TECHNIQUES FOR THE CONTROL OF SMALL MAMMAL DAMAGE TO PLANTS: A REVIEW

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1. INTRODUCTION

Rodents (mice, voles, rats and squirrels) and leporids (rabbits and hares) have proven to be a major problem in many reforestation programs in North America and Europe (Myllymaki 1975a). The success of many direct seeding techniques, for example, has been limited by the destruction of large portions of the applied seeds by small mammals or by birds (Moore 1940; Black *et al.* 1969; Radwan 1970; Radvanyi 1973). Similarly, the success of many seedling planting programs has been reduced by small mammal damage to young trees and the resultant decrease in seedling survival (Moore 1940; Staebler *et al.* 1954; Jokela and Lorenz 1959; Bang 1975; Christiansen 1975; Larsson 1975; Myllymaki 1975a,c). Most damage in seedling planting programs has resulted from the browsing of the terminal buds and twigs, or from the consumption of the phloem and outer cambium layers of the stem, roots and/or lower branches. Consumption can range from the removal of small irregular patches to the complete removal of the bark encircling the stem, roots or branches (girdling).

The afforestation program in the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1) has been only moderately successful, because of the high mortality of some species of young trees (Radvanyi 1976). Mean survival rates for the 1975-76 season for seedlings planted in 1974 on several different areas within the Great Canadian Oil Sands Limited (GCOS) reclamation site ranged from 37%-92% (Selner and Thompson in prep.). Sapling death has been attributed to disease, to nutrient deficiencies, to insect defoliation, to damage during planting, and to small mammal damage (Alberta Forest Service in prep.). A large proportion of the young trees, particularly the deciduous species, have been girdled by small mammals (Radvanyi 1976), and it is believed that small mammal damage is one of the major causes of sapling death on the reclamation areas. Several attempts to control either the numbers of small mammals or their damage to young trees on the existing reclamation areas on the GCOS lease have proved unsuccessful (Radvanyi 1976). Snowshow hares are presently increasing in the Fort McMurrary area and are expected

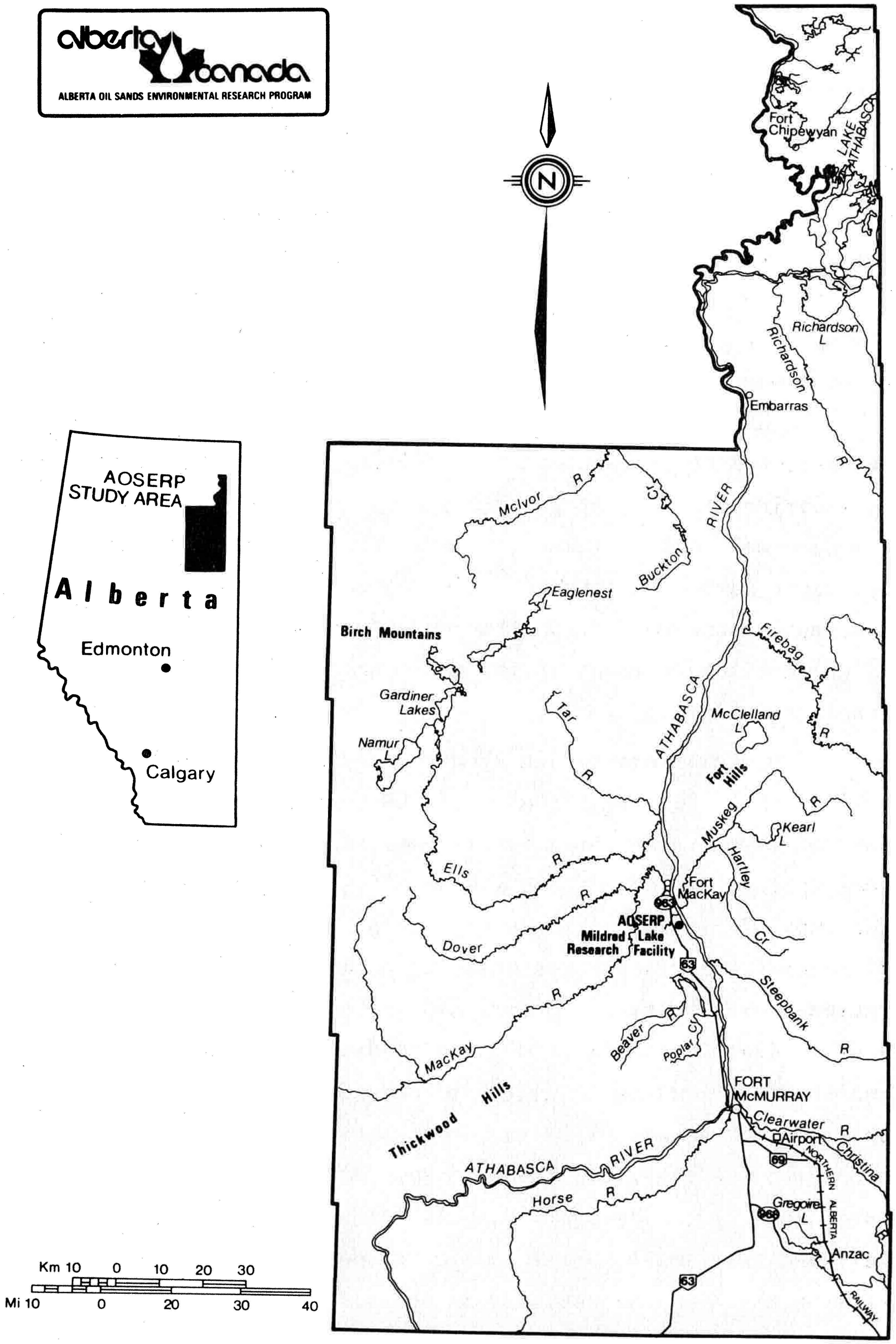

Figure 1. The Alberta Oil Sands Environmental Research Program study area.

to reach peak numbers by the fall of 1979 (L. Keith, Univ. of Wisconsin, pers. comm., 24 April 1978). Because snowshoe hares can severely damage young seedlings (Jokela and Lorenz 1959), snowshoe hare damage to seedlings in the afforestation plots on the Athabasca Oil Sands should be anticipated. With the major development of the oil sands area that is in progress or envisioned, revegetation of mined areas will be a very important part of the overall development. Damage to revegetated areas by rodents and snowshoe hares thus has the potential to be a major problem in the area.

The present study was conducted to review the literature pertaining to the problem of small mammal damage and the means of controlling such damage and to apply the results of this literature review to the specific problem of the Athabasca Oil Sands. The specific objectives of the terms of reference were the following:

1. "Review the literature on small mammal damage to revegetation areas and on small mammal control procedures."
2. "On the assumption that there will be a problem, plan research to develop an ecologically and economically acceptable small mammal control program appropriate to the problem."

In order to most effectively plan a program to control small mammal damage to revegetated areas, it is important not only to understand the ecological and economic implications of a control program, but also to have an appreciation of the ecological factors that influence the local distributions and numbers of small mammals. Consequently, the habitat preferences and feeding preferences of the small rodent species common in the vicinity of the Athabasca Oil Sands are discussed first. Methods of controlling both the abundance of small mammals and/or the damage that they cause are then discussed in terms of their modes of action. Based on the literature reviewed, recommendations are then made as to the best methods of control of small mammal damage to revegetated areas in the Athabasca Oil Sands area.

Mammalian nomenclature follows that of Banfield (1977). Plant nomenclature follows that of Moss (1967) and Hosie (1973).

2. HABITAT AND FOOD PREFERENCES OF SMALL MAMMALS

Many species of small mammals occur commonly in forested and grassland areas. They do not become 'pests' until they interfere with man's activities, at which point the need may arise to control either their abundance or the extent of their damage to economically important vegetation types. Two major questions arise from most outbreaks or occurrences of 'pests'--why is the species a problem in the area and why does it feed on specific types of plants? In order to evaluate a 'pest' problem and to formulate an effective control program, it is therefore necessary to understand both the natural habitat and food preferences of the 'pest' species and its habitat and food preferences in 'pest' situations.

Recent live-trapping studies indicate that *Microtus pennsylvanicus* and *Peromyscus maniculatus* are the most common species of small mammals on the GCOS reclamation site in the Athabasca Oil Sands (Radvanyi 1976). *Clethrionomys gapperi* is the most common species in the surrounding forests although *P. maniculatus* is abundant in some habitats (Green 1978; Westworth and Skinner 1978).

The numbers of *M. pennsylvanicus* in an area fluctuate in a cyclic fashion (Krebs *et al.* 1969). Cycles from a population low to a high and back to a low are on average about four years in length (Krebs and Myers 1974). However, both the amplitude and the period of population fluctuations of small mammals are quite variable (Krebs and Myers 1974). Populations of *C. gapperi* may also be cyclic. A twelve year study of small mammal populations in the Northwest Territories (Fuller 1969, 1977) has indicated that populations of *C. gapperi* underwent regular increases and decreases in numbers and that peak populations occurred every four to five years. *P. maniculatus* is an extremely widespread species that is characterized by variable demographic responses in different habitats. Peak population numbers can differ greatly between years; however, population numbers are generally not considered to be cyclical.

Because *M. pennsylvanicus*, *P. maniculatus* and *C. gapperi* are abundant in the oil sands area, this review has concentrated on these species with respect to habitat and food preferences. The review of control methods is more general, covering the cricetids (mice and voles) and to a lesser extent the leporids. As yet the effects of leporids on the afforestation program have not been considered. Because leporids have been known to cause severe damage to nursery stock (Jokela and Lorenz 1959; Black *et al.* 1969), there exists the potential for a similar problem on the Athabasca Oil Sands reclamation areas.

2.1 HABITAT PREFERENCES

Variations in the numbers and distributions of small mammals in different habitats can be attributed largely to the behavioural adaptations of each species towards specific habitat stimuli, such as variation in cover, effects of climate, soil types, predation pressures, food availability and interspecific competition (Krebs 1972; Hansson 1975a). It is difficult to determine if any one of these is the causative factor; the distribution of a species is more likely the result of the response of the animal to a number of these habitat stimuli. Soil types, for example, would affect the extent of burrowing and the type of plant community (and hence food availability, ground micro-climate and snow cover). Of all the habitat stimuli that affect the distribution of small mammals, the density and type of ground cover are two of the most important factors in determining local distribution patterns (Hansson 1975a).

The distributions of several rodent species, primarily *M. pennsylvanicus* and *Peromyscus* sp., have been shown to be closely related to the type of vegetative cover. Eadie (1953) found that areas with low densities of *M. pennsylvanicus* had substantially less vegetative cover than areas with higher densities of *M. pennsylvanicus*. M'Closkey (1975) showed that the distributions of *M. pennsylvanicus* and *Peromyscus leucopus* were related to the foliage height diversity; *M. pennsylvanicus* was most abundant in areas of dense grass-dominated cover, whereas *P. leucopus* was most abundant in more open shrub-dominated communities.

Studies of the response of the small mammal communities to habitat disturbances such as fire, logging or grazing have also supported the conclusion that cover is an important factor affecting the distribution of small mammals. Shifts in the species composition of the small mammal community occur after the burning or logging of a forested area; in such cases *Peromyscus* sp. frequently replace the formerly more typical forest species, such as *C. gapperi* or *Eutamias* sp. (Tevis 1956a; Gashwiler 1959, 1970; Ahlgren 1966; Krefting and Ahlgren 1974; Kelsall *et al.* 1977). The species composition of the small mammal community in grassland areas also undergoes major changes following burns, or during plant succession; microtine rodents become less common, whereas species such as *P. maniculatus* become more common after fires. The lack of dense cover has been suggested as the factor restricting the recovery of many of the species that had formerly occupied disturbed areas (Baker 1940; Cook 1959; Hirth 1959; Beck and Vogl 1972).

The close relationship between cover and small mammal distribution has been attributed to changes in predation pressure; to changes in food abundance, diversity and distribution; and to changes in the types of snow cover that are associated with different vegetation types. Mammalian and avian predation on small mammals has been shown to increase in areas of low vegetative cover following forest fires (Lawrence 1966) or crop removal (Green and Taylor 1975). LoBue and Darnell (1959) attributed the restricted distribution of *M. pennsylvanicus* in an alfalfa field to the need for cover for protection against predators and extreme environmental conditions. Dense cover was necessary for diurnal species such as *M. pennsylvanicus*, but nocturnal species such as *P. maniculatus* were not as dependent on cover. The lack of cover may also result in a limitation both of foraging areas and of the availability of food (LoBue and Darnell 1959).

The type of plant community and the amount of cover play an important role in the type of snow cover and the extent of the subnivean layer. (The subnivean layer is the snow layer immediately adjacent to the ground that is characterized by loose snow crystals in which small mammals can live.) In areas where the ground cover consists of low *Vaccinium* sp., for example, the subnivean air space is poorly developed, whereas in areas of clover (*Trifolium* sp.) and timothy (*Phleum pratense*) the subnivean space may be 3-8 cm in height (Coulianos and Johnels 1963). Coulianos and Johnels (1963) illustrated the close relationship between the development of the subnivean space and the winter distribution of small rodents; grassland areas mowed just prior to winter developed a very limited subnivean space and showed no signs of small mammal activity, whereas unmowed areas developed extensive subnivean layers and showed many signs of intense small mammal activity. Pruitt (1957) discussed the importance of the subnivean space to small mammals for maintaining a winter environment that provides moderate and comparatively constant temperatures, silence, darkness, high humidity and refuge from many predators. The moderate temperatures of the subnivean space are essential to the survival of small mammals; if exposed to external winter temperature changes they would be unable to maintain a stable body temperature because of their high surface to volume ratio and high metabolic rates. West (1977), for example, found that *Clethrionomys rutilus* tended to aggregate during very low temperatures in areas of uniformly-thick moss cover, which had a very high insulating capacity.

Small mammals appear to respond differently to cover types, food availability and snow cover; a number of studies have indicated that these responses are inherited behavioural responses rather than learned responses (Grant 1971a). *P. maniculatus bairdii*, for example, shows a preference for grassland habitats but can also survive in woodland habitat (Harris 1952). Wecker (1963) released laboratory and field-raised *P. m. bairdii* into a large pen that contained equal areas of grassland and woodland habitats. Although the laboratory raised animals did not select grassland areas to the same degree as did the field animals, both types of animals took up residence predominantly in the grassland area. The test indicated that habitat selection in this prairie sub-species was inherited and that early experience had only a minor influence on this behaviour. The distribution of *M. pennsylvanicus* and *C. gapperi* in pens containing equal areas of grassland and deciduous woodland was similarly related to an inherent behavioural response to habitats (Grant 1969, 1971b); the former selected dense grassland habitats, the latter more open forested habitats. *M. pennsylvanicus* did not begin to inhabit woodland areas until grassland densities exceeded 68-80 voles/acre. *C. gapperi*, however, was capable of excluding *M. pennsylvanicus* from woodland areas that it occupied (Morris 1969; Morris and Grant 1972). From these observations, it may be concluded that the successful colonization of woodland habitats by *M. pennsylvanicus* would occur only when increased intraspecific interactions (as a result of high densities) lead to emigration from grassland areas and would occur only into woodland areas where densities of *C. gapperi* are low.

2.2 FEEDING PREFERENCES

Of the three small rodent species common to the Athabasca Oil Sands area, one is a herbivore and two are omnivores. *M. pennsylvanicus* is a herbivore, feeding predominantly on grasses and sedges, and to a lesser extent on forbs. The summer diet may be augmented by flowers, leaves and fruits of forbs and low shrubs. In winter their diet consists largely of stored seeds, underground roots and bulbs. If food supplies become scarce, bark from the stems, roots and twigs of some shrubs and young trees may be consumed (Thompson 1965; Zimmerman 1965).

P. maniculatus is an omnivore but is primarily a seed eater. The diet commonly includes seeds of grasses and forbs, a variety of berries, and buds of shrubs and trees; it also includes a variety of insects, larvae, caterpillars and spiders

(Hamilton 1941; Whitaker 1963; Gentry and Smith 1968; King 1968).

C. gapperi is also an omnivore, feeding largely on broad-leaved forbs and shrubs. Berries supplement the diet when available. In autumn, seeds of grasses, forbs and annuals are commonly eaten. In winter, buds, twigs and petioles of a variety of shrubs and evergreens are the staple diet, but bark, particularly that of deciduous species, may also be consumed if food supplies are scarce (Hamilton 1941; Zemanek 1972).

Because girdling of trees by small rodents is common on GCOS reclamation sites (Radvanyi 1976) and has the potential to be a major problem in other afforestation programs, it is important to consider the feeding preferences of small mammals with respect to the bark of tree and shrub species. Bark is not a preferred food of most small mammals; they commonly consume bark only in very small quantities. Consumption of large amounts of bark is indicative of food shortages, particularly a lack of carbohydrates (Hamilton 1941; Thompson 1965; Zemanek 1972; Hansson 1973a, b). Hansson (1973a) showed that no girdling occurred when preferred carbohydrates were available. Heavy bark consumption thus appears to be indicative of nutritional stress.

Small mammals show definite preferences for the barks of some tree and shrub species. Littlefield *et al.* (1946) found that *M. pennsylvanicus* most often attacked Scotch pine (*Pinus sylvestris*) and Douglas-fir (*Pseudotsuga menziesii*). In the areas they examined, 50-85% of the saplings were attacked, and up to 70% were totally girdled. Norway spruce (*Picea abies*), white pine (*Pinus strobus*), red pine (*Pinus resinosa*), white cedar (*Thuja occidentalis*), jack pine (*Pinus banksiana*) and larch (*Larix laricina*) were only slightly favored; white spruce (*Picea glauca*) was undamaged. Jokela and Lorenz (1959) found white spruce, balsam fir (*Abies balsamea*), ponderosa pine (*Pinus ponderosa*), red pine, American sycamore (*Plantanus occidentalis*), and western red cedar (*Thuja plicata*) were the least susceptible to damage by cottontail rabbits (*Sylvilagus floridanus*) and by *Microtus ochrogaster*. Other studies have found that white spruce was relatively resistant to damage, whereas a number of the pines (Scotch, red, Austrian [*Pinus nigra*], jack and white pines), Norway spruce and a variety of deciduous trees (Northern red oak [*Quercus rubra*], ash [*Fraxinus* sp.], cottonwood [*Populus deltoides*], yellow poplar [*Liriodendron tulipifera*] and Osage-orange [*Maclura pomifera*]) were badly damaged by small rodents (Cayford and Haig 1961; Sartz 1970; Von Althen 1971). Recent studies on the Alberta Forest Service plots on the GCOS reclamation sites also indicated that deciduous trees were generally more susceptible to small mammal damage than were coniferous species (Table 1).

Those tree species that are least preferred by small rodents are most likely to survive, but a low preference rating does not guarantee survival. Several studies have indicated that the density of ground cover (Jokela and Lorenz 1959; Cayford and Haig 1961) and aspect of the slope (Sartz 1970) are closely related to the amount of damage sustained by the trees. The availability of more preferred carbohydrate sources also influences the amount of damage. Nevertheless, the use of less preferred tree species in afforestation programs should aid in decreasing the extent of small rodent damage and should lead to increased survival of saplings on reclamation sites.

Table 1. Percentage of rodent damage on Alberta Forest Service afforestation plots, Fort McMurray.[a]

	Percentage Girdled					
	Tailings Dike Northwest Site		Tailings Dike Southeast Site		Overburden Dump Site #5	
SPECIES PLANTED	1975	1976	1975	1976	1975	1976
Dogwood	-	36	-	-	-	-
Golden leaf willow	3	31	1	23	-	2
Russian poplar	-	22	-	-	-	-
Caragana	2	18	-	-	-	-
Acute leaf willow	15	16	1	1	-	1
Peach leaf willow	5	15	-	17	-	7
Choke cherry	24	12	-	-	-	-
Griffin poplar	6	8	-	-	-	-
Manitoba maple	-	8	-	1	-	-
Bur oak	14	8	-	-	-	-
Green ash	6	8	-	-	-	-
Laurel leaf willow	1	7	-	5	-	14
White birch	8	6	-	-	-	-
Brooks poplar	11	5	-	1	-	-
Northwest poplar	-	5	-	6	-	-
Balsam poplar	55	5	1	13	-	-
Manchurian elm	-	5	-	-	-	-
May day	13	4	-	-	-	-
Buckthorn	-	3	-	14	-	13
Honeysuckle	9	2	-	-	-	-
Speckled alder	-	1	-	-	-	-
American elm	1	-	-	-	-	-
Native poplar	-	-	-	10	-	-
Native willow	-	-	-	8	-	-
Trembling aspen	-	-	2	5	-	-
Arctic willow	-	-	-	-	-	-
Black cottonwood	-	-	-	-	-	19
Lodgepole pine	-	-	-	-	-	-
Jack pine	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-
White spruce	-	-	-	-	-	-
Colorado spruce	-	-	-	-	-	-
Balsam fir	-	-	-	-	-	-

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[a] From Radvanyi (1976); data originally provided by Alberta Forest Service.

3. METHODS OF CONTROL

Many methods have been employed or proposed to control either the abundance and distribution of 'pest' species of small mammals or the damage that they cause. These control methods can be classified as chemical, mechanical or environmental controls, depending on their mode of action. Each of these classes of control methods is considered in this section; for each of the methods, the range of techniques commonly used in the past or currently in use, proposed new techniques, the advantages and disadvantages of each method, and the feasibility of employing these methods in large-scale control programs for wild populations of small mammals are discussed.

3.1 CHEMICAL CONTROL

Chemical control of rodent populations currently includes the use of rodenticides and chemosterilants to reduce the number of small mammals and the use of repellents to discourage the consumption of specific plants, plant parts or materials. Chemical control has been the most commonly used control method in recent years, and a major portion of the literature on control methods deals specifically with the uses of chemical controls.

3.1.1 Rodenticides

A wide variety of lethal chemical compounds that exhibit a broad range of mechanisms of action are currently in use or have been used to control rodent populations. Rodenticides can be classified as either acute (single-dose) poisons or chronic (multiple-dose) poisons. The effectiveness of a poison control program is dependent largely on the toxicity and the specificity of the compound, on its acceptance by the target species, and on the risk of direct or secondary poisoning of non-target species. Direct poisoning results from the consumption of poison by non-target species; secondary poisoning results from the consumption of poisoned target species.

3.1.1.1 Acute poisons. The effectiveness of an acute poison is dependent on the target species consuming sufficient poison in a single dose to result in its death. The time lapse between the first intake of the poison and the onset of the symptoms of the poisoning is extremely important in determining the effectiveness of the poison. If symptoms occur before a lethal dose is consumed, bait shyness is invariably induced (Lund 1975). Generally, the quicker acting the poison, the less effective it will be, particularly with rats. Gratz (1973) describes the ideal acute rodenticide as a compound that is highly toxic, acceptable, and specific to rodents, and that is easily reaccepted by the target species should a sublethal quantity be consumed (i.e., failure to induce bait shyness). Also important are the persistence of the poison in the bait form (i.e., whether poison remains potent during the period of baiting required for control) and the solubility, cost, availability and ease of use. Poor bait acceptance or reacceptance can sometimes be overcome by prebaiting. The bait without the poison is provided to the 'pest' population; once the animals freely accept the non-poisoned bait, poisoned bait is substituted in its place.

The effectiveness, degree of acceptance, hazards of use, and mechanisms of action of some of the more commonly used acute rodenticides are reviewed in the following section. The review is based largely on reviews by Peoples (1970), Gratz (1973) and Lund (1975). A summary of the main characteristics of most of these acute rodenticides is presented in Table 2.

> *Alpha-chloralose*--Alpha-chloralose is a narcotic drug that causes fatal heat loss in small mammals through retardation of their metabolic processes. It is most effective when used at temperatures below 12°C. It presents few risks of direct or secondary poisoning to larger mammals, but it is hazardous to small granivorous birds. To date it has been used effectively against *Mus musculus*.

Table 2. A summary of the main characteristics and recommendations for the use of some of the most important available single-dose rodenticides.[a]

Rodenticide	Concentration Used in Baits (%)	Time to Death[b] (hours)	Degree of Effectiveness in Rats	Acceptance	Reacceptance	Tolerance Developed	Soluble in Oil or Water	Hazard to Man	Recommendation
Antu	1-3	12-36	good	good	poor	yes	neither	moderate	against urban Norway rats, single application
Arsenic (III) oxide	1-3	5-48	fair	fair	fair	yes	water	moderate	not recommended
Barium carbonate	20	2-24	poor	fair-poor	fair-poor	unknown	neither	moderage	not recommended
Norbormide	0.5-1.0[c]	0.5-4.0	good[d]	fair	fair-poor	unknown	oil	low	against Norway rats
Phosphorus (yellow)	1-3	12-48	fair	fair	poor	no	oil	moderate-extreme	not recommended
Red squill	10	6-120	fair	fair	poor	no	both	low	against urban Norway rats
Sodium fluoroacetate	0.22-0.32	1-72	good	good	good	no	water	extreme	restricted use against all species
Fluoroacetamide	2	3.5-96.0	good	good	good	no	water	extreme	restricted use against all urban species
Strychnine	0.6	0.2-2.0	poor	poor	poor	yes	water	moderate-extreme	not recommended
Thallium sulphate	0.5-1.5	12-120	good	good	good	no	water	extreme	restricted use against all species
Zinc phosphide	1.0	12-120	good	good	good	no	oil	moderate	against all urban and rural species

[a] From Gratz (1973).

[b] See Mallis (1960).

[c] For roof rats.

[d] *Rattus* only.

Antu--Antu was developed over 30 years ago by Ritcher (1945). It is effective against Norway rats but other rat species and mice are more resistant. Initial acceptance by rats and mice is good, but bait shyness does occur. Antu is not readily soluble in water, but it is readily absorbed in the intestinal tract and specifically affects the capillaries of the lungs, resulting in the development of pleural effusion and pulmonary edema. Antu is toxic to a wide variety of wildlife and should be used with caution. There are also suspected carcinogenic effects. Owing to its poor reacceptance, its low effectiveness against most rodents and the hazard it presents to other mammals, it is not recommended for general use.

Arsenic (III) Oxide--Arsenic oxide and other related compounds have been used in the past to control rodents. Arsenic is effective against rats, but not against mice. Acceptance and reacceptance are fair, but its use is limited by the danger to man, to other mammals, and to birds; its use is consequently restricted or banned in many countries. Arsenic causes death by acute irritation of the gastrointestinal tract, resulting in intestinal bleeding, secondary shock and destruction of liver tissue.

Barium Carbonate--Barium carbonate was once used extensively in Europe. It is a weak rodenticide that is poorly accepted by rodents. Barium carbonate reacts with and blocks specific receptors in smooth muscle tissue; it most seriously affects the cardiac muscle, blood veins, and the gastrointestinal tract. Its use is not recommended because it is a poor control method and because it presents a moderate hazard to other species.

Crimidine--Crimidine is a fast acting rodenticide that has been used primarily to control mice. It is extremely toxic to all mammals and its acceptance by mice is not good. Its mode of action is to block the central nervous system, resulting in fatal convulsions.

Endrin--Endrin is an organochlorine compound that was initially used to control insect pests. It is toxic to mammals and causes immediate mortality in small mammal populations (Horsfall 1956; Scott *et al*. 1959; Morris 1968, 1970). Endrin persists for long periods in the environment, is easily retained in animal fats, and has long-term toxic effects. Birds, particularly raptors, are very susceptible to secondary poisoning (Rogers 1976). Endrin affects the central nervous system resulting in tremors, muscular constrictions and convulsions. Because of the extreme hazards of direct and secondary poisoning of non-target species, and the persistence of endrin in the environment, its use is not recommended.

Flouroacetamide--Flouroacetamide is closely related to sodium flouroacetate, but it is not as toxic. It is well accepted and produces little bait shyness; however, it is not specific to rodents. Its persistence in the environment presents an extreme hazard to man and other non-target species. Flouroacetamide enters the citric acid cycle exactly as does acetate and results in the formation of flourocitric acid, which blocks the enzyme aconitase. The end result is a blocking of the TCA cycle and widespread functional changes in all organs. Cardiac failure is common.

Gophacide--Gophacide is a relatively slow-acting organophosphorus compound that is effective against most rodents (Ward *et al.* 1967; Redfern *et al.* 1975; Rowe *et al.* 1975). Its palatability is low and bait shyness may result. Gophacide is not specific, and there is a risk of direct and secondary poisoning of non-target species. Handling risks are high as it is readily absorbed through the skin.

Norbormide--Norbormide is a recently developed rodenticide that is characterized by a high degree of specificity for *Rattus* sp. and that is essentially non-toxic to mice or a variety of other wildlife species. The basic mode of action is on the smooth muscle of the peripheral blood vessels, causing them to constrict irreversibly; this results in a shortage of blood and can lead to the death of the animal.

Phosphorus (Yellow)--Yellow phosphorus has been used in commercial preparations of a 1-2% paste, which is spread on the bait. It is reasonably effective against rats, but is poorly accepted by mice. Yellow phosphorus is extremely hazardous to all wildlife, and it is not recommended for large scale pest control campaigns. It also poses a fire hazard due to its spontaneous combustion at temperatures of approximately 30°C. It produces severe irritation of the gastrointestinal tract, leading eventually to circulatory failure, and also results in destruction of liver and kidney tissues.

Red Squill--Red Squill is one of the oldest rodenticides. It is prepared by drying and powdering the fleshy inner bulb scales of the red variety of *Urginea maritima*. It is comparatively hazardless to most mammals because the high levels of oxalic acid and tannic acid in the crude drug cause most animals to vomit after ingesting it. Red squill is effective against rodents, however, because they cannot vomit to eliminate the poison. The active compound in red squill is scillaroside (a cardiac glycoside) which acts directly on the heart muscle, slowing the heart rate and culminating in cardiac arrest.

RH-787--RH-787 is one of a new series of acute target-specific rodenticides. It is effective against a broad range of rodents, but appears to be only moderately hazardous to other mammals (Peardon 1974). No secondary poisoning hazards were apparent. RH-787 is accepted by rodents in most bait and does not cause bait shyness because it is relatively slow acting. Its mode of action is not yet known.

RS-150--RS-150 is a recently developed rodenticide that is extremely toxic to all mammals. It has been used effectively against Norway rats but direct non-target poisoning hazards are high. As a result its uses are restricted. RS-150 hydrolyzes rapidly in the field (3 days); this reduces secondary poisoning hazards.

Silantrane--Silantrane is a relatively new rodenticide. It is an extremely toxic and fast-acting poison that appears to rapidly induce bait shyness. It is toxic to many animals, but shows low dermal toxicity. Secondary poisoning hazards are reduced because it eventually hydrolyzes into non-toxic products when exposed to field conditions.

Sodium flouroacetate--Sodium flouroacetate is a very similar rodenticide to flouroacetamide, but it is more toxic (Emlen *et al.* 1958; Rowley 1960, 1968; Batchelor *et al.* 1967). The risks of direct or secondary poisoning of non-target species are high (Schitoskey 1975). The mode of action is identical to that described for flouroacetamide. Sodium flouroacetate was used extensively to control rodents until its use was greatly restricted by government legislation.

Strychnine--Strychnine is an alkaloid extracted from the seeds of *Strychnos nux-vomica* and has been used as a poison in Europe since the seventeenth century. Strychnine is still widely used against vertebrate pests such as jack rabbits, coyotes and wolves, but its bitter taste may interfere with its effectiveness. Strychnine presents serious direct and secondary poisoning hazards to non-target species (Schitoskey 1975). Its mode of action is primarily on the neurons of the spinal cord, lowering the threshold for the stimulation of spinal reflexes. Death results from anoxia due to holding of the breath while in a convulsive state.

Thallium sulphate--Thallium sulphate is one of the most effective rodent poisons (Mallis 1960) and is readily accepted by most rodents (Krauch 1945; Rennison 1976). Its use has been limited, however, because it is one of the most hazardous rodenticides to non-target species, through both direct and secondary poisoning. Furthermore, it is a persistent and cumulative poison. It is believed that thallium sulphate reacts with free -SH groups in essential proteins (i.e., enzymes) and so leads to widespread damage in most organ systems.

Zinc Phosphide--Zinc phosphide is a fast-acting rodenticide that is effective against most rodents (Hood 1972; Rennison 1976). It is relatively well accepted by rodents, although bait shyness can occur if sublethal doses are consumed. There is a risk of direct and secondary poisoning to birds and large mammals (Bell and Dimick 1975, Schitoskey 1975), but this risk is of short duration (zinc phosphide deteriorates within 3-4 days in the field). To combat direct poisoning hazards of non-target species, zinc phosphide is usually mixed with a tartar emetic prior to application. Death results from the production of phosphene gas in the stomach, which readily enters the blood stream and results in heart failure and kidney damage.

Other Acute Rodenticides--Other compounds such as dimethoate (Barrett and Darnell 1967), DRC 714 (Hoffer *et al.* 1969) and a variety of organochlorine products have also been tested for use as acute rodenticides. The use of these compounds, as well as many of the others just discussed is limited because of the problems of initial acceptance, development of bait shyness, or hazards to non-target species. Furthermore, because the small mammals rapidly develop bait aversions to many acute rodenticides, it is necessary to change bait types and/or rodenticides regularly to maintain control; considerable man-power is needed as a result.

3.1.1.2 Multiple-dose rodenticides. Some of the problems of bait acceptability and the development of bait shyness have been solved by the introduction (during the 1950's) and the subsequent widespread use of multiple-dose rodenticides. Multiple-dose rodenticides should be consumed over a period of several days to be effective. Symptoms of poisoning are delayed, and the rodent consumes a lethal dose before it is warned and ceases to feed on the bait (Lund 1975). Bait shyness is not as likely to occur. Prebaiting is not necessary; control campaigns using multiple-dose rodenticides are, as a result, less manpower intensive. Two types of multiple-dose rodenticides are currently in use or are being investigated--vitamin D and anticoagulants.

The use of vitamin D as a multiple-dose rodenticide is a relatively new control technique. At a concentration of 0.01% calciferol (vitamin D), rats and mice are killed within 2-3 days. It appears to be relatively well-accepted by rodents. Death is thought to be due to renal failure as a result of abnormally high levels of calcium in the blood (Lund 1975). It has not yet been tested in a field situation.

Anticoagulant rodenticides came into use primarily as a result of the discovery that dicoumarol was the active agent in hemorrhagic disease, which is caused by the consumption of spoiled sweet clover. This discovery led to the development of two groups of compounds derived from either coumarin or 1,3-indandione (Peoples 1970). Both groups have the same mode of action; their basic chemical structure is sufficiently similar to that of vitamin K that they competitively interfere with its conversion to prothrombin in the liver. With the decrease of prothrombin levels below a critical threshold, blood clotting does not occur and internal hemorrhaging begins throughout the body. Hemorrhaging eventually becomes so severe that the animal bleeds to death (Peoples 1970).

Anticoagulants are extremely toxic to all mammals (if consumed in several successive doses), but they are less hazardous to birds (Giban 1974). Secondary poisoning hazards do not appear to be significant.

A number of anticoagulants have been commonly used during the past 25 years. Warfarin was one of the first anticoagulants developed and was widely used for the control of rats and mice in urban areas. Its use is now more restricted due to both the appearance of Warfarin-resistant rat populations in many areas (Brooks and Bowerman 1973, Greaves *et al.* 1976) and the development of more effective anticoagulants, such as the oil-soluble indandiones. Chlorophacinone and diphacinone are two of the more commonly used indandione anticoagulants; both have been shown to be effective against both rats and mice (Bentley and Larthe 1959; Rowe and Redfern 1968; Giban 1974; Horsfall *et al.* 1974; Palmateer 1974). Chlorophacinone in particular was recommended for use on *Mus musculus* (Rowe and Redfern 1968) and on *Microtus arvalis* (Groulleau 1971, cited in Giban 1974). Chlorophacinone produced high mortality (97% of a *M. arvalis* population in 3 days [see Table 3]), yet was relatively well accepted by the target species. Diphacinone has been shown to be an effective means of controlling rats (Kusano 1974; Palmateer 1974) and mice (Groulleau 1971, cited in Giban 1974; Kusano 1974). Marsh *et al.* (1977) found diphacinone was more effective than chlorophacinone against *P. maniculatus*. Radvanyi (1974, 1976) and Martell and Radvanyi (1977) used the anticoagulant Rozol in several control programs (one in an eastern Canadian hardwood forest and one on a reclamation site in the AOSERP study area). Good percentage kills were reported. More recently a new anticoagulant WBA-8119 has been tested on laboratory rats and mice; it was highly effective against rats and was one of the most active anticoagulants known for Warfarin-resistant mice (Redfern and Gill 1976; Rowe and Bradfield 1976).

The development of resistance to anticoagulants by rodents is one of the major drawbacks to long-term usage of anticoagulants for rodent control. Many populations of rats and mice that had been intensively controlled with Warfarin treatments have subsequently developed resistance to the poison (Drummond and Rennison 1973; Greaves *et al.* 1976). The resistance of these

Table 3. Mortality after *ad libitum* feeding of 0.0075% anticoagulant baits to *Microtus arvalis*.[a]

Anticoagulant	Mortality After One Feeding	Mortality After Three Daily Feedings
Coumafene	5/20 (0.25)	5/20 (0.25)
Coumafuryl	4/20 (0.20)	15/20 (0.75)
Coumatetralyl	2/20 (0.10)	17/20 (0.85)
CPPH	2/20 (0.10)	7/20 (0.35)
Pivaldione	2/20 (0.10)	9/20 (0.45)
Diphacinone	3/20 (0.20)[b]	15/20 (0.75)
Chlorophacinone	318/459 (0.69)	279/289 (0.97)

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[a] From Grolleau (1971) cited in Giban (1974).

[b] sic.

species to anticoagulants is the result of increased prothrombin levels in the blood, an increased affinity for vitamin K, and a more rapid prothrombin reaction; blood clotting is more rapid as a result (Greaves and Ayres 1967). Studies of Warfarin-resistant rat and mouse populations have found that the resistance to Warfarin is inheritable and is a dominant characteristic controlled by an autosomal gene (Bishop and Hartley 1976; Greaves *et al.* 1976). Because of the similar modes of action of most anticoagulants, development of resistance to one anticoagulant also results in increased resistance to other anticoagulants. As populations develop resistance, progressively more toxic anticoagulants must be used (Lund 1967) or other forms of control must be instituted (e.g., acute rodenticides, chemosterilants). The use of more toxic compounds leads to increasing risk of direct or secondary poisoning of non-target species.

3.1.1.3 Problems of using rodenticides. Many examples have been reported of the use of rodenticides as a control method to reduce rodent numbers, but few can claim any more than temporary success (Myllymaki 1975b). Gashwiler (1969), for example, used the acute rodenticide 1080 to reduce the number of *P. maniculatus* on a clear cut area that was to be reseeded. Numbers declined sharply following the treatment, but five months after the treatment the numbers of mice were of the same magnitude as the control population. Morris (1970, 1972) found that when a population of *M. pennsylvanicus* was reduced using the rodenticide/insecticide endrin, the population quickly recovered and thereafter consistently exceeded the density of *M. pennsylvanicus* on the control area. Smith and Aldous (1947) and Radvanyi (1974) reported similar rapid reinvasions by small mammals after the use of rodenticides.

Rapid reinvasions and increases in the number of small mammals following reductions appear to be a direct result of the disturbance of the natural regulatory processes of these populations (Tevis 1956b). Studies of populations of *M. pennsylvanicus*

(Morris 1970, 1972), and *P. maniculatus* (Gashwiler 1969) that had undergone reductions as a result of the application of rodenticides showed that more new recruits appeared on the poisoned areas and that these animals survived significantly better than animals on the control area. In addition, animals on the poisoned area came into breeding condition at an earlier age and had a longer reproductive period than animals on the control area. Because the animals on a poisoned area breed more successfully and survive better than animals in undisturbed areas, the rate of population increase on the poisoned area is far more rapid than in unpoisoned areas. Morris (1970) suggests that the phenomenon of increased breeding and survival is largely the result of the reduction in numbers and a consequent decrease in intraspecific aggressive encounters. This in turn leads to a severe disruption of the social structure and related natural regulatory processes of the population. The use of single applications of rodenticides or any other form of control to reduce the numbers of small mammals thus appears to result in a population response quite different from the desired effect of a reduction of the 'pest' species.

Radvanyi (1974) and Martell and Radvanyi (1977) attempted to solve the problem of the increased breeding and survival response by providing poisoned bait on a continuous basis. Poison bait feeders were established throughout the study areas and were supplied continuously with poisoned bait (whole oat groats and Rozol). In both studies, reductions occurred in the populations, but as populations on control areas also declined, it was not clear what proportion of the decline on the poisoned areas was due to the poison treatment. Despite the lower densities on all areas, severe girdling of young trees still occurred during the winter. Low density vole populations apparently do not assure lower levels of tree damage.

3.1.2 Chemosterilants

E.F. Knipling in 1938 was one of the first to suggest that animal populations--specifically insect populations--could be controlled by regulating their reproductive success (Smith 1966). The application of this concept to wild mammal populations was considered first by Knipling (1959) and by Davis (1961). Marsh and Howard (1973) defined a chemosterilant as a compound capable either of producing permanent or temporary sterility in either or both sexes or of reducing the number of offspring or altering the fecundity of the offspring produced through some physiological effect.

Marsh and Howard (1970) described the ideal chemosterilant as a compound that is highly specific, orally effective, and affecting either both sexes or at least females. Those chemicals that produce permanent sterility in a single feeding are more desirable than those that cause temporary sterility or that interfere with post-copulatory phases of reproduction, because the timing of the application of the chemosterilant in relation to the reproductive cycle of the target species is not as important and because reapplication is required less often. An ideal chemosterilant should also produce no bait aversion, nor should it affect libido or aggressive and territorial behaviour. It should remain biologically active for long periods when exposed to field conditions, yet should break down in the tissue of the target species so that secondary toxicity or sterility hazards to non-target species are avoided.

Chemosterilants for the control of rodent populations would be most effective if they affected both males and females. Those causing sterilization only of females would be slightly less effective, but those affecting only male animals would be the least likely to successfully affect the reproductive potential of rodent populations. Most rodent populations have a polygamous mating system (Marsh and Howard 1973), and unless a high proportion of the males in a population are effectively sterilized, the remaining fertile males could impregnate a large number of females. The sterilization of males is preferable to their elimination, however, because female rats that mate with sterile males may go through a pseudo-pregnancy and hence decrease the number of normal pregnancies (Marsh and Howard 1973). Compounds that directly affect female reproduction have the advantage that they not only reduce female fertility but also may cause abnormalities in the development of the embryo or the sexual development of the young. If both males and females are sterilized the effects are compounded, and the likelihood of successful control is increased over that of control methods in which only males or females are sterilized.

To date, much more is known of the physiological effects of using chemosterilants than is known of the ecological consequences. The known physiological modes of activity include:

1. prevention of the production of gametes or of the union of the sperm and egg,
2. prevention of the attachment of the fertilized ovum to the uterus,
3. interference with the pre-natal development of the embryo (i.e., direct chemical attack on the embryo),
4. interference in the neo-natal development of the young (i.e., a decrease in lactation), and
5. interference in the sexual development of the young such that any of the above factors may occur in the young (Jackson 1959).

Currently chemosterilants can be divided into two groups--steroidal and non-steroidal compounds. Steroidal compounds are capable of reducing gamete production, preventing the implantation of the ovum and interfering in the sexual development of the young. Estrogens and androgens can be used to inhibit reproduction (Marsh and Howard 1970). Some synthetic steroids such as mestranol, quinestrol and diethylstilbestrol may be useful chemosterilants. If mestranol, for example, is provided to female rats during lactation, their young are permanently sterilized by the mestranol contained in their mother's milk (Howard and Marsh 1969; Marsh and Howard 1969). When fed to nursing voles, mestranol has also lowered the reproductive potential of the young voles (Storm and Sanderson 1970). These compounds are of little use in large scale field programs, however, because to be effective they must be available during critical periods of the female reproductive cycle or gestation period. Either the application of the chemosterilant must be precisely timed or the chemosterilant must be continuously available.

The effectiveness of some chemosterilants has been further reduced due to both behavioural changes and unfavourable side effects, such as bait aversion. Rats and mice have rapidly developed aversions to mestranol and quinestrol (Kendle *et al.* 1973). Goulet and Sadlier (1974) and Marsh and Howard (1970) found that some chemosterilants tended to increase social tolerances and thereby disrupt natural regulatory processes.

Despite these problems some control programs using steroidal chemosterilants have been successful. Kendle *et al.* (1973) used a new chemosterilant, BDH 10131, to control a rat population in an urban garbage dump. Reproduction of rats was successfully inhibited; six months after the treatment the treated population was 25% of its former level, whereas the number of animals in the control population had remained relatively stable. Goulet and Sadlier (1974) provided mestranol to populations of Richardson's ground squirrels (*Spermophilus richardsonii*); although their reproduction was reduced, increased survival of the remaining young and increased immigration of yearlings and adults from other areas nullified the effects of the treatment.

Non-steroidal chemosterilants include a variety of compounds capable of causing effects that range from temporary inhibition of reproduction to permanent sterilization. Clomiphene and transclomiphene have been considered as female reproductive inhibitors (Marsh and Howard 1970). Colchicine, an alkaloid extract from a number of species of Liliaceae, is an effective female chemosterilant (Srivastava 1966, cited in Marsh and Howard 1970), but it is of limited use due to its toxicity hazards.

A number of alkylating agents (e.g., nitrogen mustard) are useful male reproductive inhibitors. Derivatives of nitrofuranes (nitrofurazone, nitrofurantoin) interfere with spermatogenesis (Srivastava 1966, cited in Marsh and Howard 1970). Ethyleneamine derivatives (tetramine, TEM [triethylenemelamine] and thiotepa) similarly inhibit spermatogonial development in male rats, but do not appear to affect female rats at the same oral dose (10 mg/kg) (Marsh and Howard 1970, 1973). If given to female rats shortly before parturition, however, all offspring are sterile (Skinner 1968). A new non-steroidal male chemosterilant, U-5897, was recently tested by Andrews *et al.* (1974). U-5897 causes epididymal lesions resulting in permanent male sterility after a single feeding. The lesion-producing actions of U-5897 are relatively specific to several rodent species; sterility hazards to other mammals are restricted to temporary sterility of male animals.

Chemosterilants will not produce immediate reductions in the population size of the target species, but if reproduction is successfully limited and immigration is minimal, the population will gradually decline through natural mortality. It is feasible then to consider integrated control programs of population reduction and reproductive inhibition using rodenticides and chemosterilants. Chemosterilants offer a possible means of controlling the increased breeding response that is typical of many population reduction programs (Howard 1967a; Marsh and Howard 1973). Chemosterilants may be particularly valuable against anticoagulant-resistant populations; animals that were not killed by the anticoagulant would be prevented from effectively reproducing, and the development of resistant genotypes in the population would be retarded. One of the greatest advantages of chemosterilants is that, as a result of their selectivity and the methods of use, the risks of lasting direct or secondary effects on non-target species are low. The use of chemosterilants in rodent control should thus reduce the need to use lethal rodenticides and should change the emphasis of rodent control from increased mortality to reduced natality. Considerably more work is needed, however, before wide-scale use of chemosterilants can be a practical control technique.

3.1.3 Repellents

The use of chemical repellents to deter small mammals from consuming plant material can be divided into two categories--the use of the natural repellency of plants to animals and the application of synthetic repellents.

Both the natural resistance of plants to mammals and the factors contributing to this resistance are poorly understood (Radwan 1974). Some tree species, such as white pine and Scotch pine, consistently sustain higher amounts of small mammal damage than do species such as white spruce and balsam fir (Littlefield *et al.* 1946; Jokela and Lorenz 1959; Cayford and Haig 1961; Von Althen 1971). Repellent qualities may be the result of the physical structures or chemical contents of the plants.

There are few good examples of physical mechanisms that prevent small mammal damage. Old bark on trees may aid in resisting girdling. Thorns are probably effective only in deterring larger herbivores (Hansson 1975b).

Numerous studies have related the browse preferences of ungulates and small mammals to the levels of lignin, total fibre, essential oils, phenolic compounds, toxicants and various nutrients in browse species (Heady 1964; Radwan and Campbell 1968; Hansson 1973b, 1975b; Radwan 1974; Kendall and Sherwood 1975; Kendall and Leath 1976). High levels of carbohydrates, fatty substances and minerals in browse species appear to act as attractants (Hansson 1971a, 1973b); barks of tree species commonly girdled by small mammals, for example, were frequently found to contain high amounts of carbohydrates and minerals (Hansson 1975b). Excess fertilizing has been associated with increased localized browsing by hares, grouse and rabbits on heather in Scotland (Miller 1968) and by herbivores on tall fescue hay in the U.S.A. (Reid and Jung 1965). Conversely, factors such as stilbenes (which are toxic to small mammals and which occur in many conifers), high tannin contents, cardiac glycosides, high phenolic contents or high levels of essential oils may act as repellents (Nagy *et al.* 1964; Robinson 1967; Whittaker and Feeny 1971). Extracts from some plants such as scillaroside (from red squill) or strychnine (from the seeds of *Strychnos nux-vomica*) have been used as acute rodenticides, and may also be useful as repellents.

A number of studies, many of which were associated with limiting tree seed predation during revegetation projects, have examined the feasibility of using chemical repellents to decrease small mammal damage. Contact repellents (those sprayed onto the surface of the plant) have been examined more frequently and have been used more extensively than systemic repellents (those applied in solution and subsequently incorporated into the plant tissue).

Tetramine was one of the first contact repellents used to deter small mammal predation of tree seeds (Casebeer 1954; Spencer 1954). Prior to the broadcasting of the seeds, they were coated in a mixture of tetramine and an adhesive. Seed predation by *P. maniculatus* was lowered, but was not entirely eliminated as *P. maniculatus* usually husks seeds prior to consumption and then eats only the endosperm, thus largely avoiding the repellent. Low concentrations of rodenticide solutions, such as endrin, 1080, sodium arsenite, strychnine, thallium sulphate and zinc phosphide, have been used as repellents (Dick *et al.* 1958; Welch 1967; Radvanyi 1970a). The poor initial acceptance and poor reacceptance (i.e., bait aversion) of some of these compounds actually improve their repellent qualities. Continued use of these 'rodenticide repellents' has largely been discontinued, however, due to their direct and secondary poisoning hazards and their handling risks, phytotoxic qualities and low resistance to weathering (Radvanyi 1970b).

Alternatives to these compounds have been suggested for use as contact repellents. Passof *et al.* (1974) found Antu to be a suitable replacement for endrin; it was not as effective, but it posed fewer problems and resulted in a doubling of the germination rate of untreated seeds. Lindsey *et al.* (1974) used the chemosterilant mestranol as a repellent. They used relatively low concentrations that were unlikely to reduce fertility, but that attained good repellency (Table 4). Mestranol has the advantage of being non-toxic and non-persistent. Radvanyi (1970a) found that a mixture of graphite, R55 (repellent) and acidified latex provided an effective contact repellent for white spruce and black spruce seed. TMTD (tetramethylthiuram disulphide) and ZAC (zinc dimethyldithiocarbamate) are commonly-used commercial contact repellents that have been found to be effective with ungulates (Dietz and Tigner 1968) and lagomorphs (Duffield and Eide 1962; Radwan 1969a,b). TMTD does not, however, appear to effectively repel small mammals (Radwan 1969a). The varied success of many repellents suggests that the use of repellents on their own is not an effective method of small mammal control; they may be most valuable in diverting small mammals from one food source to another (e.g., from saplings to supplementary food).

The use of contact repellents on trees would necessitate at least an annual reapplication of the repellent to renew the old repellent coating and to cover new tissue. Spraying would be best in the early fall when new plant growth has stopped. Reapplication might also be necessary in the spring or summer.

The major advantage of systemic repellents is that only occasional reapplication should be necessary. Weathering of the repellent coating would no longer be a problem, and as new growth appeared, it would be protected by the incorporation of the repellent into the tissue. Little research has been conducted on systemic repellents. Selenium was used as a systemic repellent in Douglas-fir saplings, but its use was not successful; the concentrations of selenium needed to repel small mammals were sufficient to damage or kill the plants (Rediske and Lawrence 1962). Alterations of fertilization programs could also be used as a form of systemic repellents--by increasing the concentrations of less preferred chemicals and/or by decreasing the levels of preferred chemicals in the fertilizer, similar changes should occur mammals from small plots during reseeding programs; the screens were left in place until the seeds had germinated (Keyes and Smith 1943).

Aluminium foil collars are widely used on fruit trees in Finland (Myllymaki 1975a,b,c) because of their relatively low cost. Their one disadvantage is that they must be removed each spring to allow aeration of the tree, with consequent increases in labour costs. Rigid collars constructed of plastic or of wire screen are expensive to construct and to install but do not require removal each spring for aeration because of their loose fit. Care must be taken to ensure that these rigid collars are properly positioned so that damage to the plant, caused by rubbing against the collar, does not occur. Protective sheet metal collars were installed around individual trees on the GCOS reclamation site in an attempt to combat high levels of rodent damage to newly planted seedlings; however, they did not effectively reduce the levels of small rodent damage (Radvanyi 1976).

The widespread use of mechanical guards does not appear to be a feasible method of rodent control especially on areas the size of existing and envisioned revegetation plots in the Athabasca Oil Sands. Their success in preventing small mammal damage does not merit the costs of their construction, installation and maintenance.

3.2.2 Sonic Repellents

Sound has been used successfully to deter waterfowl from specific areas (Koski and Richardson 1976), and has been suggested as a means of repelling rodents (Myllymaki 1975b). No field tests of sound deterrents on wild rodent populations have been conducted. Available studies have concerned rodent 'pest' populations in urban areas (e.g., warehouses, granaries). Sprock *et al.* (1967) found intermittent or continuous sound to be effective in repelling rats, but effective control required high noise levels. Continuous sound at levels about 120 db and at frequencies of 4-19 Kc proved effective in repelling rodents. However, these high noise levels are not acceptable for rodent control in areas of frequent human use. Greaves and Rowe (1969) used pulsed ultrasound to control *Mus musculus* in a warehouse. Two tests (of 76 and 81 days duration) indicated that ultrasound was effective in repelling mice. It is unlikely that this method is feasible in a large-scale field program, however, because high power ultrasound radiators are very expensive and energy-consuming (Stewart 1974; Myllymaki 1975b).

Myllymaki (1975b) also suggested that alarm or distress calls of rodents could be used to continuously disturb and eventually repel rodents. Like other noise repellent methods, the noise levels required for effective large-scale field use would probably be unacceptable in areas of frequent human use.

3.3 ENVIRONMENTAL CONTROL

Of all the control methods, environmental controls are the least well understood and consequently are infrequently used. Their effectiveness rests largely on an understanding of the ecology of the 'pest' species in natural and 'pest' situations and an effective use of the natural components of the system to control either the abundance and/or distribution of the 'pest' species or the amount of damage caused by the species. Environmental controls include the use of supplementary food supplies, biological control (the use of predators or disease), genetic manipulation and habitat manipulation.

3.3.1 Supplementary Food

The provision of supplementary food sources has been used to control the amount of damage by wildlife to commercial crops. Piles of fruit tree prunings have been used in orchards to draw small mammals away from (and thus prevent damage to) large fruit trees (Fitzwater 1962). Alternate foods have been valuable in luring waterfowl away from grain and vegetable crops (Howard 1967a). Sullivan (1977) is currently evaluating the effectiveness of providing an alternate food source (sunflower seeds) to populations of small mammals on reseeded areas near Haney, B.C., in order to lower the rate of seed predation by *P. maniculatus* on Douglas-fir seeds. The basic concept of this approach is that sunflower seeds are preferred to Douglas-fir seeds, and that if sunflower seeds are provided in larger proportions than the Douglas-fir seeds, the predation pressure on Douglas-fir seed should be reduced and there should be an increased chance that the Douglas-fir seed will germinate.

The underlying assumption of the use of supplementary food to control rodent damage is that, because of a shortage of alternative and more preferred food resources, the animals are forced to consume bark and twigs to obtain the necessary carbohydrates, minerals, and other nutrients that they require in order to survive. Hansson (1973a) found that *Microtus agrestis* has a low assimilation efficiency (approximately 50%), and so must consume large amounts of easily digestible material to maintain itself. In a laboratory test he offered animals a choice of several different carbohydrates, one of which was always tree stems. Animals that were offered only laboratory food pellets (in addition to the bark) continued to girdle the tree stems, but no girdling occurred when green vegetation and/or small twigs were offered in combination with laboratory pellets. Hansson (1973a) concluded that tree girdling occurred only when more preferred carbohydrate sources were unavailable. No comparable field studies have been conducted.

Supplementary food has been provided to wild populations of small mammals in a number of studies, but these studies have been concerned more with demographic responses than with changes in the feeding behaviours of these animals. Nevertheless, these studies do provide information on the ecological consequences of the provision of supplementary food. Krebs and DeLong (1965) provided a population of *Microtus californicus* with a continuous supply of oats and chick seed for 11 months, during which time demographic changes were monitored by intensive live trapping. Vegetation in the experimental area was also fertilized. Animals on the experimental area showed increased growth rates and high reproductive rates, but no large increases in population size ensued, and eventually the population decreased. Taitt (in prep.) provided supplemental food (whole oats) to populations of *M. townsendii* and *P. maniculatus* and found that the number of breeding mature animals increased in both species. However, when she removed the supplemental food supply from both populations just prior to winter, the number of breeding mature animals in both species declined sharply and both populations eventually dropped to numbers lower than those on the control areas. An *Apodemus sylvaticus* population that was provided with supplemental food had faster growth rates and better juvenile survival rates than the control population (Flowerdew 1972). In this case peak summer densities did increase, largely as a result of the increased juvenile survival, but the overwintering population densities (and hence the number of breeding animals the following spring) did not increase. Fordham (1971) provided supplemental food to several populations of *P. maniculatus*; adult survival improved, the production and recruitment of young increased, and the number of mice on the area increased. However, the increased densities were only temporary, as few of the young remained on the area. Thus, although the productivity of the population increased, the number of resident adult (breeding) animals did not change. *Peromyscus polionotus* populations increased slightly immediately after the addition of a supplemental food supply, but then followed a pattern of fluctuations in number similar to that observed on the control area (Smith 1971).

From the above examples it can be seen that the response of various small mammal populations to additional food supplies is variable. Smith (1971) proposed that resultant increases in populations of *Peromyscus* sp. that were provided with supplemental food supplies and the failure of microtine populations to do likewise was a result of the differences in the limiting factors of the populations. *Peromyscus* sp. are plant product (e.g., seed , fruit, flower) consuming omnivores, whereas microtine rodents are vegetation (e.g., whole plant) consuming herbivores. Plant product consumers are mainly limited by food supplies, whereas vegetation consumers are not (Slobodkin *et al.* 1967). Thus, although intrinsic regulating factors may be unaffected, the carrying capacity for *Peromyscus* sp. populations is increased greatly with supplemental food, but it is only moderately increased for microtine populations.

Sullivan (1977) discussed the use of an alternative food supply to control conifer seed predation in terms of the functional and numerical response of *P. maniculatus* (predators) to varying densities of Douglas-fir seed (prey). A functional response involves a change in the number of prey consumed per predator; a numerical response involves a change in the number of predators (Holling 1959, 1965). An understanding of the functional and numerical responses of 'pest' populations to changes in food supplies is useful in effectively planning a small mammal control program that involves the provision of supplementary food supplies. Buckner (1970), for example, demonstrated that the functional response (i.e., amount of girdling) of *M. pennsylvanicus* to changes in the density of jack pine seedlings was a typical sigmoidal curve; damage (i.e., bark consumption) to seedlings by *M. pennsylvanicus* increased slightly at low seedling densities, increased rapidly with increasing seedling density, and then failed to increase at high seedling density (Figure 2). Planting at low seedling densities or saturated seedling densities may thus be one method of controlling the amount of damage to seedlings by small rodents.

The addition of supplemental food to a system such as that described by Buckner (1970) requires consideration of both the effects of alternate foods on the functional response of the predator and the phenomenon of 'prey switching' by the predator (Murdoch 1969). Prey switching refers to changes in the feeding behaviour of the predator such that it exerts a disproportionately

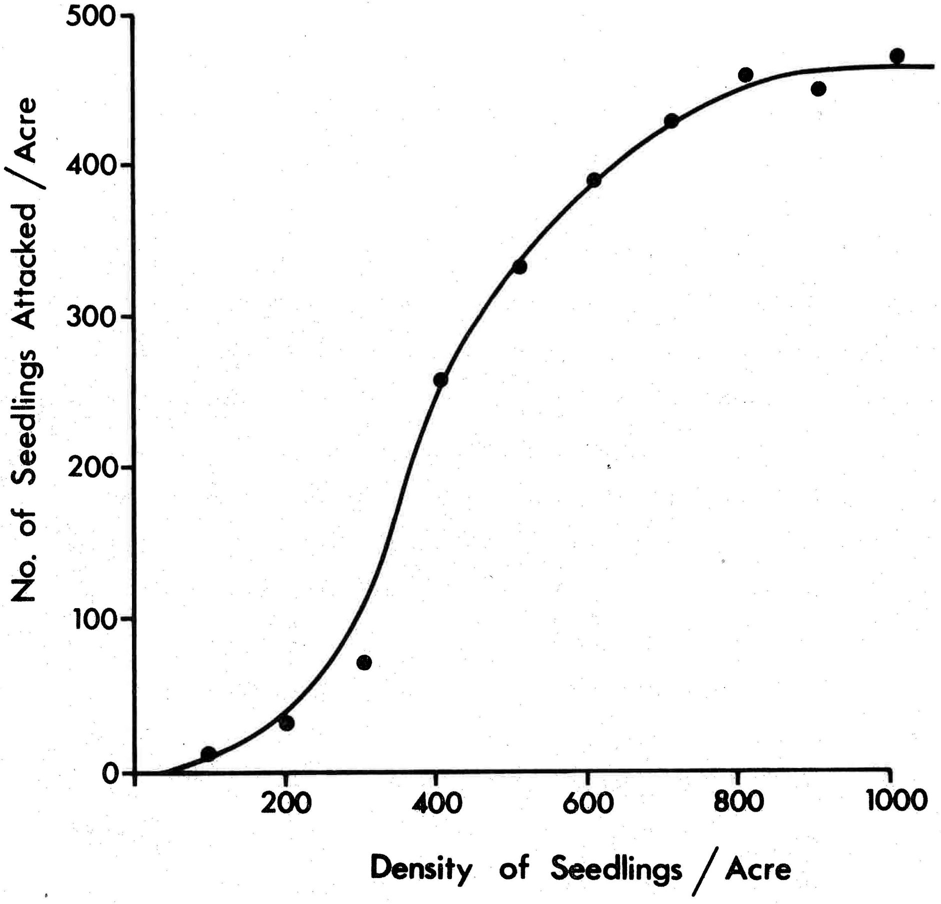

Figure 2. Functional response of *M. pennsylvanicus* to jack pine seedling density (Based on data provided by Buckner 1970:47.)

heavy predation on the most abundant prey type of comparable palatability. Sullivan (1977) suggests that by introducing alternate foods of varying palatability (preferably of increased palatability) at densities equivalent to or higher than the density of the plant or seed to be protected and with a distribution similar to that of the plant species to be protected, the switching and functional responses of the 'pest' species can be utilized to result in increased survival of the original prey (e.g., seeds, seedlings, etc.).

To effectively use supplemental foods as a means of controlling small mammal damage, one must first determine the species that is causing the damage, the preferences of the 'pest' species for the proposed alternate foods, and the relative abundances of the alternate food sources that must occur in order to affect the feeding behaviour (switching response) of the 'pest' species. Small scale studies of the numerical and functional responses of small mammal populations to supplemental food sources would not only aid in determining the feasibility of this approach on a wide scale but would also help to define the ecological consequences of the method. To date, little information is available pertaining to either the use of supplemental foods as a means of reducing small mammal damage to seedlings or the response of the 'pest' species to this method of control. Microtine rodents would probably switch from a consumption of bark and twigs to a consumption of a more preferred carbohydrate source such as whole oat groats (Hansson 1973a).

It is not clear whether supplemental food supplies will affect the population size of microtine species. Krebs and DeLong (1965) and Flowerdew (1972) found that the number of breeding mature animals in microtine populations was not affected by increased (supplemental) food supplies. Taitt (in prep.), however, found that breeding populations of *M. townsendii* and *P. maniculatus* did increase when supplemental food was available. *Peromyscus* sp. will probably increase to a maximum number that would be determined to some extent by the amount of available food; microtine species may or may not increase. Such increases are not necessarily detrimental to the success of a control program. The primary objective of a program to control rodent damage is not to reduce the population size of the 'pest' species but to lower the levels of damage caused by these animals. An effective control program may include a coincident decrease in the number of small mammals, but it need not do so.

3.3.2 Biological Control

Biological control is defined as the attempt to control the population density through the action of parasites, predators or pathogens on a host or prey population in order to produce a lower but stable population than would prevail in the absence of those agents (Wodzicki 1973). As there are no known parasites that could control rodent populations, the discussion of biological control of rodents is here restricted to the use of predators and pathogens.

3.3.2.1 Predators. The role of predation in the regulation of small mammal numbers is not well understood. Evidence suggests that predators are unable to prevent small mammal outbreaks (Pearson 1966, 1971; Erlinge 1975) and are not a necessary factor in the cyclic declines that are common to microtine species (Boonstra 1977). Following the cyclic declines of some small mammal populations, predators are able to keep the population under control for a period of time. Once the small mammal population begins to increase exponentially, however, the predators are no longer able to regulate the increase (Pearson 1966, 1971). It appears that the major reason that predators are able to maintain low populations of rodents after the decline is that the numerical response of the predators lags behind the numerical increases of small mammal populations. Thus after the small mammal decline, more predators are present than can be supported by the small mammal population. The predators can maintain control until their own numbers decrease in response to the decreasing numbers of prey;

Interest in viral or bacterial control of rodents has recently been stimulated by the success of the use of the myxoma virus to control the introduced Australian rabbit in 1950 (Fenner and Ratcliffe 1965). The specificity of the myxoma virus to leporids (and therefore the lack of a hazard to endemic Australian fauna) and the rich variety and abundance of biting insects in Australia ensured the rapid spread and maintenance of the disease in the rabbit population. Much of the current success of the control program has been attributed to the combined effects of predators and the disease. The initial rapid spread of myxomatosis through the rabbit population and the initial high mortality of the rabbits reduced the population to levels where several introduced predators (feral cat and European fox) have been able to maintain the rabbit numbers at low levels despite a fall in the virus fatality rate to 30%. Periodic outbreaks of myxomatosis have helped to further reduce the rabbit populations. Recent work has indicated that more virulent myxoma strains evolved as the rabbit population developed genetic resistance to myxomatosis. It now appears the continued success of the control program is dependent upon the continual development of increasingly more virulent myxoma strains (in natural situations or through laboratory manipulations followed by introduction to the wild population) to combat the evolution of a more resistant rabbit population.

Based on the experience of the use of the myxoma virus in Australia, several factors should be considered in any rodent control program involving pathogens:

1. the pathogen should be highly lethal to the target species,
2. the pathogen should be host specific, and
3. the pathogen should be self-perpetuating in the natural environment and capable of spreading rapidly through the target population.

At present, no known pathogen capable of controlling small rodent populations adequately fulfills these characteristics. Even if one were known, it could be anticipated that a long-term increase would occur in the survival rate of the target species as it developed a genetically-based resistance to the disease. The use of pathogens to effectively control populations of wild rodents is not yet feasible. Their use cannot be recommended until health hazards are reduced and problems associated with the rapid development of genetic resistance to disease are solved.

3.3.3 Genetic Manipulation

Genetic control of rodent populations, as defined by Marsh and Howard (1973), refers to the alteration of the gene pool within a population of rodents either by the introduction of different genotypes or by the use of specific mutagenic compounds that may induce genetic alteration. Such alteration would result in lower survival in the affected population through increased susceptibility to regulatory factors or to lethal mutations affecting the morphology, physiology or behaviour of the 'pest' species.

The release in an animal population of partially or completely sterile individuals or of fertile animals carrying genetic mutations that affect reproduction has led to the successful control of several insect populations. To date, however, it has received little attention as a means of controlling rodent populations. The advantage of genetic control is that it is highly selective--it affects a single species and only the population within that species whose genetic makeup has been altered.

All means of genetic control suffer from the drawback that, if the reproductive potential of the population carrying these genes is lower than that of the remainder of the population, fewer young will be born that carry the gene responsible for the defect (Rasmusson 1975). Similarly, if genetic sterility (either complete or partial) is introduced, fertile animals in the population will propagate and will eventually dominate the population

(Halkka 1975; Rasmusson 1975). The more effective the genetic syndrome is in reducing the population, the more it will be selected against. Further, defective characters or lethal genes that are either dominant or sex-linked recessives are diluted from a population more rapidly than recessive genes. Effective genetic control must thus rely on a combination of effects such that, through a careful program of introduction of specific recessive genes into the population, interactions among these genes will eventually result in a population that is more susceptible to specific diseases, intraspecific stress, predation, physiological imbalances or other genetic defects (Marsh and Howard 1973).

Cyclic populations of small mammals create the additional problem that selective pressures on various genotypes are known to change during different phases of the cycle. Krebs *et al.* (1973), for example, showed that the genetic composition of a small mammal population varied over a four year cycle. Introduction of new genotypes may thus be effective during one part of the cycle, but not during the remainder of the cycle.

Most investigations of the feasibility of genetic control of rodents have to date concentrated on those factors involving dominant or sex-linked recessive genes that are capable of lowering the reproductive success of a population (Gumbreck *et al.* 1972; Marsh and Howard 1973). Halkka (1975) and Rasmusson (1975) have discussed the feasibility of controlling wild rodent populations by the sterile male technique and by the release of fertile individuals with manipulated genotypes. The problems of these techniques have already been discussed; the preferred use of interacting recessive gene complexes is as yet beyond the scope of current programs.

All present means of genetic control require the rearing of substantial numbers of rodents that carry the altered genes and the release of these animals into wild populations. The acceptance of these animals into the population has itself presented a problem. Reimer and Petras (1967) found that varying proportions of the introduced mice (up to 80%) were killed by the resident mice. The proportion killed depended on the number of new mice introduced at one time. Rasmusson (1975) consequently recommended that introductions be made only at population lows or after the population had been reduced by some other method (e.g., rodenticides). Presumably at these times the breeding units and social structure of the population (such as those described for *Mus musculus* by Selander *et al.* [1969] and Selander [1970]) would be disorganized, and introduced animals would thus be able to establish themselves more easily.

Genetic manipulation does not appear to be a feasible method of controlling wild rodent populations on a large scale at this time. It may eventually be of some use in conjunction with other methods, such as to enhance the effect of anticoagulants or acute rodenticides after the target species has developed a genetically-based resistance to these substances. Before any genetic techniques are employed, however, it is imperative that the ecology of the target species (e.g., breeding units, social behaviour, cyclic fluctuations) be fully understood.

3.3.4 Habitat Manipulation

Although intrinsic factors may be important in the regulation of small mammal populations, environmental parameters are important in determining differences in the mean density or carrying capacity of an area (Hansson 1975a). Environmental factors can include behavioural adaptation to habitat stimuli; effects of climate; variation in food supply between habitat types; variation in structure, diversity and competition within a small mammal community; and the degree of habitat heterogeneity. All can be more easily manipulated than many of the intrinsic factors (e.g., social behaviour, genetic composition) (Hansson 1975a). Furthermore, the manipulation of environmental factors is much less likely to affect regulatory mechanisms than is the alteration of intrinsic factors through the removal of individuals, and the drawbacks of an increased breeding and survival response are thus largely avoided (Errington 1962; Hansson 1975a; Lund 1975; Myllymaki 1975a). The primary effect of habitat manipulation is to shift populations away from the area of concern, but it may also lead to secondary effects such as increased mortality that results from increased susceptibility to predation, increases in social stress, and/or food shortages.

Changes in habitat structure (particularly the amount of cover and the quality, abundance and diversity of food types) are one of the most effective ways of altering the environmental factors that affect both the distribution of small mammals and their resultant damage to vegetation. Hansson (1975a) reviewed the use of habitat manipulation to control rodent damage and suggested a number of methods of habitat manipulation that may be effective. These methods involve the total removal of the cover (by mowing, burning or the use of herbicides) or an alteration of the species composition of the plant community (e.g., the use of unpalatable food species, a reduction in the palatability of existing vegetation by altering fertilization schemes, changes in the types or abundance of cover, removal of refuge areas, and increases in the complexity of the plant community in order to increase the species diversity and, hence, the level of competition in the small mammal community). Changes in the amount of cover or variation in the amount of cover have been shown to affect the distribution of several small rodent species, primarily *M. pennsylvanicus* and *Peromyscus* sp. (Eadie 1953; Jokela and Lorenz 1959; Grant 1969, 1971a,b; M'Closkey 1975). More importantly, in terms of the control of rodent damage, variation in the amount of cover has been shown to be related to the amount of damage to shrubs and trees by mice and hares; areas of dense cover consistently sustained the highest levels of damage (Jokela and Lorenz 1959). Both the total removal of cover and a sharp reduction in the amount of cover have been shown to lead to increased mammalian and avian predation on small mammals (Lawrence 1966; Green and Taylor 1975). They also restrict the availability of food and the size of the foraging area because of the increased exposure to predators during the summer (Hansson 1975a) and because of the poor development of a subnivean space under the snow during the winter (Pruitt 1957; Coulianos and Johnels 1963). Poor development of the subnivean space can also lead to increased winter mortality as a result of exposure.

The removal or reduction of cover provides a relatively easy method to alter winter and summer distributions, to reduce survival and food availability and to increase predation pressures. Clean cultivation (mowing of entire areas or clearing ground cover around trees) has been used with success in orchards and tree plantations to reduce small rodent damage (Eadie 1953; Jokela and Lorenz 1959; Howard 1967b). In areas where mowing is not possible, better control of small mammal damage has been maintained through not planting platable plant species or high cover crops (Howard 1967a). Packing of the snow layer to crush the subnivean space has also been used on a small scale in orchards; it prevents the access of small mammals to the fruit trees.

To date, no studies have been conducted on the effects of manipulating the habitat heterogeneity (particularly increases in heterogeneity) or the levels of interspecific competition within the small mammal community.

Habitat manipulation appears to offer one of the best means of rodent control currently available--the results are effective as long as the habitat changes are maintained, and the hazards to non-target species are small. Although habitat manipulation may be an effective means of controlling rodents on its own, its use with other techniques of rodent control would probably be more successful. Horsfall *et al.* (1974), for example, used herbicides to increase the abundance of forbs. The abundance of forbs encouraged the consumption of rodenticide-coated vegetation by pine mice (*Pitymys pinetorum*), which prefer forbs to herbs or grasses.

4. MOST PROMISING METHODS OF CONTROL

Two factors should be considered prior to the design of any control program: (1) a means of estimating the extent of small mammal damage must be established and (2) the factors that influence the distribution of the 'pest' species must be determined. A means of reliably estimating the amount of small mammal damage is necessary in order to obtain baseline information on the location and extent of small mammal damage to young trees and on the types of saplings that are most commonly attacked. This information, plus information on habitat type and composition, will influence the type of control program that is implemented. By estimating the small mammal damage during the control program the effectiveness of the control program can be evaluated. (The success of a control program for small mammal damage is determined not by changes in the abundance of small mammals but rather by the extent of the reduction of small mammal damage to the vegetation.) Factors that influence the distribution of the 'pest' species should also be examined prior to the formulation and implementation of a control program. An understanding of feeding and habitat preferences can be used to delineate habitat and feeding stimuli that are important to the local distribution of the species and that may consequently be used to advantage in the choice of a control program.

Three basic methods of control have been reviewed--chemical control, mechanical control and environmental control. Their modes of action can be termed as either population-reducing or damage-limiting. The use of population-reducing control methods, such as rodenticides, predators and disease, offers only temporary control; survivors commonly show an increased breeding and survival response, and immigration often increases. The effects of the population reduction are thus rapidly negated. Populations controlled through the use of rodenticides or disease may also develop resistance to the agent. The use of rodenticides can also result in the development of bait shyness and can cause direct or secondary poisoning of non-target species. Chemosterilants or genetic manipulation may eventually provide effective means of control for some rodent populations; but as yet they are not practical methods--a result of technical problems in their application to wild small mammal populations. Some of the techniques that are presently available offer effective methods of increasing small mammal mortality but none appear to offer a good means of reducing or preventing small mammal damage.

Mechanical guards and sonic repellents are both expensive methods of damage-limiting control that require continued maintenance. Furthermore, sonic repellents are not acceptable in areas of human use because of the high noise levels required for effective repellency of small mammals.

At present the most promising methods of controlling small mammal damage appear to be the use of habitat manipulation, supplementary food supplies and/or repellents. These methods offer a means of control for as long as the applications are maintained, they affect the extent of the damage by small mammals rather than the numbers of small mammals (and so avoid the disruption of natural regulatory processes), and they usually present little hazard to non-target species. Control programs that utilize two or more of these methods would probably be more effective than any one method alone, because of the variety of modes of action as well as the advantage of the combined effects.

Habitat manipulation that affects the density and the type of cover appears to be the most effective method of altering the distribution of small mammals. Reduction of cover has been shown to alter the species composition of the small mammal community--most notably a reduction in the number of vegetation-consuming herbivores (e.g., microtine rodents) and an increase in the number of plant product consuming omnivores (e.g., *Peromyscus* sp.). Reduction of cover can lead to increased predation, lower food availability and increased exposure to climatic extremes (particularly during the winter).

The addition of supplemental food in order to limit damage to young trees is a control method that relies on the assumption that bark consumption is a direct result of a shortage of preferred carbohydrate food sources. Its mode of action is to draw small mammals away from young trees by providing a supply of preferred food. Studies have shown that food-limited species, such as *Peromyscus* sp., will probably increase in numbers; but it is not known how microtine species will respond to supplemental food supplies (increases and decreases in population size have both been reported).

Repellent control methods commonly include the application of slightly toxic or unpalatable chemicals to plants; this results in a lower preference for the plant by the 'pest' species. The use of repellents can include coatings that are sprayed onto the surface of the plants, systemic compounds that are incorporated into the plant tissue, or the planting of less preferred plant species (i.e., natural repellency). Repellent coatings and systemic repellents should be used with caution to avoid direct or secondary poisoning hazards. A program consisting solely of the use of repellents would probably not be effective, but the use of repellents would probably be useful in conjunction with a supplementary food program. Preferences for the supplementary food supply could be enhanced by reducing the palatability of the young trees that are to be protected.

In summary, most of the control methods that have been used to date to control the levels of small mammal damage and/or the abundance of small mammals have stressed the destruction of animals. Population-reducing control methods may temporarily reduce the abundance of small mammals in an area but these populations often increase rapidly to levels similar to or higher than the pre-treatment populations and natural regulatory mechanisms are often disturbed. Damage-limiting methods of control appear to be the only feasible methods of long-term control; their emphasis is upon the increased survival of vegetation not the increased mortality of the 'pest' species. The social structure of the population and related intrinsic regulatory mechanisms are less often disturbed. Howard (1967b:384) summarized what should be the guiding principle of all small mammal control programs:

> "Vertebrate pest control is applied ecology; i.e., it is the management of the behaviour of individual animals and the regulation of population levels...not the destruction of individuals. All animal control must be based on a prudent translation of the ecological laws of nature into an effective management policy."

5. APPLICATION TO THE AOSERP STUDY AREA RECLAMATION SITES

5.1 PRESENT SMALL MAMMAL PROBLEMS

Large tracts of land are being and will be disturbed during the operation of open pit mines and oil extraction plants in the Athabasca Oil Sands area. One oil extraction plant and open pit mine is currently operating (Great Canadian Oil Sands Limited [GCOS]) and another plant is scheduled to begin operation in the spring of 1978 (Syncrude Canada Ltd.). The mining and extraction process at GCOS has resulted in the creation of large dikes of processed sand and piles of over-burden. The Alberta Land Surface Conservation and Reclamation Act requires that these disturbed areas be revegetated. In an attempt both to meet this requirement and to minimize the erosion problem on the dikes and over-burden piles, a number of ground cover seed mixtures composed of various quantities of *Bromus* sp., *Agropyron cristatum, Festuca rubra, Melilotus* sp., *Trifolium hybridum* and *Medicago sativa* have been applied using Brillion, cyclone and hydroseeding techniques. After the establishment of a ground cover, a tree planting program was initiated in 1972, using containerized deciduous and coniferous seedlings, deciduous shrub cuttings, and some larger deciduous saplings. The success of this tree planting program has been limited, however, due to weakening or death of the young trees--a result of disease, nutrient deficiencies, insect damage, and rodent damage. Rodent damage appears to be one of the most common forms of tree damage (Radvanyi 1976) and is probably a major cause of tree death. A current study by the Alberta Forest Service (AFS) for AOSERP is quantitatively evaluating the relative impact of these various mortality factors on tree survival on the GCOS reclamation plots.

GCOS personnel have attempted to control both the extent of rodent damage and the numbers of small mammals present on the plots through the use of sheet metal guards around the young trees, kill-traps, pit-fall traps and the application of the rodenticide Warfarin; these methods have been unsuccessful (Radvanyi 1976). More recently, in 1975-1977, a population study of small mammals on the reclamation areas has been conducted by A. Radvanyi (Canadian Wildlife Service, Edmonton) and a pilot control program has been implemented that employs the anticoagulant rodenticide Rozol (Radvanyi 1976). Although the anticoagulant treatment has succeeded in killing a number of mice, immigration from neighbouring areas has lessened the effect of the population reduction and only small declines in the levels of small mammal damage to young trees have occurred.

Based on his study, Radvanyi has stressed the need to better understand the relationship between the present small mammal damage control program and the ecology of small rodents and other wildlife in the Athabasca Oil Sands area. Little is yet known of the fate of the anticoagulant poisons in the ecosystem, the importance of small mammals in the diet of furbearers, the effects of avian and mammalian predators on small mammal populations, and the rates of small mammal immigration to and emigration from the reclamation areas. Most importantly, Radvanyi has emphasized the need to more fully understand how cyclic fluctuations in the number of small rodents affect the success of a control program. Immigration of small rodents from adjacent woodland habitat to reclamation areas may increase during population highs, for example, and small mammal damage control measures that were successful during population lows may be ineffective during population highs. He recommends that the design of any small mammal damage control program for reclamation areas in the Athabasca Oil Sands area should consider the long-term effects of the program in relation to the population dynamics of the 'pest' species, and that the operation of any research program into small mammal damage control should span at least one four-year cycle of the small mammal populations.

5.2 SUGGESTED CONTROL PROGRAM

A program that would include both the reduction of ground cover and the use of supplementary food is suggested as the most promising method of controlling small mammal damage on the reclamation areas in the AOSERP study area. Repellents might also prove useful in conjunction with the use of supplementary food. The main effect of reducing the amount of cover would be to reduce the suitability of the reclamation areas for habitation by *M. pennsylvanicus* and *C. gapperi* and presumably reduce the peak numbers of these species. Supplemental food could then be used to keep the lower populations of these two microtine species from consuming bark. The reduction of ground cover and the use of supplementary food would probably result in a higher density of *P. maniculatus* on the reclamation sites in comparison to untreated areas; but because this species is not known to consume bark, this increase would probably have no significant effects on the survival of the planted seedlings. The increase could, however, affect the natural reseeding of the area from adjacent forested areas, as *P. maniculatus* is a seed consumer.

The control program would not anticipate large reductions in the numbers of *M. pennsylvanicus* or *C. gapperi*, nor are such reductions necessary to reduce the amount of damage. Increased survival of the seedlings is instead expected as a result of less feeding pressure on the seedlings by the microtine rodents.

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This bibliography discusses only those papers that were considered to be both of good quality and of relevance to the small mammal problem in the Athabasca Oil Sands area.

Aldous, C.M. and S.E. Aldous. 1944. The snowshoe hare: a serious enemy of forest plantations. J. Forest. 42:88-94.

The types of tree losses on forest plantations as a result of snowshoe hare predation and the ways of controlling such losses are reviewed. Means of control include planting of saplings following the decline of the cyclic fluctuations of the hare populations, site selection (hares prefer more closed areas), use of less palatable tree species, limiting the amount of ground cover and shrub growth, the use of repellents, and the addition of supplemental food supplies. More direct control methods such as hunting and snaring are not considered to be practical.

Andrews, R.V., R.W. Belknap and E.J. Keenan. 1974. Demographic and endocrine responses of Norway rats to antifertility control. J. Wildl. Manage. 38:868-874.

The use of the male chemosterilant α-chlorhydrin (U-5897) for the control of Norway rats in landfill sites was tested over a two year period (April 1971-1973). U-5897 produces permanent lesions in the epididymus. Non-toxic doses of U-5897 eventually resulted in a 50% decline in the number of pregnant females but there was an initial response lag of several months. Toxic doses of U-5897 resulted in an immediate reduction of rat numbers by nearly 50%. The level of social stress, the fertility rate, and recruitment were reduced substantially when surviving males were also affected by the drug. It was concluded that U-5897 may be a useful rat control agent by virtue of its dual rodenticide and chemosterilant effects. Toxic doses would be useful in reducing spring increases in population size, while sterilization of surviving males would provide a means of control during the remaining months.

Besser, J.F. and J.F. Welch. 1959. Chemical repellents for the control of mammal damage to plants. Trans. N. Amer. Wildl. Conf. 24:166-173.

The use of three chemical repellents--TNB-A (trinitrobenzene-anilene), ZAC (zinc dimethyldithiocarbamate cyclohexylamine) and TMTD (tetramethylthiuram disulphide)--to protect plants from small mammal damage was examined in a three year study (1953-1956) in Colorado and western Washington. ZAC and TMTD reduced hare damage to saplings by 82%; TNB-A was slightly more effective but sometimes damaged the foliage. TMTD reduced damage to Douglas-fir seedlings by *Microtus montanus* in Colorado by 80% and reduced damage to Douglas-fir seedlings by *Microtus townsendii* in Washington by 74%. ZAC was found to be effective in protecting Douglas-fir seedlings in Colorado (it reduced damage by 82%) but not in Washington (it only reduced damage to young seedlings by 29%).

Black, H.C., E.J. Dimock II, W.E. Dodge and W.H. Lawrence. 1969. Survey of animal damage on forest plantations in Oregon and Washington. Trans. N. Amer. Wildl. Conf. 34:388-407.

A survey of animal damage to forest plantations in Oregon and Washington was begun in 1963 and continued until 1969. The effects of various types of tree damage by mammals on a number of common local tree species were considered. Most seedling mortality that was related to other types of damage (e.g., insect damage, nutrient deficiencies) occurred shortly after planting. Based on differences between the survival of caged and uncaged seedlings, animals caused 35% of the mortality of Douglas-fir and 51% of the mortality of pines. Browsing and clipping were the principal causes of seedling injury. Browsing by deer was the most common source of animal damage on all plots. Animals that injured seedlings, ranked by frequency of damage, were ungulates, hares and rabbits, grouse, mountain beaver, pocket gophers, domestic stock, porcupine, microtine rodents, and moles.

Black, H.C. and E.H. Hoven. 1974. Response of small mammal communities to habitat changes in western Oregon. Pages 177-186 *in*: H.C. Black, ed. Wildlife and forest management in the Pacific Northwest. School of Forestry, Oregon State University, Corvallis.

Habitat changes after wildfire, clearcutting or herbicide treatments resulted in changes in the species composition of small mammal communities. Deer mice (*Peromyscus maniculatus*), Townsend's chipmunks (*Eutamias townsendii*), western red-backed voles (*Clethrionomys gapperi*), and Oregon voles (*Microtus oregoni*) were most common in the mature Douglas-fir and mixed conifer stands. Oregon voles were abundant during the early successional stages after wildfire or clearcutting, but red-backed voles were uncommon. Herbicide treatments on areas that had been clearcut resulted in a decline in the number of voles and an increase in the abundance of deer mice.

Changes in the species composition of the plant community and in the amount of cover present were thought to be the main causes for the changes in the species composition of the small mammal community.

Boonstra, R. 1977. Predation on *Microtus townsendii* populations: impact and vulnerability. Can. J. Zool. 55:1631-1643.

The impact of avian and mammalian predation on natural populations of *Microtus townsendii* near Vancouver, B.C., during the winter and spring of both 1972-73 and 1973-74 was assessed. In particular, the relationship of predation to the spring decline was considered. Scats and pellets found during intensive searches of the study area were analysed for the remains of small mammals. Comparisons of sex ratios and weight distributions between the tagged population and the voles eaten by predators indicated that neither sex nor any one weight class was more vulnerable to predation. It was concluded that predation is not necessary to initiate or maintain a decline of a small mammal population.

Buckner, C.H. 1970. Strategy for controlling rodent damage to pines in the Canadian mid-west. Proc. Vert. Pest Conf. 4:43-48.

Tree damage and population changes of small mammals were studied in Manitoba and Saskatchewan from 1955-1969. Tree regeneration programs in the transitional zone between forest and prairie in Manitoba and Saskatchewan were often unsuccessful due to climatic conditions and depredation by small mammals (particularly by *Microtus pennsylvanicus*). Population data for *M. pennsylvanicus* from 1955-1969 showed that four major irruptions had occurred--in 1956, 1960, 1964 and 1967. The peak numbers of mice in 1956 and 1964 were particularly high. Key factor analysis indicated that increases in juvenile vole survival were indicative of increases in population density. Rodent damage estimates during the same period indicated that rodent damage was highest in 1956 and 1964. The effect of stand density on rodent damage was also investigated. Damage by *M. pennsylvanicus* increased in a sigmoidal fashion in relation to jack pine seedling density. It is suggested that by monitoring juvenile vole survival, the degree of damage may be predicted and that during years of predicted highs, control measures such as the use of rodenticide should be used. Alteration of seed or seedling density may also lessen the degree of damage.

Cayford, J.H. and R.A. Haig. 1961. Mouse damage to forest plantations in southeastern Manitoba. J. Forest. 59:124-125.

During the spring of 1959 extensive girdling of Scotch pines occurred in a number of tree plantations in the Sandiland Forest Reserve in southeastern Manitoba. Most damage was caused by browsing by *Microtus pennsylvanicus*. Scotch pine was most susceptible to damage; red pine and white spruce were undamaged. Severe damage was confined to sites with a moderate to dense grass and shrub cover. Conversely, damage was low wherever ground cover was sparse. Rodent damage was a factor in tree survival up to 13 years after planting.

Coulianos, C.C. and A.G. Johnels. 1963. Note on the subnivean environment of small mammals. Arkiv. Zool. Series 2, 15:363-370.

During a two year study (1960-61) in Sweden, the local winter distribution of small mammals was considered in relation to both the type and density of cover and the subsequent development of the subnivean air space within these areas. Just prior to the onset of winter, most of the study field (that had been planted in clover and timothy) was mowed and only one strip was left uncut. In spring only the unmowed section showed extensive signs of mouse activity (runways, tunnelling). The formation of the subnivean air space is largely dependent on the presence and support of delicate vegetation parts near the ground surface; this layer provides small mammals with an environment of moderate and comparatively constant temperatures, silence, darkness, and high humidity. As a result, areas of dense vegetation attract mice during the winter. It is postulated that the lack of snow cover, and thus the lack of a subnivean air space, can lead to a drastic reduction in the number of small mammals present on a specific area.

Davis, D.E., K. Myers and J.B. Hoy. 1976. Biological control among vertebrates. Pages 501-519 *in* C.B. Huffaker and P.S. Messenger, eds. The theory and practice of biological control. Academic Press, New York.

This paper reviews the feasibility of biological control of vertebrates. Biological control is defined as the use of predators or disease to limit the number of 'pest' vertebrates. Several case histories of attempts at biological control of vertebrate 'pests' are included--most notably the use of myxomatosis for control of the European rabbit in Australia, and the use of the mongoose in

Hawaii to control rats. Attempts to control vertebrates through biological means have been unsuccessful; the successful control of the introduced European rabbit in Australia is the one exception to date.

Eadie, W.R. 1953. Response of *Microtus* to vegetative cover. J. Mammal. 34:363-364.

This paper attempts to illustrate the relationship between the density of ground cover and the distribution of *M. pennsylvanicus* activity. The study was conducted during 1950 in an old field in New York that was predominantly inhabited by *M. pennsylvanicus*. Areas in which *M. pennsylvanicus* occurred in low densities had substantially less vegetative cover (as indicated by the weight of above ground cover) than did areas of high densities of *M. pennsylvanicus*. It is suggested that the density of microtines and thus the amount of damage to vegetation that they cause, can be controlled by keeping the height of ground vegetation low and by keeping areas near the base of trees free of ground cover.

Erlinge, S. 1975. Predation as a control factor of small rodent populations. Pages 195-200 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rodents. Swedish Natural Science Research Council, Stockholm.

Studies of predation and the use of predation to control microtines are reviewed. Predators appear to be unable to prevent rodent oubreaks. The impact of predators is hardest on sparse populations of small rodents or on greatly fluctuating populations during the low phase of the cycle. Predation pressure decreases during the increase phase of the cycle and is low when the population reaches peak numbers. Reasons for the failure of predators to effectively control rodents include the low reproductive potential of predators in comparison to rodents, the slow numerical response of predators to the density of rodents, an insufficient functional response of predators to high rodent density, and the limitation of the predator population size due to territorial behaviour. Often matters are further complicated by the simplification of the ecosystem by man (e.g., monocultures), which in turn promotes instability of the system because there are few interconnections in the ecosystem. When considering predation as a means of controlling small mammal populations, one must consider not only the number of rodents in relation to the number of predators but also the vulnerability of rodents to the predator, the quality (genotype, behaviour, physical condition) of individuals in the rodent population, and the age and sex ratios of the rodent and predator populations. If predators are used as a means of control, facultative rather than obligatory predators (e.g., fox *vs.* weasel) are best for long-term control. Chances of successful control can be increased by using several predator types, while at the same time increasing the vulnerability of rodents (e.g., reduced cover).

Flowerdew, J.R. 1972. The effect of supplementary food on a population of wood mice (*Apodemus sylvaticus*). J. Anim. Ecol. 41:553-566.

Supplementary food (whole oats) was provided to a population of wood mice (*Apodemus sylvaticus*). One experimental area and one control area were trapped regularly. Supplementary food increased the survival of juveniles, but it did not change the number of resident mice that overwintered on the area. Growth of animals on the experimental areas increased by as much as 20%. Increased densities during the summer were attributed to the better survival of juvenile mice and mice that had overwintered.

Fordham, R.A. 1971. Field populations of deer mice with supplemental food. Ecology 52:138-146.

Supplemental food (whole oat groats) was provided to *Peromyscus maniculatus* populations on three experimental sites in a mature forest area near Vancouver, B.C. Three control areas were also established. Both the population size and the production of young increased with additional food; adult survival and juvenile survival both improved. The population density on the experimental area increased temporarily because of the increased recruitment of young animals. Few young remained on the experimental area, however, and the density of breeding animals on the area remained constant throughout the study. Additional food also affected the reproductive condition of the adults; both males and females on the feeding areas bred earlier, and significantly greater proportions bred throughout the season. Supplemental food appeared to have the greatest effect on the overall productivity of the population, but it did not appear to cause significant changes in the number of resident adult (reproducing) animals.

Gashwiler, J.S. 1969. Deer mouse repopulation on a poisoned Douglas-fir clearcut. J. Forest. 67:494-497.

The repopulation of a clearcut area in a Douglas-fir timber type by *Peromyscus maniculatus* was studied in Mt. Hood National Forest, Oregon, from November 1952 to December 1953. Part of the clearcut area was initially baited with the rodenticide 1080 to remove all resident animals. Although the poisoning program was effective, new *P. maniculatus* began to immigrate 15-19 days after the poison treatment. Within 5 to 7 months of the treatment, the population had reached levels similar to those on the control area. Most of the increase was attributed to the immigration of animals from adjacent areas; most of these recruits were subadults. The data suggested that mice on the poisoned area came into breeding condition sooner and had a longer reproductive period than mice on the control area; they were thus able to quickly repopulate a vacated area.

Grant, P.R. 1969. Experimental studies of competitive interactions in a two-species system. I. *Microtus* and *Clethrionomys* species in enclosures. Can. J. Zool. 47:1059-1082.

Habitat selection by and interactions between *Microtus pennsylvanicus* and *Clethrionomys gapperi* were studied in central Ontario on three 1-acre enclosures that contained equal blocks of deciduous and grassland habitat. In each enclosure all resident small mammals were removed; three pairs of *C. gapperi* were then released in enclosure 1, four pairs of *M. pennsylvanicus* were released in enclosure 2 and three pairs of *C. gapperi* and four pairs of *M. pennsylvanicus* were released in enclosure 3. *C. gapperi* were placed in the woodland areas and *M. pennsylvanicus* were placed in the grasslands section. During the two-year study, only one *M. pennsylvanicus* moved into woodland habitat. *C. gapperi*, however, often entered the grassland areas. Most of the *C. gapperi* that entered the grassland habitat were subadults. It was proposed that the carrying capacity of the woodland for *C. gapperi* was exceeded by the initial number of *C. gapperi* and that the stimulus to move into the grassland areas arose from aggressive social interactions.

Grant, P.R. 1971. The habitat preference of *M. pennsylvanicus* and its relevance to the distribution of this species on islands. J. Mammal. 52:351-361.

The habitat preference of *Microtus pennsylvanicus* was studied in enclosures in central Ontario. Each enclosure contained equal amounts of grassland and woodland habitats. All resident animals in each enclosure were removed. Adults raised in grassland areas or young without exposure to either grassland or woodland habitat, were then released in the woodland areas. All individuals moved to the grassland areas of the enclosures where they remained. Only after the population reached densities of 68-80 voles per acre in the grassland areas did animals begin to inhabit woodland areas.

Gratz, N.G. 1973. A critical review of currently used single-dose rodenticides. Bull. World Health Organ. 48:469-478.

This paper reviews the properties (lethal dosages, time of death, effectiveness, acceptance, reacceptance, tolerance development, hazards to man) of 11 of the most important available single-dose rodenticides, and recommends uses for each. Barium carbonate, yellow phosphorus, and strychnine were not recommended for use as rodenticides because of high secondary poisoning hazards or poor acceptance. Red squill was recommended for Norway rats, but was only moderately effective. Sodium flouroacetate, flouroacetamide and thallium sulphate were effective rodenticides, but because of their hazard to man, were only recommended for restricted use. Antu, norbormide and zinc phosphide were listed as effective and only moderately hazardous to man, and were accordingly recommended for more wide-scale use.

Green, M.D. and K.D. Taylor. 1975. Preliminary experiments in habitat alteration as a means of controlling field rodents in Kenya. Pages 175-181 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rodents. Swedish Natural Science Research Council, Stockholm.

The effects of weed and herbaceous cover on the local distributions of several field rodent species in Kenya were studied during the early part of the dry season. Areas of medium cover were selected and rodent populations were trapped before, during and after the cover alteration. One field was gyromowed, a second was gyromowed and then cattle were released to graze, and a third was hand-cut. Removal of the cover allowed increased predation of the rodents. All methods led to a sharp decline in the numbers of all but one of the rodent species.

Hansson, L. 1973. Habitat, food and population dynamics of the field vole, *Microtus agrestis* L., in south Sweden. Viltrevy 8:265-373.

This paper is a comprehensive review of a 6 year study of the field vole, *M. agrestis* in southern Sweden (1964-1970). Of interest to this report were the experiments related to bark consumption by this species. *M. agrestis* consumed some bark in all years of the study and appeared to prefer the bark of *Salix* sp. It was believed that bark consumption occurred as a result of the lack of easily metabolized energy (foods). *M. agrestis* has a low assimilation efficiency (approximately 50%) and so must consume large amounts of easily digestible material to maintain itself. In laboratory tests *M. agrestis* were offered alternative sources of carbohydrates to determine if this could prevent bark consumption. Animals offered only laboratory food pellets as an alternative continued to consume tree bark. Those offered green vegetation or a combination of laboratory food and twigs did not consume any bark from the stems. It was concluded that *M. agrestis* girdled trees during the winter largely as a result of a lack of more preferred carbohydrate sources.

Hansson, L. 1975a. Effects of habitat manipulation on small rodent populations. Pages 163-173 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rodents. Swedish Natural Science Research Council, Stockholm.

This paper reviews the factors that affect the dynamics of small rodent populations--particularly those that determine differences in densities among various habitats. Various types of habitat manipulation and their effects on small mammal populations are considered. Habitat manipulation may affect small mammals through changes in the microclimate of the area (in relation to the specific climate preferences of the different species), changes in food supply, variation in competition between small mammal species, and changes in the levels of predation. Suggested means of habitat manipulation include alterations of the food supply (use of unpalatable plant species, use of protective barriers around palatable foods, and decrease in the amount of fertilization), an increase in the complexity of the plant community in order to increase the number of small mammals and hence the degree of interspecific competition, the use of facultative predators, the removal of refuge areas, the removal of cover by mowing or grazing, a disturbance of the soil (such as plowing), the use of herbicides to remove food supplies, and burning of the habitat.

Hansson, L. 1975b. Natural repellence of plants toward small mammals. Pages 213-219 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rodents. Swedish Natural Science Research Council, Stockholm.

A variety of physical, chemical, numerical and distributional means of defence that are displayed by plants are discussed in terms of their effectiveness in limiting predation by small rodents. No clear examples of physical mechanisms are known, although older bark on trees may prevent girdling. Chemical mechanisms may involve nutritional contents, allomones (substances that repel grazers) or kairomones (substances that attract grazers). The barks of preferred tree species, for example, were often found to contain high amounts of carbohydrates and minerals. Excess fertilization has also been associated with more pronounced damage by small rodents, hares, moose and deer. Allomones may be effective repellents;

some such as stilbenes (which occur commonly in conifers) are toxic to rodents. A number of synthetic contact repellents are available for external use but have not been effective in field situations. Systemic repellents may be more effective than contact repellents. Systemic repellents could involve the reduction of micro-nutrients and minerals, an increase in allomones, and/or a decrease in kairomones.

Horsfall, F., Jr., R.E. Webb and R.E. Byers. 1974. Dual role of forbs and rodenticides in the ground spray control of pine mice. Proc. Vert. Pest Conf. 6:112-126.

A pine mouse (*Pitymys pinetorum*) population was effectively controlled in apple orchards in New York, Ohio and West Virginia by the application of both a herbicide and a rodenticide (chlorophacinone). The herbicide reduced the density of grasses; the density of forbs subsequently increased. Chlorophacinone was then sprayed on the forb ground cover. Because pine mice prefer forbs to herbs, they consumed more of the rodenticide-coated ground cover and the mortality of resident pine mice increased. The wide diversity of forbs also provided an alternative and preferred food source for the mice and so reduced the browsing pressure on the trees by the surviving mice.

Howard, W.E. 1967. Biological control of vertebrate pests. Proc. Vert. Pest Conf. 3:137-157.

Biological control of vertebrate pests can involve the reduction of a 'pest' population by increasing predation, by manipulating the habitat, by introducing disease epidemics, or by applying antifertility agents. The use of habitat alteration as a means of 'pest' control is considered to be a much more desirable method than the selective destruction of the target species (e.g., the use of predators or disease) because intrinsic regulatory mechanisms (social behaviour and territoriality) are much less likely to be affected. Predation is also not recommended as a good form of control as it often results in maintaining the 'pest' population at or near the carrying capacity. If predators are to be used as a means of control, the population dynamics of both the predator and prey must be considered, as well as the size of the affected area and the period of control that is desired. Regardless of the method of biological control that is used, an understanding of the dynamics of the vertebrate 'pest' population is a necessary prerequisite to the effective formulation of any control program.

Jokela, J.J. and R.W. Lorenz. 1959. Mouse injury to forest planting in the prairie region of Illinois. J. Forest. 57: 21-25.

Browsing by cottontail rabbits (*Sylvilagus floridanus*) and prairie meadow mice (*Microtus ochrogaster*) was found to be the chief factor limiting the early success of forest plantations in Illinois. Ten years of observations of injury by mice and rabbits are reported; the paper considers in detail the data for the period 1951-53. Ash, cottonwood, Douglas-fir, Osage-orange, yellow poplar and most pines were severely injured. Balsam fir, ponderosa pine, red pine, American sycamore, northern white cedar and white spruce were less susceptible. Damage by mice was highest in areas with dense ground cover; clean cultivation (removal of dense ground cover) was suggested as a means of limiting seedling depredation.

Kendle, K.E., A. Lazarus, F.P. Rowe, J.M. Telford and D.K. Vallance. 1973. Sterilization of rodent and other pests using a synthetic oestrogen. Nature 244:105-108.

The effectiveness of several chemosterilants in controlling rat populations was tested in a laboratory and field study. Mestranol was one of the first synthetic oestrogens to be used in the control of wild mammal populations; it was largely ineffective because of a rapidly-developed bait aversion. Quinestrol was better accepted, but a complete inhibition of reproduction was not achieved and it required too frequent applications. A new chemosterilant, BDH 10131 was tested; a single dose could inhibit reproduction for periods from several days to six months. In the laboratory experiments rats were prebaited with a grain mixture, and 0.015% BDH 10131 was then added to the same mixture. Addition of this mixture once every 8 weeks completely inhibited reproduction. Single-dose experiments using 3.2 mg/kg body wt. and 16 mg/kg body wt. inhibited reproduction for 15 and 19 weeks respectively. The field experiment involved part of a rat population in a garbage dump. The area was prebaited for 3 weeks, and the 0.05% BDH 10131 grain mixture was then provided for 6 days. Reproduction of the test population was successfully inhibited and 6 months after the treatment, the population was only 25% of its former level, even though the control population showed few numerical changes.

Krebs, C.J. and K.T. DeLong. 1965. A *Microtus* population with supplemental food. J. Mammal. 46:566-573.

A low density population of the California vole (*Microtus californicus*) in southern California was provided with supplemental food for 11 months, during which time its demographic changes were monitored by intensive live trapping. The density of the experimental population first increased moderately, then abruptly decreased in spite of high growth rates and sustained high reproductive rates. It was concluded that supplemental food was not sufficient to produce a rapidly increasing population or to prevent a decline to low numbers.

Kverno, N.B. 1964. Forest animal damage control. Proc. Vert. Pest Conf. 2:81-89.

The use of repellents to control small rodent damage in Scandinavia was examined. Meadow mouse damage was controlled to some extent by spraying or painting a thiuram repellent on the plant stem. Habitat manipulation, especially the removal of vegetation cover, was found to be the most successful means of control.

Lawrence, G.E. 1966. Ecology of vertebrate animals in relation to chaparral fire in the Sierra Nevada foothills. Ecology 47:278-291.

Changes in the populations of small mammals following a chaparral fire in the Sierra Nevada foothills were followed from 1954 to 1957. There was a sharp decline in the number of small mammals following the fire, but small mammal abundance gradually increased thereafter. The chaparral rodents (*Peromyscus truei* and *P. californicus*) were unable to maintain their pre-burn numbers, whereas the grassland species (*Perognathus californicus, Peromyscus maniculatus* and *Reithrodontomys megalotis*) were able to increase in number in the newly established grassland areas. The lack of vegetative cover after the fire resulted in increased avian and mammalian predation, and also limited the area of successful foraging and the availability of food. An index of the body condition of rodents (body weight divided by body length) decreased. It was concluded that the secondary effects of reduced cover had a greater impact on the species composition of small mammal populations than the direct effect (that of being killed by fire).

Littlefield, E.W., W.J. Schoomaker and D.B. Cook. 1946. Field mouse damage to coniferous plantations. J. Forest. 44: 745-749.

In the fall of 1938 extensive damage to planted conifers on the Montgomery county reforestation area in California was evident. Most damage was attributed to browsing by *Microtus pennsylvanicus*. A review of several years of data indicated that the highest levels of damage occurred during peaks of the mouse population. Damage was caused mainly by the removal of bark and phloem from the roots, basal portion of the stem and the lower branches. Most damage occurred during the early winter. Scotch pine and Douglas-fir were the most favored species; 50-85% of the trees were attacked, and as many as 70% of the trees were totally girdled. Norway spruce, white pine, red pine, white cedar, balsam fir, jack pine and larch were only slightly favored. White spruce showed no signs of damage.

LoBue, J. and R.M. Darnell. 1959. Effect of habitat disturbance on a small mammal population. J. Mammal. 40:425-437.

The distribution of *Microtus pennsylvanicus* and *Peromyscus maniculatus* was examined on an alfalfa field and in adjacent edge habitat throughout one growing season. Initially, *M. pennsylvanicus* utilized the edge areas and *P. maniculatus* used the main field. As the vegetation increased in height and density, *M. pennsylvanicus* began to inhabit more of the field area and *P. maniculatus* increased its use of the edge areas. After the alfalfa was cut, the number of *M. pennsylvanicus* declined in the open field, whereas the numbers of *P. maniculatus* increased. It was suggested that because *M. pennsylvanicus* is diurnal it requires a dense vegetative cover for protection against predators and extreme physical conditions. *P. maniculatus* is nocturnal, however, and can move more freely in open areas without the benefit of cover.

Lund, M. 1967. Resistance of rats to rodenticides. World Rev. Pest. Cont. 6:131-138.

The resistance of various rodents (particularly rats) to various rodenticides (acute poisons, anticoagulants and bacterial poisons) is reviewed. Most resistance of rodents to various rodenticides is acquired, but some have been shown to be inheritable (e.g., resistance of Norway rats to anticoagulants). Acute poisons were initially effective, but some small mammals (particularly rats) become increasingly resistant to such acute poisons as Antu, zinc phosphide, norbormide, endrin, arsenious oxide, strychnine, sodium flouroacetate, and barium carbonate. Increasing resistance to anticoagulants has also been shown for rats and mice. Bacterial poisons (disease vectors) such as Ratin (*Salmonella interidis*) were initially effective, but rats soon developed an immunity to the disease. It was suggested that more effective control of rodent 'pests' may be obtained by using several different poisons during the control program.

Lund, M. 1975. Control of rats and mice. Pages 129-137 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rats. Swedish Natural Science Research Council, Stockholm.

Present methods of controlling populations of rats and mice are reviewed and the advantages and drawbacks for each method or group of chemicals are discussed. The use of a variety of both acute and multiple-dose rodenticides, chemosterilants (primarily those affecting females) and fumigation are considered as well as means of permanent removal such as kill trapping. Means of rodent exclusion, such as barriers, chemical repellents, ultrasound and the use of alarm or distress calls, are discussed. Changes in the environment that specifically lead to a reduction in the carrying capacity of the habitat for rodents are suggested as an important means of controlling rodents over long periods.

Marsh, R.E. and W.E. Howard. 1970. Chemosterilants as an approach to rodent control. Proc. Vert. Pest Conf. 4:55-63.

A wide variety of compounds have been considered for their practical value in inhibiting reproduction to suppress 'pest' populations. This paper discusses the qualities of an ideal chemosterilant and the advantages of chemosterilants over other methods of control. In particular, chemosterilants are more selective and present much less of a hazard to humans, pets, domestic stock and non-target wildlife than do some of the rodenticides that are now commonly used. Further, with their use it is less likely that the natural regulatory mechanisms will be disturbed. The potential values of chemosterilants that act on males, females or both sexes are considered; those chemosterilants that affect only males were considered to be the least effective in controlling rodent populations due to the polygamous breeding behaviour of most rodents. The use of chemosterilants in integrated programs that use rodenticides for the initial reduction of the population and that then use chemosterilants to maintain the population at low levels is recommended as an effective means of rodent control.

M'Closkey, R.T. 1975. Habitat succession and rodent distribution. J. Mammal. 56:950-955.

The distribution of *Microtus pennsylvanicus* and *Peromyscus leucopus* in Point Pelee National Park, Ontario was shown to be associated with habitat structure and diversity and, in particular, with the different stages of seral succession. *M. pennsylvanicus* occurred predominantly in grassland and disturbed plant communities, whereas *P. leucopus* occupied forest and shrub habitats. The distribution of the two small mammal species in these habitats was closely related to foliage height diversity; *M. pennsylvanicus* was more abundant in densely vegetated areas, and *P. leucopus* was more abundant in open, shrubby areas. Changes in the species composition of the small mammal community with seral succession were attributed to structural changes in the local habitats.

Miller, G.R. 1968. Evidence for selective feeding on fertilized plots by red grouse, hares and rabbits. J. Wildl. Manage. 32:849-853.

In three experiments on a Scottish moor, the different quantities of feces deposited by red grouse (*Lagopus lagopus scoticus*), mountain hare (*Lepus timidus*) and European rabbit (*Oryctolagus cuniculus*) on fertilized and unfertilized plots were used as indices of selective feeding. Preferences for browse on the fertilized plots were shown by each of the above vertebrates. During the winter grouse preferred heather that contained a high level of nitrogen. In winter hares and rabbits both selected heather with a high content of nitrogen and phosphorus, but in summer they selected plants that were high in nitrogen. The results indicated that grouse, hares and rabbits are able to readily detect localized variations in the physiological condition of vegetation.

Morris, R.D. 1970. The effects of endrin on *Microtus* and *Peromyscus*. I. Unenclosed field populations. Can. J. Zool. 48:695-708.

The effects of endrin on unenclosed populations of *Microtus pennsylvanicus* and *Peromyscus maniculatus* were investigated from June 1966 to October 1968. Adjacent control and experimental areas were regularly live trapped before and after the application. The *M. pennsylvanicus* population showed immediate and significant post-spray declines on the experimental plots, but rapidly recovered again to eventually exceed pre-spray numbers in two years and exceed corresponding control numbers in all three years. More new *M. pennsylvanicus* were captured during post-spray periods on the experimental plots than on the control plots; these recruits survived significantly better than the new individuals that entered the more stable control population. It is suggested that the reduction in numbers and the presumed decrease in intraspecific aggressive encounters disrupted the social structure to such an extent that normal regulation of numbers was no longer possible. *P. maniculatus*, on the other hand, declined significantly after the endrin application and did not recover during the study.

Morris, R.D. 1972. The effects of endrin on *Microtus* and *Peromyscus*. II. Enclosed field populations. Can. J. Zool. 50:885-896.

The effects of endrin on *Microtus pennsylvanicus* and *Peromyscus maniculatus* were investigated in two-acre enclosures near Saskatoon, Saskatchewan. Enclosures were used to eliminate the effects of immigration and emigration. Endrin caused immediate and significant mortality in the experimental population. Those *M. pennsylvanicus* that survived the spray application survived as well as did those on the control plot. Recruits to the experimental population during post-spray periods survived significantly better than did recruits to the control population. Due to the increased survival rate and the active breeding of the experimental population, the number of *M. pennsylvanicus* on the experimental plot soon exceeded that of the control plot.

Mossman, A.S. 1955. Light penetration in relation to small mammal abundance. J. Mammal. 36:564-566.

The distribution of *M. pennsylvanicus* in relation to light penetration in a predominantly grass-covered field in Wisconsin was studied during a summer. Dropping boards were used to estimate the relative abundance of *M. pennsylvanicus*. A photoelectric meter was used to measure the amount of light penetration near each board. The relative density of *M. pennsylvanicus* was found to be negatively correlated (F=4.34) with the amount of light penetration at ground level. Because light penetration was directly related to the amount of herbaceous vegetation, it was concluded that the distribution of *M. pennsylvanicus* was associated with areas of more dense herbaceous cover.

Myllymaki, A. 1975. Conventional control of field rodents and other harmful small mammals. Pages 113-127 *in* L. Hansson and B. Nilsson, eds. Biocontrol of rodents. Swedish Natural Science Research Council, Stockholm.

The control of damage to vegetation by small mammals through exclusion techniques, repellents, rodenticides, disease, chemosterilants and habitat manipulation, and the practical problems that are associated with each of these methods are reviewed. Exclusion techniques (e.g., screen guards, aluminum or plastic collars) do not appear to be feasible on a large scale. Surface repellents have generally been unsuccessful; systemic repellents are now being considered. Both acute rodenticides and anticoagulants have been successful in reducing rodent populations but kills of 90-100% of the 'pest' populations were required for successful control of damage by small mammals. Chemosterilants may effectively control small mammal populations, but at present are not well tested in field situations. Disease agents should be used only if a specific pathogen (such as the myxoma virus in rabbits) can be found for specific rodent species. From an ecological viewpoint, artificial manipulation of habitats would be the most effective long-term method for altering population levels of 'pest' species, largely because both the increased survival and the breeding response of reduced populations (which commonly occur when using chemical or other lethal methods) are avoided. It was concluded that habitat manipulation or exclusion techniques are presently the preferable methods of controlling damage by small mammals.

National Academy of Science. 1970. Small mammal pest problems. Pages 83-89 *in* Principles of plant and animal pest control. Volume 5. Vertebrate pests: problems and controls. National Academy of Science (Printing and Publishing Office), Washington, D.C.

Small mammal pest problems and means of control are reviewed. There are two major approaches to reducing forest wildlife damage--a reduction of the numbers of animals or an alteration of the habitat such that the plants are less attractive or unavailable. Physical barriers such as wire mesh collars are useful in protecting young trees, but are expensive to use. Clean cultivation has been shown to substantially reduce mouse damage, particularly in orchards. Where ground vegetation is required, better control of mouse damage can be maintained by avoiding the use of more preferred food species and high cover crops. Pest population reductions through the use of rodenticides or kill traps usually provide little more than temporary relief. Environmental control appears to provide a better and more long-lasting means of control.

Passof, P.C., R.E. Marsh and W.E. Howard. 1974. Alpha-napthylthiourea as a conditioning repellent for protecting conifer seed. Proc. Vert. Pest Conf. 6:280-292.

The use of alpha-napthylthiourea (Antu) as an alternative rodent repellent to endrin was tested in a field and laboratory study in California. Endrin (a chlorinated hydrocarbon insecticide) was a widely used rodent repellent for conifer seeds used in reforestation programs, but its use is now largely prohibited due to the persistance and the extent of the environmental pollution that has been caused by chlorinated hydrocarbons. The effectiveness of Antu as a repellent was tested primarily as a means of controlling deer mice (*Peromyscus maniculatus*) seed predation. Antu posed less of a risk of secondary poisoning to non-target species, but was not as effective as endrin in preventing seed predation. Antu-treated seed produced almost twice as many germinants as untreated seed. It was suggested that Antu should be used as a rodent repellent in conjunction with the use of a rodenticide such as chlorophacinone.

Peoples, S.A. 1970. The pharmacology of rodenticides. Proc. Vert. Pest Conf. 4:15-18.

This paper reviews the modes of action of some common rodenticides. Rodenticides are classified as organic rodenticides (anticoagulants, Antu, sodium flouroacetate, strychnine sulphate, red squill, norbormide, chemosterilants, and chlorinated insecticides), inorganic rodenticides (zinc phosphide, thallium sulphate, barium carbonate, phosphorus, and arsenic trioxide) or fumigants (carbon monoxide, methyl bromide, and hydrogen cyanide).

Radvanyi, A. 1971. Lodgepole pine seed depredation by small mammals in western Alberta. Forest Sci. 17:213-217.

Consumption of lodgepole pine seed by small mammals on a cutover area near Hinton, Alberta was measured using radioactively tagged seeds and patterns of seed destruction were assessed. Assuming that the rates of consumption of radioactive seeds were comparable to the rates of consumption of untreated seed, animals consumed 5-10% of the available seeds during winter months and 21-33% of the available seeds during the summer. Deer mice (*Peromyscus maniculatus*) and red-backed voles (*Clethrionomys gapperi*) consumed the largest portion of the seeds.

Radvanyi, A. 1974. Small mammal census and control on a hardwood plantation. Proc. Vert. Pest Conf. 6:9-19.

Following several years of severe small mammal damage to trees on a hardwood plantation in Ontario, an attempt was made to control small mammal populations using the anticoagulant Rozol. Two pounds of grain treated with Rozol were broadcast on one 20-acre area of the plantation. Several weeks later the treatment was repeated but at a rate of 15 lb/acre. The population showed a sharp decline, presumably as a result of the poison. New mice present on the area were thought to be immigrants. Re-invasion was rapid and quickly negated the effects of the poisoning program. To overcome the short-term effects of poisoning, Rozol-treated grain was supplied continuously by installing poison-bait feeder stations.

Radvanyi, A. 1976. Continued monitoring of the harmful small mammal problem in the Alberta Oil Sands reclamation and afforestation program. Preliminary Data. Dep. Fish. Envir. Can., Can. Wildl. Serv. 54 p.

A field study was conducted in 1976 of the small mammal populations and a means of controlling these populations on the Great Canadian Oil Sands reclamation site. Seven live trapping grids were trapped in 1976; three areas were used as control areas, and poison bait feeding stations (Rozol-treated whole oat groats) were placed throughout the remaining four areas. Estimates of the densities of small mammals in the early summer and early fall on the four test sites and two of the control sites indicated comparable large declines on both poisoned and control areas. It appears that although the poison bait feeders did kill a large number of resident mice, the reduction of the small mammal population was negated by the immigration of animals from adjacent areas.

Radwan, M.A. 1974. Natural resistance of plants to animals. Pages 85-94 *in* H.C. Black, ed. Wildlife and forest management in the Pacific Northwest. School of Forestry, Oregon State University, Corvallis.

The natural resistance of plants to mammals and the factors influencing this resistance (particularly those related to plant chemistry) are reviewed. Examples are given of seed resistance to rodents and resistance by trees and shrubs to girdling and clipping by rodents and lagomorphs and to browsing by deer. Factors contributing to resistance are discussed in terms of both nutritional chemicals and non-nutritional chemicals such as fibre, lignin, essential oils, phenolic compounds and toxicants. Numerous inconsistencies exist throughout the literature. It is suggested that only naturally occurring chemical complexes should be considered and that comparisons of the total nutritive value and the ratios of nutrients to inhibitors may be of more biological significance.

Sartz, R.S. 1970. Mouse damage to young plantations in southwestern Wisconsin. J. Forest. 68:88-89.

A study of mouse damage to young trees on plantations in southwestern Wisconsin was conducted in 1966-1967. Ground cover, snow cover, slope aspects and tree species were considered. Northern red oak, European larch, red pine and Norway spruce sustained the heaviest damage; white pine showed only slight damage and white spruce showed no damage. These differences were not correlated with snow cover or ground cover. South aspect plantings suffered little damage, whereas those on north and west aspects were extensively damaged.

Smith, C.F. and S.E. Aldous. 1947. The influence of mammals and birds in retarding artificial and natural reseeding of coniferous forests in the United States. J. Forest. 45:361-369.

Small mammals and birds have been largely responsible for the failure of artificial reseeding programs in coniferous forests in the United States. Various means of population-reducing control were tried (acute poisons, kill trapping, etc.), but were unsuccessful due to the rapid re-invasion of small mammals and the relatively long pre-germination period of the seed. Repellents applied to the seeds were largely unsuccessful, because rodents commonly shell seeds and consequently discard the repellent-coated seed coat. To date, mechanical protection devices (screens, fence guards, etc.) have consistently produced the best results, but are prohibitively expensive in most cases.

Smith, M.H. 1971. Food as a limiting factor in the population ecology of *Peromyscus polionotus* (Wagner). Ann. Zool. Fenn. 8:109-112.

Supplementary food was continuously provided to a population of oldfield mice (*Peromyscus polionotus*). The population on the supplemental food area increased slightly, but continued to follow fluctuations in number that were similar to those observed on the control area. Varying levels of additional food had approximately the same effect. The differences between the response of *Microtus* sp. and *Peromyscus* sp. to the addition of supplemental food are discussed in terms of food-limited populations and populations that are not limited by food.

Von Althen, F.W. 1971. Mouse damage in an 9-year old plantation. Forest. Chron. 47:160-161.

In 1967-1968 forestry plantations in southern Ontario suffered severe mouse damage; microtine species completely or partially girdled many of the commonly planted species. A rodenticide was used, but it failed to prevent further damage. Microtine rodents showed preferences for some tree species. White spruce, white pine, white ash and basswood were available on the plantation; white pine was most severely attacked, white spruce was the most resistant species to mouse damage.

Welch, J.F. 1967. Review of animal repellents. Proc. Vert. Pest Conf. 3:36-44.

The effectiveness of three animal repellents--TNB-A (trinitrobenzene-anilene), ZAC (zinc dimethyldithiocarbamate cyclohexylamine) and TMTD (tetramethylthiuram disulphide) --in protecting woody plants from browsing by mammals is reviewed. All three repellents have been used extensively in the forest industry to protect coniferous seedlings from hare damage and have also been successful in protecting deciduous trees from jack rabbits and cottontails. None of these repellents have been very successful in limiting seed predation.

Wodzicki, K. 1973. Prospects for biological control of rodent populations. Bull. World Health Organ. 48:461-467.

The uses of pathogens and predators to control rodent pest populations are considered. Pathogens, such as *Salmonella typhinurium*, have been used in Europe to control outbreaks of microtines. More widespread use of pathogens is not presently recommended, as known pathogens are too general and may lead to disease outbreaks in man or in other wildlife populations. In addition, rodents are capable of rapidly developing resistance to many disease strains. Predators appear to be capable of maintaining low rodent numbers for several years following a decline, but are unable to prevent cyclic outbreaks. If predators are used, at least one secondary prey species must be available to carry carnivores through periods of low primary prey availability. It is stressed that prior to any predator introduction, all secondary ecological consequences should be considered (i.e., effects on non-target prey species).

7. AOSERP RESEARCH REPORTS

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3.	HE 1.1.1	Structure of a Traditional Baseline Data System
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