shows that the treated and buffer zone side of clearcut grids did not show any significant difference in the capture rate for *P. maniculatus*. Although *P. maniculatus* utilization of the cut side of these grids was usually higher than use of the uncut side in 1994, this difference was not consistent on all grids and the trend was eliminated by 1995 (see Chapter 3). It is therefore not likely that *P. maniculatus* density regulated the home range size of the female P. *maniculatus* associated with clearcut treatment areas during this study.

Examination of the movement data for male *Peromyscus maniculatus* revealed that their 90% and 80% harmonic mean home range sizes were larger on shelterwood treatment areas than on controls. Although the confidence that can be placed in the universality of this difference is limited due to the small number of male *P. maniculatus* radio-collared during this study, it could still be of biological importance. As with the female *P. maniculatus* on clearcut treatments, it is unlikely that *P. maniculatus* density was responsible for the difference in home range size observed for male *P. maniculatus* on shelterwood and in uncut forests of the current study. Comparison of shelterwood and control livetrapping grid captures of *P. maniculatus* in 1994 and 1995 revealed no significant differences between these treatments (Chapter 1). When the treated and buffer zone sides of shelterwood trapping grids were compared, differences in the number of *P. maniculatus* captures only occurred when *P. maniculatus* populations appeared to be higher, in 1995, with greater capture success occurring on the treated side of shelterwood grids (Chapter 3). Lack of a difference in the 80% and 90% harmonic means home range estimates for male *P. maniculatus* radio-tracked on shelterwoods in the year of low capture success, 1994, and a year of higher capture success, 1995, indicates that density was not a factor in determining the home range size of male *P. maniculatus* as estimated by radio-telemetry in this study.

Perhaps female *Peromyscus maniculatus* did not display as drastic a difference between the control and shelterwood habitats as male *P. maniculatus* did because of their less extensive use of elevated day refuges. Results of the current study differ from those of Wolff and Hurlbutt (1982) who also investigated the vertical segregation of day refuges for male and female *P. maniculatus* but found no difference between the sexes. Their population of *P. maniculatus* were sympatric with the *Peromyscus leucopus* so it is possible that interspecific associations between the two species could have influenced the habitat use patterns of male and female *P. maniculatus* in their study.

Of interest to this theory is the vertical separation of day refuges for these two species as observed by Wolff and Hurlbutt (1982). In their research, *Peromyscus maniculatus* used more arboreal than ground refuges, and they used more arboreal refuges than did *Peromyscus leucopus*. If, as in the current study, *P. maniculatus* not living in association with *P. leucopus* tend to use more ground refuges, perhaps the difference in habitat use demonstrated by this work and Wolf and Hurlbutt (1982) is related to the absence of *P. leucopus* from the Black Sturgeon Boreal Mixedwoods ecosystem. The research of Sharpe and Millar (1990) would seem to support this theory because they found female *P. maniculatus* made substantial use of ground day refuges in the Kananaskis Valley of Alberta, a region which also does not support *P. leucopus* (Kurta 1995).

Another explanation for this difference is that during the work of Wolff and Hurlbutt (1982) an uncut forest was monitored, while in the current study both harvested and uncut forests were monitored. Perhaps *Peromyscus maniculatus* in the current study made more substantial use of ground than elevated day refuges because in some treatment areas elevated day refuges had been eliminated. When day refuges of female *P. maniculatus* located only in uncut forests of the current study are considered, use of day refuges at ground level was still three times more prominent than use of elevated day refuges. Therefore, for female *P. maniculatus*, it does not seem that loss of elevated day refuges is the only reason for the difference in day refuge elevations found by the current study and that of Wolff and Hurlbutt

(1982). This also agrees with the results of Sharpe and Millar (1990) as their work monitored female *P. maniculatus* in uncut forest and also found use of ground day refuges to be most prevalent.

For male *Peromyscus maniculatus*, however, loss of elevated habitat in harvested areas of the current study appears to have influenced the height of their day refuges. When positions only within uncut forest are considered, male *P. maniculatus* used elevated day refuges three times more often than ground day refuges. This was opposite to the trend observed for these mice in shelterwood areas of the current work. Thus, there appears to be some agreement between the results of Wolff and Hurlbutt (1983) and those of the current work for male *P. maniculatus* in uncut forests. However, male *P. maniculatus* use of ground habitat was still much more substantial in the current study than for male *P. maniculatus* studied by Wolff and Hurlbutt (1983).

One explanation for this difference would be that in areas where *Peromyscus maniculatus* and *Peromyscus leucopus* live in sympatry, *P. leucopus*, which have been shown to be more aggressive than *P. maniculatus* (Fitch 1963), secure ground day refuges for themselves. However, *P. maniculatus* may be able to utilize arboreal day refuges more successfully than *P. leucopus*, allowing the two species to coexist in certain regions of North America. In areas where *P. leucopus* are absent, both sexes of *P. maniculatus* use more ground day refuges. However, female *P. maniculatus*, perhaps by being more aggressive, by having a weight advantage during aggressive encounters, or by being the only sex using habitat features to choose home ranges, attain a higher proportion of ground day refuges for themselves. This leaves more elevated day refuges for use by their male counterparts.

Lack of evidence for direct competition between *Peromyscus maniculatus* and *Peromyscus leucopus* where they live in sympatry (Buckner and Shure 1985; Harney and Dueser 1987; Dooley and Dueser 1990), and between female and male *P. maniculatus* where *P. maniculatus* live in allopatry does not necessarily negate this hypothesis as the reason for vertical segregation of day refuge by these groups. It is possible that all direct competition between these groups could have occurred in the distant past, so that through natural selection, genetically related differences have developed in each group so that now they prefer the habitat they use over other available habitats (Harney and Dueser 1987; Dooley and Dueser 1990). Perhaps a study that searched for direct competition between *P. leucopus*, and *P. maniculatus* taken from areas where *P. leucopus* are absent could help uncover the reason for this difference as it relates to these two species. Such a study cannot be developed so easily for investigating the relevance of this hypothesis to the difference in day refuge location displayed by female and male *P. maniculatus* because no population of wild *P. maniculatus* in which the two sexes have not come in contact exists.

Regardless of the mechanism that has caused segregation of male and female *Peromyscus maniculatus* day refuges, understanding the type of ground and elevated habitat features *P. maniculatus* use is of importance to the forest industry because changes in the availability of these features may affect the success of *P. maniculatus* population and subsequently the success of ecosystem based forest management. It is evident that timber extraction influenced the movement patterns of male *P. maniculatus* in the shelterwood areas of the current study. When the most common habitat feature used by male *P. maniculatus*, decay class 3-5 tree/snags, is considered, the reason for this difference becomes obvious. That is, loss of tree/snags from shelterwood areas caused male *P. maniculatus* to use ground day refuges more extensively there. In contrast, stumps and decayed logs were of more importance to female *P. maniculatus*. This predominant use of habitat features not removed during timber extraction was largely responsible for the lack of change in the elevated to ground level day refuge ratio for female *P. maniculatus* at harvest intensities lower than used for the clearcut treatment of this study. However, at the clearcut harvest intensity it appears that loss of almost all trees decreased female *P. maniculatus* use of elevated day refuges, in relation to ground day refuge use, from levels observed in the uncut and shelterwood cut habitats.

Each of the habitat features used by *Peromyscus maniculatus* as day refuges during the current study have also been used by *P. maniculatus* investigated by other researchers (Wolff and Hurlbutt 1982; Sharpe and Millar 1990; Kurta 1995). However the importance of these habitat features changes among studies. As in the current work, high use of decaying tree/ snags, logs, and rootballs was noted by Wolff and Hurlbutt (1982). In contrast, Sharpe and Millar (1990) noted that use of rock piles for day refuges was most common. In the current study, use of rocks and erratics by both sexes was less frequent than with other habitat features. However, when use data are considered in combination with knowledge of the low availability of rocks and erratics in the Black Sturgeon Research forest, the data suggests that *P. maniculatus* preferred to locate day refuges in rocks as opposed to many of the other habitat features available. Wolff and Hurlbutt (1982) also noted high use of rocks in relation to their availability by *P. maniculatus* in their forest. The extent that the differences in habitat features used by *P. maniculatus* noted by these researchers are related to their availability is not known because none of these studies have reported detailed information on habitat feature availability. Studies which compare the habitat features used for day refuges by *P. maniculatus* in relation to their availability within the studied forest would be of great value in better understanding the habitat preferences of these mice.

CONCLUSIONS

The forest manager's choice of silvicultural system and harvest method have both been shown to influence small mammal communities over the first two years after timber harvest in a boreal mixedwood forest of Ontario. Evaluation of abundance data revealed that small mammal species responded to alternative harvesting strategies in different ways. When the clearcut and shelterwood silvicultural systems were compared, *Clethrionomys gapperi*, and *Tamias minimus* populations demonstrated contrasting responses. *C. gapperi* were more abundant in controls and at shelterwood edges than at clearcut edges, while *T. minimus* were present at the edges of harvested land and absent from uncut controls (Table 9). When the harvest methods used within the shelterwood treatment were compared there was a higher abundance of *Synaptomys cooperi* on cut-to-length shelterwood cut edges and on controls than on the other shelterwood treatments, yet this trend was not evident for any other species monitored during this comparison (Table 13).

Species richness and diversity measures also demonstrated some differences in the small mammal communities when silvicultural systems were compared. Species richness was higher on controls and at clearcut edges than on shelterwood edges in 1994 (Table 9). By the second post-harvest year both species richness and Hill's N1 species diversity measurements demonstrated differences among the small mammal communities within clearcut, shelterwood, and control treatments (Table 9). Such strong differences were not observed when the harvest methods used within the clearcut and shelterwood silvicultural systems were compared. However, Hill's species diversity numbers N1 and N2 both approached significance and were lower on the cut-to-length and part-tree shelterwood edges than on the full-tree edges and in controls during the comparison of harvest methods used under the shelterwood silvicultural system (Table 13).

These different responses to timber harvest shown by small mammal species indicate that no single silvicultural system or harvesting method will be appropriate for their conservation in managed boreal mixedwood forests. Also, changes in species richness and diversity measures on areas harvested with different techniques indicate that forest managers must consider small mammal species richness and diversity during forest management planning. Evidence from this study indicates that forest managers must provide sections of mature, and recently harvested areas within a managed forest to conserve small mammal species diversity.

Although mixedwood forests comprise a large portion of northern Ontario landscape, other forest types exist there as well. In an effort to conserve the species diversity of the entire region, foresters may wish to concentrate on conserving species that are more successful in mixedwood forests, where this forest type occurs. Results of the current study, and of other researchers (Nagorsen and Peterson 1981; Naylor *et al.* 1981) indicate that *Phenacomys intermedius* and *Sorex hoyi* populations are more successful in regenerating mixedwood cuts than in other forest types.

Another species which probably deserves special consideration during mixedwood forest management, especially in areas of severe spruce budworm infestation and die-back, is *Glaucomys sabrinus*. In the current study the capture rate for this species was affected by both the silvicultural system, and the harvest method used during timber extraction (Tables 9 and 12). The higher prevalence of *G. sabrinus* on the edges of full-tree clearcuts than at tree-length clearcuts, and on the edges of clearcuts than at shelterwood edges and on controls during the current work does not necessarily represent the abundance patterns of this species. Results from Chapter 3 support this suggestion because *G. sabrinus* were captured predominantly on the uncut side of clearcut grids (Tables 15 and 16). This indicates that the species does not prefer clearcuts but appears on the ground more often at clearcut edges. It is probably differences in the activity pattern of *G. sabrinus* within uncut forests and at forest edges that was successfully monitored during this work and not actual *G. sabrinus* abundance.

Unfortunately, detailed analysis of *G. sabrinus* activity patterns were not completed during this project. Such research would be helpful for understanding the effect timber harvesting has on *G. sabrinus* and in turn assist in the development of detailed management strategies for this species.

Work with radio-collared *Peromyscus maniculatus* revealed that alternative harvesting practices can affect the activity patterns and habitat use of small mammals without causing significant differences in their abundance at habitat edges (Chapter 4). This was displayed by the greater number of *P. maniculatus* day refuges in trees than in the ground on uncut areas when compared with harvested lands (Table 20). Whether this difference in habitat use indicates a change in the habitat quality of harvested areas for *P. maniculatus*, or a change in the long term survival of this species at harvest edges was not determined during the current work but could be investigated with further research.

Also in question was whether *Peromyscus maniculatus* movement amongst the different treatments of the current study was prevalent enough for this species to encounter, and thus detect, areas of higher habitat quality. Analysis of *P. maniculatus* movement amongst the treatments revealed that *P. maniculatus* day refuges were generally within the same harvest treatment where mice were radio-collared (Table 19). However, there were also some day positions outside of these areas. In general these other positions were within the forested buffer zones surrounding the harvest treatments usually associated with the mice. This indicates that in most cases *P. maniculatus* were able to compare the habitat quality of harvested areas to that of uncut forest. However, only two *P. maniculatus* were located in more than one harvested treatment during this study. This suggests that each individual *P. maniculatus* did not spend enough time on the different harvest treatments to identify and choose among all the treatments for the ones of better habitat quality. Therefore, the ability of *P. maniculatus* to choose between the treatment they were commonly associated with and uncut forest was high but the ability of each individual mouse to choose the best harvest treatment of all those included in this study was severely limited. This is not to say that the *P. maniculatus* population as a whole could not determine which treatment was most appropriate because reproductive success should have been better in those areas, which should lead populations in better habitat quality to be more densely populated than in the other habitats.

RECOMMENDATIONS FOR FUTURE RESEARCH

For other small mammal researchers this study has demonstrated the importance of using more than one trapping method when assessing small mammal community composition. The much higher capture rate for Soricidae in pitfall traps than in live traps, and the occurrence of *Peromyscus maniculatus*, *Napaeozapus insignis*, *Phenacomys intermedius*, and *Microtus chrotorrhinus* only in live traps during the current project support this suggestion. It would also be advantageous to put traps both on the ground and in trees if the occurrence and activity patterns of ground dwelling and arboreal species are of interest.

A large amount of variation was found among the replicates for each treatment of the current study. If fewer, or no replicates of these treatments were conducted the conclusions drawn from this work could have been very different. It also would have been more difficult to assign any differences observed to the treatments themselves, instead of to random events (Wiens 1981).

Many studies that have investigated the effect of timber harvesting on the small mammal community have been based on single samples (Kirkland 1990). Some studies discussed during the current work had only one or two study sites in many of the forest types investigated (Monthey and Soutiere 1985; Parker 1989; Sekgororoane and Dilworth 1995). As with the current study these researchers found a large degree of variation among study replicates, even though some of these replicates were in relatively homogeneous spruce and jack pine plantations. With less than three replicates it is impossible to determine if the results from any particular site are outside the normal values for areas under that treatment. The limitations related to studies without replication, or with very few replicates should be considered when interpreting their conclusions. Wiens (1981) states that if these researchers restricted their comments to differences that were of statistical significance then the trends suggested are probably appropriate. However, often researchers with low sample sizes, or few replicates, are tempted to discuss differences of biological significance, regardless of their statistical significance. In these situations readers should be cautious about accepting the conclusions of that study (Wiens 1981).

Finally, it is appropriate to discuss the effect harvest season had on the results from this project. Harvesting in the fall and winter generally causes less ground disturbance than harvesting during the spring and in the summer. This occurs because in the late fall and winter the ground is frozen so it can support heavier harvesting equipment than in the spring and summer when the ground is warm. Harvesting in the spring is particularly destructive to the integrity of the forest floor because at that time of year the ground is saturated with water making it vulnerable to severe soil compaction (Hausenbuiller 1985). For small mammals the less severe ground disturbance associated with the fall/winter harvesting period of this study probably left important habitat features, such as ground level nests and travel pathways intact. Since harvesting at other times of year may have destroyed such features, it is possible that such harvesting could have had a more severe impact on the small mammal community. Research into the effect of harvest season on the post-harvest characteristics of the small mammal community would be appropriate and useful in forest management planning.

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APPENDIX I: Harvesting Methods

Full-tree Harvest Method (conventional timber harvesting)

Full-tree harvesting is the most widely practised means of timber extraction in Canada within the region east of Alberta (Gingras 1995). Of all the harvest methods employed at the Black Sturgeon Boreal Mixedwood Research Project, full-tree harvesting removed the most woody material. It also has the highest landing requirements because all processing occurs at the landings. After harvest these landings usually remain void of trees because the severe soil compaction hampers forest re-growth at these sites.

With full-tree harvesting trees are cut and delivered to roadside without further processing (Grammel 1984; Pulkki 1996). Usually trees are moved to landings with a cable or grapple skidder. At the landing, trees may be delimbed, topped, and debarked, or they may be transported to the mill without further processing (Pulkki 1996). If trees are processed before transport, the landing becomes covered with large amounts of slash (tree limbs, tops, and bark) which is either left at the landing or redistributed onto the cut area. If this slash is left in piles at the roadside it can reduce the speed of forest regeneration there, increase the fire risk at roadside, and restrict water flow through roadside culverts (Deslauriers 1996). However, if slash is redistributed onto the site it could prevent soil erosion, return nutrients to the stand (Morrison and Wickware 1996), and assist with wildlife re-establishment after timber harvest. Unfortunately, the extra movement of heavy equipment required for slash redistribution could result in more severe soil compaction on the harvested area than if the slash was left in piles at the roadside.

At the Black Sturgeon Boreal Mixedwood Research Project, full-tree harvesting was employed to treatment areas harvested under the clearcut, and the shelterwood silvicultural systems. In both cases a feller buncher (John Deere 693) (Figure 9) was used for cutting and bunching the trees while a grapple skidder (Figure 10) was employed to skid the trees to the roadside landings. Processing occurred at the landings and involved topping, and delimbing of

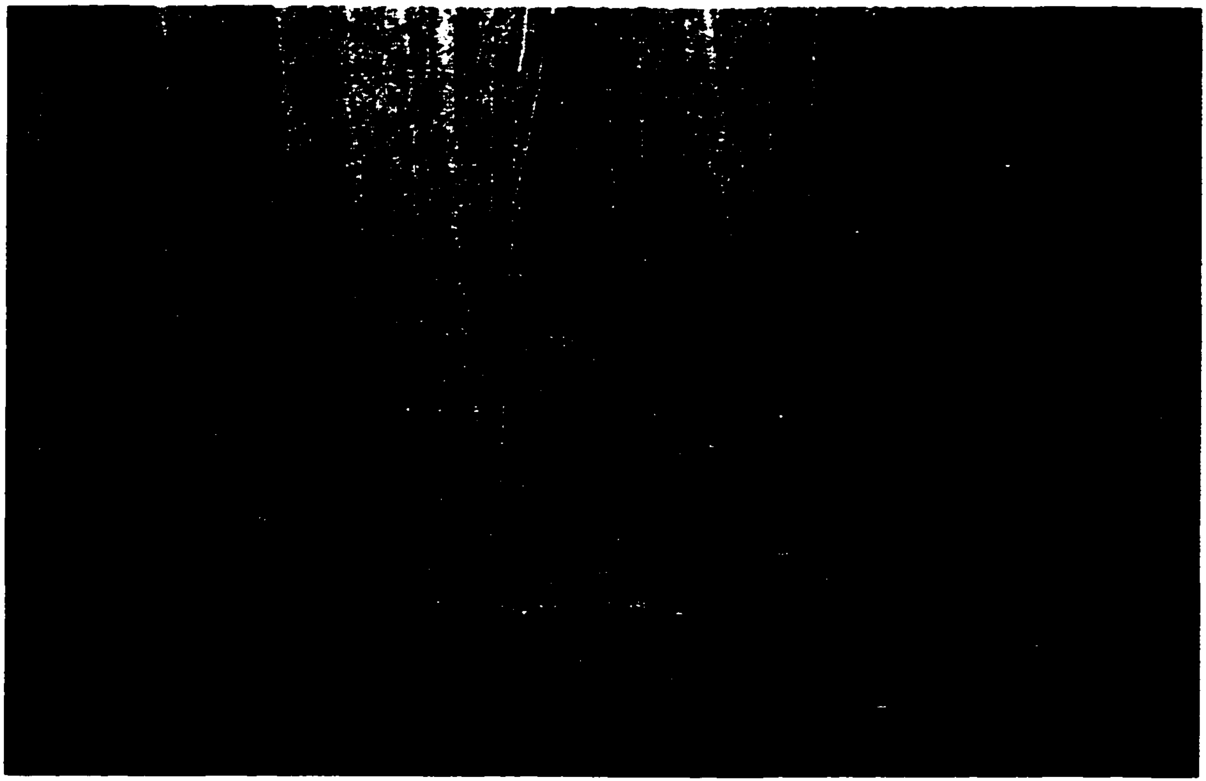

Figure 9. The feller-buncher used for full-tree extraction at the Black Sturgeon Boreal Mixedwood Research Project site.

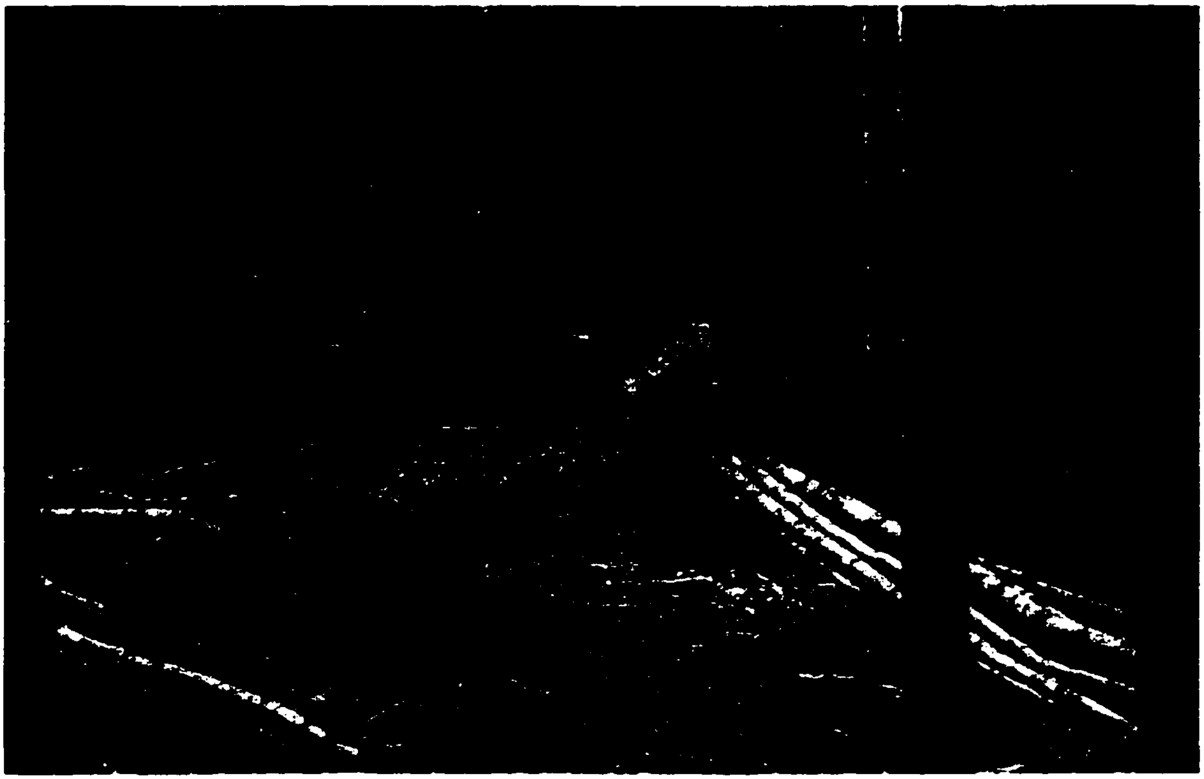

Figure 10. The grapple skidder used to transport full-trees from the stump site to roadside during timber extraction for the Black Sturgeon Boreal Mixedwood Research Project.

trees with a stroke delimber (Figure 11) followed by bucking of trees with a slasher (Figure 12). In addition, some trees, limbs, and tops were chipped (Figure 13) before transport to the mill. The remaining slash was left in piles along the roadside with much of this later being removed in order to reduce the risk of fire in the research area.

Part-tree (tree-section) Harvest Method

Part-tree harvesting leaves more slash on the harvested area than full-tree extraction does, however, much of the processing still occurs at roadside landings. As a result the problems associated with roadside landings as discussed for full-tree harvesting are also evident with this process. However, these difficulties are generally not as severe with part-tree extraction because some processing does occur in the stand.

In the process of part-tree extraction, trees are felled and the lower part of the tree is delimbed at the stump. Then the trees are cut into easy-to-handle sections and delivered to the roadside landing where they are further processed (Grammel 1984; Silversides and Sundberg 1989). As with full-tree harvesting, skidding is usually conducted with a cable or grapple skidder.

During the Black Sturgeon Boreal Mixedwood Project, part-tree harvesting was employed to remove timber from the patch cut and the shelterwood areas. Trees were felled and partially delimbed manually, with hand-held chainsaws. Cable skidding (Figure 14) was used to transport the partially delimbed trees to roadside. As with full-tree extraction, part-trees were processed at the landings and the remaining slash was piled at the roadside.

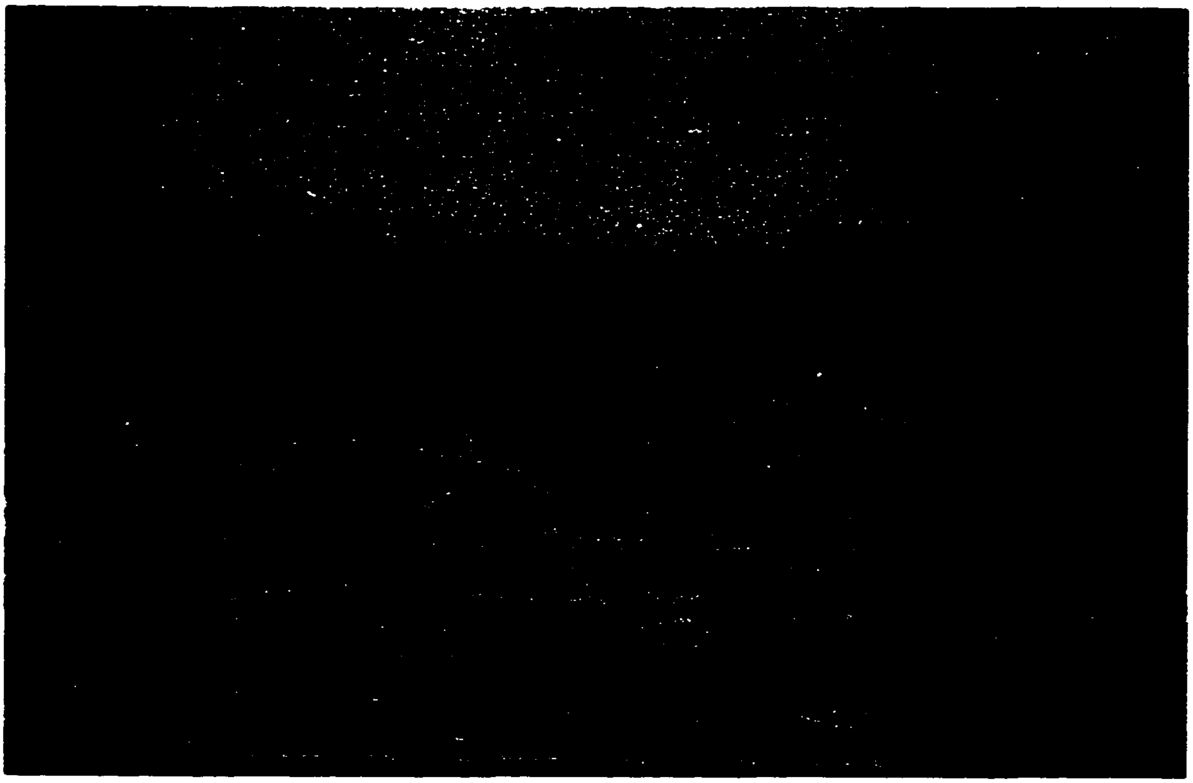

Figure 11: The stroke delimber used to delimb full-trees at roadside during the Black Sturgeon Boreal Mixedwood Research Project.

Figure 12: The slasher used for bucking delimbed trees during the Black Sturgeon Boreal Mixedwood Research Project.

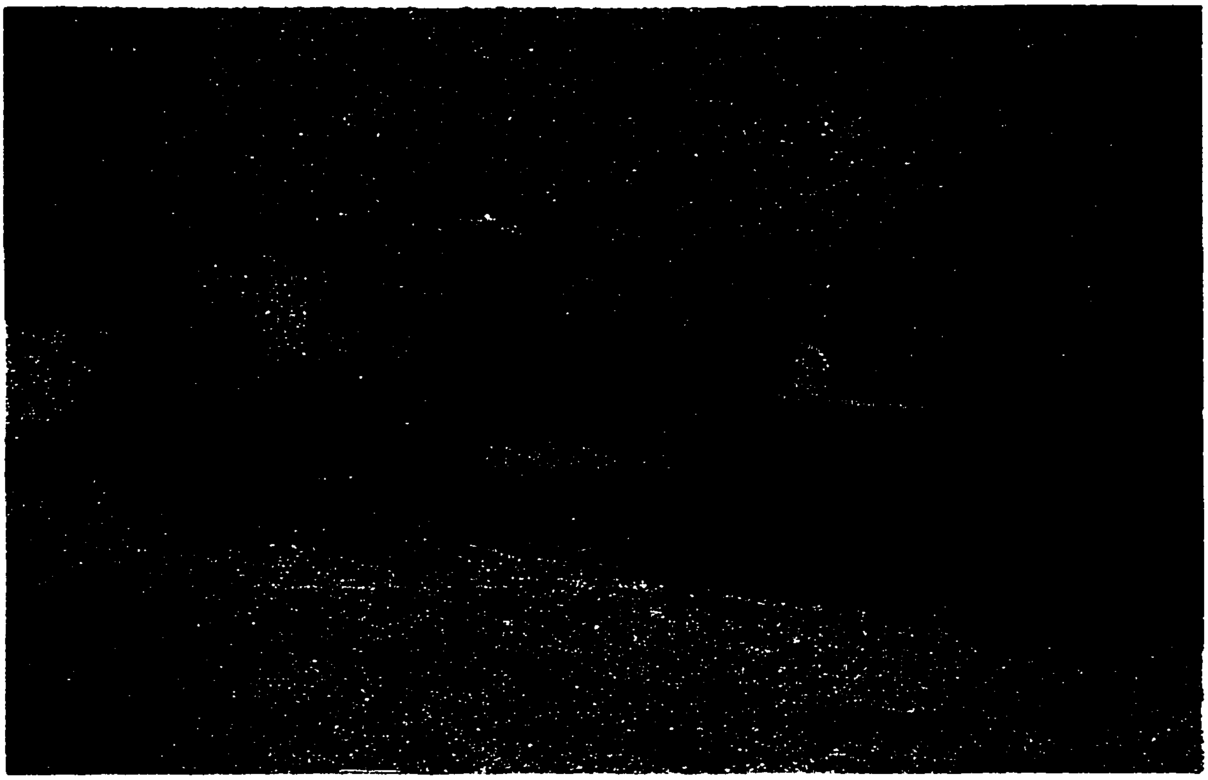

Figure 13: A chipper and wood chip truck similar to those used for the Black Sturgeon Boreal Mixedwood Research Project.

Figure 14: A cable skidder similar to the one used to transport part-trees from the stump to roadside during the Black Sturgeon Boreal Mixedwood Research Project.

Tree-length Harvest Method

The tree-length harvest method leaves more slash in the harvested area than the full-tree or the part-tree extraction methods because much less processing occurs at roadside landings than within the harvested stands. Subsequently the slash buildup, at roadsides, and the soil compaction, at landings, is less substantial than with the full-tree and part-tree timber harvesting methods. Finally, more slash is left on the harvested stands when tree-length extraction is used than with full and part tree extraction methods. This slash is relatively evenly distributed throughout the harvested area and as such may benefit wildlife communities, help moderate the climate close to the soil surface, return nutrients to the soil, and prevent soil erosion after timber harvest.

During the process of tree-length extraction trees are felled, delimbed, and topped within the harvested area (Grammel 1984; Pulkki 1996). They are then piled and transported to the roadside landing, by cable or grapple skidders, although other systems are also occasionally used (Pulkki 1996). Logs are then either sent to the mill without further processing or they can be bucked into assortments before transport.

At the Black Sturgeon Boreal Mixedwoods Research Project tree-length harvesting was employed to extract timber from clearcut areas. A single-grip harvester (Ultimate 4500) (Figure 15) was used to fell, top, and delimb the trees at the stump. A grapple skidder then transported these tree-lengths to roadside landings where they were piled and later transported to the mill.

Cut-to-length (shortwood) Harvest Method

The cut-to-length harvest method can be used with any silvicultural system from clearcutting to selective harvesting. It is promoted as an 'environmentally friendly' method of timber harvest since soil compaction, nutrient removal, and residual tree damage are lower with this method than with the other timber extraction methods (Deslauriers 1996; Pulkki 1996).

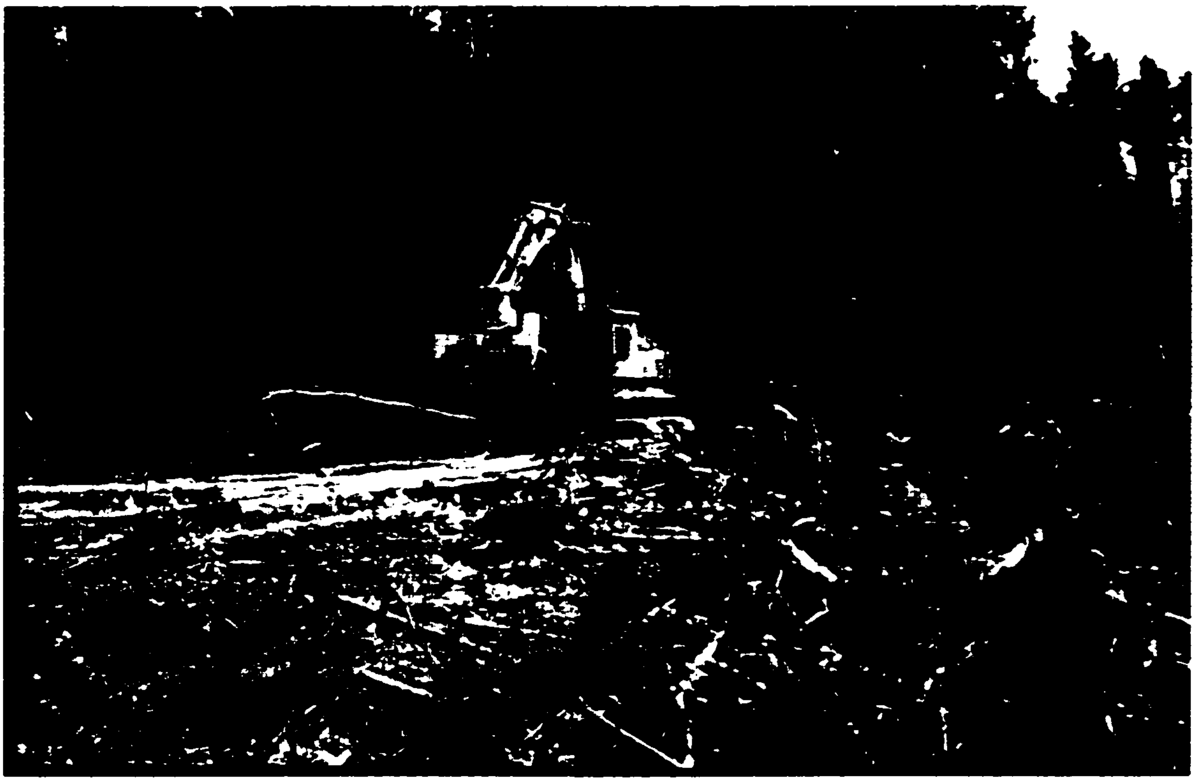

Figure 15: The single-grip harvester used to fell, delimb, and top trees during tree-length extraction at the Black Sturgeon Boreal Mixedwood Research Project site.

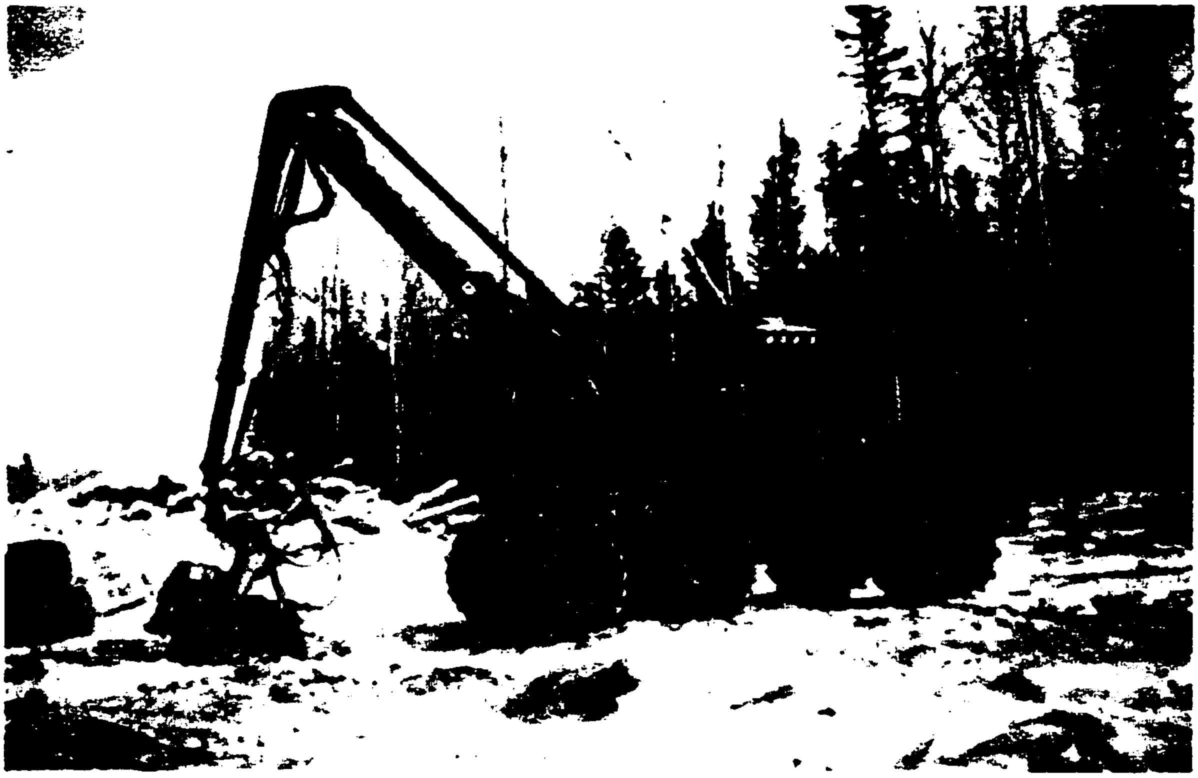

Figure 16: The single-grip harvester used to fell, delimb, top, and buck trees during cut-to-length extraction for the Black Sturgeon Boreal Mixedwood Research Project.

Soil compaction is prevented in two ways. First, all processing occurs at the stump which eliminates the need for large roadside landings that characteristically have soil compaction problems. Second, the equipment used travels on a bush mat made of slash so it does not disturb the ground (Deslauriers 1996; Gingras 1996; Pulkki 1996). Nutrient removal is minimized because only the material which will be used by the mill is actually removed from the stand (Morrison and Wickware 1996). Finally, residual tree damage is low because the single-grip harvester handles the descent of trees and bucks (mechanically cuts) them into shortwood which is easier to handle during transportation to the roadside than longer material (Gingras 1996; Pulkki 1996).

With cut-to-length extraction, trees are felled, topped, delimbed, and bucked into assortments (pulpwood, sawlogs, veneer bolts etc...) all at the stump (Grammel 1984; Pulkki 1996). Usually a forwarder carries these assortments to the roadside, however, other skidding equipment is occasionally used (Pulkki 1996). If a forwarder is used this further decreases damage to the site because logs are carried over, instead of dragged on, the ground. This prevents development of ruts which can collect and transport water and soil over the ground surface; a process which can result in severe erosion (Hausenbuiller 1985).

During the Black Sturgeon Boreal Mixedwoods Research Project, cut-to-length extraction was employed to harvest within the shelterwood silvicultural system. A single grip harvester (Timberjack 1270) (Figure 16) was used to fell, top, delimb, and buck the trees into assortments. Then a forwarder (Figure 17) was used to carry assortments to the roadside for later transport to the mill.

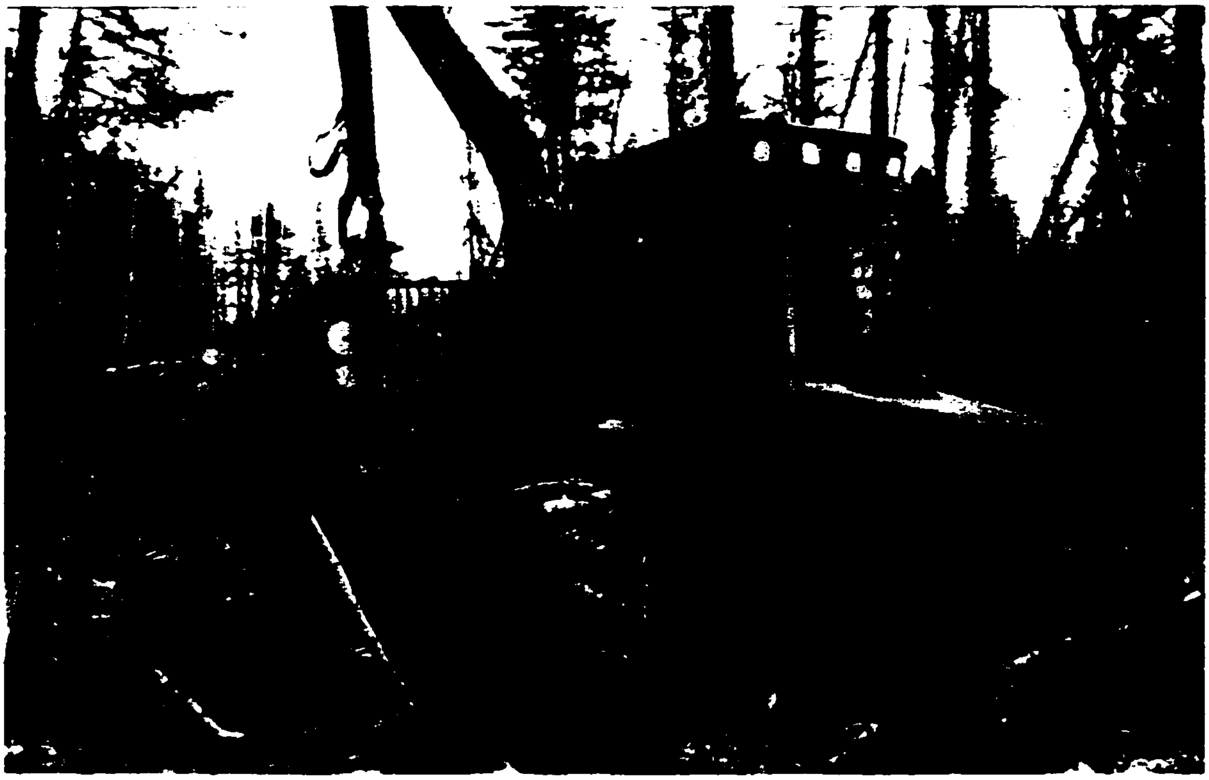

Figure 17: The forwarder used to transport assortments to roadside during cut-to-length extraction for the Black Sturgeon Boreal Mixedwood Research Project.

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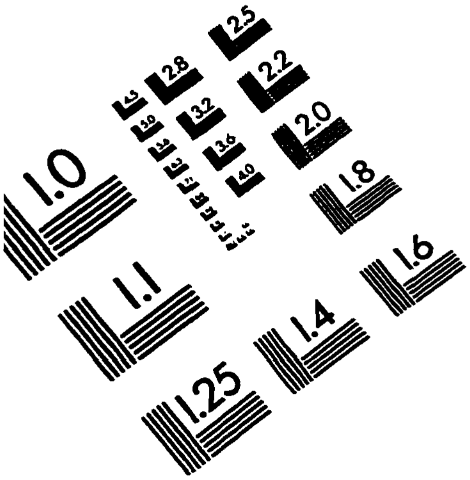

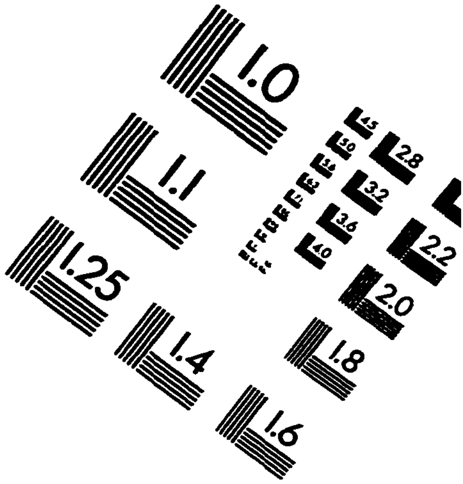

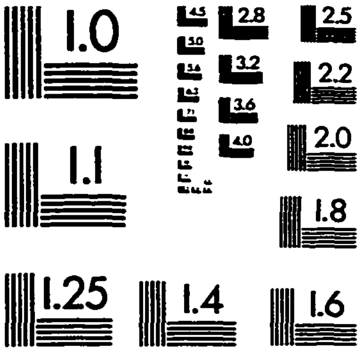

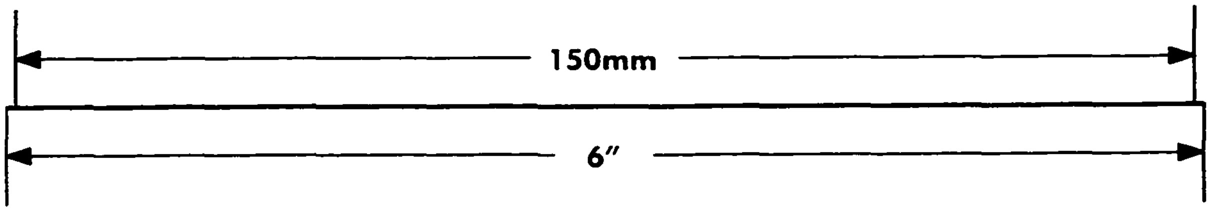

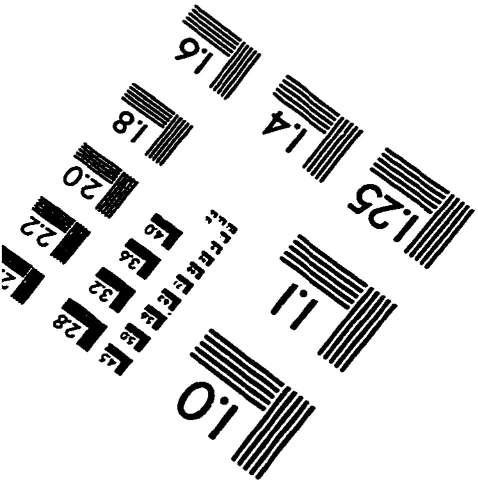

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989