SMALL MAMMAL POPULATIONS OF NORTHEASTERN ALBERTA
II. POPULATIONS IN RECLAMATION AREAS

by

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ABSTRACT

A study of small rodent populations, habitat use, and amounts of small mammal damage to woody-stemmed plants on reclamation areas of the Suncor Inc. lease was begun in July 1978 and continued until November 1979. Three species of small rodent were present in these areas; *Microtus pennsylvanicus* was the most abundant species followed by *Peromyscus maniculatus* and *Clethrionomys gapperi*. *Microtus pennsylvanicus* and *P. maniculatus* were captured in all study areas, whereas *C. gapperi* were captured only in an area dominated by natural regrowths of trees and shrubs. A number of other small mammal species such as *Mustela erminea, Eutamias minimus, Microsorex hoyi, Sorex cinerius,* and *Phenacomys intermedius* were captured in the reclamation study areas but numbers were extremely limited.

Microtus pennsylvanicus and *P. maniculatus* populations in older reclamation areas were composed primarily of resident, breeding animals, whereas *C. gapperi* were only seasonally abundant. *Microtus pennsylvanicus* and *P. maniculatus* in new reclamation areas were mostly transient animals.

Older reclamation areas with dense grass/legume cover appeared to provide highly suitable habitats for *M. pennsylvanicus*, moderately suitable habitats for *P. maniculatus*, and poor quality habitats for *C. gapperi*. New reclamation areas did not appear to provide suitable habitats for any of these three species. Aspects of habitat structure that were associated with small rodent abundance also are discussed.

Small rodent damage to woody-stemmed plants was limited in all reclamation areas during 1978 and 1979. Amounts of damage were highest in older reclamation areas with dense grass/legume cover. The close association between grass cover and amounts of damage and between amounts of damage and numbers of *M. pennsylvanicus* suggests that the high numbers of *M. pennsylvanicus* in areas of dense grass cover may be associated with the high amounts of damage in these same sites.

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1. INTRODUCTION

Land disturbances that are characteristic of many nonrenewable resource extraction developments throughout Alberta have generated increased interest in land reclamation. In particular, large tracts of land disturbed during the mining of the Athabasca Oil Sands will require extensive programs of reclamation and revegetation. A number of research programs subsequently have investigated methods of reclamation and revegetation of processed oil sands (Berry and Klym 1974; Lesko 1974; Langevin and Lulman 1977; Selner and Thompson 1977; Takyi et al. 1977; Dai and Langevin 1978; Fedkenheuer and Langevin 1978), and some plant species suitable for the short term stabilization and revegetation of tailings sand have been identified.

The long-term objective of these reclamation programs is to establish a self-sustaining plant community of similar productivity to that of the pre-disturbed state (Fedkenheuer 1979). To facilitate these goals, and to determine the feasibility of a large-scale afforestation program, several experimental planting programs using native and exotic species of trees and shrubs have been implemented in the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1) (Selner and Thompson 1977; Takyi et al. 1977; Sherstabetoff et al. 1978; Fedkenheuer 1979). These afforestation research programs have been only moderately successful, however, because of the high mortality of some species of young trees (Selner and Thompson 1977; Dunsworth et al. in prep.; Fedkenheuer 1979). Sapling death has been attributed to insect defoliation, to damage during planting, to disease, to nutrient and moisture deficiencies, to competition with ground cover (e.g., grasses and legumes), and to small rodent[1] damage (Radvanyi 1978; Sherstabetoff et al. 1978; Fedkenheuer 1979). Damage by small rodents, particularly *Microtus pennsylvanicus*, is believed to be the major cause of sapling death (Dunsworth et al. in prep.) but conclusive evidence is not yet available. Should afforestation become an integral part of reclamation and revegetation

[1] The term small rodent will be used to collectively describe all cricetids (i.e., microtine and cricentine rodents).

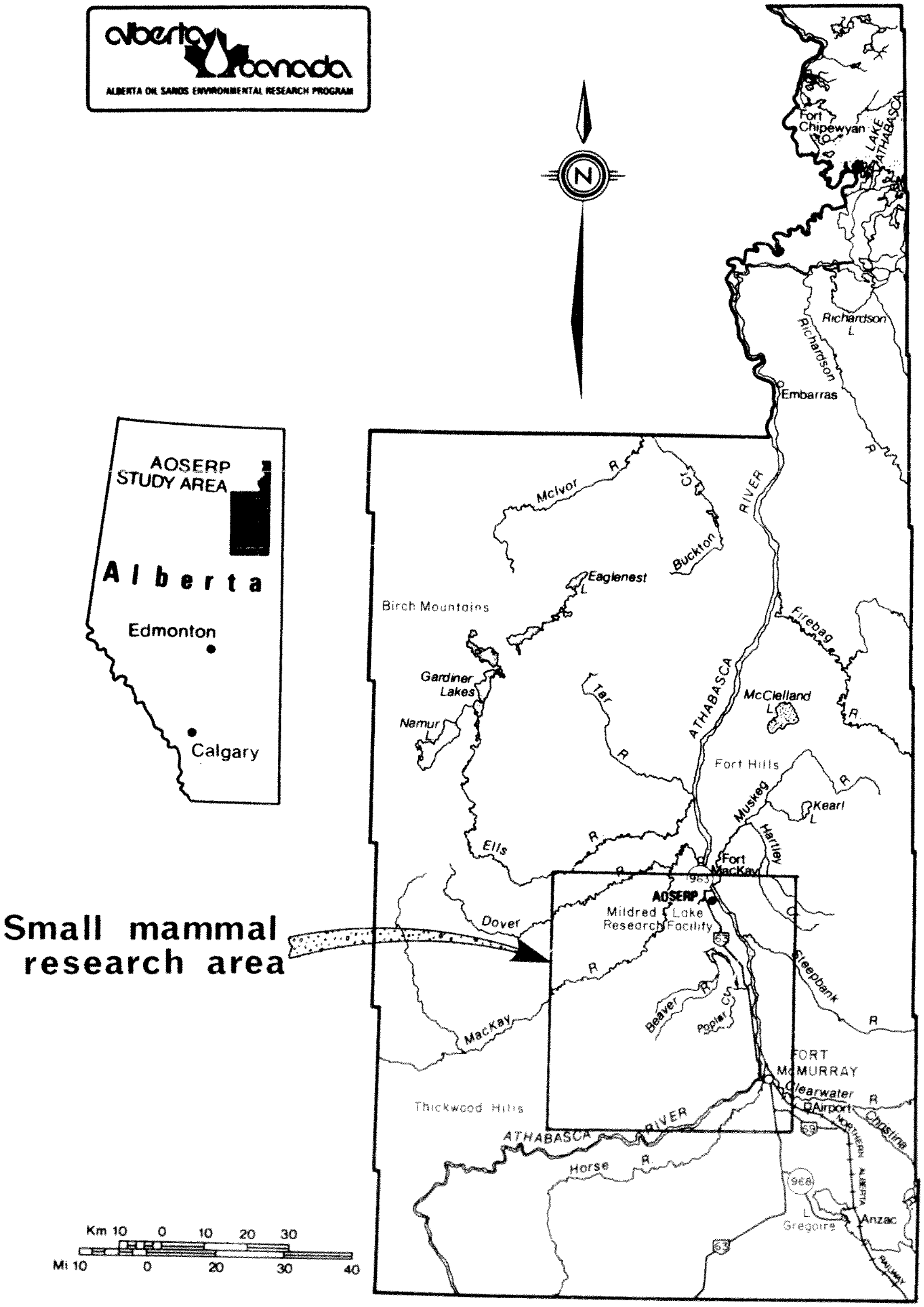

Figure 1. Location of the AOSERP study area.

programs, damage to young trees by small mammals has the potential to become a major problem in the Athabasca Oil Sands area. There is consequently a need to determine the true extent of the small mammal problem in revegetation areas and, if small rodent damage is indeed a major problem, there is a need to develop an effective small mammal damage control program that is economical and ecologically acceptable.

A number of different methods of control of small rodent damage to trees have already been assessed in the Suncor Inc. [formerly Great Canadian Oil Sands Limited (GCOS)] sites. Short-term efforts to control small mammal damage (i.e., the use of kill-traps, the use of Warfarin, and the use of metal guards around the base of the young trees) did not prove successful (Radvanyi 1976a). And although a four-year study of the effectiveness of the anti-coagulant poison, Rozol, in controlling levels of small rodent damage on these reclamation areas (Radvanyi 1978; Michielsen and Radvanyi 1979), demonstrated that a large proportion of the resident small rodents (*M. pennsylvanicus* and *Peromyscus maniculatus*) in each treatment area were killed by the application of Rozol, the study did not show that the poisoning program resulted in significant reductions in the levels of small rodent damage to trees. Perhaps the most important facet of this study was the demonstrated need to begin long-term studies of the small rodent populations and small rodent damage immediately after the initial revegetation of a disturbed area. If assessment of the problem is not begun until damage occurs, an understanding of the factors contributing to the problem is difficult, if not impossible.

Several major data gaps are evident in the data required for the effective evaluation of the severity of the small mammal problem in reclamation areas. Firstly, it has not been documented that small mammals are the major cause of tree mortality. Secondly, little information is available on either the demography of small mammal populations in newly reclaimed sites (most previous studies of small mammals on reclamation sites have involved areas two or three years after establishment) or the relationships between the early history of these populations and the eventual levels of small rodent damage. Thirdly, the relationships between habitat structure (e.g., species composition, density of cover, accumulations of ground litter) and the levels of small rodent damage in reclamation areas are poorly understood, if indeed small rodent damage is a major cause of sapling mortality. And fourthly, no concurrent studies have been carried out in adjacent natural areas to determine if small mammal populations in revegetation areas are demographically similar to those in natural communities.

In order to obtain information relevant to these deficiencies, a study of small rodent populations and small rodent damage was begun in 1977. First, an extensive review of the literature on small mammal damage to plants and methods of control was completed (Green 1978). Field studies of small rodent populations and small rodent damage in revegetation and natural areas were begun in 1978. The present study of small mammals in revegetation areas complements a baseline study of small mammals in natural areas (Green 1980).

This report represents an assessment of the information on small rodent populations and related damage to trees and shrubs that was obtained during field studies in revegetation areas that were conducted from July 1978 to November 1979. The objectives of this program, as described in the terms of reference, were the following:

1. To monitor the small mammal populations on five experimental tree-planting areas and on two monitoring plots on an overburden revegetation area;
2. To assess and compare the effects of vegetation and ground litter on the distribution of small mammals in disturbed sites;
3. To identify the levels of small mammal damage to saplings on each tree planting area and on the two monitoring plots; and
4. To compare habitat relationships and population dynamics of small mammals in natural areas with the relationships determined from this project.

It was anticipated initially that the research program would continue for 4 years in order that these factors could be evaluated over at least one population cycle of the major small rodent species. [Microtine rodents such as *M. pennsylvanicus* typically show cyclic population fluctuations; each cycle averages four years in duration (Krebs et al. 1969; Krebs and Myers 1974).] Because the study could not be continued for the full 4 year duration, some objectives could not be adequately fulfilled. Nevertheless, the existing information suggests some interesting comparative aspects and trends that are considered to be directly relevant to the problem of small rodent damage to woody-stemmed plants.

Mammalian nomenclature follows that of Banfield (1977). Plant nomenclature follows that of Moss (1967) for grasses, forbs, and shrubs, and that of Hosie (1973) for trees. Common and scientific names of plants discussed in this report are provided in Appendix 9.1, Table 14.

2. METHODS

2.1 STUDY PLOTS

Seven small mammal study areas were established on the Suncor Inc. lease (Figure 2).

Two study plots, the Muskeg Reclamation Plot and the Muskeg Overburden Plot, were established on Overburden Storage Site 5. The main purpose of these plots was to monitor both small mammal populations and the levels of small mammal damage to young trees on existing revegetation areas. Each plot was 0.81 ha in size.

The Muskeg Reclamation Plot was located on the eastern slope of Overburden Storage Site 5. The original dike, composed of inorganic overburden fill, was prepared for seeding in March to May 1977. The details of the preparation and seeding have been provided by Suncor Inc. (letter dated 27 November 1978 from D. Klym, Environmental Affairs, Suncor Inc.). Muskeg overburden (primarily peat) was spread over the entire slope to a depth of 10 cm and fertilizer (14-14-7 at 560 kg/ha) was applied. The muskeg and fertilizer were then incorporated to an average depth of 15 cm using a Klodbuster chain. Following this initial soil preparation, a number of species of nursery-reared tree and shrub saplings were planted at approximately 2.1 m spacings. Species planted included *Shepherdia canadensis*, *Ulmus americana*, *Populus* spp. (Vernirubens poplar, Walker poplar, and Northwest poplar), *Salix* spp. (acute willow, Basford willow, and Laurel willow), *Ulmus pumila*, *Elaegnus angustifolia*, and *Fraxinus pennsylvanica*. The entire slope was then hydroseeded 20 to 24 June 1977 with a slurry composed of hydromulch (Silva-Fibre at 1232 kg/ha), fertilizer (14-14-7 at 112 kg/ha), barley (45 kg/ha), grasses [78 kg/ha composed of 25% crested wheatgrass (Fairway), 30% tall wheatgrass (Orbit), 25% bromegrass (Carlton), and 20% creeping red fescue (Boreal)], and legumes [34 kg/ha composed of 40% alfalfa (Rambler), 30% alsike clover (Aurora), and 30% white clover]. Legumes were inoculated with nitrogen-fixing bacteria at three times the conventional rate.

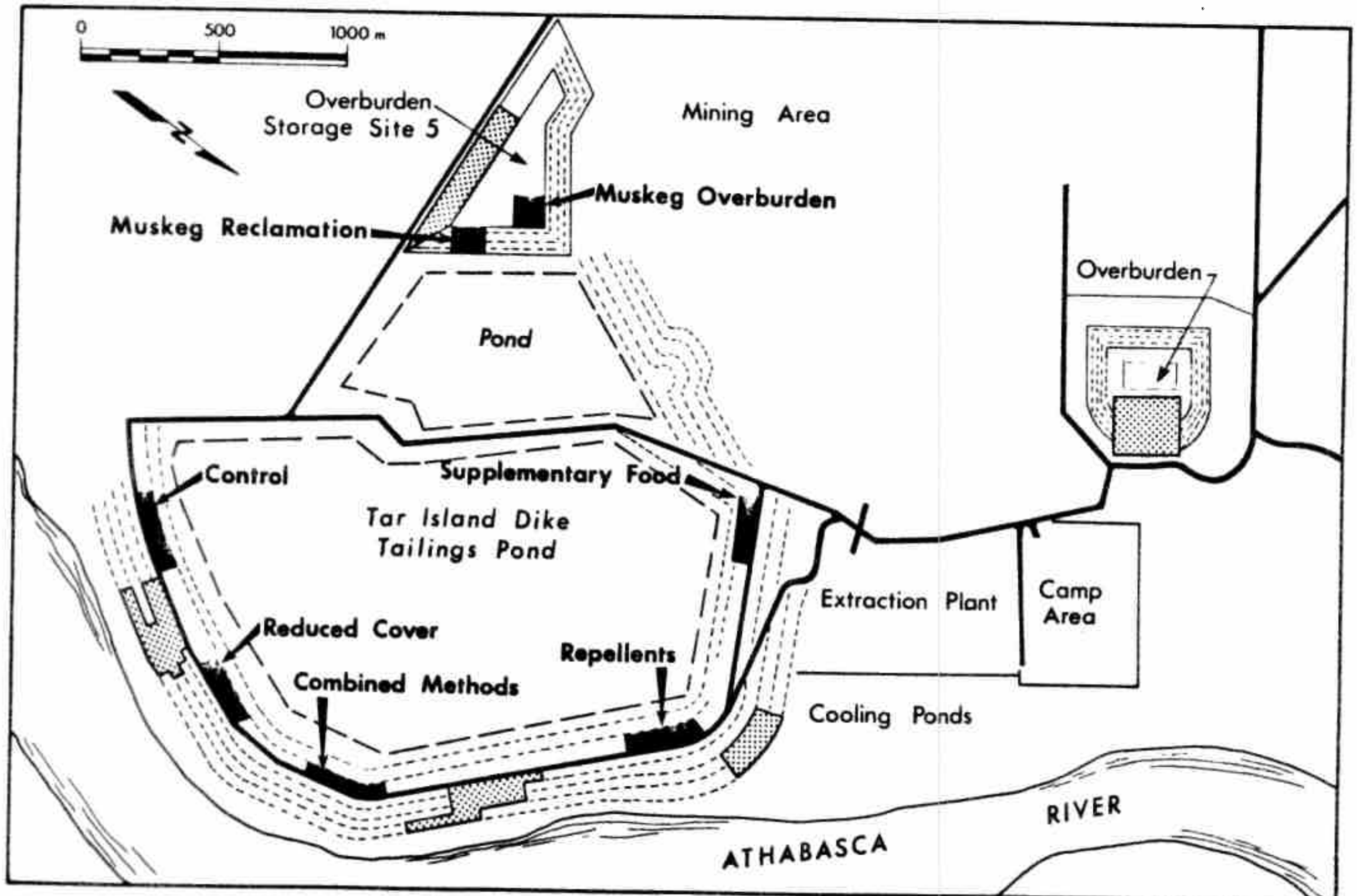

Figure 2. Small mammal study plots on the Suncor Inc. lease. [Locations of the seven trapping grids on the Suncor lease are indicated by black shading. Locations of existing trapping areas (Michielsen and Radvanyi 1979) are indicated by stipling.]

The Muskeg Overburden Plot was located on top of Overburden Storage Site 5. Large frozen blocks of muskeg overburden from the main mining site were brought to this site for storage in early 1973. The area has received no further treatment to date and has been allowed to revegetate by natural means (letter dated 29 November 1978 from D. Klym, Environmental Affairs, Suncor Inc.). Root balls and, in some cases, mature plants of some shrub and tree species (*Betula glandulosa*, *Salix* spp., *Populus balsamifera*, *Populus tremuloides*, and *Larix laricina*) survived the transfer of the overburden. As a result, some trees and shrubs have been present since 1973.

Five experimental plots were established on a recently completed reclamation site on Berm 6 (305 to 320 m level) of the Suncor Inc. Tar Island dike. The main purpose of these study areas was to monitor small mammal populations and levels of small mammal damage to woody-stemmed plants in newly established reclamation areas. The five study areas were situated so as to provide maximum separation both among the experimental plots and between the experimental plots and the existing Suncor small mammal trapping areas (Michielsen and Radvanyi 1979) (Figure 2). Construction of Berm 6 was completed in the fall of 1977 and preparation for seeding was begun in the spring of 1978. Details of preparation and seeding have been provided by Suncor Inc. (letter dated 29 November 1978 from D. Klym, Environmental Affairs, Suncor Inc.). Approximately 15 cm of muskeg overburden were spread over the entire slope and fertilizer was applied (6-24-24 at 224 kg/ha) to the northern and southern thirds of the berm. The muskeg and fertilizer were then incorporated into the tailings sand (to a depth of 20 cm) using a highway construction disc. On the remaining portion of the berm, muskeg was initially incorporated into the tailings sand without fertilizer.

All areas on Berm 6 (with the exception of two 45 m x 250 m plots) were hydroseeded on 27 July to 11 August with a slurry composed of hydromulch [Silva-Fibre (at 1230 kg/ha), barley (45 kg/ha), grasses (67 kg/ha) composed of 35% crested wheatgrass (Nordon), 16.5% pubescent wheatgrass (Greenleaf), 32% bromegrass (Carlton), and

16.5% creeping red fescue (Boreal)] and legumes [45 kg/ha composed of 35% alfalfa (Canada No. 1), 32% Alsike Clover (Dawn), and 33% Sanfoin]. Fertilizer (6-24-24) was included in the hydroseeding slurry applied to the northern and southern thirds of the berm at 280 kg/ha and to the remaining portions of the berm at 336 kg/ha. After the hydroseeding of Berm 6, 34-0-0 fertilizer was broadcast over the northern third of the berm at a rate of 280 kg/ha and over the remaining two-thirds of the berm at a rate of 112 kg/ha.

All experimental plots were of similar design, with the exception of slope aspect, soil treatment (i.e., some small variations in rates of fertilization and soil preparation occurred between major areas of the berm as described above), and the method of controlling small mammal damage to saplings. Each experimental plot was 1.13 ha in size (250 m x 45 m) and contained a small mammal live-trapping grid, a small mammal exclosure, and an open tree plot (Figure 3). The small mammal live-trapping grids were 0.76 ha in size and were situated centrally in each experimental plot such that a 30 m buffer area was created on both ends of the trapping grid. The open tree plots (areas where trees were first planted in 1978) were 200 m^2 in size (10 m x 20 m) and were located near the centre of each small mammal trapping grid. Exclosures were 100 m^2 in size (10 m x 10 m) and were of similar construction to those of Krebs et al. (1969) (in this study exclosures were used to evaluate tree survival without the influence of small rodent damage).

In conjunction with a study of the effectiveness of several methods of controlling small rodent damage to woody stems, each of the five experimental plots received a different treatment. Three methods of controlling small rodent damage that were recommended by Green (1978) were employed--the application of an animal repellent to seedlings, the provision of supplementary food supplies, and the reduction of ground cover. The five experimental plots included a control plot, three single treatment plots, and one plot that combined the three treatments. The results of these different

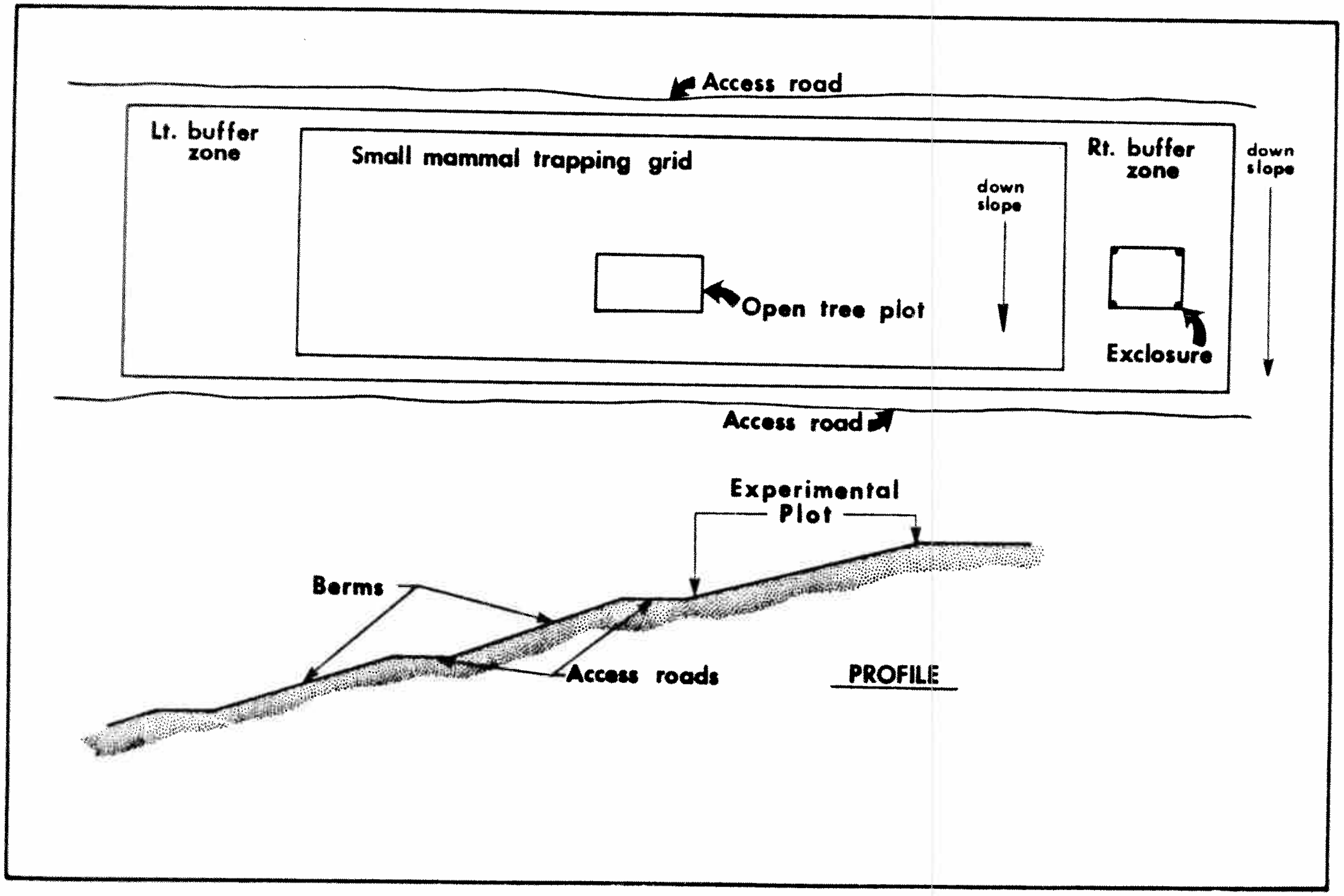

Figure 3. Standard design of the five experimental plots. (Each experimental plot was 45 m x 250 m in size. Each plot contained a small mammal trapping grid, open tree plot, and mouse-proof exclosure, as illustrated.)

treatments will not be fully discussed in this report; more detailed descriptions of the four treatments are provdied in Appendix 9.2.

Tree and shrub seedlings were planted in each of the experimental areas in 1978 and 1979. In 1978, 77 aspen (*Populus tremuloides*) and 77 alder (*Alnus rugosa*) were planted in each of the open tree plots and 27 of each species were planted in each exclosure during the period of 12 October to 18 November. Seedlings were planted at 1 m spacings such that the same sequence of the three species [aspen, alder, and jack pine[1] (spaces were left for jack pine)] was repeated along each row. The starting point for each row was chosen (i.e., Row 1, aspen; Row 2, alder; Row 3, jack pine) in order to provide maximum separation of each species of seedlings within a plot.

In 1979 Suncor, Inc. planted approximately 1200 tree and shrub seedlings on each experimental plot during May and early June. Twelve species of trees and shrubs were planted at 2.1 m spacings in blocks consisting of double rows of each species that varied from 14 to 20 seedlings long. Species planted were dogwood, laurel willow, Siberian larch, Basford willow, caragana, Northwest poplar, acute willow, white spruce, Scots pine, chokecherry, Walker poplar, and Russian olive (see Appendix 9.1, Table 14 for scientific names). Three blocks of seedlings were established on each study plot.

2.2 VEGETATION ANALYSES

Vegetation analyses were conducted on the Muskeg Overburden and Muskeg Reclamation plots on 31 July 1978 and on all seven areas during 23 to 25 June 1979. Estimates were made of the density, species composition, and levels of small rodent damage to saplings (trees and shrubs), and of the density, species composition, and vertical distribution of ground cover. Thirty sample points were chosen using coordinates selected from a table of random numbers. At each sample point, a 4 m x 4 m quadrat and a 1 m x 1 m quadrat were placed on the ground as shown in Figure 4.

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[1] Jack pine seedlings were to be made available for planting in the spring of 1979; however, due to extremely high mortality of nursery stock as a result of frost kill, no jack pine seedlings were available.

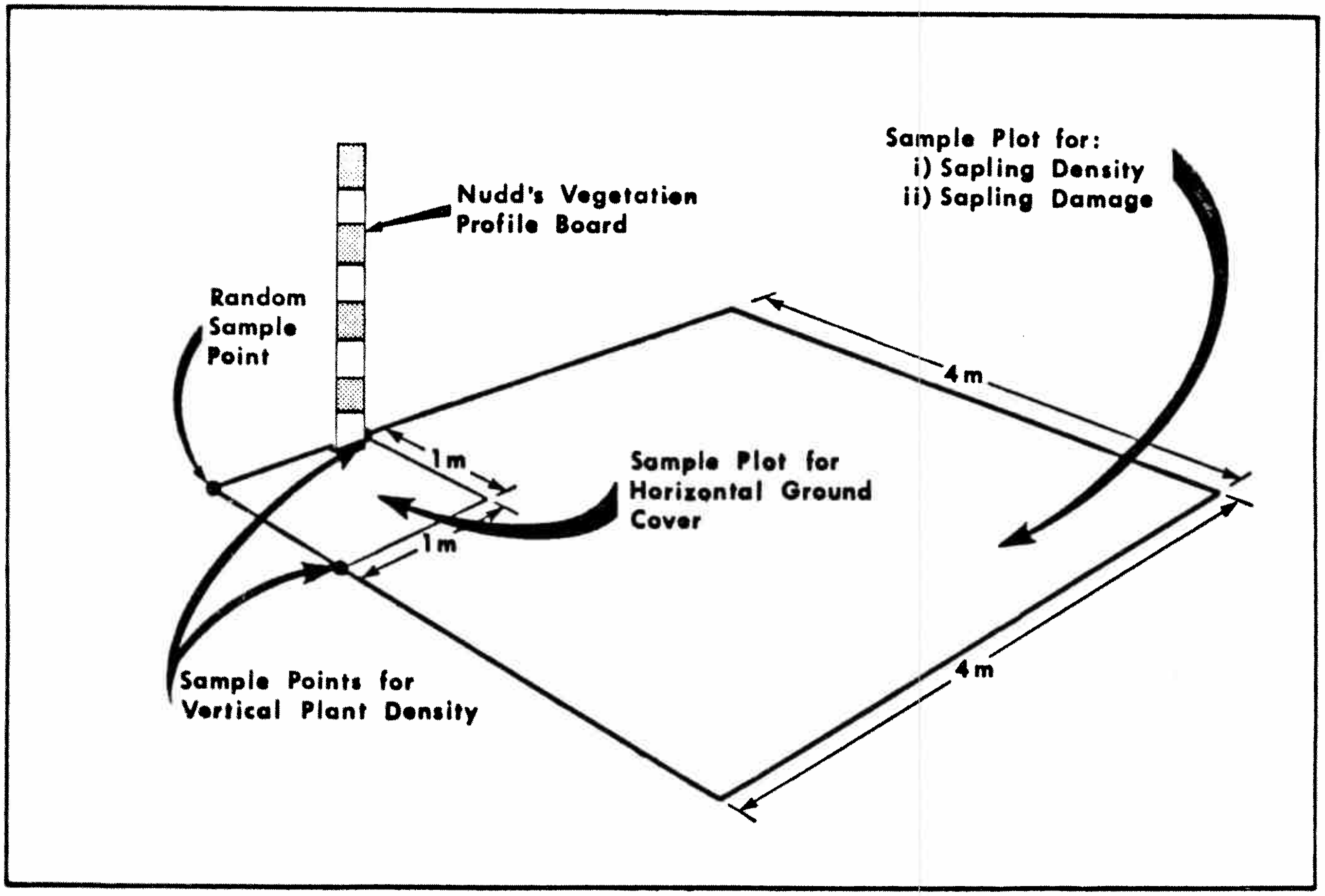

Figure 4. The configuration of vegetation on sampling quadrats. (The 16 m^2 quadrat for sapling densities and damage, the 1 m^2 quadrat for ground cover densities, and the vertical cover sample points are shown.)

Sapling density and species composition were estimated by counting the number of each species of sapling present in the 16 m^2 quadrat. For the purpose of this study, saplings were defined as individual young coniferous or deciduous trees with a stem diameter of 3 cm or less at a height of 15 cm above ground level. Individual shrubs were similarly termed as saplings if all main branches had diameters of 3 cm or less at a height of 15 cm above the ground. Single deciduous or coniferous saplings and distinct shrubs (i.e., a distinct grouping of branches at ground level) were each counted as one sapling. In 1979, the total number of stems of each tree and shrub species in the quadrat was also recorded.

Two types of small mammal damage to saplings were recognized--girdling by small rodents and browsing by snowshoe hares. Girdling refers specifically to the removal of the phloem and the outer cambium layers of the stem, roots, and/or branches. Damage to these layers was included as girdling only if rodent teeth marks were visible in the remaining woody tissue. Girdling damage was rated according to the percentage (in 25% increments) of the total circumference of the stem that had been damaged; five girdling classes were recognized ($0\% < \text{Class } 1 < 25\%$, $25\% \leq \text{Class } 2 < 50\%$, $50\% \leq \text{Class } 3 < 75\%$, $75\% \leq \text{Class } 4 < 100\%$, and total girdling=Class 5). Browsing refers to the clipping of terminal and lateral twigs and buds. Browsing and girdling damage was described as old (exposed woody tissue weathered, calloused growth around the wound) or new (exposed woody tissue not weathered).

Estimates of the percent ground coverage (on the horizontal plane) of each plant species and ground litter within the 1 m x 1 m quadrat were estimated using a Braun-Blanquet cover scale (Kershaw 1966).

The vertical composition of the ground cover was measured at two opposite corners of the ground cover quadrat (Figure 4). The vertical density (percent cover) of all vegetation in each 0.25 m vertical increment was visually estimated using the vegetation profile board method of Nudds (1977), which provides a cumulative estimate for all components of vertical plant cover. More specific information on vertical plant cover was collected for each of the three most dominant plant species in each horizontal ground cover quadrat (based on the estimates of percent horizontal cover). For each dominant species, the vertical zone with the highest density of cover was estimated and the minimum height of this zone (from the ground surface) was recorded. Two minimum heights for each dominant species were obtained--one at each of the corners of the quadrat that were sampled for vertical cover. The depth of the plant litter (i.e., dead grasses, twigs, leaves, etc.) was also measured at each of these sample points.

2.3 SMALL MAMMAL TRAPPING TECHNIQUES

Live-trapping and snap-trapping techniques were used to obtain information on the demography, distribution, and habitat preferences of the major species of small mammals present in reclamation-afforestation areas and on the species composition of the small mammal community.

2.3.1 Live-trapping Techniques

Small mammal live-trapping techniques were similar to those described by Krebs et al. (1969). Each small mammal trapping grid on the experimental plots consisted of a 5 x 20 grid of trapping stations at 10 m intervals; each small mammal trapping grid on the monitoring plots consisted of a 10 x 10 grid of trapping stations at 10 m intervals. One Longworth Trap was placed within a 1.5 m radius of each trap station. Traps were prebaited (trap doors were locked open to allow animals free access to the traps) for 2 wk before commencing live-trapping. Cotton felt for bedding and oat groats for bait were placed in the nest box of each trap and were replenished when necessary. Between trapping periods, doors on all traps were locked open.

Each trapping period involved 3 d of live-trapping. All traps were set during the afternoon of the first day. All traps were checked and reset the following morning and again in the afternoon. On the morning of the third day, all traps were checked and locked open until the next trapping period.

All new animals were ear-tagged with a numbered fingerling fish tag when first captured. After tagging or when tagged animals were captured during subsequent trapping periods, the tag number, species, trap location, sex, breeding condition, weight, number of wounds on the posterior portion of the body, and number of sub-dermal parasites (*Cuterebra* spp.) were recorded.

In 1978, the two monitoring plots were trapped at 2 wk intervals from 15 August to 14 November. The five experimental plots were trapped only during two trapping periods in 1978 (20 to 22 October and 15 to 17 November). In 1979, all seven areas were trapped at 3 wk intervals from 13 May to 11 November.

2.3.2 Snap-trapping Techniques

Snap-trap censuses of small rodents were conducted according to techniques outlined for the North American Census of Small Mammals program (Calhoun and Casby 1958). Each snap-trap line consisted of 20 stations spaced at 15 m intervals along a straight line. Three Woodstream Museum Special Snap Traps were set at each station and were baited with peanut butter. Traps were set in the afternoon of the first day and were checked daily for 3 d. Two parallel lines placed approximately 100 m apart were set at each sampling location. In 1978, four snap-trap lines were set on the Suncor lease during 16 to 19 October. Two parallel lines were set (one on Berm 2, one on Berm 3) immediately below the combined treatment grid on the Tar Island dike, and two parallel lines were set (one on Berm 1, one on Berm 3) on the north slope of Overburden Storage Site 5. In 1979, eight snap-trap lines were set on the Suncor lease between 5 and 8 September. Four parallel lines were set immediately below both the control and the repellent areas on the Tar Island dike--one on each of Berms 1, 2, 4, and 5.

All animals captured in snap-traps were autopsied to measure reproductive characteristics and to obtain indices of nutritional condition. Procedures followed were similar to those described by Krebs (1964). For each animal autopsied, the body weight, total length, tail length, skull (zygomatic) breadth, reproductive condition, number of sub-dermal parasites (*Cuterebra* spp.), and an index of the amount of fat in the abdominal mesentery [no fat (1) to very fat (5)] were recorded. Reproductive conditions noted for males were testes position (abdominal or scrotal), testes weight, and size of the epididymis tubules (visible or not visible). Reproductive conditions noted for females were size of mammary glands (small, medium, or large), vaginal opening (perforate or non-perforate), uterus size (threadlike, normal, slightly enlarged, or large), uterus weight, number of placental scars, number of living embryos, and number of resorbing embryos. All testes and uteri from mature animals were preserved in formalin and later weighed on an analytical balance.

2.4 DATA ANALYSES

Small mammal live-trapping and snap-trapping data were analyzed using computer programs provided by Dr. C.J. Krebs of the University of British Columbia. Additional programs for specific analyses of population data were developed as needed.

3. SMALL RODENT DEMOGRAPHY

3.1 POPULATION CHANGES

Population densities of small mammals commonly have been assessed using mark-recapture methods of estimating population size. To avoid the assumptions of mark-recapture techniques (Roff 1973; Boonstra and Krebs 1978), a complete enumeration of small mammals within each study area was attempted. The minimum number known to be alive (MNA) (Chitty and Phipps 1966) during each trapping period was used as a biased estimate of population size.

Biases in population estimates (usually underestimates) may be caused by poor trappability (Van Vleck 1968; Boonstra and Krebs 1978), poor trap availability, or social interactions (Davis and Emlen 1956; Kikkawa 1964; Andrzejewski et al. 1967; Gliwicz 1970; Joule and Cameron 1974). An attempt was made to minimize the biases inherent in this small mammal trapping study by (1) saturating trapping areas with traps (i.e., by using a small inter-trap distance) and (2) by using MNA estimates only when the trappability exceeded 50% (Hilborn et al. 1976).

Estimates of the trappability were used to assess the reliability of the calculated MNA. Minimum unweighted trappability was calculated for a population of N captured individuals according to the following formula (Boonstra and Krebs 1978):

$$\text{Minimum Unweighted Trappability} = \frac{1}{N}\sum_{i=1}^{N} \frac{\text{number of trapping periods during which an animal was captured}}{\text{number of possible trapping periods for that animal}}$$

The first and last capture of each individual are not included in these calculations (because all animals are necessarily caught at these times).

In 1978, estimates of minimum unweighted trappability could be calculated only for animals on the Muskeg Overburden and the Muskeg Reclamation study areas (the five experimental plots were trapped too few times). Trappabilities for all major species exceeded 65% (Table 1) and the MNA consequently should underestimate

Table 1. Seasonal estimates of minimum unweighted trappability (MUT). [Calendar equivalents of the summer and fall periods in each year were, 1978: 1 July to 25 September and 26 September to 9 November; 1979: 24 June to 20 September and 21 September to 9 November. The number of animals captured in three or more trapping periods (N) is indicated. No *C. gapperi* were captured in three or more trapping periods in either season on the Muskeg Reclamation, Feeding, Repellent, Combined Treatment, Reduced Cover, or Control study areas.]

		1978				1979			
		Summer		Fall		Summer		Fall	
Grid	Species	MUT	N	MUT	N	MUT	N	MUT	N
Muskeg Overburden	*C. gapperi*	100.0	3	100.0	10	-	0	16.7	6
	M. pennsylvanicus	77.8	18	76.3	19	-	0	-	0
	P. maniculatus	88.8	18	88.7	21	95.0	10	100.0	8
Muskeg Reclamation	*M. pennsylvanicus*	72.5	49	74.5	69	28.6	7	11.1	21
	P. maniculatus	66.2	23	83.8	16	66.7	3	100.0	1
Feeding	*M. pennsylvanicus*	-	-	-	-	75.0	4	14.3	7
	P. maniculatus	-	-	-	-	100.0	1	-	0
Repellent	*M. pennsylvanicus*	-	-	-	-	20.0	5	16.7	6
	P. maniculatus	-	-	-	-	-	0	-	0
Combined Treatment	*M. pennsylvanicus*	-	-	-	-	-	0	-	0
	P. maniculatus	-	-	-	-	80.0	5	88.9	3
Reduced Cover	*M. pennsylvanicus*	-	-	-	-	-	0	-	0
	P. maniculatus	-	-	-	-	100.0	2	0.0	1
Control	*M. pennsylvanicus*	-	-	-	-	0.0	2	-	0
	P. maniculatus	-	-	-	-	100.0	2	0.0	1

the trappable population sizes by acceptably small amounts. In 1979, trappabilities were calculated for all species (if present) on the seven study areas. During the summer and fall periods, trappability estimates for *C. gapperi* on the Muskeg Overburden study area and for *M. pennsylvanicus* on most study areas (the only exception was the population on the Feeding area during the summer) were less than 50%; the MNA in these cases will be considered an underestimate of the trappable population size. In contrast, most trappability estimates for *P. maniculatus* were greater than 50% (with the exception of the populations on the Reduced Cover plot and the Control plot in the fall of 1979).

Comparisons of MNA estimates of *C. gapperi*, *M. pennsylvanicus*, and *P. maniculatus* populations on each of the seven study areas (Figures 5 to 11) indicate that habitat use and seasonal population trends differed between areas. Because of the poor trappability of some species and the low number of trapping periods on the experimental areas in 1978, longer term population changes could not be assessed.

Clethrionomys gapperi was only common on the Muskeg Overburden study area; one individual was captured on each of the Muskeg Reclamation and Control study areas, whereas no *C. gapperi* were captured on the remaining study areas. Numbers of *C. gapperi* on the Muskeg Overburden study area increased in August of each year.

Microtus pennsylvanicus was most abundant on the Muskeg Reclamation area, Muskeg Overburden, and Feeding study areas. Numbers of *M. pennsylvanicus* were low on the Repellent and Control study areas and only one animal was captured on the Reduced Cover and Combined Treatment study areas. In 1978, *M. pennsylvanicus* populations on both monitoring plots increased throughout August and September. In 1979, however, seasonal trends differed among areas. The population on the Muskeg Overburden area increased until mid-July then declined; the population on the Muskeg Reclamation area declined throughout the late spring and summer and increased in late August; numbers on the Feeding area declined

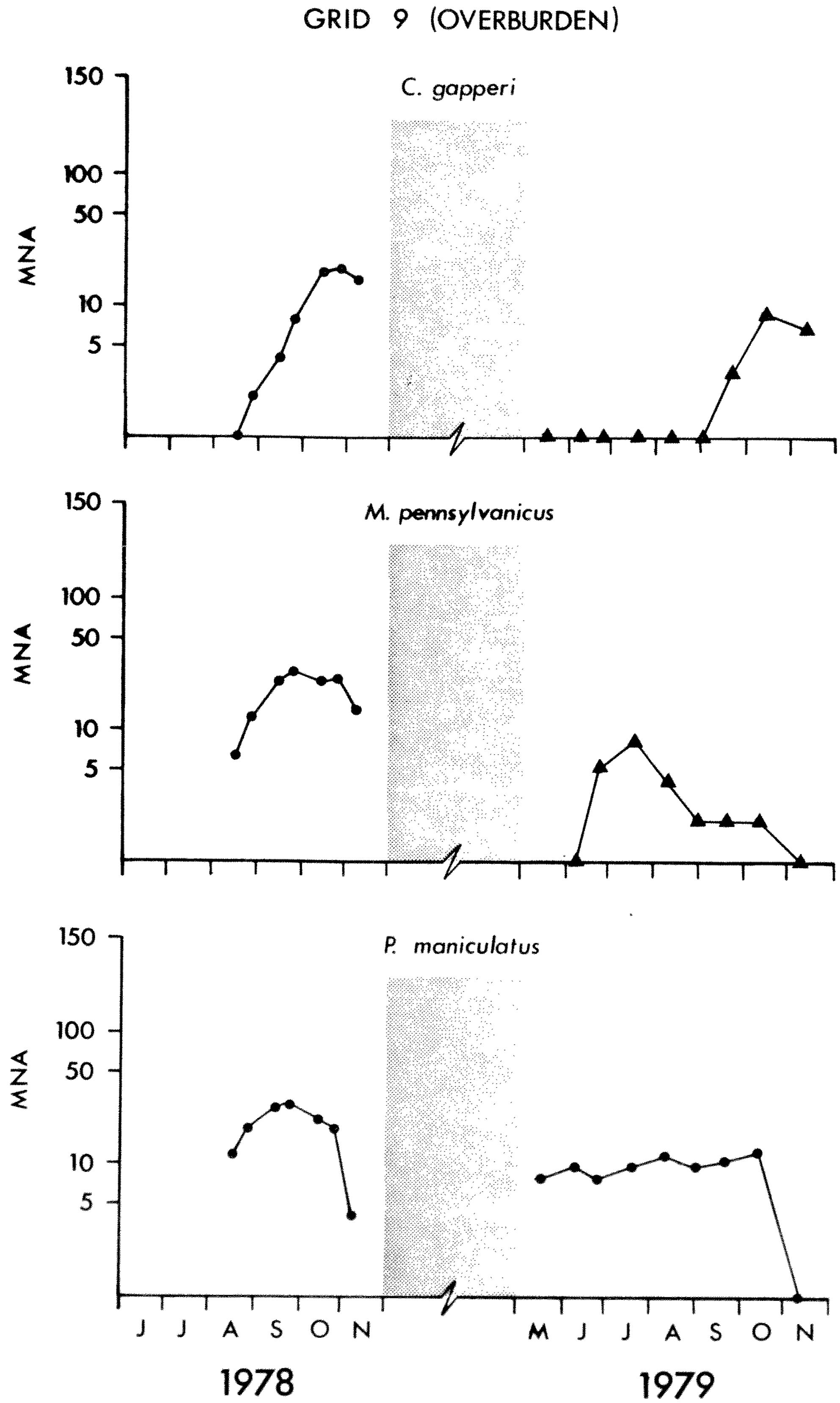

Figure 5. Numbers (MNA) of small rodents on the Muskeg Overburden study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

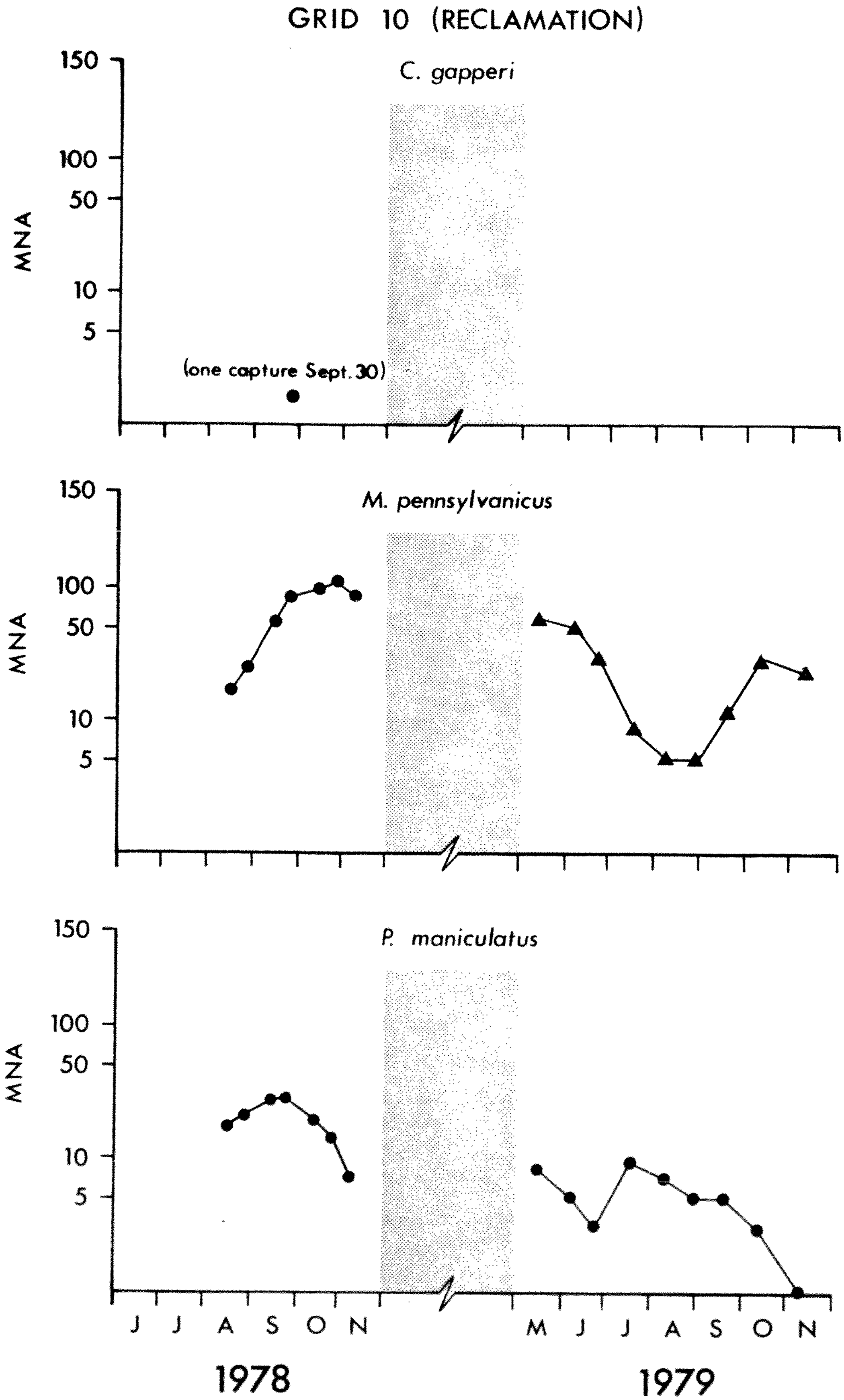

Figure 6. Numbers (MNA) of small rodents on the Muskeg Reclamation study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

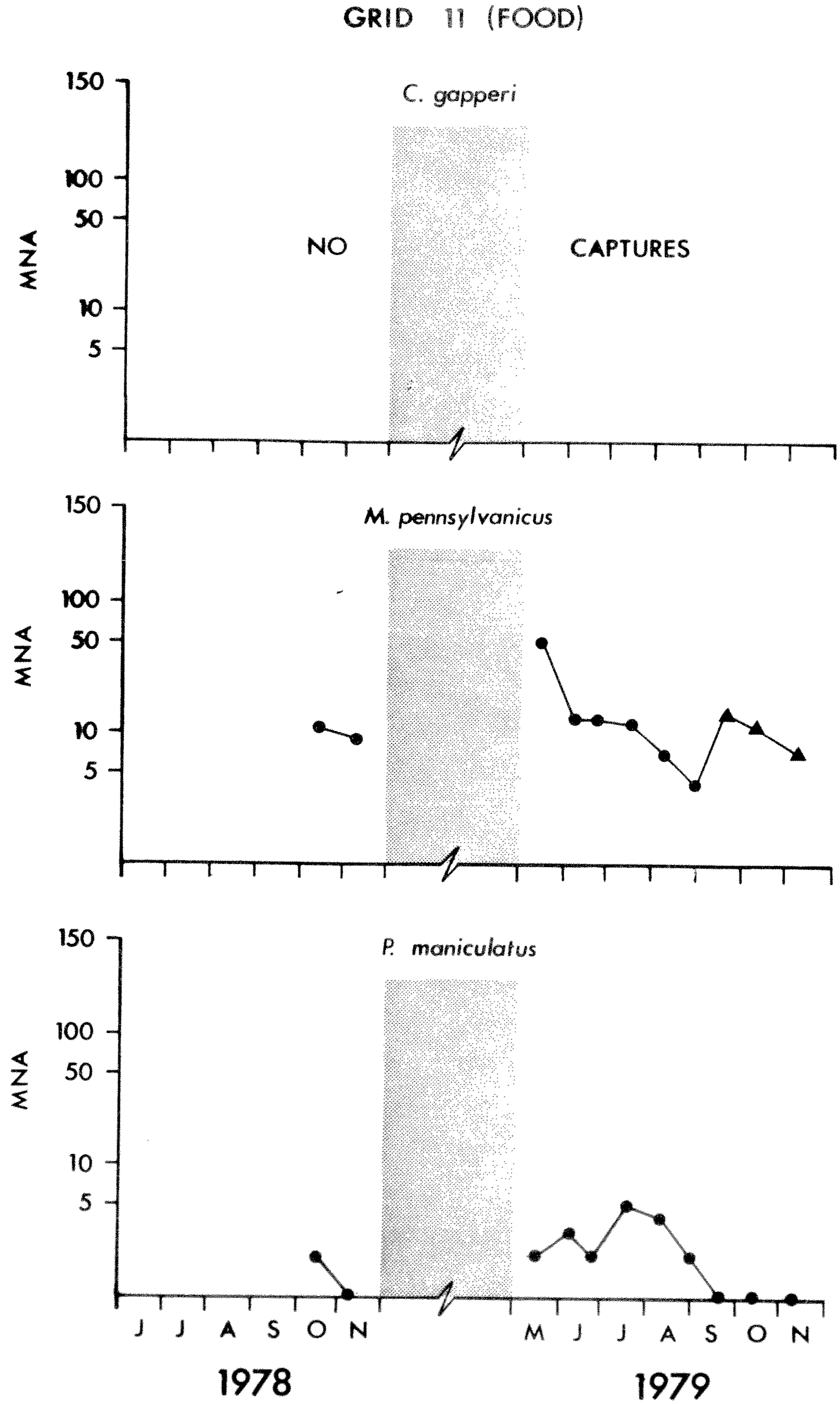

Figure 7. Numbers (MNA) of small rodents on the Feeding study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

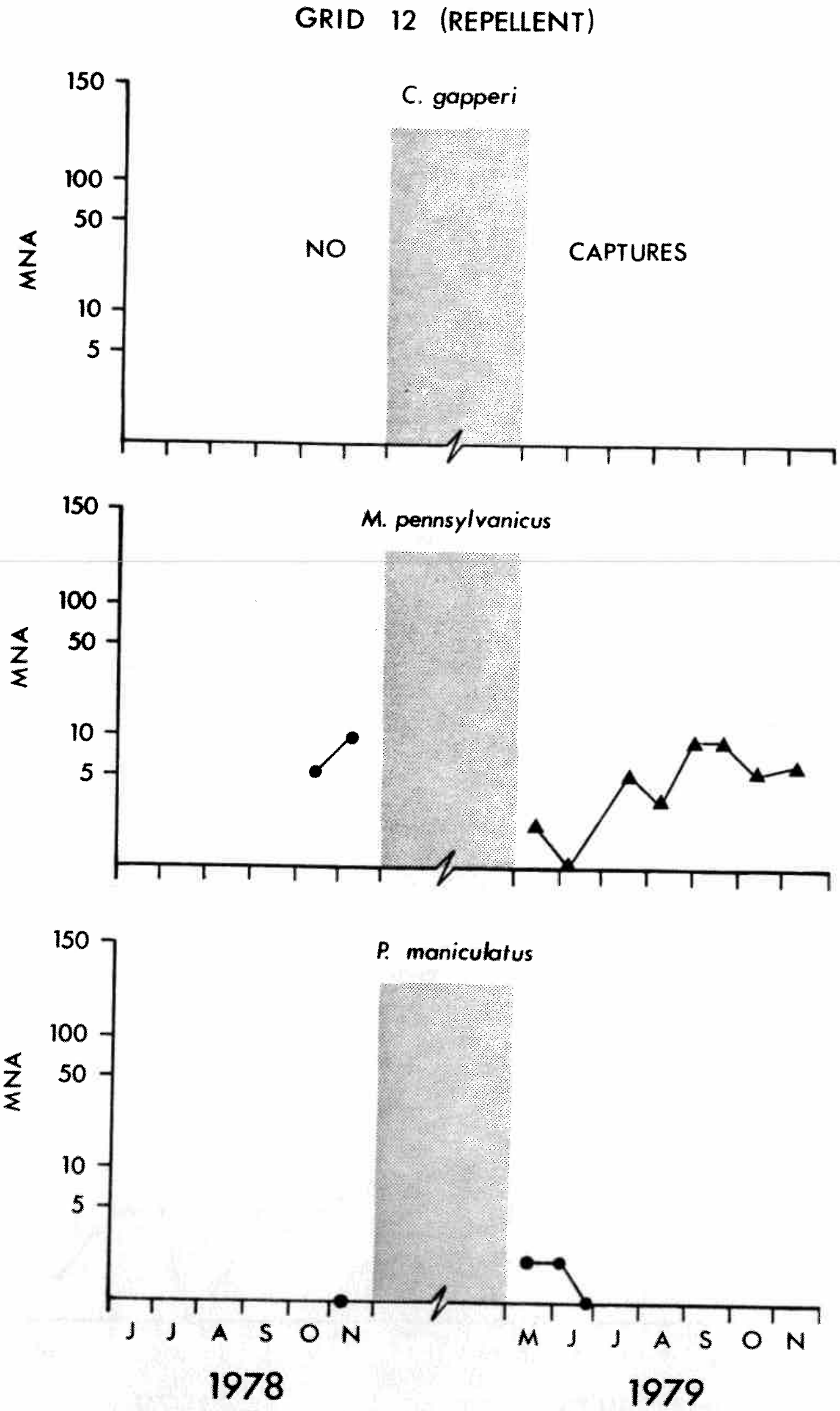

Figure 8. Numbers (MNA) of small rodents on the Repellent study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

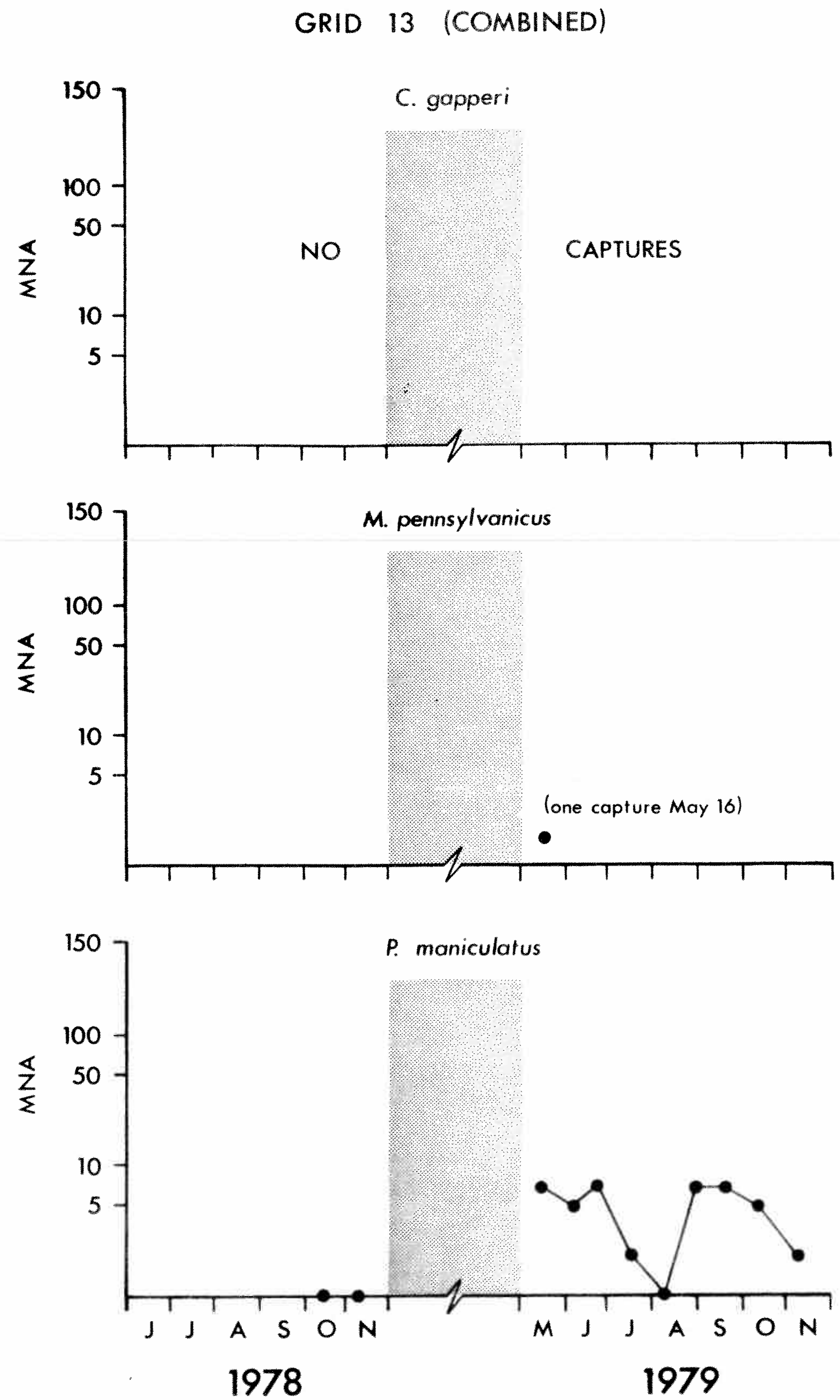

Figure 9. Numbers (MNA) of small rodents on the Combined Treatment study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

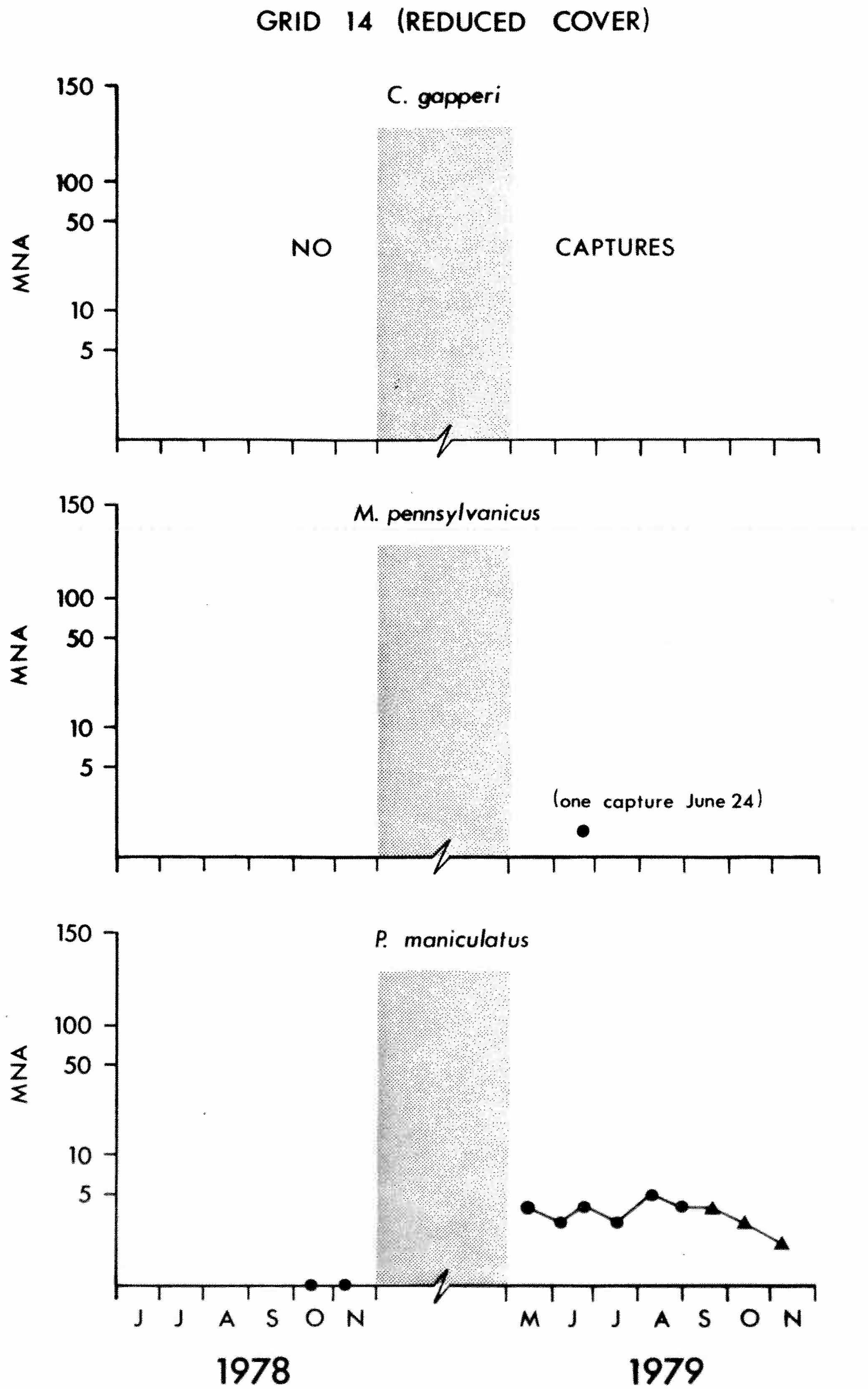

Figure 10. Numbers (MNA) of small rodents on the Reduced Cover study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

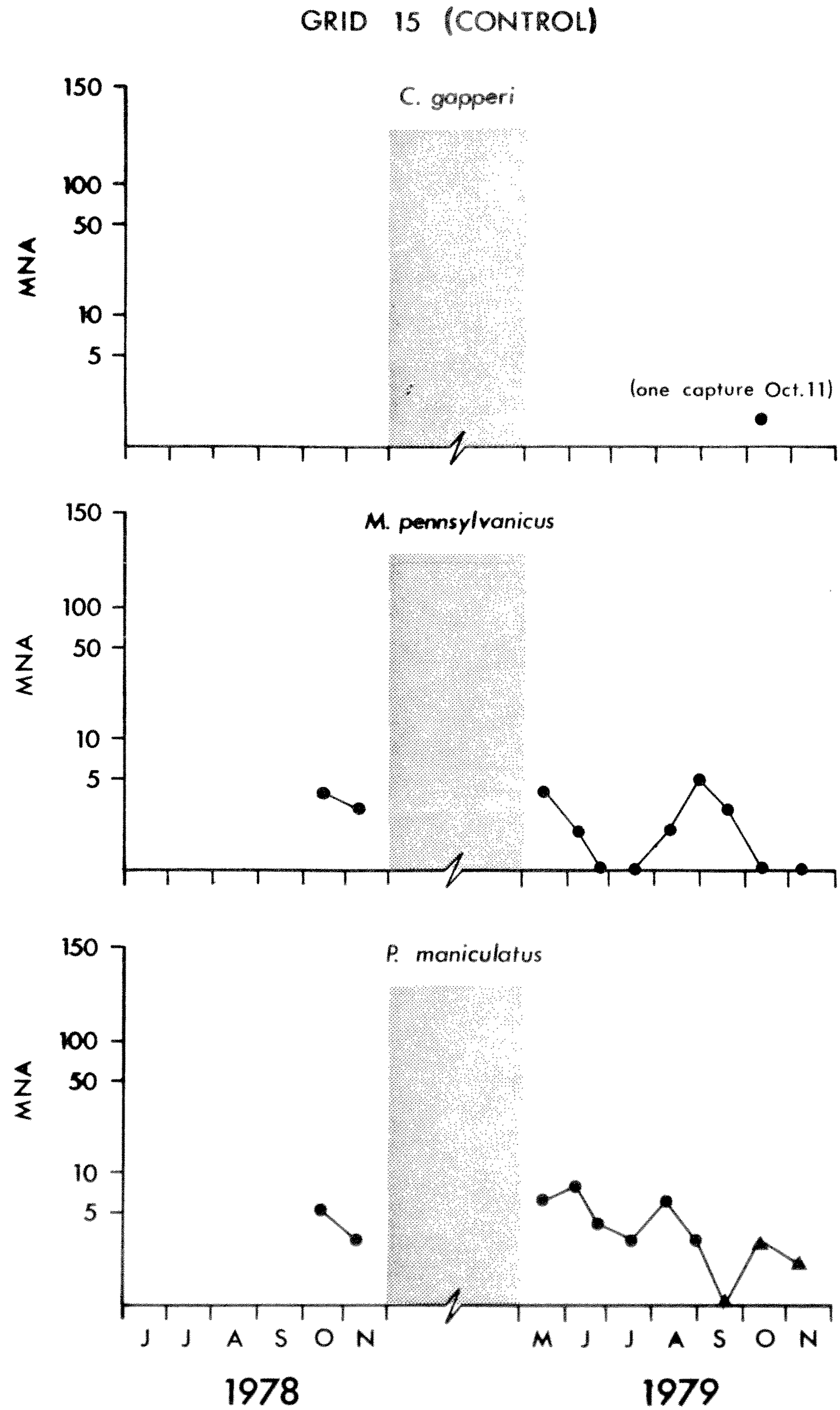

Figure 11. Numbers (MNA) of small rodents on the Control study area. (Triangles indicate that trappabilities were less than 50% and MNA estimates likely underestimate the real trappable population size.)

in May and remained low; the population on the Repellent area increased throughout the year; and numbers on the Control area remained low. Despite poor trappability in 1979, the large reduction in numbers on the two monitoring areas suggest that *M. pennsylvanicus* populations declined between 1978 and 1979.

Peromyscus maniculatus were most abundant on the two monitoring plots; only a few *P. maniculatus* were captured in the other areas. In 1978, *P. maniculatus* populations on both monitoring plots increased until mid-September. Late fall declines in numbers likely reflect reduced trappability as a result of reduced activity levels of *P. maniculatus* (i.e., torpor) during the late fall and winter (Stebbins 1971). In 1979, however, seasonal trends differed among areas. Numbers of *P. maniculatus* on the Muskeg Overburden and Reduced Cover study areas changed little throughout 1979; populations on the Muskeg Reclamation and Control areas declined; the population on the Feeding area increased until July then declined; and numbers on the Combined Treatment study area declined to August, then increased to September. Population trends on the two monitoring plots indicate that *P. maniculatus* populations declined slightly between 1978 and 1979.

A number of other species of small mammals were also captured in 1978 and 1979 during the course of the live-trapping program; other species captured were *Sorex cinereus*, *Microsorex hoyi*, *Eutamias minimus*, *Phenacomys intermedius*, and *Mustela erminea*. Because of small sample sizes (Appendix 9.3, Table 15), analyses of the demography and habitat use of these five species are limited.

Snap-trap censuses were conducted once each year on the Suncor Inc. reclamation sites and provided crude indices of annual changes in the abundance of small rodents. For each species, the mean numbers of animals captured per 100 trap-nights (TN) were used as indices of abundance. Based on 698 TN, *M. pennsylvanicus* was the most abundant small rodent species in October 1978 (8.88 ± 2.27 captures/100 TN), followed by *P. maniculatus* (2.15 ± 0.98) and *C. gapperi* (0.15 ± 0.15). Based on 1374 TN, *M. pennsylvanicus* was also the most abundant small rodent species in September 1979 (1.89 ± 0.42 captures/100 TN). *Peromyscus maniculatus* was the only other species of small rodent captured (0.36 ± 0.29). Low numbers of *S. cinereus/M. hoyi* were also captured in each year (0.5 ± 0.40 and 0.15 ± 0.15 captures/100 TN in 1978 and 1979, respectively). Snaptrap indices suggest, as did live-trapping indices of abundance, that *M. pennsylvanicus* and *P. maniculatus* populations declined in numbers between 1978 and 1979.

3.2 SURVIVAL AND RECRUITMENT

Changes in the numbers of small rodents are a result of population losses (mortality and emigration) and recruitment (births and immigration). Survival and recruitment rates were calculated for each species as a means of assessing the magnitude of population losses and recruitment. Minimum survival rates were calculated as the proportion of animals caught in a trapping period t + 1 (or later on the same grid) that were also caught in trapping period t. Recruitment rates for each grid were calculated, as the proportion of the MNA that were newly tagged on each grid during that trapping period. The trapping season in each year was divided into two seasons, summer (16 August to 25 September 1978 and 16 May to 20 September 1979) and fall (25 September to 9 November 1978 and 20 September to 9 November 1979) and seasonal survival and recruitment estimates were calculated for each species. Because survival and recruitment estimates for each trapping period are ratio estimates and are not independent (i.e., the same animal may occur in two or more samples), it is not appropriate to compare seasons using arithmetic means. Seasonal comparisons, therefore, were made using multiple regression analyses (MRA) with 'dummy' variables (Johnston 1972) according to the methods described by Fairbairn (1977a). Specific details are provided in Green (1980).

Because of the low numbers of sampling periods on the five experimental areas in 1978, analyses of seasonal survival and recruitment rates in 1978 were limited to estimates from populations on the two monitoring study areas. In 1979, analyses included only those populations where animals were present throughout most of the trapping season (i.e., study areas with only one or two captures during the summer or fall period were excluded).

In 1978, *C. gapperi* on the Muskeg Overburden study area tended to survive less well during the fall (seasonal survival estimate: 0.24) than during the summer (0.42); however, seasonal estimates of survival for these periods did not differ significantly ($F = 0.50$; 1,6 df; $P > 0.10$). In contrast, *C. gapperi* in 1979 survived better during the fall (0.46) than during the summer (0.00) ($F = 8.23$; 1,6 df; $0.05 < P < 0.01$).

Survival rates of *M. pennsylvanicus* on the Muskeg Overburden and the Muskeg Reclamation study areas in 1978 were not significantly different ($F = 0.02$; 1,12 df; $P > 0.10$) (Figure 12); survival rates also did not differ significantly between the summer and the fall periods ($F = 0.12$; 1,12 df; $P > 0.10$). Seasonal survival rates of *M. pennsylvanicus* on the two monitoring study areas and the Feeding, Repellent, and Control experimental areas in 1979 tended to differ between study areas ($F = 2.58$; 4.40 df; $0.10 > P > 0.05$) but did not differ with season ($F = 0.45$; 1,40 df; $P > 0.10$) (Figure 12). Animals on the Muskeg Reclamation study area appeared to survive better than animals on the Muskeg Overburden and Control study areas.

Seasonal survival rates of *P. maniculatus* on the Muskeg Overburden and the Muskeg Reclamation study areas in 1978 did not differ significantly between areas ($F = 0.03$; 1,12 df; $P > 0.10$) or seasons ($F = 0.16$; 1,12 df; $P > 0.10$) (Figure 13). However, seasonal survival rates of animals on the monitoring and experimental study areas in 1979 did differ significantly between areas ($F = 7.52$; 1,48 df; $P < 0.001$) and with season ($F = 3.41$; 5,48 df; $P < 0.01$) (the Repellent study area was not included in the analysis because of the low number of *P. maniculatus* present). Survival rates on the Muskeg Reclamation, Feeding, Reduced Cover, and Control study areas declined between the summer and fall periods, whereas survival rates of animals on the Muskeg Overburden and Combined Treatment study

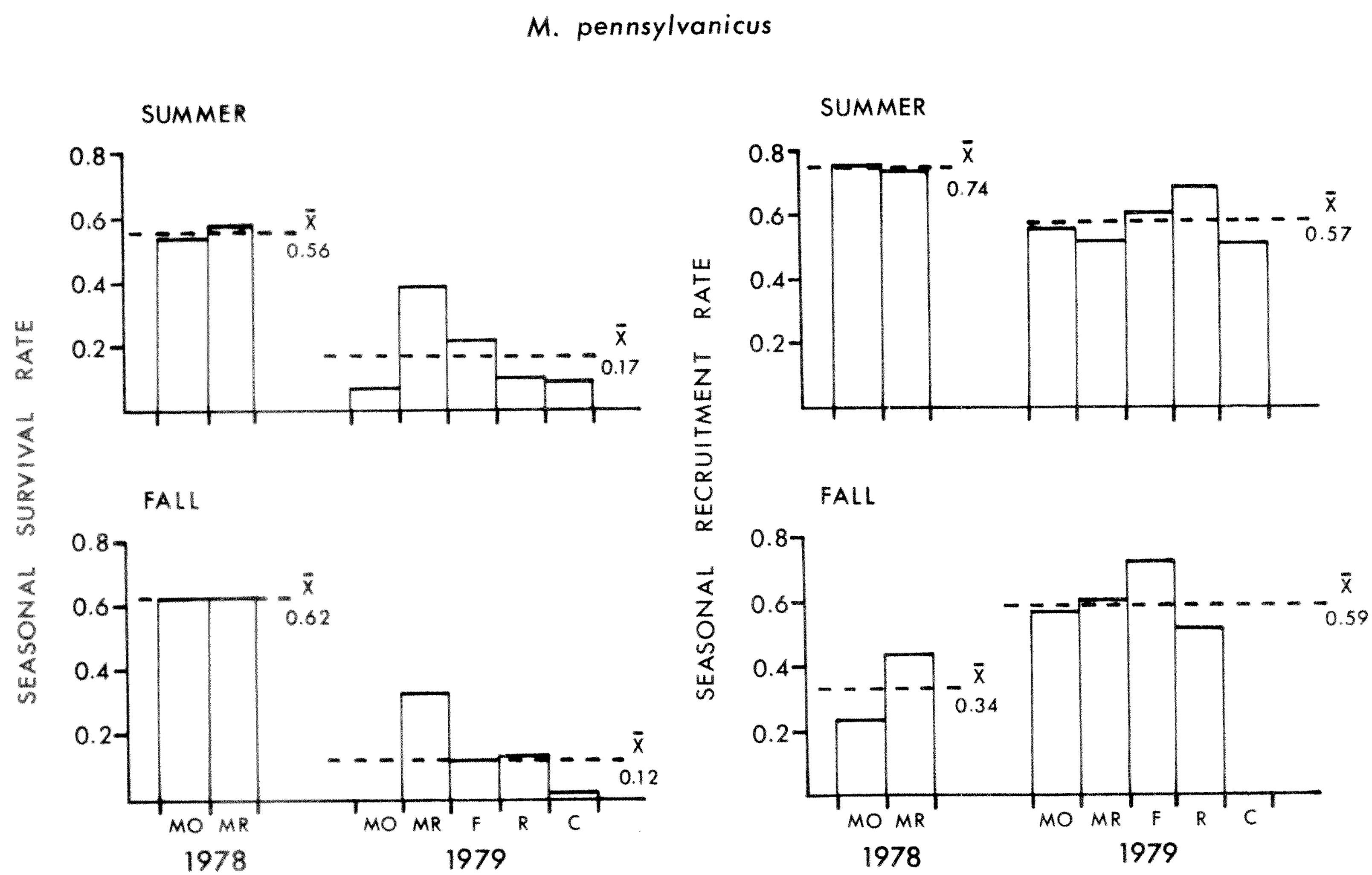

Figure 12. Seasonal survival and recruitment rates of *M. pennsylvanicus*. (Rates were obtained from an MRA described in text. The arithmetic means for all study areas are indicated. Abbreviations for study areas: MO = Muskeg Overburden, MR = Muskeg Reclamation, F = Feeding, R = Repellent, CT = Combined Treatment, RD = Reduced Cover, and C = Control.)

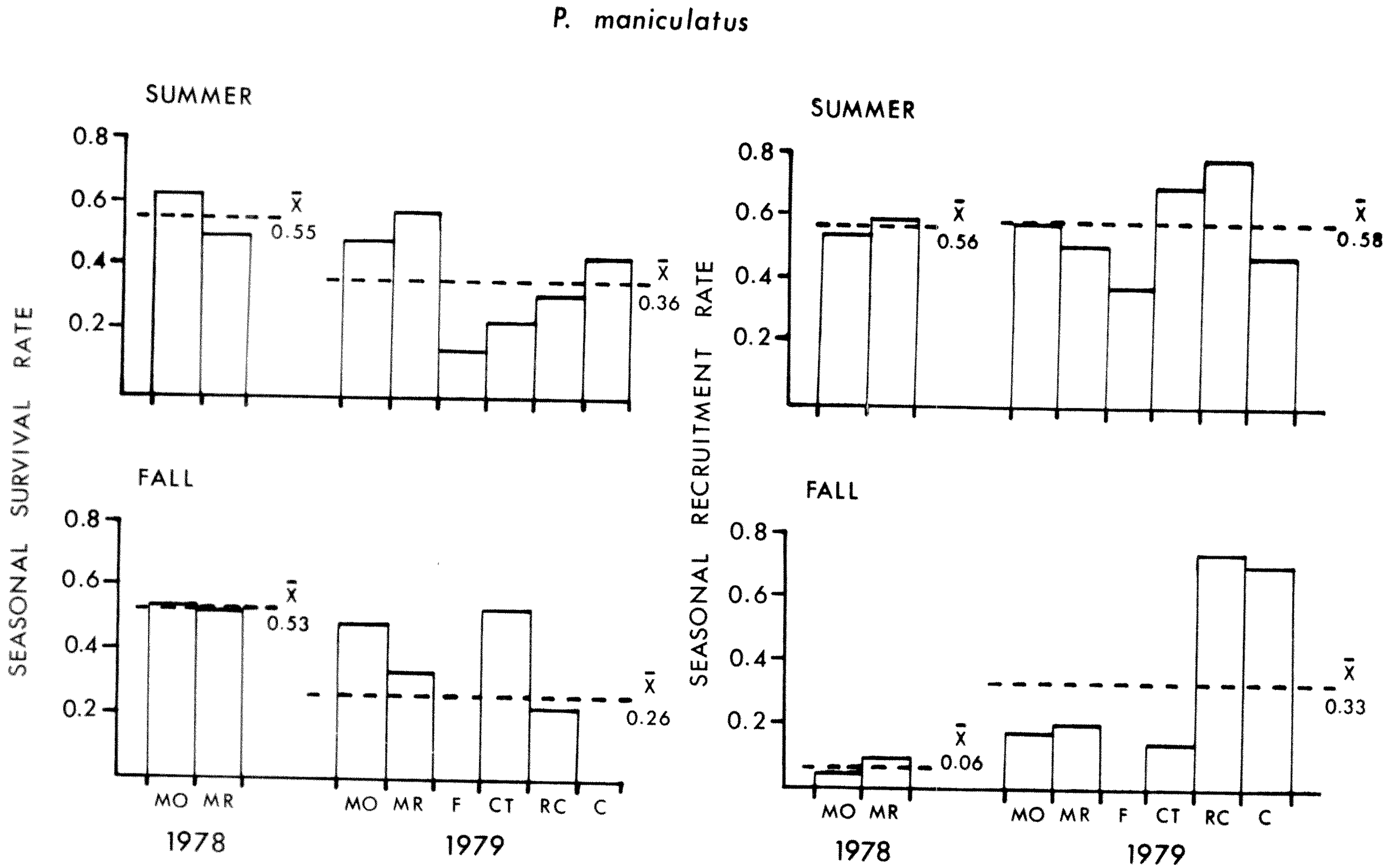

Figure 13. Seasonal survival and recruitment rates of *P. maniculatus*. (Rates were obtained from an MRA described in text. The arithmetic means for all study areas are indicated. Abbreviations for each study area are provided in Figure 12.)

areas increased between seasons. Overall, it appeared that animals on the experimental areas did not survive as well as animals on the two monitoring study areas (with the exception of animals on the Control and the Combined Treatment study areas during the summer and fall of 1979, respectively).

Seasonal recruitment rates of *C. gapperi* on the Muskeg Overburden study area did not differ significantly between the summer and fall periods in either 1978 or 1979 (1978: F = 0.58; 1,6 df; P > 0.10; 1979: F = 2.01; 1,6 df; P > 0.10); recruitment rates were generally high during the summer (seasonal recruitment rates of 0.64 in 1978 and 0.14 in 1979) and fall (0.42 and 0.56) periods.

Recruitment to *M. pennsylvanicus* populations on the two monitoring study areas in 1978 did not differ significantly between areas (F = 0.46; 1,12 df; P > 0.10) but did decline significantly between the summer and fall periods (F = 20.00; 1,12 df; P < 0.001) (Figure 12). Recruitment rates of *M. pennsylvanicus* on the two monitoring areas and on the Feeding, Repellent, and Control study areas in 1979 did not differ between reclamation sites (F = 0.79; 4,40 df; P > 0.10) or with seasons (F = 0.50; 1,40 df; P > 0.10). Recruitment to the Control population during the fall of 1979 was notably low.

Recruitment rates of *P. maniculatus* on the Muskeg Reclamation and the Muskeg Overburden study areas were similar in 1978 (F = 0.22; 1,12 df; P > 0.10) but declined significantly between the summer and fall periods (F = 17.11; 1,12 df; P < 0.001). In 1979, recruitment rates differed significantly between study areas (F = 2.49; 5,48 df; 0.05 < P < 0.01); recruitment to the Feeding study area was low throughout the summer and fall periods, whereas recruitment to the Reduced Cover and Control study areas during the fall tended to be higher than in other populations. Recruitment rates also differed significantly between the summer and fall periods (F = 6.67; 1,48 df; 0.05 > P > 0.01); recruitment rates on the Muskeg Overburden, Muskeg Reclamation, Feeding, and Combined Treatment study areas were lower during the fall than during the summer, whereas recruitment rates on the Reduced Cover and the Control study areas remained high.

3.3 POPULATION STRUCTURE

Changes in the age structure or sex ratio of a small rodent population can affect reproductive rates and consequently intrinsic rates of increase (Cole 1954; Wilson 1975). For example, increasing populations commonly are characterized by a predominance of younger age classes while stable or declining populations are not (Krebs 1978). Populations with a predominance of females may also have higher reproductive rates than populations with a predominance of males (Williams 1966). Because no reliable techniques are available to accurately age live cricetid rodents from wild populations, age structures were not considered in this study. Sex ratios, expressed as the proportion of animals captured one or more times that were males, were calculated for the three major small rodent species during the summer and fall periods (see Section 3.2 for calendar dates). Although sex ratios varied widely among study areas, none of the ratios for any species were significantly different from 0.5[1] (Table 2).

3.4 REPRODUCTION

Assuming that habitat selection is related to reproductive success, one of the better measures of habitat quality would be the number of young within each litter that survives to breeding age. Because of the difficulty in obtaining such a measure in free-ranging populations of small rodents, three indices of reproductive success and reproductive activity were used in this study: the proportions of animals in breeding condition, pregnancy rates, and juvenile recruitment.

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[1] Yates correction for continuity applied.

Table 2. Seasonal sex ratios of small rodents on live-trapping areas. (Sex-ratios are expressed as the proportion of animals captured one or more times that were males.)

Species	Date	Muskeg Overburden		Muskeg Reclamation		Food		Repellent	
		Ratio	N	Ratio	N	Ratio	N	Ratio	N
C. gapperi	summer 1978	0.33	3	-	0	-	0	-	0
	fall 1978	0.30	20	1.00	1	-	0	-	0
	summer 1979	0.67	3	-	0	-	0	-	0
	fall 1979	0.67	6	0.50	2	-	0	-	0
M. pennsylvanicus	summer 1978	0.50	26	0.46	59	-	0	-	0
	fall 1978	0.45	40	0.47	176	0.53	15	0.56	9
	summer 1979	0.71	14	0.48	111	0.49	88	0.58	19
	fall 1979	1.00	2	0.63	8	0.57	14	0.75	8
P. maniculatus	summer 1978	0.46	28	0.63	37	-	0	-	0
	fall 1978	0.48	27	0.59	29	0.00	1	-	0
	summer 1979	0.59	34	0.38	21	0.44	9	0.50	2
	fall 1979	0.40	10	0.50	4	-	0	-	0

continued...

Table 2. Concluded.

Species	Date		Combined Treatment		Reduced Cover		Control	
			Ratio	N	Ratio	N	Ratio	N
C. gapperi	summer	1978	-	0	-	0	-	0
	fall	1978	-	0	-	0	-	0
	summer	1979	-	0	-	0	-	0
	fall	1979	-	0	-	0	-	0
M. pennsylvanicus	summer	1978	-	0	-	0	-	0
	fall	1978	-	0	-	0	0.60	5
	summer	1979	1.00	1	1.00	1	0.33	9
	fall	1979	-	0	-	0	-	2
P. maniculatus	summer	1978	-	0	-	0	-	0
	fall	1978	-	0	-	0	1.00	5
	summer	1979	0.63	22	0.50	16	0.63	16
	fall	1979	0.67	6	0.33	3	-	0

3.4.1 Breeding Condition

Male animals captured on live-trapping plots were considered to be in breeding condition if their testes were fully or partially descended (scrotal). Females were considered to be in breeding condition if the vagina was perforate, if nipples were obviously swollen, or if the pubic symphysis was open. Only mature animals captured during the summer period of 1979 (16 May to 20 September) were included in the analysis. *Microtus pennsylvanicus* and *P. maniculatus* were considered mature if their body weights exceeded 16 g or 14 g, respectively; weights are based on an analysis of median weights at sexual maturity of animals captured during snap-trap censuses in natural areas (Green 1979). (Proportions of mature males and females in breeding condition during each trapping period are summarized in Appendix 9.3, Tables 16 to 18.)

Breeding activity of male and female *M. pennsylvanicus* did not differ between study areas (Friedman's two-way ANOVA; males: $\chi^2 = 7.51$; N = 7; K = 4; P = 0.11; females: $\chi^2 = 7.03$; N = 7; K = 4; P = 0.13) (because so few *M. pennsylvanicus* were captured on the Reduced Reduced Cover and Combined Treatment study areas, these two areas were not included in the analyses). Male and female breeding activity on the Muskeg Reclamation and Feeding study areas, however, was consistently higher than in other areas. Breeding activity of *P. maniculatus* also did not differ significantly among reclamation sites (males: $\chi^2 = 4.57$; N = 7; K = 5; P = 0.47; females: $\chi^2 = 2.10$; N = 7; K = 5; P = 0.84) (because so few *P. maniculatus* were captured on the Repellent study area, this area was excluded from the analysis).

3.4.2 Pregnancy Rates

Pregnancy rates also are an important index of reproductive condition in polyestrous mammals such as microtine or cricetine rodents. Pregnancy rates, expressed as the proportion of mature female animals captured one or more times during the summer period of 1978 (16 August to 25 September) and 1979 (16 May to 20 September) that were pregnant, were calculated for each species on each area (Table 3). Because of the late initiation date of trapping on the five experimental study areas in 1978, no pregnancy rates could be calculated.

Pregnancy rates of *M. pennsylvanicus* in 1978 were similar on the two reclamation monitoring areas. In 1979, however, pregnancy rates were highest on the Muskeg Reclamation and Repellent study areas.

No pregnant *P. maniculatus* were captured in 1978 and few mature females were captured in either year. Based on a small number of samples in 1979, pregnancy rates appeared highest on the Reduced Cover and Control study areas.

3.4.3 Juvenile Recruitment

Juvenile recruitment rates, expressed as the number of new immature animals captured per mature breeding female during each summer trapping period, were used as a third index of reproductive success. Maturity was determined based on body weights described earlier (Section 3.4.1). Juvenile recruitment rates for each species, summarized in Appendix 9.3, Tables 19 and 20, were compared among reclamation areas using Friedman's two-way ANOVA (Siegel 1956). Because of the low number of animals on most study areas in 1978, only juvenile recruitment rates during the summer of 1979 were considered. Juvenile recruitment of *M. pennsylvanicus* and *P. maniculatus* did not differ significantly among reclamation sites [*M. pennsylvanicus*: $\chi^2 = 3.08$; N = 7; K = 4; $0.70 > P > 0.50$ (because of small sample sizes, the Reduced Cover and Combined Treatment study areas were not included in the analysis); *P. maniculatus*: $\chi^2 = 4.84$; N = 7; K = 5; $0.50 > P > 0.30$ (the Repellent study area was not included in the analysis)].

3.5 CONDITION

Use of various reclamation areas by small rodents may reflect the availability and quality of food resources in an area. In turn, the quality and quantity of food resources may influence

Table 3. Pregnancy rates of small rodents on the reclamation study areas. (Pregnancy rates, expressed as the number of pregnancies per mature breeding female[a] captured one or more times during the summer period[b] of 1978 and 1979, and numbers of mature breeding females captured one or more times are indicated.)

	Muskeg Overburden		Muskeg Reclamation		Feeding		Repellent		Combined Treatment		Reduced Cover		Control	
	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N
C. gapperi														
summer 1978	0.50	2	-	0	-	0	-	0	-	0	-	0	-	0
summer 1979	0.00	2	0.00	1	-	0	-	0	-	0	-	0	-	0
M. pennsylvanicus														
summer 1978	0.25	4	0.20	15	-	0	-	0	-	0	-	0	-	0
summer 1979	0.00	8	0.11	45	0.05	43	0.17	6	-	0	-	0	0.00	6
P. maniculatus														
summer 1978	0.00	7	0.00	9	-	0	-	0	-	0	-	0	-	0
summer 1979	0.00	11	0.00	12	0.00	4	0.00	1	0.00	6	0.17	6	0.50	4

[a] The following body weights were used to determine maturity: *C. gapperi* ≥ 10 g; *M. pennsylvanicus* ≥ 16 g; and *P. maniculatus* ≥ 14 g.

[b] Calendar equivalents of the summer period are: 16 August to 25 September 1978 and 16 May to 20 September 1979.

the 'condition' of animals in these areas. Although no suitable information on conditions of animals captured in live-trapping areas was obtained during this study, Le Cren's (1951) index of condition and an index of fat deposition were used to assess the condition of animals captured during snap-trap censuses. These indices are useful in comparisons of conditions of animals in reclamation areas with those in natural habitats.

3.5.1 Le Cren's Index of Condition

Le Cren (1951) developed an index of relative condition based on the ratio of observed weight to weight predicted from body length. Condition factors of this type have been commonly employed in fish population studies. Krebs and Myers (1974) have also applied this index of condition to small rodent population studies.

Assuming that the indices of condition of animals in natural habitats were the norm for each species, Le Cren's indices of condition for small rodents on the Suncor reclamation sites were determined from the functional relationship between body weights and body lengths of animals captured during snap-trap censuses in natural areas (Green 1980). All body weight and body length data that were obtained for each species in 1978 and 1979 were pooled to calculate the body weight (Y)-body length (X) regression for each species. Weights of pregnant females were corrected by subtracting the weight of the uterus and embryos form the total body weight. Predicted weights of individuals were then obtained from the regression.

In 1978, the average condition (± 1 S.E.) of *M. pennsylvanicus* captured during snap-trap censuses on reclamation areas was 1.08 ± 0.02 (N = 58) whereas, in 1979, the average index of condition was 0.99 ± 0.03 (N = 25). Assuming that an index of condition of 1.00 is representative of the average condition of animals in natural habitats, *M. pennsylvanicus* captured on reclamation areas in 1978 appeared to be in better than average condition. Animals captured in 1979 appeared to be in average condition.

The average index of condition of *P. maniculatus* captured in 1978 was 1.02 ± 0.02 (N = 12). In 1979, only four animals were captured; the average index of condition for these animals was 1.12 ± 0.05. This suggests that *P. maniculatus* on reclamation areas in 1978 were in average condition, whereas animals in 1979 were in above average condition.

3.5.2 Indices of Fat Deposition

Krebs (1964) used an arbitrary fat index to assess changes in the condition of lemmings (*Lemmus sibiricus* and *Dicrostonyx torquatus*) during a population cycle. A similar index was used in this study. *Microtus pennsylvanicus* captured on reclamation areas had a mean fat index (± 1 S.E.) of 2.5 ± 0.1 (N = 58) and 1.7 ± 0.1 (N = 25) in 1978 and 1979, respectively, suggesting that animals in 1978 were in better condition than animals in 1979. Similarly, *P. maniculatus* captured in 1978 had higher fat indices (2.4 ± 0.2; N = 14) than animals captured in 1979 (1.8 ± 0.3; N = 4).

3.6 DISCUSSION: POPULATION TRENDS

A 4 year study of small rodent populations on established revegetation areas on the Suncor Inc. lease during the period of 1975 to 1978 (Radvanyi 1978; Michielsen and Radvanyi 1979) suggested that *M. pennsylvanicus* populations in these areas undergo cyclic fluctuations in numbers typical of this species in natural areas [see Krebs and Myers (1974) for a review]. *Microtus pennsylvanicus* populations reached high numbers in 1975, declined to a low in 1976, and increased to a peak population size in 1978. Numbers of *P. maniculatus* in these revegetation sites, however, did not appear to follow any obvious long-term trends.

Because of the short duration of this study in relation to the longer term fluctuations of microtine populations, it was not possible to adequately assess cyclic changes in the seven study populations. Changes in population sizes of *M. pennsylvanicus* on the two monitoring study areas between 1978 and 1979, however, suggest that these populations reached high numbers in 1978 and declined sharply in 1979. In contrast, *P. maniculatus* populations declined slightly.

Microtus pennsylvanicus populations in older, established reclamation sites do appear to undergo cyclic fluctuations in population density. On the other hand, numbers of *M. pennsylvanicus* on newly established reclamation areas (i.e., the five experimental areas) were low and highly variable and did not appear synchronous with populations on the two monitoring areas. Birney et al. (1976) suggested that a threshold level of vegetative cover is necessary for *Microtus* spp. to increase sufficiently in numbers to undergo a multi-year cycle; specifically, areas with little vegetative cover are unable to support adequate numbers of resident, breeding animals. Perhaps the poor development of vegetative cover on the experimental plots during 1978 and 1979 direclty influenced the stability of and the cyclic behaviour of *M. pennsylvanicus* populations on these sites.

Peromyscus maniculatus populations in natural forested habitats have been shown to undergo annual cycles in number (Fuller 1969; Petticrew and Sadlier 1974). Densities of mice typically increase throughout the late spring and summer period, reaching peak numbers shortly after the cessation of breeding when juvenile recruitment to the population is high (Verts 1957; Petticrew and Sadlier 1974; Fairbairn 1977a, 1978). During the non-breeding (winter) period and spring, however, populations decline to typically low numbers at the start of the breeding period (Sadlier 1965; Fairbairn 1977a, 1977b). Only the *P. maniculatus* populations on the Muskeg Overburden and Muskeg Reclamation study areas in 1978 appeared to undergo an annual cycle in abundance. The poor definition of annual cycles in the remaining populations may reflect the low numbers of animals present and, consequently, the limited influence of density-dependent factors in initiating annual cyclic changes in density [as suggested by Sadlier (1965) and Fairbairn (1977a, 1977b)].

3.7 DISCUSSION: SMALL RODENT POPULATIONS IN DISTURBED AND NATURAL HABITATS

Although small rodent damage to woody-stemmed plants has been shown to be a serious detriment to reforestation programs in disturbed areas (e.g., Jokela and Lorenz 1959; Cayford and Haig 1961; von Althen 1971, 1979; Radvanyi 1974; Hansson 1975), extensive damage by small rodents to trees and shrubs appears to be a rare phenomenon in natural habitats or in naturally revegetating areas (Green 1980). Even though small rodent damage to saplings on some reclamation areas on the Suncor Inc. lease during 1977 and 1978 was severe (Dunsworth et al. in prep.), amounts of small rodent damage to saplings in nearby natural habitats was extremely limited (Green 1980). This strongly suggests that conditions on reclamation areas stimulate abnormally high levels of bark consumption by small rodents.

Long-term field and laboratory studies of a European microtine, *Microtus agrestis* (Hansson 1971, 1973a, 1973b; Larsson and Hansson 1977), have indicated that bark consumption by this species was common only when other food supplies were limited. Hansson (1971) showed in a laboratory experiment that no girdling occurred when preferred carbohydrates were available, suggesting that girdling of young trees is indicative of nutritional stress. If nutritional stress is a major influence on amounts of bark consumption by small rodents in northeastern Alberta, differences between the condition of small rodent populations in reclamation areas and in natural habitats may be associated with the apparent high amounts of damage to woody-stemmed species on reclamation sites.

Green (1980) conducted an intensive live-trapping program of *C. gapperi*, *M. pennsylvanicus*, and *P. maniculatus* populations in six of the major habitat types common to the AOSERP study area [as described by Stringer (1976)] and in two recently disturbed but naturally-revegatating areas. Populations in each habitat type were evaluated based on comparisons of seasonal and annual population trends, peak population sizes, population structure, reproductive success, and an index of dispersal. Field and analytical techniques employed in this study were identical to those used by Green (1980) in order to facilitate comparisons.

Because some demographic variables are known to vary with cyclic fluctuations in small rodent populations, such comparisons must be made with some caution. For example, increased lengths of breeding season, an older age at sexual maturity, high adult and low juvenile survival, high growth rates, larger body weights, and high rates of dispersal have all been associated with increasing small rodent populations [see Krebs and Myers (1974) for a review]. Other variables such as litter size, pregnancy rates, and sex ratios appear less sensitive to cyclic changes in population densities. To minimize the possibility of incorrectly attributing cyclic changes in some demographic parameters to differences between habitats, comparisons were made only between synchronous populations of small rodents.

3.7.1 *Clethrionomys gapperi* Populations

3.7.1.1 Population trends. Of the three major small rodent species in the AOSERP study area, *C. gapperi* was the least common species on reclamation areas; in contrast, this species was the most abundant species in the natural forest communities of the AOSERP study area (Green 1980). Because *C. gapperi* is limited primarily to forested habitats within the boreal montane forest biome (Criddle 1932; Williams 1955; Gunderson 1959; Hoffman 1960; Miller and Getz 1972, 1977; Lovejoy 1975; Kucera and Fuller 1978), the absence of *C. gapperi* in most reclamation areas is expected. *Clethrionomys gapperi* was moderately abundant only on the Muskeg Overburden study area--notably, the only reclamation study area with moderate densities of shrubs and trees.

Numbers of *C. gapperi* declined on the Muskeg Overburden study area between 1978 and 1979, as did *C. gapperi* populations in the six natural habitat types and in the two naturally revegetating areas (Green 1980). *Clethrionomys gapperi* on the Muskeg Overburden area, however, appeared to be only seasonal inhabitants; no *C. gapperi* were present until late August of each year, suggesting that most animals captured on the Muskeg Overburden area were immigrants. Peak population numbers of the Muskeg Overburden population were lower than on any of the eight natural study areas in either 1978 or 1979.

3.7.1.2 Survival and recruitment. *Clethrionomys gapperi* on the Muskeg Reclamation area generally were characterized by moderate survival, whereas *C. gapperi* in most natural areas were characterized by high survival during the summer and fall periods (Green 1980). Seasonal survival estimates of *C. gapperi* in an older successional area (the Poplar Creek cutline study area) were generally low and were most similar to those on the Muskeg Overburden study area. In contrast, recruitment rates of *C. gapperi* on the Muskeg Overburden study area were higher than on any of the natural study sites.

Fairbairn (1977a) described a means of evaluating the relative magnitude of dispersal based on comparisons of survival and recruitment estimates. Assuming that increased emigration reflects increased movements of animals in the surrounding population, as well as in the study population, then high rates of emigration should be associated with high rates of immigration. Increased movements (dispersal) of animals, as a result, should be characterized by decreased survival and increased recruitment. Conversely, limited dispersal of animals should be characterized by increased survival and decreased recruitment. Low survival rates and poor recruitment rates likely reflect increased mortality, whereas high rates of survival and recruitment are probably associated with increased recruitment of animals born on the study area.

Comparisons of seasonal survival and recruitment estimates of *C. gapperi* on the Muskeg Overburden study area indicate that dispersal rates in this population were high throughout the summer and fall periods of both years; this suggests that most of the increase in numbers during the late summer and fall of each year were associated with immigration, as previously suggested, rather than recruitment of young born on the area. Dispersal rates of *C. gapperi* populations in naturally revegetating areas and in willow scrub habitat were most similar to dispersal rates of the Muskeg Overburden population. In contrast, dispersal rates of *C. gapperi* in natural forested habitats were limited (Green 1980).

3.7.1.3 Reproduction. Indices of reproductive success of *C. gapperi* on the Muskeg Overburden study area suggested that shrub-dominated reclamation areas are unable to support breeding *C. gapperi* populations; very few of the adult or sub-adult animals captured were in breeding condition, no pregnant females were captured in either year, and juvenile recruitment was extremely limited. Reproductive attributes of this population were similar to those of *C. gapperi* populations on the Willow, Poplar Creek cutline, and Thickwood cutline study areas. In contrast, most *C. gapperi* populations in forested communities appeared to have moderate to high reproductive success (Green 1980).

3.7.1.4 Summary: *C. gapperi* populations. *Clethrionomys gapperi* captured on the Muskeg Overburden study area appeared to be mainly immigrants, probably from adjacent forest habitats; animals were only present during the late summer and fall, peak population sizes were small, dispersal (immigration) was high during the summer and fall, and reproduction was limited. *Clethrionomys gapperi* in the Muskeg Overburden study area were most similar to *C. gapperi* populations in older (3 to 4 year old) successional areas and in willow shrub habitat and tended to differ most from populations in forested habitats. Reclamation areas that are dominated by grass/legume cover were totally avoided by *C. gapperi*, whereas shrub-dominated reclamation areas were only marginally suitable habitats for this species. The latter types of reclamation areas may serve as 'dispersal' sinks for young *C. gapperi* forced out of more suitable, adjacent forested habitats.

3.7.2 *Microtus pennsylvanicus* Populations

3.7.2.1 Population sizes and trends. Based on peak population densities and seasonal population trends, *M. pennsylvanicus* was the most abundant species of small rodent on most reclamation study sites. In contrast, *M. pennsylvanicus* was generally the second or third most abundant species in natural forested areas but was the predominant species in both naturally revegetating areas and in willow shrub habitat.

Peak population sizes on the Muskeg Reclamation study area (Table 4) were higher than in any of the baseline study areas (Green 1980, Table 12). Numbers of *M. pennsylvanicus* in young seral communities and in tamarack forest were most similar to those in older, better established reclamation areas. *Microtus pennsylvanicus* was least abundant in newly established reclamation sites and in jack pine and aspen communities.

Snap-trap indices of abundance (± 1 S.E.) similarly indicated that *M. pennsylvanicus* were significantly more abundant in reclamation areas than in natural forest communities in both 1978 (8.9 ± 2.3 captures/100 TN versus 1.5 ± 0.5 captures/100 TN) and in 1979 (1.9 ± 0.4 captures/100 TN versus 0.2 ± 0.1 captures/100 TN).

Numbers of *M. pennsylvanicus* in seven of the eight baseline study areas and in both monitoring study areas declined sharply between 1978 and 1979 [Table 4 and Green (1980), Table 12]. Peak population estimates for the five experimental areas in 1978 were inadequate for comparison with estimates in 1979.

In 1978, most *M. pennsylvanicus* populations in natural areas and in the two monitoring study areas increased throughout the summer, reaching peak numbers in September to October. Conversely, most *M. pennsylvanicus* populations declined throughout the summer of 1979; only populations in willow shrub and balsam poplar communities, and in the Muskeg Overburden and Repellent reclamation areas increased during the summer period.

Table 4. Characteristics of *M. pennsylvanicus* populations on the seven reclamation study areas. (Monitoring study areas were live-trapped from August to November 1978; the five experimental areas were only trapped in October and November 1978. All areas were trapped from May to November 1979. Only one *M. pennsylvanicus* was captured on each of the Combined Treatment and Reduced Cover study areas.)

Characteristic	Monitoring Study Areas		Experimental Study Areas		
	Muskeg Overburden	Muskeg Reclamation	Feeding	Repellent	Control
Population trends	- declined between years; increased to September 1978; increased to July 1979, then declined to November	- declined sharply between years; increased to high numbers in September 1978; declined to August, slight increase to October	- generally low numbers--except for peak in May 1979	- low numbers; gradual increase throughout summer 1979	- low numbers; decline in spring 1979; in late summer 1979
Peak MNA: 1978	- 23	- 106	- 10	- 8	- 3
1979	- 7	- 29	- 47 (14)[a]	- 8	- 4
Sex ratio	- equal	- equal	- equal	- equal	- equal
Breeding:					
Adult males	- average	- consistently higher	- consistently higher	- average	- average
Adult females	- average	- consistently higher	- consistently higher	- average	- average
Pregnancy rates	- average	- moderately high	- average	- moderately high	- nil
Juvenile recruitment	- low	- moderate	- low	- low	- nil
Seasonal survival[b]:					
Summer	- average in 1978; below average in 1979	- average in 1978; above average in 1979	- average	- average	- below average
Fall	- average in 1978; below average in 1979	- average in 1978; above average in 1979	- average	- average	- below average
Seasonal recruitment[b]:					
Summer	- average	- average	- average	- average	- average
Fall	- below average in 1978; average in 1979	- above average in 1978; average in 1979	- above average	- below average	- extremely low

continued...

Table 4. Concluded.

Characteristic	Monitoring Study Areas		Experimental Study Areas		
	Muskeg Overburden	Muskeg Reclamation	Feeding	Repellent	Control
Dispersal index[c]:					
Summer	- average in 1978; moderate dispersal in 1979	- average in 1978; low in 1979 (moderate in-situ recruitment	- average	- average	- moderate dispersal
Fall	- low in 1978; moderate in 1979	- moderate in 1978; low in 1979	- moderate to low	- low (moderate in-situ recruitment)	- low (high mortality)

[a] The peak MNA of 47 likely reflects the influence of supplemental food that was supplied overwinter; second highest MNA estimate on this area was 14.

[b] Based on comparisons of seasonal estimates.

[c] Based on comparisons of survival and recruitment rates for that period (Fairbairn 1977a, 1977b).

Overall, it appeared that peak population sizes and trends in better established reclamation areas were similar to trends in successional communities; peak population sizes were large, populations declined sharply between 1978 and 1979, and seasonal population changes were similar. Population sizes in mature forested communities (with the exception of tamarack and black spruce forests) tended to be moderate to low but seasonal and inter-year trends in population size were similar to those in older reclamation areas and naturally revegetating communities. Population changes in the Balsam poplar study area appeared to be asynchronous with the other study populations. Numbers of *M. pennsylvanicus* on the experimental areas were limited and highly variable and suggested that populations were still becoming established in these new reclamation sites.

3.7.2.2 Survival and recruitment. Seasonal survival rates of *M. pennsylvanicus* in the two monitoring study areas during 1978 and 1979 were generally lower than survival rates of *M. pennsylvanicus* in most natural areas [Table 4 and Green (1980), Table 12]. Survival rates of mice on the Muskeg Reclamation study area were notably higher than in any other reclamation site and were similar to the average seasonal survival rates for natural populations. On the other hand, seasonal recruitment rates of *M. pennsylvanicus* on the two monitoring reclamation plots in both years were generally higher than recruitment rates in most natural areas.

These differences in seasonal survival and recruitment rates suggest that, although population losses (emigration and death) on reclamation areas were greater than in natural communities, recruitment (natality and immigration) to populations on reclamation sites was greater than in natural habitats. As previously discussed for *C. gapperi*, comparisons of survival and recruitment rates (as described by Fairbairn 1977a) can be used to assess the relative importance of the components of population losses and recruitment.

Overall, the lower survival rates and higher recruitment rates of *M. pennsylvanicus* populations on reclamation areas, in comparison to the rates of animals in natural communities, suggest that rates of dispersal were proportionately greater in reclamation areas than in most natural communities.

Within the reclamation study areas, dispersal appeared to be highest in the Muskeg Overburden and Control study areas during the summer of 1979, in the Muskeg Reclamation study area during the fall of 1978, and in the Muskeg Overburden and Feeding study areas during the fall of 1979. This suggests that most of the population increases or decreases in these areas during these periods were largely the result of immigration and emigration, respectively, rather than to natality and increased mortality. In contrast, low survival and recruitment rates in the Muskeg Reclamation study area during the summer of 1979 and in the Control study population during the fall of 1979 suggest that population declines during these periods were probably the result of increased mortality.

In natural communities, rates of dispersal were high in the Balsam Poplar and Poplar Creek Cutline study areas during the summer of 1978, in the Aspen, Willow, and Poplar Creek Cutline study areas during the fall of 1978, and in the Jack Pine, Black Spruce, and both successional study areas during the fall of 1979 (Green 1980). The trend for consistently higher levels of immigration and/or emigration in the Poplar Creek cutline population (where *M. pennsylvanicus* reached peak population numbers similar to those on the Muskeg Reclamation study area) suggests that the turnover of animals in natural successional areas is similar to that observed in several of the reclamation sites. The similarity between the rates of dispersal and seasonal trends of *M. pennsylvanicus* populations in reclamation areas and in successional communities suggest that similar factors in these habitats may be influencing population change.

3.7.2.3 Reproduction. Indices of reproductive success for *M. pennsylvanicus* populations in natural forest communities, in naturally revegetating areas, and in reclamation areas suggest that habitat factors in reclamation areas may have stimulated reproductive activity in these populations. Male and female *M. pennsylvanicus* on the Muskeg Reclamation study area in 1978 were still reproductively active in November when trapping ceased, pregnancy rates remained high, and juveniles continued to recruit to the population throughout the fall period (Table 4). In contrast, male and female *M. pennsylvanicus* in forested areas, willow shrub communities, and in young successional areas were no longer in breeding condition after mid-September, pregnancy rates dropped sharply in the early fall, and few juveniles were present in any population after early October. Breeding activity was very limited on the Muskeg Overburden study area.

In 1979, similar trends in reproductive success were apparent but differences between populations in reclamation areas and natural communities were not as distinct. Breeding activity of animals in natural habitats ceased by mid-September, whereas breeding activity in reclamation areas, particularly in males, continued until trapping ceased in November. However, pregnancy rates in 1979 were limited in all reclamation areas, but were moderate in the two naturally revegetating areas and in tamarack and black spruce forest. Juvenile recruitment was low in all study populations.

Indices of reproductive success for animals captured during snap-trap censuses similarly indicated that *M. pennsylvanicus* in reclamation areas remained in breeding condition longer than did animals in natural communities. Few of the *M. pennsylvanicus* captured in natural habitats in October 1978 were in breeding condition, and only two females were pregnant (Green 1980). In contrast, 33% of the males and 55% of the females in reclamation areas were in breeding condition and 50% of the females were pregnant. Similarly, no breeding *M. pennsylvanicus* were captured in natural communities in October 1979, whereas 83% of the females captured in reclamation sites were in breeding condition and 66.7% were pregnant.

Differences between the quality and/or quantity of food supplies in reclamation areas and in natural habitats may explain these differences in reproduction. Provision of supplementary food to wild populations in small rodents has resulted in higher reproductive rates in several studies (Krebs and DeLong 1965; Taitt 1978). A similar increase in the number of *M. pennsylvanicus* on the Feeding area during the winter of 1978 to 1979 was noted in this study. Differences in reproductive activity suggest that the dense grass/legume cover in most reclamation areas may have provided abundant and possibly high quality food resources throughout the summer to early winter period. This suggestion is supported by the known preferences of this species for a number of grass and legume species (Thompson 1965; Zimmerman 1965). Increased breeding activity, as a possible consequence of the high quality food sources in reclamation areas, likely contributed greatly to the high peak population sizes in some reclamation sites in 1978.

3.7.2.4 Condition. If food resources do differ greatly between reclamation areas and natural communitites, this should be reflected in the condition of animals in these areas; small rodents in reclamation areas should be in better condition than animals in most natural habitats.

Comparisons of Le Cren's index of condition and amounts of fat deposition for *M. pennsylvanicus* captured during snap-trap censuses in natural forest types (seven major forest cover types were recognized) and in reclamation areas on the Suncor Inc. lease generally indicated that conditions of *M. pennsylvanicus* did not differ greatly among these areas. Fat indices did not differ significantly among habitats in 1978 (Kruskal-Wallis one-way ANOVA[1]: $\chi^2 = 10.38$; $N = 175$; $P = 0.10$) or in 1979 ($\chi^2 = 4.59$; $N = 51$; $P = 0.33$). In 1978, however, Le Cren's index of condition did vary significantly

[1] The χ^2 value indicated has been corrected for ties (Sokal and Rolf 1969).

with habitat type (one-way ANOVA: $F = 2.89$; 7,193 df; $P = 0.007$); animals captured in reclamation areas or in habitats dominated by *A. balsamea* or *P. glauca* tended to be in better condition than animals in other forest communities (Student-Newman-Keuls procedure). No significant differences in condition were apparent in 1979 ($F = 0.67$; 4,50 df; $P = 0.62$).

3.7.2.5 Summary: *M. pennsylvanicus* populations. *Microtus pennsylvanicus* was the most abundant species in most reclamation sites and was exceptionally abundant in established revegetation areas. In contrast, this species was generally only the second or third most abundant species in natural areas. Of the major natural communities studied, *M. pennsylvanicus* was most abundant in successional habitats, open tamarack forest, and willow shrub habitats.

Microtus pennsylvanicus populations in the Muskeg Reclamation, Poplar Creek cutline, Thickwood cutline, and Tamarack study areas were quite similar and appeared to be highly productive. Animals in these habitats generally were characterized by moderate survival, moderate to high recruitment by immigration and/or natality, moderate levels of dispersal, and moderate to high reproductive success.

In contrast, *M. pennsylvanicus* populations in the five experimental reclamation areas and in aspen, jack pine, and balsam poplar forest were relatively unproductive; survival rates were moderately poor, recruitment by immigration was moderately high, recruitment by natality was moderate to low, mortality was moderate to high, and reproductive success was limited.

Overall, older reclamation areas and successional areas appeared to support the largest numbers of *M. pennsylvanicus*. Demographic parameters suggest that these populations consisted of large numbers of breeding animals and that turnover rates in these populations were high. In contrast, evidence suggests that populations in new reclamation sites were still becoming established. Some reclamation areas, such as the Muskeg Overburden study area, do not support large numbers of breeding, resident mice but may serve as 'dispersal sinks' for animals from higher density populations in established reclamation sites.

3.7.3 *Peromyscus maniculatus* Populations

3.7.3.1 Population sizes and trends. *Peromyscus maniculatus* was the second most abundant species of small rodent present on most reclamation areas and was the most abundant species in the two experimental areas with reduced cover. In natural communities, however, *P. maniculatus* was generally one of the less abundant species of small rodents.

Within the natural forest and naturally revegetating habitats studied by Green (1980), *P. maniculatus* was most abundant in balsam poplar forest and in young successional areas. Peak population sizes in these two communities were much larger than the peak numbers on any of the reclamation areas [Table 5 and Green (1980), Table 13].

Snap-trap indices of abundance (± 1 S.E.) suggested that numbers of *P. maniculatus* on reclamation sites in October 1978 were similar to those in natural areas (2.2 ± 1.0 captures/100 TN and 3.0 ± 1.6 captures/100 TN, respectively). In September 1979, however, *P. maniculatus* was far more abundant in natural habitats (3.2 ± 1.6 captures/100 TN) than in reclamation areas (0.4 ± 0.3 captures/100 TN).

As mentioned earlier, *P. maniculatus* populations do not appear to undergo long-term cyclic fluctuations in number but instead undergo an annual cycle of abundance. *Peromyscus maniculatus* populations on the Muskeg Overburden and the Muskeg Reclamation study areas in 1978 underwent similar annual cycles in numbers; populations increased gradually during the summer to a peak in September and declined overwinter. Similar seasonal patterns in abundance were also apparent in most natural habitats (with the exception of balsam poplar, tamarack, and willow communities) in 1978. In contrast, seasonal population trends in 1979 were poorly defined in

Table 5. Characteristics of *P. maniculatus* populations on the seven reclamation study areas. (Monitoring study areas were live-trapped from August to November 1978; the five experimental study areas were only trapped in October and November 1978. All areas were trapped from May to November 1979. Numbers of *P. maniculatus* were very limited on the Repellent study area.)

Characteristic	Monitoring Study Areas		Experimental Study Areas			
	Muskeg Overburden	Muskeg Reclamation	Feeding	Combined Treatment	Reduced Cover	Control
Population trends	- increased until September 1978; little change in 1979	- increased until September 1978; declined in 1979	- increased to July 1979, then declined	- declined to August 1979, slight increase in fall	- relatively constant numbers	- declined throughout 1979
Peak MNA: 1978	- 21	- 18	- 1	- 0	- 0	- 4
1979	- 12	- 8	- 4	- 6	- 4	- 7
Sex ratio	- equal	- equal	- equal	- equal	- equal	- equal
Breeding:						
Adult males	- average	- average	- average	- average	- average	- average
Adult females	- average	- average	- average	- average	- average	- average
Pregnancy rates	- nil	- nil	- nil	- nil	- moderate	- moderate
Juvenile recruitment	- low	- low	- nil	- low	- low	- low
Seasonal survival[a]:						
Summer	- average 1978; above average 1979	- average 1978; above average 1979	- below average	- below average	- average	- average
Fall	- average 1978; above average 1979	- average	- below average	- above average	- average	- below average
Seasonal recruitment[a]:						
Summer	- average	- average	- below average	- above average	- above average	- below average
Fall	- average 1978; below average in 1979	- average 1978; below average in 1979	- below average	- below average	- above average	- above average

continued...

Table 5. Concluded.

Characteristic	Monitoring Study Areas		Experimental Study Areas			
	Muskeg Overburden	Muskeg Reclamation	Feeding	Combined Treatment	Reduced Cover	Control
Dispersal index[b]:						
Summer	- low	- low	- low (high mortality	- high	- moderate	- low (moderate mortality)
Fall	- low	- low	- low (high mortality)	- low (high in-situ recruitment)	- moderate	- high

[a] Based on comparisons of seasonal estimates

[b] Based on comparisons of survival and recruitment rates for that period (Fairbairn 1977a, 1977b).

almost all reclamation study areas and natural habitats; obvious population increases and fall declines were apparent only in the Aspen study area.

Overall, it appeared that population changes of *P. maniculatus* in reclamation areas were similar to those in surrounding natural habitats. Populations in the two monitoring study areas increased to moderate peak numbers, similar to those in some forest types, and underwent seasonal trends in abundance that were similar to those in most natural habitats and in naturally revegetating areas.

3.7.3.2 Survival and recruitment. Seasonal survival rates of *P. maniculatus* in the Muskeg Overburden and the Muskeg Reclamation study areas during 1978 and the summer of 1979 were generally lower than survival rates of *P. maniculatus* in most natural forest or naturally revegetating areas [Table 5 and Green (1980), Table 13]. Survival rates in the experimental areas, however, were quite low. During the fall of 1979, survival rates in natural areas were almost identical to those in reclamation areas. In contrast, recruitment rates of *P. maniculatus* populations on reclamation areas, generally were higher than recruitment rates of populations in natural areas (the only exception was the fall of 1978 when recruitment rates were similar in all areas).

Comparisons of survival and recruitment rates, as described previously, suggest that dispersal was limited in the two monitoring study areas but was moderate to high in the five experimental areas, particularly during the fall (Table 5). Population changes in the monitoring areas probably reflect the combined effects of losses due primarily to mortality and increases due to natality, whereas population changes in the experimental areas likely reflected increased immigration or emigration. Declines on several experimental areas during the summer, however, also resulted from increased mortality. Relative differences in levels of dispersal, natality, and mortality between the seven study populations suggest that populations in older reclamation areas were more stable than those in the newly established sites; the high mortality rates and the transient nature of animals in the experimental areas suggest that populations were still becoming established in these sites and that numbers of breeding, resident animals were limited.

Factors contributing to the loss or gain of *P. maniculatus* in older, reclamation areas generally appeared to be similar to those in most natural forest communitites and in young seral communities; survival and recruitment were average, both mortality and emigration were sources of population loss, and natality and immigration were sources of recruitment. Factors associated with population losses and gains in newly established reclamation areas, however, were similar to those in black spruce forest and older successional areas; dispersal was high and mortality accounted for a major portion of population losses. Whereas these latter three habitat types supported predominantly transient animals, older reclamation areas, most natural forest communities, and young seral habitats supported proportionately larger numbers of resident animals.

3.7.3.3 Reproduction. Breeding activity of *P. maniculatus* on reclamation areas was limited in 1978. This likely reflects the late start of the live-trapping program in these areas in 1978 rather than poor reproductive success--populations in all natural communities, for example, had ceased breeding activity by August (Green 1980).

Reproductive success of *P. maniculatus* in almost all reclamation areas in 1979 was low throughout the year. Moderate numbers of breeding males and females were present in each area but pregnancy rates were low and juvenile recruitment was limited in most areas. Animals in the two monitoring areas, however, remained in breeding condition until October, up to 2 mo longer than in some of the experimental areas.

In natural communities, distinct differences in reproductive success were apparent between populations in different forest and successional habitats. No *P. maniculatus* were captured in willow shrub or tamarack communities, suggesting that this species was unable to inhabit, let alone reproduce in these areas. Jack pine, black spruce, and aspen forests and older successional areas supported only limited numbers of breeding adults and reproductive success appeared low (low juvenile recruitment; few or no pregnancies). In contrast, balsam poplar and young successional areas supported relatively high numbers of breeding adults, juvenile recruitment was moderately good, and pregnancy rates were moderate to high.

Reproductive success of *P. maniculatus* in reclamation areas was comparable to the reproductive success of animals in most natural communities. Breeding activity of *P. maniculatus* in balsam poplar and young successional habitats was higher than in any other natural communities or in any of the reclamation sites. Population sizes and population trends in balsam poplar and young successional communities were also different from those in reclamation areas and may be associated with these differences in reproductive activity.

3.7.3.4 Condition. As previously discussed for *C. gapperi* and *M. pennsylvanicus*, differences in habitat quality and consequently in the quantity and quality of food may result in differences in the condition of animals among habitats.

Le Cren's (1951) index of condition suggested that conditions of *P. maniculatus* did differ among habitats in 1978 (one-way ANOVA: $F = 2.74$; 7,119 df; $P = 0.01$) but did not differ among these communities in 1979 ($F = 1.09$; 6,136 df; $P = 0.37$). Multiple comparisons of the condition of animals captured in 1978 (Student-Newman-Keuls procedure) suggested that animals in jack pine forest and reclamation areas were in better condition than animals in aspen, white spruce, or black spruce forests.

In contrast, indices of fat deposition suggested that conditions of *P. maniculatus* did not differ among habitats in 1978 (Kruskal-Wallis one-way ANOVA[1]: $\chi^2 = 10.36$; $N = 136$; $P = 0.17$) but did differ in 1979 ($\chi^2 = 20.13$; $N = 159$; $P = 0.003$). Animals captured in areas dominated by *A. balsamea* had larger fat deposits than animals

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1 The χ^2 value indicated was corrected for ties (Sokal and Rolf 1969).

in any other cover type, whereas fat deposits of animals captured in areas dominated by *B. papyrifera* were smaller.

3.7.3.5 Summary: *P. maniculatus* populations. *Peromyscus maniculatus* was the second most abundant species of small rodent on the reclamation areas and was commonly the second or third most abundant species in natural habitats. Population sizes in established reclamation areas were moderate (in relation to population sizes in balsam poplar or young successional habitats) but were comparable to population sizes in most natural areas. Numbers were extremely limited on the five experimental study areas throughout the study.

Characteristics of *P. maniculatus* that were captured in balsam poplar and young successional areas generally implied that *P. maniculatus* populations in these habitats were more productive than populations in other natural habitats and in reclamation areas. Animals in balsam poplar habitat and young successional areas were characterized by high survival, moderate in situ recruitment, limited dispersal, and high reproductive success.

Peromyscus maniculatus populations in established reclamation sites were most similar to populations in aspen, older successional, and perhaps jack pine habitat. Animals in these areas generally were characterized by moderate survival, moderate recruitment by immigration and natality, and moderate reproductive success.

Peromyscus maniculatus populations in newly established reclamation sites and in black spruce communities appeared to be composed primarily of transient animals and productivity was low. Animals in these areas tended to have a poor survival rate, recruitment through immigration was moderate to high, natality was low, dispersal (emigration and immigration) was moderate to high, and reproductive success was low.

Overall, established reclamation areas with dense shrub and/or grass/legume cover supported only moderate numbers of *P. maniculatus*. These populations appeared to be composed mainly of breeding, resident animals. In contrast, populations in newly established reclamation areas appeared to be composed predominantly of non-breeding, transient animals. Populations in these areas did not appear to be well-established and most population gains and losses probably reflect immigration from or emigration to surrounding areas.

4. SMALL RODENT USE OF RECLAMATION AREAS

The selection and use by small rodents of reclamation areas represents a specialized subset of the responses of different small rodent species to habitat variation. Small rodents in disturbed sites may be responding to intrinsic and/or extrinsic factors which may also vary with the age of the reclamation area, season, or changes in the densities of small rodents. Intrinsic factors may include physiological and behavioural responses, whereas extrinsic factors may include biotic or abiotic environmental cues such as substrate composition, microclimate, drainage, vegetation structure, or interspecific competition.

The major objectives of this study were to quantify the habitat affinities of the major species of small rodents in reclamation areas and to assess the relationship between specific components of habitat structure and the abundance of small rodents. A better understanding of the habitat affinities of small rodents in reclamation areas is useful not only in assessment of factors contributing to development of small rodent pest problems, but also in the design of ecologically and economically acceptable means of controlling small rodent damage.

Responses of *C. gapperi*, *M. pennsylvanicus*, and *P. maniculatus* to habitat variation on reclamation sites were assessed by several methods; these included comparisons of peak population densities, comparisons of snap-trap captures within specific plant communities with the availability of those communities, and univariate and multivariate analyses of small rodent abundance and habitat structure. Because so few animals were captured on the experimental areas, analyses for these populations are limited.

4.1 PEAK DENSITIES OF SMALL RODENTS

A number of studies of habitat use by small rodents have defined preferred or optimal habitats as those plant communities where a species is most abundant (e.g., Hodgson 1972; Pollard and Relton 1973; Richens 1974; Douglass 1976; Krebs and Wingate 1976; Green 1980). In this study, peak population densities were used as one index of habitat use by small rodents. Because the five experimental areas were trapped only in October and November 1978, only MNA estimates for comparable periods on the two monitoring plots in 1978 were considered. All trapping periods were considered in 1979.

Clethrionomys gapperi was moderately abundant only on the Muskeg Overburden study area (Table 6). None of the other seven areas supported populations of this species; one capture of a single animal was recorded on the Muskeg Reclamation and the Control study areas, whereas no captures were recorded on the remaining study areas.

Microtus pennsylvanicus were most common on the Muskeg Reclamation study area, followed by the Feeding and Repellent study areas (Table 6). In 1979, the Feeding area appeared to be the most highly utilized area by *M. pennsylvanicus* followed by the Muskeg Reclamation, Repellent, and Muskeg Overburden study areas. However, high numbers of animals were present on the Feeding area only in early May; the population declined rapidly by early June and never increased above 14 animals during the remainder of the year. The high spring numbers likely reflect the influence of supplemental food that was supplied overwinter; although this area temporarily supported large numbers of *M. pennsylvanicus*, it would appear that the Muskeg Reclamation area was a more preferable habitat throughout the year. Both treatment areas with reduced cover supported low numbers of *M. pennsylvanicus* during both years of the study.

Peromyscus maniculatus consistently appeared to prefer the Muskeg Overburden and the Muskeg Reclamation study areas over other reclamation sites; these two areas supported the largest number of *P. maniculatus* during both years of the study (Table 6). All five of the new reclamation areas supported very low numbers of *P. maniculatus*.

Table 6. Peak MNA estimates of small rodents on the seven live-trapping areas. (Because the five experimental areas were trapped only in October and November 1978, only MNA estimates for comparable periods on the two monitoring plots were considered in 1978.)

Grid	Peak MNA Estimates					
	C. gapperi		*M. pennsylvanicus*		*P. maniculatus*	
	1978	1979	1978	1979	1978	1979
Muskeg Overburden	18	8	23	7	21	12
Muskeg Reclamation	0	0	106	29	18	8
Feeding	0	0	10	47(14)[a]	1	4
Repellent	0	0	8	8	0	1
Combined Treatment	0	0	0	1	0	6
Reduced Cover	0	0	0	1	0	4
Control	0	1	3	4	4	7

[a] The peak MNA of 47 likely reflects the influence of supplemental food that was supplied overwinter; second highest MNA estimate on this area was 14.

4.2 SMALL RODENT USE AND AVAILABILITY OF GROUND COVER COMMUNITIES

Comparisons of snap-trap indices of small rodent abundance in specific plant communities with the availability of those communities [as described by Neu et al. (1974)] were used as one means of assessing small rodent use of reclamation sites. Based on the dominant ground cover species within 1 m of each trap station on each of the snap-trap census lines, two major ground cover communities were present on the Suncor reclamation areas; those areas dominated by agronomic grasses and those dominated by legumes (*Medicago* spp., *Melilotus* spp.). [Trees and shrubs were minor components of vegetation structure in all areas (except the Muskeg Overburden study area), and consequently, were not considered in this analysis.] In 1978, neither *M. pennsylvanicus* nor *P. maniculatus* showed significant preferences for either of those community types (*M. pennsylvanicus*: $\chi^2 = 0.05$; 1 df; P = 0.83; *P. maniculatus*: $\chi^2 = 3.82$; 1 df; P = 0.06). In 1979, *M. pennsylvanicus* similarly did not prefer either of the ground cover types ($\chi^2 = 3.19$; 1 df; P = 0.07), whereas *P. maniculatus* showed a highly significant preference for areas dominated by grass cover ($\chi^2 = 36.98$; 1 df; $P < 0.001$).

4.3 HABITAT STRUCTURE AND SMALL RODENT DISTRIBUTIONS

Small rodent distributions, particularly those of microtine rodents, have been shown to be closely related to the type and amount of vegetative cover (e.g., Eadie 1953; Mossman 1955; Hodgson 1972; Birney et al. 1976). In this study, univariate and multivariate analyses were used to assess the relationship between small rodent abundance and habitat structure.

4.3.1 Small Rodent Abundance and the Density of Ground Cover

Simple correlation analyses were used to assess the relationship between small rodent abundance and the density of ground cover. The total number of captures per trap-night (CTN) for the four closest trap-stations to each vegetation sample was used as an index of small rodent abundance. Because information on plant communities was representative of summer vegetation structure, indices of small mammal abundance were calculated only for the period 16 August to 25 September 1978 and for the period 24 June to 31 August 1979. Cumulative CTN for *M. pennsylvanicus* and *C. gapperi* were based on three trap checks (= nights) per trapping period minus any trap setoffs during that period (e.g., accidental closure of traps, captures of other species of small rodents and birds). Because *P. maniculatus* is primarily nocturnal, numbers of trap nights were based on only two trap checks per trapping period minus any trap setoffs. An index of ground cover density for each vegetation sample was obtained by summing the coverage of each plant species present in the 1 m^2 quadrat. Only the two monitoring plots were included in the 1978 analysis.

The relationship between *C. gapperi* and cumulative ground cover densities was assessed only for the Muskeg Overburden study area (too few *C. gapperi* were captured on the other six study areas). In 1978, local abundances of *C. gapperi* were not significantly correlated with the total ground cover densities ($r^2 = 0.09$; $P = 0.32$; $N = 30$). In 1979, no *C. gapperi* were captured on the Muskeg Overburden study area during the summer period.

The abundance of *M. pennsylvanicus* on the two monitoring plots was negatively correlated with total ground cover densities in both 1978 and 1979 (1978: $r^2 = -0.39$; $P = 0.001$; $N = 60$; 1979: $r^2 = -0.28$; $P = 0.01$; $N = 60$). In contrast, numbers of *M. pennsylvanicus* on the five monitoring plots in 1979 were positively correlated with the cumulative density of ground cover ($r^2 = 0.47$; $P < 0.001$; $N = 150$).

Numbers of *P. maniculatus* on the two monitoring plots (1978: $r^2 = 0.14$; $P = 0.14$; $N = 60$; 1979: $r^2 = -0.04$; $P = 0.39$; $N = 60$) and on the five experimental grids (1979: $r^2 = -0.12$; $P = 0.06$; $N = 150$) were not significantly associated with ground cover densities.

4.3.2 Small Rodent Distributions and Slope

Six of the seven study areas in this study were located on sloping berms with grades of 16 to 20% (D. Klym, Environmental Affairs, Suncor Inc., pers. comm.). Differences in vegetation density and soil moisture were apparent along the downhill gradients on each of the six areas and likely reflect the downslope movement of seeds, soil, fertilizer, and water. It also appeared that the distribution of small rodents may differ with position on the slope.

To assess differences in small rodent distributions in relation to slope, the total number of captures along each of the horizontal rows of trapping stations on each trapping area (10 horizontal rows on the Muskeg Reclamation study area and five horizontal rows on each of the experimental plots) was determined. These distributions were then compared to those expected if slope had no influence on small rodent numbers.

During the summer and fall periods of 1978, distributions of *M. pennsylvanicus* on the Muskeg Reclamation study area were influenced by slope (summer: $\chi^2 = 43.0$; fall: $\chi^2 = 50.9$; 9 df; $P < 0.001$). During the summer of 1978, *M. pennsylvanicus* preferred the bottom rows [Bonferonni *Z*-statistic; 95% confidence interval (Neu et al. 1974)], but avoided the upper two rows of the study area. A similar avoidance of the upper two rows of the trapping grid was apparent during the fall of 1978. In 1979, summer distributions of *M. pennsylvanicus* were again influenced by slope ($\chi^2 = 39.1$; 9 df; $P < 0.001$), whereas fall distributions were not ($\chi^2 = 10.3$; 9 df; $P = 0.33$). During the summer months, *M. pennsylvanicus* preferred the bottom rows of the study area and avoided two of upper rows.

Distributions of *M. pennsylvanicus* on the five experimental study areas during the fall of 1978 and the summer and fall of 1979 also appeared to be significantly influenced by slope (fall 1978: $\chi^2 = 31.8$; summer 1979: $\chi^2 = 23.0$; fall 1979: $\chi^2 = 28.4$; 4 df; $P < 0.001$). In all cases, *M. pennsylvanicus* avoided the top row and preferred at least two of the bottom three rows of each study area.

Peromyscus maniculatus distributions on the Muskeg Reclamation study area similarly were affected by slope (summer 1978: $\chi^2 = 57.8$; fall 1978: $\chi^2 = 62.8$; summer 1979: $\chi^2 = 26.4$; fall 1979: $\chi^2 = 33.9$; 9 df; $P < 0.002$). During the summer of 1978 and the summer and fall of 1979, *P. maniculatus* consistently avoided the bottom half of the study area (two to four of the five rows were avoided), but prefered at least one of the five rows on the upper half of the study plot. During the fall of 1978, however, *P. maniculatus* were most abundant on the bottom row of the trapping grid.

Peromyscus maniculatus distributions on the five experimental plots during the fall periods of 1978 and 1979 also were significantly associated with slope (1978: $\chi^2 = 12.4$; 4 df; $P = 0.01$; 1979: $\chi^2 = 19.9$; 4 df; $P = 0.001$); animals avoided the upper row of the berm during the fall of both 1978 ($P = 0.10$) and 1979 ($P = 0.05$). In contrast, distributions of *P. maniculatus* captures during the summer of 1979 were not influenced by slope ($\chi^2 = 1.6$; 4 df; $P = 0.82$).

4.3.3 Principal Components of Habitat Structure and Small Rodent Distributions

Use of plant communities within reclamation sites by small rodents may be influenced by a number of factors related to vegetation structure or microhabitat differences. Variation in these factors is probably not accurately defined by the major discrete reclamation types (e.g., age of the reclamation site, grass cover versus legume cover), mainly because the values of these variables are continuous rather than discrete units. In addition, other factors that are not used in the categorization of these plant communities nevertheless may be important in determining the distribution and abundance of a particular species of small rodent. Multivariate statistical techniques were used in this study as one means of assessing the relationship between habitat structure in reclamation areas and small rodent habitat use; these analytical techniques permit the simultaneous consideration of all habitat data and so avoid the necessity for arbitrary classification of habitat types.

Because the number of small rodents on the five experimental study areas were small, these analyses were restricted to relationships between habitat structure and small rodent numbers on the two monitoring study plots. Two techniques were used to assess these relationships. Initially a factor analyses was run on the combined vegetation data from 1978 and 1979 using the BMDP4M program (Dixon and Brown 1979). This reduced the 24 habitat variables to a set of four independent factors (see Appendix 9.4.1 for details of the analysis). Rotated factor loadings are provided in Appendix 9.4, Table 21); biological interpretations of the four habitat factors are summarized in Table 7. Relationships between these four independent factors and the abundances of small rodents were then assessed using step-wise multiple regression (SMR) techniques. Captures per trap-night (CTN), as described in Section 4.3.1, were used as an index of small rodent abundance. A separate SMR analysis was run for *M. pennsylvanicus* and *P. maniculatus* captures in 1978 and in 1979 using the BMDP2R program (Dixon and Brown 1979); because *C. gapperi* occurred only on the Muskeg Overburden study area, no analyses were performed for this species. Only factors with F-ratios larger than 3.0 were allowed to enter the SMR model.

The SMR model assumes that residuals (prediction errors) are normally distributed with constant mean and variance across the range of each predictor variable and the range of the estimated dependent variable (Cohen and Cohen 1975). Because preliminary SMR analyses indicated that the variance in the residuals was greater for high than for low estimates of the dependent variable (mouse abundance), dependent variables were transformed using a log (x+1) transformation.

4.3.3.1 *Microtus pennsylvanicus*: habitat structure relationships. In 1978, two habitat factors explained 29.2% of the variation in abundance of *M. pennsylvanicus* on the two monitoring study areas (Appendix 9.4, Table 22). Muskeg shrub understory was the most important predictor variable of abundance (accounting for 25.5% of the variance in captures) and was negatively associated with numbers

Table 7. Description of habitat variables that characterize the four habitat factors for the two monitoring study areas. (Rotated factor loadings are provided in Appendix 9.4, Table 21. Only variables whose factor loadings were greater than ± 0.250 are included in the descriptions. High factor loadings represent areas where a habitat variable is abundant, whereas low factor loadings represent areas where a habitat variable is rare or absent. Names assigned to each factor are used in all further discussions of the analysis.)

Factor	Name	Description
1	Muskeg Shrub Understory	- characterized by the presence of high stem densities of *P. balsamifera*, *Salix* spp., *B. glandulosa*, and *P. tremuloides*, high ground and vertical cover densities of *Equisetum angustifolium*, *Hieracium umbellatum*, and *P. balsamifera*, and moderate cumulative vertical cover densities over 50 cm above ground level. Also reflects an absence of dense alfalfa and clover cover.
2	Dense Vertical Cover	- measures the presence of high vertical cover (by all plant species) up to a height of 1.5 m as well as moderate stem densities, vertical cover, and/or ground cover of *Salix* spp., *B. glandulosa*, and *P. balsamifera*.
3	Grass Cover	- represents a dense vertical cover and moderate ground cover of grasses/sedges, thick accumulations of plant litter, moderate cumulative vertical cover at ground level (0 to 25 cm), and the absence of tree and shrub cover.
4	Grass/Legume Cover	- characterizes a high percent ground cover of plant litter, moderate ground cover densities of grasses/sedges, moderate to low ground cover densities of alfalfa and common clover (*Trifolium pratense*), moderately dense vertical cover at ground level (0 to 25 cm), sparser ground cover between 25 cm and 50 cm above ground level, and moderate to low *Salix* spp. cover.

of *M. pennsylvanicus*. In contrast, the grass cover factor accounted for only 3.8% of the remaining variance in abundance and was positively associated with numbers of *M. pennsylvanicus*.

Based on the importance of these habitat factors as predictors of abundance and the direction of their relationship with abundance, how do the results of the SMR model relate to use of these reclamation areas by *M. pennsylvanicus*? Mean factor scores for each habitat factor were calculated for the 30 vegetation samples on each study area (Appendix 9.4, Table 23). The expected number of CTN for one trap station on each study area was then predicted using the SMR equation (Appendix 9.4, Table 22). Expected numbers of CTN for *M. pennsylvanicus* indicate that the Muskeg Reclamation study area (0.066 CTN) was more suitable for this species than was the Muskeg Overburden study area (0.014 CTN).

In 1979, the same factors were again the most important predictor variables of abundance; overall, muskeg shrub understory and grass cover accounted for 24.4% of the variation in numbers of *M. pennsylvanicus* (Appendix 9.4, Table 24). Muskeg shrub understory was again the most important predictor variable, accounting for 19.0% of the variation and was negatively correlated with numbers of *M. pennsylvanicus*. Grass cover accounted for 5.4% of the remaining variance and was again positively associated with the abundance of this species. As in 1978, expected numbers of CTN, as predicted by the SMR model and the mean factor scores for each study area, indicate that the Muskeg Reclamation study area was a more suitable habitat for *M. pennsylvanicus* than was the Muskeg Overburden study area (0.014 verses 0.006 CTN, respectively).

4.3.3.2 <u>*Peromyscus maniculatus*: habitat structure relationships.</u> In both 1978 and 1979, numbers of *P. maniculatus* were not significantly correlated with habitat structure (1978: $F = 3.07$; 1,58 df; $P > 0.05$; 1979: $F = 3.92$; 1,58 df; $P > 0.05$). In 1978, the SMR analysis suggested that *P. maniculatus* abundance may be positively associated with muskeg shrub understory, whereas in 1979, it appeared that the abundance of this mouse may be negatively associated with grass/legume cover.

4.4 DISCUSSION

Assuming that small rodents are a serious hindrance to the effective reclamation and afforestation of tailings sand and overburden, it is important to determine for each species:

1. Which types of reclamation areas are most commonly inhabited;
2. What features of these habitats are most closely associated with levels of use; and
3. If responses of animals in reclamation areas to habitat structure are similar to those of animals in natural habitats.

Such information on habitat use and habitat selection would be useful in formulating reclamation strategies that minimize the suitability of reclamation habitats for small rodents. The resultant manipulation of habitat structure may also provide economical, long-term methods of controlling small rodent damage to woody stems.

To facilitate comparisons of habitat use and responses by small rodents to vegetation in reclamation sites and natural areas, analyses in this study were identical to those used in the baseline study of small rodents in the AOSERP study area (Green 1980).

4.4.1 *Clethrionomys gapperi*

Clethrionomys gapperi was not common in most reclamation areas and was present in only limited numbers on the Muskeg Overburden study area where it appeared to be a seasonal resident during the fall (and possibly winter) of each year. Very few *C. gapperi* were captured in any other reclamation sites (this study; Michielsen and Radvanyi 1979). Reclamation areas were poorly suited for this species; population numbers were low, animals were only seasonally present, reproductive success was low (short breeding season, few pregnant females, and poor juvenile recruitment), and dispersal was high.

The limited use of reclamation areas by *C. gapperi* is in direct agreement with the close association of this species with forested habitats (Criddle 1932; Williams 1955; Gunderson 1959; Hoffman 1960; Miller and Getz 1972, 1977; Green 1980). Tree and shrub densities on the Muskeg Overburden study area were higher than on any other reclamation study area (Section 5.1) and probably were associated with the higher numbers of *C. gapperi* in this area.

Because of the low numbers of captures of *C. gapperi* in most reclamation areas, it was not possible to adequately evaluate the responses of this species to habitat structure within reclamation sites. The restricted distribution of *C. gapperi* to the one reclamation study site with abundant trees and shrubs, however, suggests that moderate to dense ground cover and vertical cover by woody-stemmed plants is an important factor associated with the local abundance of this species. Multivariate analyses of the relationship between vegetation structure and the abundance of *C. gapperi* in natural communities (Green 1980) suggested that the species composition and density of the shrub understory, the density of ground cover, the accumulation of leaf litter, and the presence of deadfall were important habitat components associated with high numbers of *C. gapperi*. Dense shrub understories of *C. stolonifera*, *Ribes* spp., *Alnus* spp., or *R. melanolasius* were positively correlated with numbers of *C. gapperi*, whereas moderate to dense shrub understories composed of *A. alnifolia*, *Lonicera* spp., *S. canadensis*, *S. albus*, *Rosa* spp., *Salix* spp., *B. glandulosa*, or *Viburnum* spp. were associated with lower numbers of *C. gapperi*. The shrub canopy on the Muskeg Overburden study area was composed primarily of *Salix* spp. and *B. glandulosa* (Section 5.1, Table 8), both of which were associated with lower numbers of *C. gapperi*. The presence of these shrubs and/or habitat factors associated with these shrubs may explain the low numbers and seasonal occupancy of *C. gapperi* in this area. Similarly, the lack of a shrub understory, limited ground litter accumulations, and the absence of deadfall in established and newly established reclamation areas in this study may explain the avoidance of these areas by *C. gapperi*.

Available moisture has also been shown to affect the distribution of *C. gapperi* (Butsch 1954; Hoffman 1960; Miller and Getz 1972, 1973, 1977) and may have influenced the distributions of *C. gapperi* in reclamation areas. Getz (1968) concluded from a laboratory study of water balance of *C. gapperi* that the relatively inefficient kidney of this species necessitated a relatively high daily intake of water. As a result, the species is often restricted to low, wet areas or to areas where abundant, succulent food is available (Miller and Getz 1972, 1973). Although water availability was not measured during this study, measurements of soil moisture by Fedkenheuer (1979) in reclamation areas in the adjacent Syncrude Canada Ltd. lease indicated that soil moisture was limited during late June and early July but recovered by August. Such seasonal water shortages also may have restricted the distribution of *C. gapperi* in this study.

4.4.2 *Microtus pennsylvanicus*

Microtus pennsylvanicus was the most common species of small rodent in almost all reclamation sites during this study. *Microtus pennsylvanicus* on the Muskeg Reclamation study area reached higher peak population numbers than in any other reclamation study site or in any natural habitat. Peak population numbers of this species on the Poplar Creek cutline study area (an older, naturally revegetating site) were most similar to numbers on the Muskeg Reclamation area in 1978. Based on peak population numbers, older reclamation areas and older successional areas were the most heavily used habitats. Younger successional areas, tamarack forest, willow shrub communities, and black spruce forests also supported moderate to high numbers of mice. In contrast, new reclamation sites with little ground cover supported extremely few *M. pennsylvanicus* and generally were avoided by this species. Jack pine and aspen forests were also not commonly inhabited by this species.

Distributions of *M. pennsylvanicus* have been shown to be closely related to the type and amount of vegetative cover--habitats with dense grass-dominated or sedge-dominated ground cover appear to be the most preferable habitats (Findley 1951, 1954; Connor 1953; Eadie 1953; Mossman 1955; Getz 1960; Hoffman 1960; Zimmerman 1965; Iverson et al. 1967; Wrigley 1969; Grant 1971a; Hodgson 1972; M'Closkey 1975; Douglass 1976). All but two of the habitats supporting large numbers of *M. pennsylvanicus* in this study and that of Green (1980) contained moderate to dense ground covers of grasses and sedges, whereas habitats supporting low numbers of this species were generally open habitats with little ground cover. Assuming that peak population numbers do adequately reflect habitat use by this species, it appears that established reclamation sites and natural habitats with a predominance of dense grass and sedge ground covers are the most suitable habitats for *M. pennsylvanicus*.

Numbers of *M. pennsylvanicus* in reclamation areas were also significantly associated with total ground cover densities in both years of the study. Numbers of this species were negatively associated with ground cover densities on the two monitoring study areas but were positively associated with ground cover densiites on the experimental study areas. Multivariate analyses indicated that numbers of *M. pennsylvanicus* in reclamation areas were positively associated with factors characterizing moderate to dense growths of grasses, sedges, and forbes, moderate to thick accumulations of plant litter, and low densities of trees and shrubs. Dunsworth et al. (in prep.) similarly implied that numbers of small rodents (primarily *M. pennsylvanicus* and some *P. maniculatus*) on other reclamation areas on the Suncor Inc. lease were associated with increasing forage cover. The close associations of *M. pennsylvanicus* in reclamation sites and natural communities with dense ground cover suggests that populations in both these types of areas were responding to similar aspects of habitat structure.

Similar associations between the densities of *M. pennsylvanicus* and the density and structure of the ground cover canopy have been observed in a number of studies of *M. pennsylvanicus* throughout central and northern North America (Eadie 1953; Zimmerman 1965; Hodgson 1972; Birney et al. 1976). Birney et al. (1976)

suggested that a threshold level of vegetation cover was necessary before cyclic fluctuations in population densities could occur.

Variations in soil moisture, as described for *C. gapperi*, may also affect the distribution of *M. pennsylvanicus* in reclamation areas. Miller (1969) showed that distributions of *M. pennsylvanicus* in Indiana were associated with areas of greater amounts of soil moisture. The preference for lower areas, and avoidance of upper areas of most reclamation areas in this study supports the hypothesis that distributions of this species are influenced by soil moisture. *Microtus pennsylvanicus* may have been responding directly to the resultant gradients in soil moisture or to variation in plant cover resulting from these gradients in soil moisture.

4.4.3 *Peromyscus maniculatus*

Peromyscus maniculatus was the second most abundant species of small rodent in most reclamation areas. Based on peak population densities in each study area, *P. maniculatus* most commonly used older, better established reclamation sites. Although numbers of *P. maniculatus* were limited in most newly established reclamation areas, it was the most common species of small rodent on the two reduced cover plots.

Comparisons of peak population densities of *P. maniculatus* in natural areas and in reclamation sites suggest that balsam poplar forest was the most suitable habitat for this species in the Athabasca region (Green 1980). Peak population sizes of *P. maniculatus* in young successional communities were also high. Older reclamation areas, older successional communities, and aspen forest supported moderate numbers of *P. maniculatus*. Newly established reclamation areas, jack pine communities, and black spruce forests were only marginally suitable habitats for this species, and willow and tamarack habitats were totally avoided. Peak population sizes suggest that older reclamation areas were only moderately suitable habitats for this species and that populations were still becoming established in the new reclamation sites.

Within the Athabasca region, responses of *P. maniculatus* to habitat structure in both reclamation sites and natural areas are in close agreement with existing knowledge of habitat use by this species. *Peromyscus maniculatus* have been shown to chiefly inhabit woodland areas, particularly mature, deciduous-coniferous forests with dense shrub understories and damp soils (Hoffman 1960; Iverson et al. 1967; Sheppe 1967; Baker 1968; Wrigley 1969; Dyke 1971; Grant 1971b; Richens 1974; Lovejoy 1975; Krebs and Wingate 1976). However, *P. maniculatus* is also a common resident of prairie habitats throughout most of the north-central United States (Hays 1958; LoBue and Darnell 1959; Wecker 1963; Brown 1964; Iverson et al. 1967; Beck and Vogl 1972) and is known to readily colonize disturbed areas such as post-burn or post-logging successional areas (Williams 1955; Tevis 1956a, 1956b; Gashwiler 1959, 1970; Ahlgren 1966; Lawrence 1966; Hooven 1969; Hooven and Black 1976; Martell and Radvanyi 1976). In this study, older disturbed areas (i.e., the Muskeg Overburden and the Poplar Creek cutline study area) supported moderate numbers of *P. maniculatus* but did not appear to be as suitable a habitat as young successional areas or balsam poplar habitat. Recent studies of *P. maniculatus* populations in disturbed sites and in adjacent forest habitats have similarly indicated that successional areas are poorer quality habitats than mature forest communities (Petticrew and Sadlier 1974; Lovejoy 1975; Sullivan 1979a, 1979b). Populations in disturbed communities typically underwent a rapid turnover of animals throughout the year; recruitment to disturbed areas during the late spring and summer was high but populations declined overwinter as a result of higher mortality and emigration than in forested areas (Sullivan 1979a, 1979b).

What factors within the reclamation study of this program and the natural habitat study areas of Green (1980) were most often associated with higher numbers of *P. maniculatus*? Numbers in this study were not closely correlated with many of the aspects of habitat structure examined. In 1979, captures of *P. maniculatus* during snap-trap censuses suggest that cover was not preferred.

Relationships between ground cover or habitat structure and numbers of deermice, however, suggested that this species was not closely associated with any of the major aspects of habitat structure that were measured during this study. Similar broad ranges of habitat requirements for *P. maniculatus* have been noted by Williams (1955), Rickard (1960), Baker (1968), and Krebs and Wingate (1976).

Peromyscus maniculatus in natural areas similarly showed few restrictions in habitat use (Green 1980). This species most commonly inhabited areas with dense shrub understory (primarily of *Ribes* spp., *Rubus* spp., *Alnus* spp., and *C. stolonifera*), moderate accumulations of leaf litter and deadfall, and sparse grass cover but also utilized open habitats such as young successional communities.

These local variations in habitat use in natural habitats and reclamation sites may reflect differing responses to shrub understory and ground cover but may also reflect competitive interactions between *P. maniculatus* and other species of small rodents. Grant (1971b) showed that, although *P. maniculatus* most often inhabited woodland areas, when densities in woodland areas increased, more intense intraspecific competition forced young animals into grassland areas. However, in the presence of high density *M. pennsylvanicus* populations, *P. maniculatus* was totally excluded from grassland areas. Similar relationships between *P. maniculatus* and *Microtus oregoni* populations in British Columbia were observed by Petticrew and Sadlier (1974) and Taitt (1978). Because *M. pennsylvanicus* populations in the Athabasca Basin declined sharply between 1978 and 1979, changes in the relationships between habitat structure and *P. maniculatus* abundance may have been related to changes in levels of interspecific competition between these species and the possible expansion of *P. maniculatus* into previously unexploited or marginal habitats. The significant preference by *P. maniculatus* for the upper areas of some study areas in contrast to the preference by *M. pennsylvanicus* for the lower areas further suggests that interspecific competition and the resultant habitat segregation may have influenced habitat use by these species.

5. SMALL RODENT DAMAGE TO WOODY-STEMMED PLANTS

Small rodents are capable of damaging large numbers of young trees and shrubs and, as a result, may restrict afforestation and reforestation programs (e.g., Jokela and Lorenz 1959; Cayford and Haig 1961; von Althen 1971, 1979; Radvanyi 1974; Hansson 1975). Surveys of small rodent damage to woody-stemmed plants were conducted on the two monitoring plots in 1978 and on all seven study areas in 1979 in order to: (1) determine the extent of small rodent damage in different reclamation sites; and (2) assess the relationships between numbers of small rodents, habitat structure, and amounts of damage.

5.1 AMOUNTS OF SMALL RODENT DAMAGE

Girdling indices for each species of tree and shrub within each of the 30 sampling plots on each study area were standardized by expressing levels of girdling damage as a girdling index/plant in 1978 and as a girdling index/stem in 1979. Girdling indices/plant or stem can range in value from 0.0 to 5.0; a value of 0.0 indicates that no plants or stems were girdled, whereas a value of 5.0 indicates that all stems or plants were totally girdled.

In 1978, damage surveys were conducted only on the Muskeg Overburden and the Muskeg Reclamation study areas. Girdling damage to woody-stemmed plants was limited on both areas (Tables 8 and 9). On the Muskeg Overburden study area, *Salix* spp. sustained moderate amounts of damage and *Larix laricina* sustained low amounts of damage; the remaining six species of trees and shrubs were not damaged by small rodents. On the Muskeg Reclamation study area, *Ulmus americana* sustained moderately low amounts of damage and *Salix* spp. sustained very low amounts of damage. A number of woody-stemmed plants, which were dead at the time of the survey, sustained moderate amounts of damage; based on the species planted in this area (letter dated 29 November 1978 from D. Klym, Environmental Affairs, Suncor Inc.), these may have included *Shepherdia canadensis*, *U. americana*, *Populus* spp. (Vernirubens poplar, Walker poplar,

Table 8. Summary of small mammal damage on the Muskeg Overburden study area in 1978 and 1979. (Means and 1 S.E. of the 30 samples on each study area in each year are shown for tree and shrub densities, girdling densities, girdling indices, and hare damage. Units in 1978 were plants. Units in 1979 were stems. The numbers of stems/ha were only estimated in 1979.)

Species	# Plants/ha	# Stems/ha	Small Rodent Damage: # Plant Units Girdled/ha	Small Rodent Damage: Girdling Index/Plant Unit	Hare Damage/ha: New Damage	Hare Damage/ha: Old Damage
1978						
P. tremuloides	1 500 ± 383		0	0	0	0
P. balsamifera	7 271 ± 1 044		0	0	0	0
L. laricina	63 ± 35		21 ± 21	0.07 ± 0.07	0	0
B. papyrifera	63 ± 53		0	0	0	0
Salix spp.	8 438 ± 1 205		584 ± 153	1.19 ± 0.33	0	0
B. glandulosa	3 021 ± 598		0	0	0	0
S. canadensis	42 ± 29		0	0	0	0
R. triste	896 ± 753		0	0	0	0
1979						
P. tremuloides	625 ± 175	625 ± 175	0	0	0	0
P. balsamifera	11 188 ± 1 609	11 313 ± 1 671	0	0	0	0
L. laricina	83 ± 50	83 ± 50	0	0	0	0
B. papyrifera	375 ± 149	375 ± 149	0	0	0	0
Salix spp.	7 146 ± 725	33 313 ± 3 448	63 ± 46	0.20 ± 0.15	63 ± 44	0
B. glandulosa	4 583 ± 940	25 125 ± 5 594	0	0	63 ± 44	0
C. stolonifera	21 ± 21	63 ± 63	0	0	0	0
S. canadensis	21 ± 21	229 ± 229	0	0	0	0

Table 9. Summary of small rodent damage on the Muskeg Reclamation study area in 1978 and 1979. (Means and 1 S.E. of the 30 samples on each study area in each year are shown for tree and shrub densities, girdling densities, and girdling indices. No showshoe hare damage was observed in either year. Units in 1978 were plants. Units in 1979 were stems. The number of stems/ha were only estimated in 1979.)

Species	# Plants/ha	# Stems/ha	# Plant Units Girdled/ha	Girdling Index/Plant Unit
<u>1978</u>				
U. americana	417 ± 113		292 ± 93	0.67 ± 0.23
Dead[a]	854 ± 191		500 ± 121	1.41 ± 0.32
Salix spp.	21 ± 21		21 ± 21	0.30 ± 0.03
<u>1979</u>				
U. americana	479 ± 213	1813 ± 1477	250 ± 139	0.26 ± 0.12
Salix spp.[b]	104 ± 61	104 ± 61	83 ± 50	0.32 ± 0.18

[a] Species could not be determined because of the lack of foliage and the small size of the cuttings.

[b] Includes acute willow, Basford willow, and laurel willow.

Northwest poplar) and *Salix* spp. (acute willow, Basford willow, and laurel willow).

In 1979, small rodent damage to woody-stemmed plants was only recorded on the Muskeg Overburden, the Muskeg Reclamation and the Feeding study areas (Tables 8 to 11). Only *Salix* spp. were damaged on the Muskeg Overburden study area; a small number of the *Salix* spp. and *Betula glandulosa* on this area also were browsed by snowshoe hares. *Ulmus americana* and *Salix* spp. were the only woody-stemmed plants encountered on the Muskeg Reclamation area and both sustained low amounts of small rodent damage. On the Feeding study area, only *Populus* spp. were damaged by small rodents; the remaining eight species or species groups of trees and shrubs were not damaged. The lack of small rodent damage to these tree and shrub species likely reflects the fact that, with the exception of the *Populus tremuloides* and *Alnus* spp. planted during the fall of 1978, all other trees and shrubs present on this area had only been planted the month before the vegetation surveys.

5.2 SMALL RODENT DAMAGE AND POPULATION SIZE

The use of rodenticides, chemosterilants, and a number of other techniques for the control of small rodent damage to woody-stemmed plants [see Green (1978) for a review] implicitly assumes that amounts of damage are directly related to the size of the small rodent (pest) population. Correlation analyses were used in this study to assess the relationship between the abundance of small rodents and levels of girdling damage to trees and shrubs in natural areas. Because damage to trees and shrubs was extremely limited on the five experimental study areas, only the Muskeg Overburden and the Muskeg Reclamation study areas were included in the analyses. The total number of CTN for the four trap stations closest to each vegetation sample (as described in Section 4.3.1) was used as an index of abundance for *M. pennsylvanicus* and *P. maniculatus*. Estimates of the amount of damage per plant and the amount of damage per stem in each vegetation quadrat were used as indices of small rodent damage in 1978 and 1979, respectively.

Table 10. Summary of small rodent damage on the Feeding study area in 1979. (Means and 1 S.E. of the 30 samples on each study area are shown for tree and shrub densities, girdling densities, and girdling indices. No snowshoe hare damage was observed.)

Species	# Plants/ha	# Stems/ha	# Plant Units Girdled/ha	Girdling Index/Plant Unit
Populus spp.[a]	604 ± 207	646 ± 221	21 ± 21	0.13 ± 0.13
P. glauca	21 ± 21	21 ± 21	0	0
L. laricina	83 ± 58	83 ± 58	0	0
P. sylvestris	125 ± 92	125 ± 92	0	0
P. pensylvanica	63 ± 46	63 ± 46	0	0
B. glandulosa	63 ± 46	63 ± 46	0	0
E. commutata	83 ± 83	188 ± 188	0	0
Salix spp.[b]	708 ± 179	1271 ± 329	0	0
Alnus spp.	167 ± 120	167 ± 120	0	0

[a] Includes Walker poplar, Northwest poplar, and *P. tremuloides*.

[b] Includes acute willow, Basford willow, and laurel willow.

Table 11. Small rodent damage on the Repellent, Combined Treatment, Reduced Cover, and Control study areas in 1979. (No small rodent damage or snowshoe hare damage was observed. Means and 1 S.E. of the 30 samples on each study area are shown for tree and shrub densities.)

	Study Area							
	Repellent		Combined Treatment		Reduced Cover		Control	
Species	# Plants/ ha	# Stems/ ha	# Plants/ ha	# Stems/ ha	# Plants/ ha	# Stems/ ha	# Plants/ ha	# Stems/ ha
Populus spp.[a]	271 ± 146	271 ± 146	188 ± 109	208 ± 125	188 ± 74	188 ± 74	167 ± 79	167 ± 79
P. glauca	83 ± 58	104 ± 74	146 ± 77	146 ± 77	167 ± 67	167 ± 67	83 ± 58	83 ± 58
L. laricina	83 ± 58	83 ± 58	125 ± 92	125 ± 92	42 ± 42	42 ± 42	83 ± 83	83 ± 83
P. sylvestris	104 ± 85	104 ± 85	167 ± 99	167 ± 99	83 ± 50	83 ± 50	125 ± 70	125 ± 70
P. pensylvanica	188 ± 117	229 ± 148	125 ± 92	146 ± 102	21 ± 21	21 ± 21	42 ± 42	42 ± 42
B. glandulosa	42 ± 42	42 ± 42	42 ± 29	83 ± 58				
E. commutata	208 ± 21	521 ± 386	167 ± 130	542 ± 481	42 ± 29	188 ± 131	63 ± 46	83 ± 65
C. aborescens	125 ± 92	125 ± 92	42 ± 42	42 ± 42	208 ± 81	250 ± 106	125 ± 70	188 ± 117
Salix spp.[b]	500 ± 135	896 ± 247	521 ± 156	771 ± 264	333 ± 130	500 ± 208	229 ± 110	542 ± 237
Alnus spp.	188 ± 120	188 ± 120						
C. stolonifera	250 ± 111	271 ± 119	542 ± 205	1688 ± 903	63 ± 35	63 ± 35		

[a] Includes Walker poplar, Northwest poplar, and *P. tremuloides*.

[b] Includes acute willow, Basford willow, and laurel willow.

During the summer of 1978, amounts of girdling damage to woody-stemmed plants were positively correlated with numbers of *M. pennsylvanicus* (r^2 = 0.24; P = 0.03; N = 60); however, numbers of *M. pennsylvanicus* explained only 5.7% of the variation in damage. In 1979, amounts of damage to trees and shrubs were not significantly correlated with the abundance of this species during the summer period (r^2 = 0.06; P = 0.34; N = 60).

Amounts of damage to saplings were significantly correlated with numbers of *P. maniculatus* only in 1979 (1978: r^2 = -0.07; P = 0.30; N = 60; 1979: r^2 = -0.27; P = 0.02; N = 60); damage was negatively correlated with the abundance of this species in 1979 but local differences in the abundance of *P. maniculatus* were associated with only 7.0% of the variation in amounts of damage.

5.3 SMALL RODENT DAMAGE AND HABITAT STRUCTURE

Previous studies of small mammal damage to saplings and shrubs have suggested that components of habitat structure, such as the density of ground cover, the abundance and diversity of food types, and the density of trees and shrubs can influence levels of small rodent damage to plants (Eadie 1953; Jokela and Lorenz 1959; Howard 1967; Buckner 1970; Dunsworth et al. in prep.). In this study, the relationship between three aspects of habitat structure and amounts of small rodent damage was examined; the correlation between levels of small rodent damage and densities of ground cover, and between levels of small rodent damage and sapling densities was determined, and a multivariate analysis of the relationship between habitat structure and levels of girdling damage was performed. Because of the low levels of small rodent damage to woody-stemmed plants on the five experimental plots, these analyses were restricted to the two monitoring study areas.

5.3.1 Ground Cover Densities and Small Rodent Damage

The relationships between amounts of small rodent damage and ground cover densities were assessed using the cumulative percent coverage of all plant species present in the 1 m^2 sampling quadrat and the amount of damage per plant (i.e., no. of damaged plants per sample/no. of plants per sample) in 1978 and the amount of damage per stem in 1979 for each vegetation sampling quadrat (16 m^2). In 1978 and 1979, amounts of small rodent damage were inversely correlated with total ground cover densities; however, this relationship was significant only in 1978 (1978: $r^2 = -0.43$; $P < 0.001$; $N = 60$; 1979: $r^2 = -0.17$; $b = -0.007$; $P = 0.09$; $N = 60$). Although this relationship was significant, only 18.5% of the variation in the amounts of small rodent damage was explained by variation in ground cover densities.

5.3.2 Plant Densities and Levels of Girdling Damage

The relationship between the density of woody-stemmed plants and amounts of small rodent damage was assessed using the total number of plants (in 1978) and stems (in 1979) and the amount of damage per plant or stem (as described above) for each vegetation sampling quadrat (16 m^2). In both 1978 and 1979, amounts of small rodent damage to woody-stemmed plants were inversely correlated with the density of tree and shrub saplings (1978: $r^2 = -0.37$; $P = 0.002$; $N = 60$; 1979: $r^2 = -0.31$; $P = 0.001$; $N = 60$). Overall, the relationships between plant/stem densities and girdling damage were weak and explained only 13.7% and 9.3% of the variance in damage in 1978 and 1979, respectively.

5.3.3 Components of Habitat Structure and Girdling Damage

The multivariate assessment of the relationship between indices of small rodent damage to woody stems and vegetation involved two steps. Initially, a factor analysis was used to reduce a larger number of habitat variables to a small number of independent factors that characterized vegetation structure on the two monitoring study areas; details of this analysis have already been discussed in Section 4.3.3. An SMR analysis [BMDP2R (Dixon and Brown 1979)] was then used to assess and quantify the relative importance of each of these new variables (factors) in predicting levels of damage by small rodents. Habitat factors were allowed to enter the SMR model only if their F-ratios exceeded 3.0. To correct for heteroscedasticity all estimates of damage were transformed using a square root (x+1) transformation.

In 1978, 27.0% of the variation in amounts of small rodent damage was explained by habitat structure (Table 12). Both muskeg shrub understory and dense vertical cover were negatively correlated with amounts of rodent damage, whereas grass cover was positively correlated. The muskeg shrub understory factor was the most important predictor variable followed by the dense vertical cover and the grass cover factors.

In 1979, differences in habitat structure were associated with only 11.6% of the variance in amounts of small rodent damage (Table 13). Grass cover was the only statistically significant predictor variable included in the SMR model, and was positively correlated with amounts of small rodent damage.

5.4 DISCUSSION

Of the major small rodent species present during this study, only two are commonly known to consume bark. Studies of the food habits of *M. pennsylvanicus* and *C. gapperi* in natural areas have indicated that bark, twigs, and buds of some species of trees and shrubs are regularly consumed by these species (Bailey 1924; Jameson 1955; Zimmerman 1965; Dyke 1971; Zemanek 1972; Green 1980). *Peromyscus maniculatus*, however, feeds primarily on insects and on seeds and fruits of a variety of plants (Jameson 1952, 1955; Williams 1959; Dyke 1971) but may consume bark of some shrub species during the spring and fall periods (Green 1980). Because *C. gapperi* are uncommon to most reclamation areas on the Suncor Inc. lease (Radvanyi 1978; Michielsen and Radvanyi 1979; this study) and because bark consumption by *P. maniculatus* is limited, it appears that *M. pennsylvanicus*, the most common small rodent species on these reclamation areas, is the probable cause of most girdling damage.

Table 12. SMR analysis of the relationship between amounts of small rodent damage and habitat factors in 1978. (See Table 7 for explanation of variable names. Multiple R-square = 0.27; standard error of estimate = 0.09; df = 3,56; F-ratio = 6.91; P < 0.001.)

Variable Name	Step at which Factor Entered Equation	Regression Coefficient at Last Step	S.E. of Regression Coefficient at Last Step	R^2 at Each Step	Increase in R^2 Attributable to Factor	P[a]
Constant		0.064				
Muskeg shrub understory	1	-0.048	0.013	0.1585	0.1585	**
Dense vertical cover	2	-0.023	0.010	0.2294	0.0709	***
Grass cover	3	0.021	0.012	0.2702	0.0408	***

[a] Two-sided significance levels: * 0.05 ≥ P > 0.01; ** 0.01 ≥ P > 0.001; *** 0.001 ≥ P.

Table 13. SMR analysis of the relationship between amounts of small rodent damage and habitat factors in 1979. (See Table 7 for explanation of variable names. Multiple R-square = 0.12; standard error of estimate = 0.08; df = 1,58; F-ratio = 7.63; 0.001 < P < 0.001.)

Variable Name	Step at which Factor Entered Equation	Regression Coefficient at Last Step	S.E. of Regression Coefficient at Last Step	R^2 at Each Step	Increase in R^2 Attributable to Factor	P[a]
Constant		0.049				
Grass cover	1	0.040	0.014	0.1162	0.1162	**

[a] Two-sided significance levels: * 0.05 ≥ P > 0.01; ** 0.01 ≥ P > 0.001; *** 0.001 ≥ P.

Microtus pennsylvanicus populations in the Suncor Inc. reclamation sites, and in natural habitats in adjacent areas, appear to have undergone a 4 year cycle of abundance between 1975 and 1978 (Radvanyi 1978; Michielsen and Radvanyi 1979; Green 1980; this study); numbers were high in 1975, declined in 1976, increased rapidly in 1977 and 1978, and declined in 1979. If bark consumption occurs primarily during the winter [as suggested by Bailey (1924), Jameson (1955), Zimmerman (1965), and Larsson and Hansson (1977)], this research program has effectively sampled small rodent damage during the winter prior to (1977 to 1978) and following (1978 to 1979) the peak population phase of the population cycle.

Based on vegetation surveys conducted during this study, however, the severity of the small rodent damage problem was limited in both 1978 and 1979. Girdling damage was most severe on the Muskeg Reclamation and the Muskeg Overburden study areas. All tree and shrub species present on the Muskeg Reclamation area suffered some small rodent damage, whereas only two of the tree and shrub species present on the Muskeg Overburden study area were damaged.

In contrast, previous studies of tree and shrub survival on reclamation areas on the Suncor Inc. and Syncrude Limited leases have indicated that small rodent damage to woody-stemmed plants was severe. Dunsworth et al. (in prep.) attributed much of the decreased survival of tree and shrub saplings on a number of experimental areas to small rodent damage--in a number of cases, spring and fall survival rates of saplings were significantly and inversely correlated with amounts of small rodent damage. Fedkenheuer (1979) similarly showed that between 25% and 83% of the tree and shrub seedlings planted in reclamation sites in the Poplar Creek area of the Syncrude lease were damaged by small rodents. Surveys of girlding damage to saplings on other reclamation sites on the Suncor Inc. lease have also indicated that small rodent damage to trees and shrubs during the period of 1976 to 1978 was severe (D. Klym, Environmental Affairs, Suncor Inc., pers. comm.).

Why are the results of this study discrepant with results of these previous surveys? Several factors may have influenced the amounts of damage recorded in different reclamation sites in different years:

1. Small rodent abundance;
2. Tree availability;
3. Feeding preferences in relation to the diversity of tree and shrubs; and
4. Variation in ground cover density.

Correlations between small rodent abundance and amounts of damage in this study suggest that mouse numbers do partly influence amounts of damage; greater amounts of damage were associated with higher numbers of *M. pennsylvanicus* and lower numbers of *P. maniculatus*. Low amounts of damage in all study areas in 1979 may have been associated with the decline in *M. pennsylvanicus* populations during the winter 1978-1979. Moderately low numbers of *M. pennsylvanicus* may also partly explain the low amounts of damage on the Muskeg Overburden study area in 1978. In contrast, *M. pennsylvanicus* were very abundant on the Muskeg Reclamation study area in 1978 yet damage was limited. This, as well as the small amount of variation in damage (5.7%) accounted for by numbers of *M. pennsylvanicus*, suggest that other factors also influenced the severity of the damage problem.

Poor tree availability in almost all study areas, particularly during 1978 (when mouse numbers were highest), probably also resulted in low amounts of damage in this study as compared to other surveys. No trees were present on the five experimental areas during the peak winter (1977-1978), whereas only 154 seedlings, planted in a very concentrated area in each study plot, were available during the post-peak winter of 1978-1979. A very small number of naturally-propagating seedlings may also have been present in the two reduced cover treatments. Similarly, few living seedlings were available on the Muskeg Reclamation study area despite the 1500 seedlings planted in this area in June to July 1977 (letter dated 29 November 1978 from D. Klym, Environmental Affairs, Suncor Inc.)--a large proportion of the stock planted had leafed out by the time of planting and mortality from planting shock and desiccation was high (D. Klym, Environmental Affairs, Suncor Inc., pers. comm.). On the other hand, although the availability and diversity of trees and shrubs on the Muskeg Over-Burden study area was high, damage was limited.

Perhaps the low levels of damage observed in this study reflect preferences or avoidances of some tree and shrub species by small rodents. Some species of trees and shrubs such as *Pseudotsuga menziesii*, *Pinus* spp., *Quercus rubra*, *Fraxinus* spp., *Populus* spp., *Liriodendron tulipfera*, *Maclura pomifera*, and *Salix* spp. are highly susceptible to small rodent damage (Jokela and Lorenz 1959; Cayford and Haig 1961; Sartz 1970; von Althen 1971; Dunsworth et al. in prep.). Dunsworth et al. (in prep.) also indicated that preferences were closely related to species availability--as species were eliminated or severely reduced in number by tree death, those species remaining tended to receive more damage. Although preferences were not assessed in this study because of the low number of seedlings damaged, differences in species compositions, in addition to species availabilities, among reclamation areas may also have accounted for part of the large differences in levels of damage.

Variation in ground cover densities between areas may also have influenced amounts of tree damage--a number of studies have shown that components of habitat structure such as ground cover densities, and the abundance and diversity of food types are associated with amounts of damage (see Section 5.3). In particular, Dunsworth et al. (in prep.) found that mouse damage increased markedly as forage cover increased. Because numbers of microtine rodents (*Microtus* spp.) and cyclic fluctuations in number are partially influenced by ground cover densities (Eadie 1953; Mossman 1955; LoBue and Darnell 1959; Hansson 1971; Birney et al. 1976), increases in amounts of damage with increasing forage cover may reflect the influence of increased numbers of small rodents. However, correlations between the amounts of damage and the density of ground cover in this study suggested that ground cover density was negatively correlated with amounts of damage. This negative correlation may reflect the increased availability of trees in areas of sparse cover as seedlings in areas of dense cover were killed by excessive girdling damage during previous winters or the death of trees in areas of dense cover as a result of competitive interactions with the grass/legume cover for water, nutrients and light (Dunsworth et al. in prep.).

Overall, population sizes, tree availability, and amounts of ground cover all appeared to be associated with amounts of small rodent damage. Multivariate analyses that were used in this study permit the examination of some of the interactions between these factors, and the association of these factors with amounts of damage.

In both years of the study, the grass cover factor was positively and significantly associated with amounts of damage. The habitat variables comprising the grass cover factor imply that the three dimensional aspect of ground cover (i.e., vertical and horizontal densities), the accumulation of plant litter, and moderately dense plant cover at ground level were all correlated with amounts of damage. This is in direct agreement with studies of microtine abundance and ground cover structure already discussed. Dunsworth et al. (in prep.) used estimates of forage cover biomass (air-dried weight of clippings from a 1 m^2 quadrat) as a quantitative assessment of forage cover--these estimates would also reflect the three dimensional aspects of ground cover. The positive associations between the three dimensional structure of ground cover and amounts of damage that were observed in this study and by Dunsworth et al. (in prep.) suggest that both the density and three dimensional structure of ground cover is an important factor associated with increased amounts of damage.

Numbers of *M. pennsylvanicus* in 1978 and 1979 were also positively correlated with the grass cover factor (Section 4.3.3) and were negatively associated with the muskeg shrub factor. In addition, the muskeg shrub factor was negatively associated with amounts of small rodent damage to woody stems. The close associations between numbers of *M. pennsylvanicus* and amounts of damage with the same habitat factors, the direction of these associations (i.e., the sign of the correlation coefficient), and the lack of such relationships with *P. maniculatus* (*P. maniculatus* numbers were not significantly associated with any of the habitat factors) lends support to the hypothesis that *M. pennsylvanicus* is the species of small rodent principally responsible for damage to woody stems on these reclamation sites.

6. CONCLUSIONS

Three species of small rodents were present on the reclamation study areas within the Suncor Inc. lease. *Microtus pennsylvanicus* was the most abundant species of small rodent in almost all reclamation areas, followed by *P. maniculatus* and *C. gapperi*. Comparisons of small rodent populations in reclamation areas and natural habitats suggest that:

1. Older reclamation areas with dense grass/legume cover were highly suitable habitats for *M. pennsylvanicus*. Reproductive success of populations in older reclamation areas with dense grass/legume cover was higher than in other reclamation areas or in natural communities. Numbers of breeding, resident animals in this area were also high. *Microtus pennsylvanicus* populations in older successional habitats were most similar to populations in older reclamation sites.
2. Reclamation habitats were moderately suitable for *P. maniculatus*. However, peak population sizes and population characteristics of animals in balsam poplar forest and young successional areas suggested that these habitats were the most suitable habitats for *P. maniculatus* in the Athabasca region. Population characteristics and peak numbers of *P. maniculatus* in older reclamation sites were most similar to populations in older successional communities and aspen habitats.
3. Reclamation habitats were poor quality habitats for *C. gapperi*. *Clethrionomys gapperi* were only seasonally abundant on the Muskeg Overburden study area and were absent or extremely limited in all other reclamation sites. Demographic parameters and seasonal changes in abundance suggest that animals in the Muskeg Overburden area were immigrants from adjacent areas.

Significant relationships between local abundances of small rodents and habitat structure indicated that distributions of each species were associated with specific habitat factors and may also be influenced by micro-climatic and edaphic conditions. In particular:

1. Numbers of *M. pennsylvanicus* appeared to be most strongly associated with moderate to dense vertical cover and ground cover of grasses, sedges, and forbes, moderate to thick accumulations of plant litter, moderately dense plant cover at ground level, and limited tree and shrub cover. Variations in captures of this species along the slope gradient of each study area suggest that the distribution of this species may also be influenced by gradients of soil moisture within each reclamation site.
2. Numbers of *P. maniculatus* in reclamation areas were poorly correlated with habitat structure (as measured during this study)--this suggests that the habitat requirements of this species in reclamation sites were quite broad. In contrast, *P. maniculatus* numbers in natural areas were significantly associated with a number of habitat factors related to dense shrub cover, thick accumulations of leaf litter and deadfall, sparse grass cover, and dense vertical cover.
3. *Clethrionomys gapperi* distributions in both natural habitats and in reclamation areas appeared to be associated with moderate to dense shrub cover (both vertical and ground cover); populations in natural areas were also significantly correlated with moderate to thick accumulations of leaf litter and deadfall, and dense ground cover.

Based on these associations between small rodent numbers and habitat structure, it appears that most of the present reclamation areas in the Athabasca region (that are characterized by dense grass/legume cover and few shrubs and trees) were highly suitable habitats for

M. pennsylvanicus, moderately suitable habitats for *P. maniculatus*, and poor quality habitats for *C. gapperi*.

Small rodent damage to woody stems was extremely limited in all study areas in both 1978 and 1979. Low numbers of mice (particularly overwintering numbers of mice) and limited availability of trees in each of the reclamation areas (with the exception of the Muskeg Overburden study area) during this study probably resulted in the low amounts of damage. Because amounts of damage observed in this study were limited, statistical analyses were also limited. However, the significant and positive associations between amounts of small rodent damage and grass cover in both years suggests that alterations in grass cover or factors associated with grass cover may be one means of effectively reducing amounts of small rodent damage to saplings. The similarity in the significant predictor variables (i.e., habitat factors) of small rodent damage and numbers of *M. pennsylvanicus* suggests that *M. pennsylvanicus* may be the major cause of damage to seedlings in these areas.

7. RECOMMENDATIONS

The results of the first 2 years of the study of small rodent populations, habitat use, and damage to woody-stemmed plants in reclamation areas in the Athabasca region of Alberta have shown that colonization of reclamation sites on tailings sand areas is slow and that populations of small rodents have not become well established 18 mo after the revegetation of these sites. Population characteristics indicate that resident breeding populations of *M. pennsylvanicus* and *P. maniculatus* do eventually become established in older (3 to 4 year old) reclamation areas, whereas *C. gapperi* do not. Because of the current low numbers of small rodents in the newly established reclamation sites, analyses of the relationships among small rodent damage, small rodent numbers, and habitat structure are limited. Analyses such as these for the two monitoring study areas were also limited because of low numbers of small rodents and/or amounts of damage. In view of the limitations of this study in relation to cyclic population phenomena of small rodents, it is recommended that:

1. The small rodent live-trapping be continued on the five experimental areas for at least another 2 years or until populations have increased to peak numbers and declined. Continued studies would permit the collection of population information throughout one complete cycle of small rodent numbers (particularly *M. pennsylvanicus*).
2. That live-trapping programs on the two monitoring areas (overburden storage areas) be discontinued; in particular, tree availability is currently too limited on the Muskeg Reclamation area to adequately evaluate the problem of small rodent damage. However, if additional overburden storage sites are revegetated, a monitoring program of small rodent populations in these areas should be established to provide comparative information to populations on tailings sand areas.

3. Tree evaluations and vegetation analyses on the five experimental study areas should be continued to provide concurrent information to the live-trapping program. If new small rodent live-trapping areas are established in an overburden storage site, vegetation analyses and damage surveys should also be conducted.

More complete demographic information for the three major species of small rodents in reclamation areas and continued evaluations of habitat use and damage to woody stems over an additional two-year period would permit the assessment of the relationships between numbers of small rodents and amounts of damage, and between habitat structure and amounts of damage over a complete population cycle of *M. pennsylvanicus* (the species believed to cause most damage to seedlings in these reclamation sites). At present, this study has only evaluated these associations during the peak population year and during the year of the decline. It is important to continue evaluations throughout the increase phase and peak population period of this species when amounts of tree damage are expected to be highest.

8. REFERENCES CITED

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9. APPENDICES

9.1 SCIENTIFIC NAMES AND COMMON EQUIVALENTS OF PLANTS (Table 14)

Table 14. Scientific names and common equivalents of plants.

Scientific Name	Common Name
Agropyron albicans	pubescent wheatgrass
Agropyron cristatum	crested wheatgrass
Agropyron trachycaulum	tall wheatgrass
Alnus rugosa	speckled alder
Alnus spp.	alders
Amelanchier alnifolia	Saskatoon
Betula glandulosa	dwarf birch
Betula papyrifera	paper birch
Bromus spp.	bromegrasses
Caragana aborescens	caragana
Cornus stolonifera	dogwood
Elaegnus angustifolia	Russian olive
Elaegnus commutata	wolf willow
Equisetum spp.	horsetails
Festuca rubra	creeping red fescue
Fraximus pennsylvanica	red ash
Fraxinus spp.	ashes
Hieracium umbellatum	hawkweed
Hordeum spp.	barley
Larix laricina	tamarack
Larix siberica	Siberian larch
Liriodendron tulipfera	tulip tree
Lonicera spp.	honeysuckles
Maclura pomifera	osage-orange
Medicago spp.	alfalfas; sanfoin
Melilotus spp.	sweet clovers

continued...

Table 14. Continued.

Scientific Name	Common Name
Picea glauca	white spruce
Picea mariana	black spruce
Pinus banksiana	Jack pine
Pinus spp.	pines
Pinus sylvestris	Scots pine
Populus deltoides spp. *angulata* Alt. x *P. nigra plantierensis* L.	Vernirubens poplar
Populus deltoides Dartr. x (*P. balsamifera* x *Petrowskyana* Schneid.)	Walker poplar
Populus deltoides x *Populus balsamifera* Bartr. cv. 'Northwest'	Northwest poplar
Populus balsamifera	balsam poplar
Populus spp.	poplars
Populus tremuloides	trembling aspen
Prunus pensylvanica	chokecherry
Pseudotsuga menziessi	Douglas fir
Quercus rubra	red oak
Ribes spp.	currants
Ribes triste	wild red currant
Rubus melanolasius	red raspberry
Rubus spp.	raspberries
Rosa spp.	roses
Salix acutifolia	acute willow
Salix fragilis L. var. *basfordiana*	Basford willow
Salix petandra	Laurel willow
Salix spp.	willows

continued...

Table 14. Concluded.

Scientific Name	Common Name
Shepherdia canadensis	buffaloberry
Symphoricarpos albus	snowberry
Trifolium hybridum	alsike clover
Trifolium pratense	common clover
Trifolium repens	white clover
Ulmus americana	American elm
Ulmus pumila	Siberian elm
Viburnum spp.	shrub cranberries

9.2 METHODS OF CONTROL OF SMALL MAMMAL DAMAGE EMPLOYED ON THE FIVE EXPERIMENTAL PLOTS IN 1978 AND 1979

The three methods of controlling small mammal damage to woody stems that were recommended by Green (1978) were employed in 1978 and 1979--the application of an animal repellent to seedlings, the provision of supplementary food supplies, and the reduction of ground cover. The five experimental areas included a control plot, three single treatment plots, and one plot that combined the three treatments.

9.2.1 Control Plot

No treatments were applied to the control plot. The area was prepared, seeded, and fertilized as described earlier.

9.2.2 Repellent Application

Thiuram (tetramethylthiuram disulphide[1]) was chosen as a suitable animal repellent for this program because of its apparent effectiveness when properly applied (Brendon Casement, Horticultural Research Station, Brooks, Alberta, pers. comm.) and its availability. Thiuram (97%) was mixed with untinted latex paint (0.3 kg/L). The resulting slurry was applied to the seedlings (after planting) with a small paint brush. The repellent was applied so that the entire stem and lower branches of the seedlings were covered up to a height of 15 cm above the ground. On saplings shorter than 15 cm (i.e., most alder saplings), the entire plant was coated with the repellent. Thiuram was applied to seedlings on the repellent treatment plot and on the combined treatment plot in October 1978 and in late September 1979.

9.2.3 Supplementary Food

A supplementary food source was provided to animals on two of the plots (a single treatment plot and the combined treatment

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1 $[(CH_3)_2 NCS]_2S$

plot) to determine whether the lack of high quality food, particularly during the winter months, was a factor in determining the levels of rodent damage to young trees. One feeder (Figure 14) was installed near each trapping station on the two plots. Each feeder had a capacity of approximately 5.6 kg of grain. Feeders were installed and filled with whole or crushed oats on 6 to 7 October 1978. During the winter of 1978 to 1979, the levels of grain were refilled as necessary. Feeders were emptied and cleaned in June 1979 and were not refilled until 3 to 4 November. Levels of grain were checked on 1 December 1979 and 28 January 1980 and were refilled as necessary.

9.2.4 Habitat Manipulation

Hansson (1975) and Green (1978) concluded that habitat manipulation, especially reduced ground cover, was one of the best means of controlling rodent populations currently available. It was initially planned to use a seed mix and application rates [based on the results of Langevin and Lulman (1977)] that would have provided some measure of erosion control but that would have yielded substantially reduced vegetative cover in comparison with that yielded by the seed mix presently used by Suncor Inc. After discussions with AOSERP and Suncor personnel, it was decided that, in order to maximize the effects of habitat reduction, no artificial seeding would be carried out and the two plots (a single treatment plot and the combined treatment plot) would be allowed to revegetate by natural methods (i.e., seed dispersal, root regeneration). Fertilizer would be applied each year at rates similar to those used on the adjacent reclamation areas. As a result, after the incorporation of the muskeg overburden with the tailings sand and the application of fertilizer, the area received no further treatment.

9.2.5 The Combined Treatment Plot

Provision of supplementary food, application of thiuram, and reduction of cover were all conducted in the combined treatment plot in order that the interactive effects of these treatments could

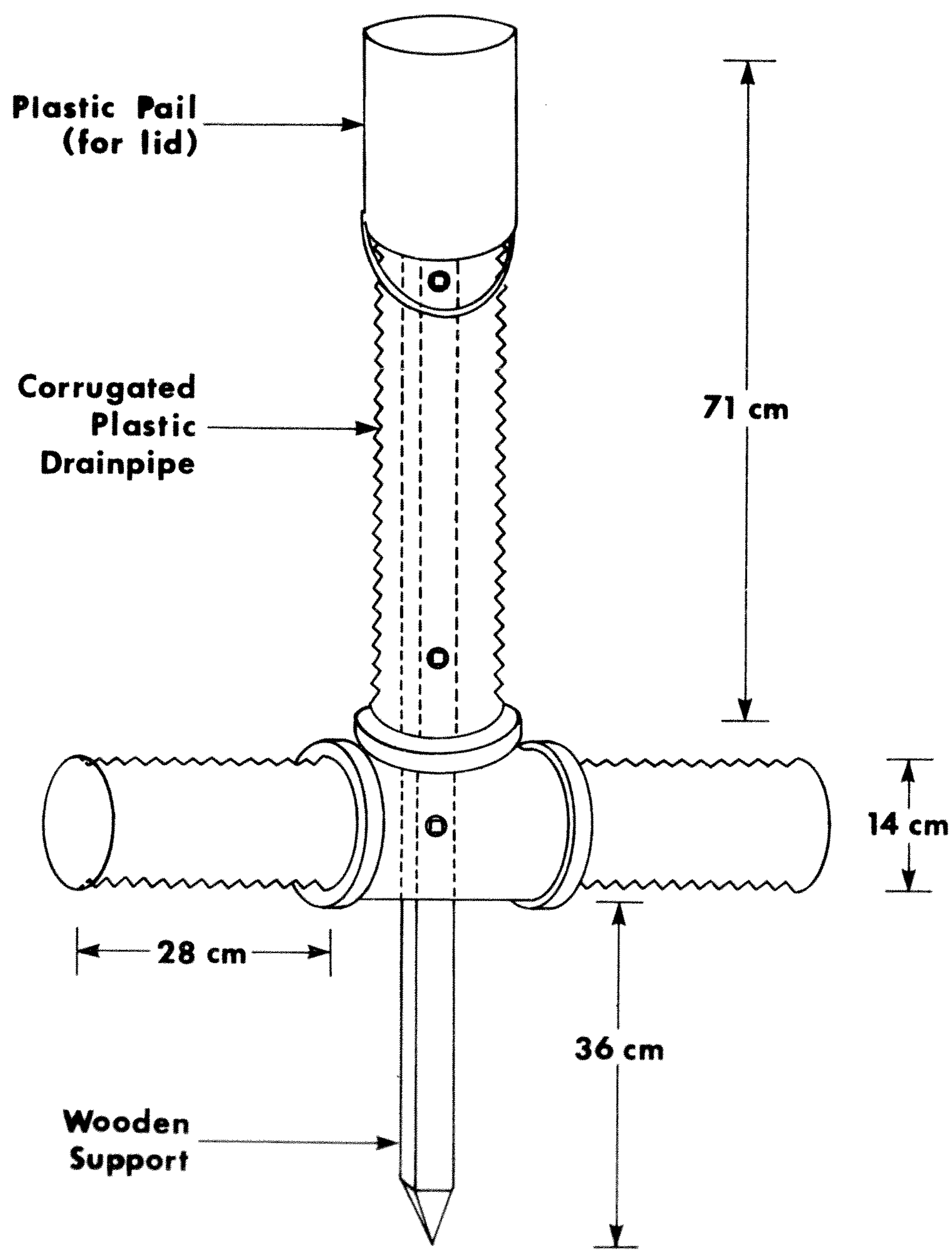

Figure 14. Design of feeders used on the Feeding study area.

be evaluated. All treatments on this plot were identical to those just described for the specific treatment plots.

9.3 DEMOGRAPHY (Tables 15 to 20)

Table 15. Total numbers of live-captures of less-commonly occurring species of small mammals on reclamation sites. (None of these species were captured on the Feeding, Repellent, Combined Treatment, or Reduced Cover study areas.)

		Total Number of Captures			
Study Area	Year	*Sorex cinereus/ Microsorex hoyi*[a]	*Phenacomys intermedius*	*Eutamias minimus*	*Mustela erminea*
Muskeg Overburden	1978	3	0	6	1
	1979	0	0	2	4
Muskeg Reclamation	1978	1	0	0	0
	1979	2	0	0	3
Control	1978	0	0	0	0
	1979	0	1	0	0

[a] *Sorex cinereus* and *M. hoyi* could not be reliably differentiated on the basis of external characteristics and consequently have been grouped together.

Table 16. Breeding activity of mature *C. gapperi*. [Proportions of mature animals (body weight $\geq$ 10 g) that were in breeding condition during each summer trapping period are indicated. Numbers of mature animals captured are also shown. Mature *C. gapperi* were only captured on the Muskeg Overburden and Muskeg Reclamation study areas during the summer periods.]

		Muskeg Overburden				Muskeg Reclamation			
		Males		Females		Males		Females	
	Date[a]	Prop.	N	Prop.	N	Prop.	N	Prop.	N
1978	16 August	-	0	-	0	-	0	-	0
	27 August	-	0	-	0	-	0	-	0
	15 September	0.00	1	0.00	2	-	0	-	0
1979	16 May	-	0	-	0	-	0	-	0
	8 June	-	0	-	0	-	0	-	0
	24 June	-	0	-	0	-	0	-	0
	18 July	0.00	1	0.00	1	-	0	0.00	1
	10 August	-	0	-	0	0.00	1	-	0
	31 August	-	0	0.00	2	-	0	-	0
	20 September	0.00	2	0.00	1	-	0	-	0

[a] Dates shown are the mid-point of each trapping period.

Table 17. Breeding activity of mature *M. pennsylvanicus*. [Proportions of mature animals (body weight ≥ 16 g) that were in breeding condition during each summer trapping period are indicated. Numbers of mature animals captured are also shown.]

		Muskeg Overburden				Muskeg Reclamation				Feeding				Repellent			
		Males		Females		Males		Females		Males		Females		Males		Females	
	Date[a]	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N
1978	16 August	0.00	2	0.00	1	0.40	5	0.67	3	-	0	-	0	-	0	-	0
	27 August	0.00	1	0.00	3	0.50	2	0.50	4	-	0	-	0	-	0	-	0
	15 September	0.00	4	0.00	5	0.33	9	0.90	10	-	0	-	0	-	0	-	0
1979	16 May	-	0	0.00	1	1.00	23	0.63	32	1.00	20	0.58	24	-	0	0.00	1
	8 June	-	0	0.00	1	0.91	11	0.89	18	1.00	3	0.57	7	-	0	-	0
	24 June	1.00	2	1.00	2	1.00	9	0.71	7	1.00	2	1.00	7	-	0	-	0
	18 July	1.00	2	0.25	4	0.67	3	0.50	2	0.75	4	0.50	6	0.00	2	1.00	2
	10 August	0.50	2	1.00	1	-	0	1.00	1	0.50	4	0.00	1	0.00	1	1.00	1
	31 August	0.00	1	-	0	0.00	1	-	0	1.00	1	0.50	2	1.00	2	1.00	1
	20 September	0.00	1	-	0	0.60	5	0.33	3	0.71	7	0.50	6	0.50	6	1.00	2

continued...

Table 17. Concluded.

	Date[a]	Combined Treatment				Reduced Cover				Control			
		Males		Females		Males		Females		Males		Females	
		Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N
1978	16 August	-	0	-	0	-	0	-	0	-	0	-	0
	27 August	-	0	-	0	-	0	-	0	-	0	-	0
	15 September	-	0	-	0	-	0	-	0	-	0	-	0
1979	16 May	0.00	1	-	0	-	0	-	0	1.00	1	0.00	2
	8 June	-	0	-	0	-	0	-	0	-	0	0.00	1
	24 June	-	0	-	0	-	0	-	0	-	0	-	0
	18 July	-	0	-	0	-	0	-	0	-	0	-	0
	10 August	-	0	-	0	-	0	-	0	1.00	1	-	0
	31 August	-	0	-	0	-	0	-	0	1.00	1	0.00	3
	20 September	-	0	-	0	-	0	-	0	-	0	0.50	2

[a] Dates shown are the mid-point of each trapping period.

Table 18. Breeding activity of mature *P. maniculatus*. Proportions of mature animals (body weight ≥ 14 g) that were in breeding condition during each summer trapping period are indicated. Numbers of mature animals captured are also shown.]

		Muskeg Overburden				Muskeg Reclamation				Feeding				Repellent			
		Males		Females		Males		Females		Males		Females		Males		Females	
	Date[a]	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N
1978	16 August	0.00	2	0.00	1	0.00	6	0.00	2	-	0	-	0	-	0	-	0
	27 August	0.00	3	0.33	3	0.00	4	0.00	3	-	0	-	0	-	0	-	0
	15 September	0.00	7	0.00	4	0.00	5	0.00	5	-	0	-	0	-	0	-	0
1979	16 May	1.00	4	0.00	2	0.50	2	0.40	5	-	0	0.00	1	1.00	1	-	0
	8 June	1.00	1	0.67	3	1.00	1	1.00	2	-	0	0.00	1	-	0	0.00	1
	24 June	1.00	2	1.00	2	-	0	1.00	2	1.00	1	-	0	-	0	-	0
	18 July	0.17	6	1.00	2	0.67	3	0.40	5	1.00	2	0.50	2	-	0	-	0
	10 August	1.00	3	0.40	5	1.00	2	0.50	4	0.00	2	1.00	1	-	0	-	0
	31 August	0.67	3	0.50	2	1.00	2	0.00	1	-	0	1.00	1	-	0	-	0
	20 September	0.50	4	0.00	5	1.00	2	0.00	2	-	0	-	0	-	0	-	0

continued...

Table 18. Concluded.

	Date[a]	Combined Treatment				Reduced Cover				Control			
		Males		Females		Males		Females		Males		Females	
		Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N	Prop.	N
1978	16 August	-	0	-	0	-	0	-	0	-	0	-	0
	27 August	-	0	-	0	-	0	-	0	-	0	-	0
	15 September	-	0	-	0	-	0	-	0	-	0	-	0
1979	16 May	1.00	3	0.00	3	1.00	1	0.50	2	1.00	4	0.00	1
	8 June	1.00	1	1.00	2	1.00	1	0.50	2	1.00	3	1.00	3
	24 June	1.00	2	1.00	1	-	0	1.00	2	-	0	1.00	2
	18 July	0.00	1	1.00	1	1.00	1	1.00	1	1.00	1	-	0
	10 August	-	0	-	0	-	0	-	0	-	0	1.00	1
	31 August	1.00	1	0.00	2	1.00	1	0.00	2	-	0	1.00	2
	20 September	0.50	4	0.00	2	0.00	1	0.00	2	-	0	-	0

[a] Dates shown are the mid-point of each trapping period.

Table 19. Juvenile recruitment rates of *M. pennsylvanicus*. [Rates shown are expressed as the number of new immature animals (body weight < 16 g) captured per mature breeding female during each summer trapping period. The number of mature breeding females captured during each period are also indicated.]

	Date[a]	Muskeg Overburden		Muskeg Reclamation		Feeding		Repellent		Combined Treatment		Reduced Cover		Control	
		Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N
1978	16 August	-	0	0.50	2	-	0	-	0	-	0	-	0	-	0
	27 August	-	0	0.00	2	-	0	-	0	-	0	-	0	-	0
	15 September	-	0	1.00	9	-	0	-	0	-	0	-	0	-	0
1979	16 May	-	0	0.00	20	0.21	14	-	0	-	0	-	0	-	0
	8 June	-	0	0.94	16	0.50	4	-	0	-	0	-	0	-	0
	24 June	0.50	2	2.00	5	0.43	7	-	0	-	0	-	0	-	0
	18 July	1.00	1	1.00	1	0.00	3	0.00	2	-	0	-	0	-	0
	10 August	0.00	1	0.00	1	-	0	0.00	1	-	0	-	0	-	0
	31 August	-	0	-	0	0.00	1	5.00	5	-	0	-	0	-	0
	20 September	-	0	0.00	1	0.33	3	0.00	2	-	0	-	0	0.00	1

[a] Dates shown are the mid-point of each trapping period.

Table 20. Juvenile recruitment rates of *P. maniculatus*. [Rates shown are expressed as the number of new immature animals (body weight < 14 g) captured per mature breeding female during each summer trapping period. The number of mature breeding females captured during each period are also indicated.]

	Date[a]	Muskeg Overburden		Muskeg Reclamation		Feeding		Repellent		Combined Treatment		Reduced Cover		Control	
		Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N
1978	16 August	-	0	-	0	-	0	-	0	-	0	-	0	-	0
	27 August	0.00	1	-	0	-	0	-	0	-	0	-	0	-	0
	15 September	-	0	-	0	-	0	-	0	-	0	-	0	-	0
1979	16 May	-	0	0.00	2	-	0	-	0	-	0	-	0	-	0
	8 June	0.00	2	0.50	2	-	0	-	0	0.50	2	0.00	1	0.33	3
	24 June	1.50	2	1.00	2	-	0	-	0	3.00	1	0.50	2	0.50	2
	18 July	0.50	2	0.00	2	0.00	1	-	0	-	0	0.00	1	-	0
	10 August	1.00	2	0.50	2	0.00	1	-	0	-	0	0.00	4	4.00	1
	31 August	3.00	1	-	0	0.00	1	-	0	-	0	-	0	0.00	2
	20 September	-	0	-	0	-	0	-	0	-	0	-	0	-	0

[a] Dates shown are the mid-point of each trapping period.

9.4 HABITAT USE

9.4.1 Principal Component Analyses of Vegetation on the Two Monitoring Study Areas

A factor (principal components) analysis was used to reduce a larger number of habitat variables to a smaller number of independent factors. Based on the results of the vegetation sampling programs on the two monitoring plots in 1978 and 1979, a total of 50 species or species groups of plants were recorded; measures of horizontal ground cover, estimates of stem densities (for woody-stemmed plants only), and/or estimates of vertical cover were recorded for each species. Estimates of cumulative vertical cover (for all species) in six 25 cm vertical increments were recorded as well.

A number of these variables were non-zero in only a few cases and, consequently, relationships between small rodent abundance and these variables were unlikely to be detectable, even if real. Because of this, plus the need to reduce the number of variables to a more manageable value, only those variables recorded as non-zero in at least 20 samples were included in the factor analysis. This reduced the number of variables to 24. All estimates of stem densities were transformed using a log (x + 1) transformation (where x equals the estimate of stem density) prior to the factor analysis to correct for non-normality.

Factor analyses were run on the combined vegetation data from 1978 and 1979 using the BMDP4M program (Dixon and Brown 1979). By combining the 2 years of vegetation data, changes in the distribution and abundance of small rodents between years can be more effectively evaluated. The factor analysis was performed by a standard method--a principal components analysis followed by Varimax (orthogonal) rotation of those principal components with eigenvalues exceeding 1.0. This reduced the 24 habitat variables to a set of four independent factors. Rotated factor loadings (correlation coefficients between the 24 habitat variables and the 4 habitat factors) are provided in Table 21. Biological interpretations of the four habitat factors are summarized in Table 7).

Table 21. Results of the factor analysis of the 24 habitat variables for the two monitoring plots. [Only the correlations between the original 24 variables and the four factors with absolute values that were > 0.250 are shown. VP's (total variance in vegetation structure that was explained by the factor) are also indicated for each factor in the SMR. The variable prefixes GC, VC, and ST refer to percent ground cover, percent vertical cover, and density of stems/16 m^2, respectively.]

	Factor 1	Factor 2	Factor 3	Factor 4
VC - *M. sativa*	-0.862	0.0	0.0	0.279
ST - *P. balsamifera*	0.855	0.0	-0.280	0.0
GC - *M. sativa*	-0.852	0.0	0.0	0.299
ST - *Salix* spp.	0.850	0.279	0.0	0.0
GC - *T. pratense*	-0.839	-0.306	0.0	0.0
VC - *T. pratense*	-0.805	0.0	0.0	0.257
GC - *E. angustifolium*	0.760	0.0	0.0	0.0
VC - *E. angustifolium*	0.727	0.0	0.0	0.287
GC - *H. umbellatum*	0.726	0.0	0.0	0.0
ST - *B. glandulosa*	0.682	0.322	0.0	0.0
ST - *P. tremuloides*	0.661	0.0	0.0	0.0
GC - *Salix* spp.	0.636	0.450	0.0	0.331
VC - *Salix* spp.	0.611	0.399	-0.250	0.383
VC - 50 to 75 cm	0.318	0.898	0.0	0.0
VC - 100 to 125 cm	0.255	0.888	0.0	0.0
VC - 125 to 150 cm	0.0	0.878	0.0	0.0
VC - 75 to 100 cm	0.374	0.878	0.0	0.0
VC - 25 to 50 cm	0.0	0.815	0.0	0.292
VC - 0 to 25 cm	0.0	0.551	0.266	0.516
VC - Grasses/Sedges	0.0	0.0	0.854	0.0
VC - Litter	0.0	0.0	0.821	0.0
GC - Litter	0.0	0.0	0.0	0.782
GC - Grasses/Sedges	0.0	0.0	0.435	0.592
GC - *P. balsamifera*	0.365	0.287	-0.417	0.0
VP	8.208	5.123	2.282	2.155

Table 22. SMR analysis of the relationship between *M. pennsylvanicus* abundance and habitat factors in 1979. (See Table 7 for explanation of variable names. Multiple R-square = 0.2438; standard error of estimate = 0.0097; df = 2.57; F-ratio = 9.19; P < 0.001.)

Variable Name	Step at which Factor Entered Equation	Regression Coefficient at Last Step	S.E. of Regression Coefficient at Last Step	R^2 at Each Step	Increase in R^2 Attributable to Factor	P[a]
Constant		0.011				
Muskeg Shrub Understory	1	-0.003	0.001	0.1900	0.1900	***
Grass Cover	2	0.002	0.002	0.2438	0.0537	***

[a] Two-sided significance levels: *** 0.001 ≥ P.

Table 23. Mean factor scores for the two monitoring study areas in 1978 and 1979. (Mean factor scores and 1 S.E. are indicated for each factor based on the factor scores for each of the 30 samples on each study area.)

Study Area		Factor	
		Muskeg shrub understory	Grass cover
Muskeg Overburden	1978	0.88 ± 0.72	-0.54 ± 1.43
	1979	0.88 ± 0.51	-0.84 ± 0.66
Muskeg Reclamation	1978	-0.75 ± 0.24	0.29 ± 0.40
	1979	-1.00 ± 0.23	0.01 ± 0.54

Table 24. SMR analysis of the relationship between *M. pennsylvanicus* abundance and habitat factors in 1978. (See Table 7 for explanation of variable names. Multiple R-square = 0.2923; standard error of estimate = 0.0399; df = 2,57; F-ratio = 11.77; P < 0.001.)

Variable Name	Step at which Factor Entered Equation	Regression Coefficient at Last Step	S.E. of Regression Coefficient at Last Step	R^2 at Each Step	Increase in R^2 Attributable to Factor	P[a]
Constant		0.043				
Muskeg Shrub Understory	1	-0.027	0.006	0.2545	0.2545	***
Grass Cover	2	0.009	0.005	0.2923	0.0378	***

[a] Two-sided significance levels: *** 0.001 ≥ P.

10. LIST OF AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35.	AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
39.	ME 1.0	The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
40.	WS 3.3	Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43.	TF 6.1	A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44.	VE 3.1	Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53. HY 3.1.2 Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54. WS 2.3 A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55. HY 2.6 Microbial Populations in the Athabasca River
56. AF 3.2.1 The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57. LS 2.3.1 Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58. AF 2.0.2 Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59. TF 3.1 Semi-Aquatic Mammals: Annotated Bibliography
60. WS 1.1.1 Synthesis of Surface Water Hydrology
61. AF 4.5.2 An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62. TF 5.1 Amphibians and Reptiles in the AOSERP Study Area
63. ME 3.8.3 Analysis of AOSERP Plume Sigma Data
64. LS 21.6.1 A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65. LS 21.6.2 A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66. AS 4.3.2 An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67. WS 1.3.2 Aquatic Biological Investigations of the Muskeg River Watershed
68. AS 1.5.3 AS 3.5.2 Air System Summer Field Study in the AOSERP Study Area, June 1977
69. HS 40.1 Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70. LS 28.1.2 An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71. HY 2.2 Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72. LS 7.1.2 The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73. LS 23.2 Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74. AS 4.5 Air Quality Modelling and User Needs
75. WS 1.3.4 Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76. AF 4.5.1 An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77. HS 20.1 Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78. LS 22.1.1 Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79. AF 3.6.1 The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80. HS 10.2 & HS 10.1 History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.
81. LS 22.1.2 Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.
82. LS 22.2 Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.
83. LS 22.2 The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.
84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
85. HY 2.5 An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.
86. AS 3.7 An Observational Study of Fog in the AOSERP Study Area.
87. WS 2.2 Hydrogeological Investigation of Muskeg River Basin, Alberta
88. AF 2.0.1 Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta
89. AF 4.3.2 Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1
90. AS 3.2 A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta
91. LS 5.2 Characterization of Stored Peat in the Alberta Oil Sands Area
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