Refining the Control of Northern Pocket Gophers (*Thomomys talpoides*) in Agro-Manitoba

by Melanie Dubois-Claussen

A Practicum Submitted in
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Abstract

The northern pocket gopher is a serious pest in Manitoba forage fields. It is estimated that damages to forage crops and harvesting machinery exceeds $15 million annually (estimated in 1996).

The objectives of this study were to (1) develop an accurate census method for northern pocket gophers; (2) to study burrow ranges and movements of the northern pocket gopher; (3) to evaluate the efficacy of a zinc phosphide rodenticide on northern pocket gophers; (4) to compare the performance of two artificial burrow building machines; and (5) to provide management recommendations for forage producers.

A census method with a time period of three days was the most efficient, with an acceptable level of accuracy of 92.3%. Burrow ranges of Manitoba northern pocket gophers were found to be similar to those described in the literature. A male that was radio-collared had a range double the size of the collared female. The zinc phosphide rodenticide (B.O.B®), reduced mounding activity by 38%-61%, and B.O.B® is recommended for application in the spring at a rate of 6.6 kg/2.5 ha with the Gofer® burrow builder.

A management decision worksheet was developed and is outlined in a user-friendly format, designed for forage producers. This worksheet allows for quick determination of the most cost-effective method of controlling northern pocket gophers.

Acknowledgments

I would like to thank the Manitoba Forage Council for their support of this project in all of its phases. This research would not have been possible without the Council and their commitment to finding solutions for forage producers in Manitoba. A special thanks goes to George Bonnefoy, who has made the control of pocket gophers a personal quest. He has been and continues to be the driving force behind funding for pocket gopher research in this province. I would like to thank the cooperators for the knowledge that they shared with such enthusiasm, as well as allowing me on their fields, lending me tractors and often a well needed hand.

I would also like to thank the members of my committee for their insights through out the editing process and their patience in the duration of the commitment. I would especially like to thank Dr. Rick Baydack for not losing his temper when I told him that I wanted to change my practicum topic to feral cats after I had completed all of my field work. He showed amazing restraint under the circumstances.

I must tip my hat to the intelligent and determined women who came before me in pocket gopher research at the NRI, Yvette Deniset (1993) and Marcia DeWandel (1997). I had the pleasure and privilege of spending countless hours walking alfalfa fields with both of them and I am a better researcher and person for it.

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Chapter 1

1.0 Introduction

1.1 Natural History

The northern pocket gopher (*Thomomys talpoides*) is a medium-sized rodent, modified in body and behavior for a life below-ground (Case 1988) (Figure 1). Large, external, fur-lined cheek pouches are the defining characteristic of the pocket gopher, giving the species its name. They have stout forefeet, with large claws for digging, small but functional eyes, small ears, and ever-growing incisors. As a consequence of using their incisors for digging, their lips have been modified to close behind the incisors to exclude soil from the mouth during excavation (Case 1988). Pocket gophers do not hibernate, and are rarely seen above-ground.

The pocket gopher is commonly referred to as a 'mole' by many agricultural producers in Canada, and as 'salamanders' in the United States (Case 1988). A number of other small mammals have been given the common name 'gopher'. The three mammals most commonly called a 'gopher' include the Richardson ground squirrel (*Citellus richardsoni*), the Franklin ground squirrel (*Citellus franklini*), and the thirteen-lined ground squirrel (*Citellus tridecemlineatus*) (Figure 2). These grassland species live in burrow systems and are a common sight on the prairies. The Richardson ground squirrel and the Franklin ground squirrel range in colour from gray to light brown or buffy, the Richarson's tail is tipped with black and its quick movements give rise to the common name of 'Flicker-tail' for this species. The Franklin's tail is longer than its body and their bodies are larger than the Richardson ground squirrel. The thirteen-lined ground squirrel is distinguished by the 13 whitish stripes running down the length of its body. These ground squirrels can immediately be distinguished from the pocket gopher by the gopher's naked, pink tail and external cheek pouches. Also, the burrows of a pocket gopher have no open holes and have characteristically fan-shaped mounds.

Figure 1. The pocket gopher.

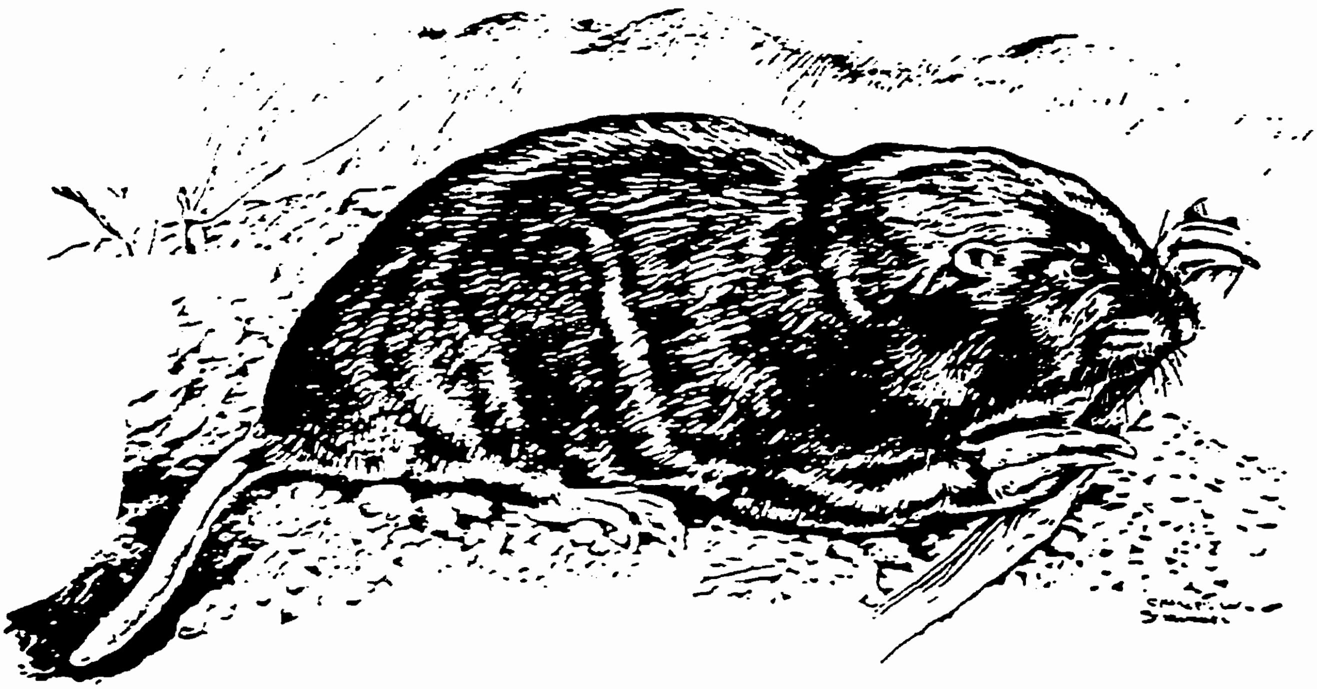
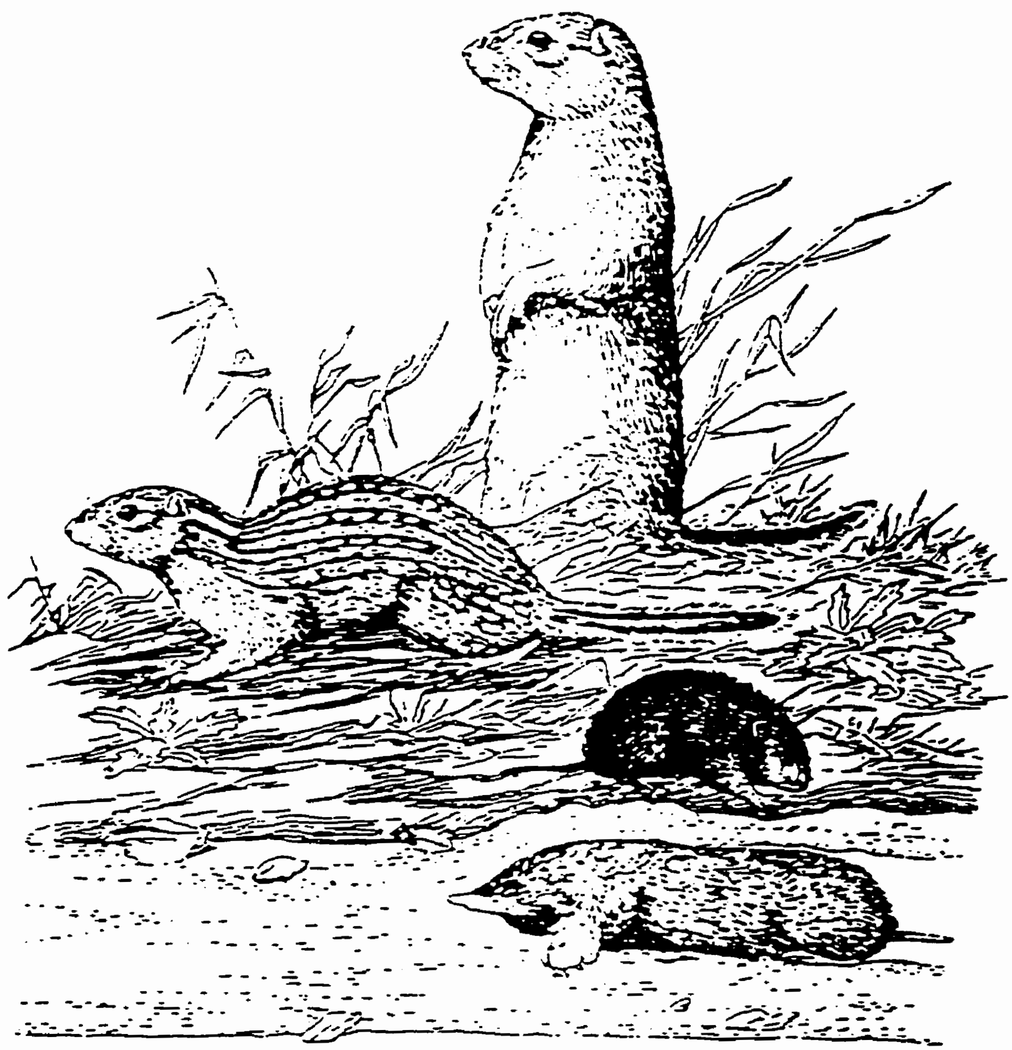


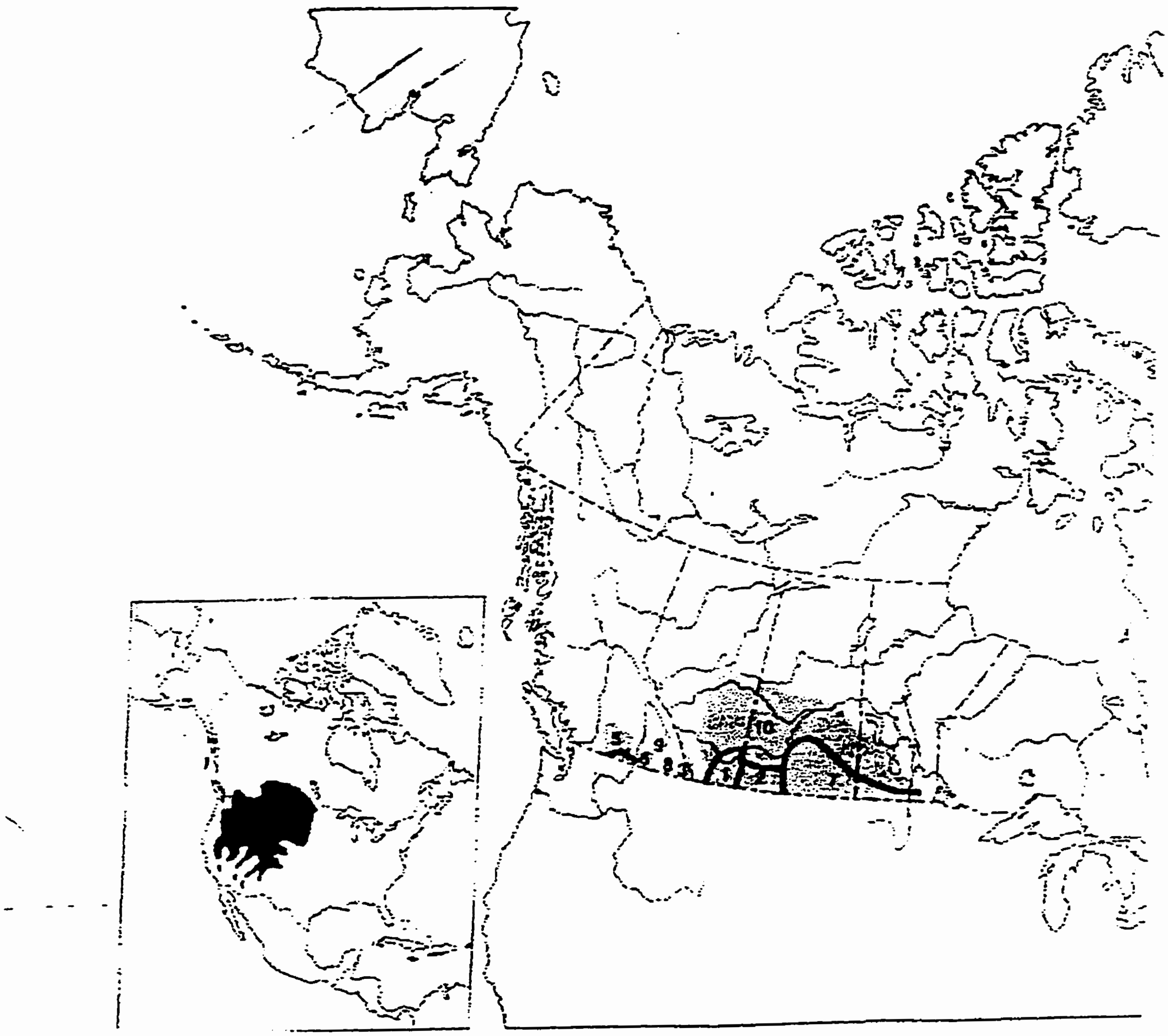
Figure 2. Animals often called gophers; from top to bottom, the Richardson ground squirrel, the thirteen-lined ground squirrel, the vole and the mole (from Case 1988)



Through the establishment of cultivated forage fields, farmers have inadvertently created ideal habitat for gophers. Agricultural practices have provided abundant forbs, often on light textured, porous soils with good drainage that allow for firm tunnels, and adequate gas exchange (Case 1988). This profile fits many of the alfalfa fields found in Manitoba.

The northern pocket gopher is highly dependent on forbs for food (Mayers and Vaughan 1964). Food choice studies have also shown that pocket gophers will consume alfalfa preferentially, due in part to the high water content (Ward and Keith 1962, and Mayers and Vaughan 1964). As a result, pocket gophers will preferentially live in alfalfa fields, and choose to consume alfalfa over native grasses while in those fields. It is currently believed that the northern pocket gopher is present in over 500,000 hectares in agro-Manitoba (DeWandel, 1997) (Figure 3).

Figure 3. The range of the northern pocket gopher, *Thomomys talpoides:* 1. *T.t. andersoni,* 2. *T.t. bullatus,* 3. *T.t. cognatus,* 4. *T.t. fuscus,* 5. *T.t. incensus,* 6. *T.t. medius,* 7. *T.t. rufescens,* 8. *T.t. saturatus,* 9. *T.t segregatus,* 10. *T.t. talpoides* (Banfield 1974)



Burrowing is one of the most important behaviours of the pocket gopher. This fossorial herbivore constructs a complex burrow system and uses the tunnels to locate and gain access to food items, as well as to secure shelter, to disperse and to obtain mates (Thorne and Anderson, 1989). The construction of feeding tunnels is the focus of all forage activity and these feeding tunnels run parallel to the surface of the ground (Vleck, 1981). During construction of these tunnels, large amounts of soil are brought to the surface, and deposited as soil mounds. A study of the larger species of gopher, the plains pocket gopher (*Geomys bursarius)* estimated that burrowing activity results in the surface deposition of 2489 lb of soil per gopher annually (Mupondwa, 1993).

It is the construction of the burrow system and the resulting surface mounds which have (in part) caused pocket gophers to be considered a pest in forage fields in Manitoba. Manitoba Agriculture estimates that pocket gophers are responsible for losses to producers of $15-22 million dollars per year (1987). The estimated losses are a combination of reduced alfalfa yields, reduced hay quality and damage to machinery (specifically swathing knives). Reduced yields are due to plant-smothering and grazing of both the tap root and above-ground parts by the gophers. A common response of producers to heavy gopher infestations is the premature break up of a stand. This represents a source of economic losses to the producer, as shown by DeWandel (1997). In her study, DeWandel found that over a period of five years, the annual cost of re-establishing a stand every three years would be $527.18/ha. This was compared to the annual cost of no control ($361.65/ha) and the cost of applying a rodenticide annually

($29.64/ha - $229.72/ha). DeWandel (1997) showed that an effective rodenticide could be a cost-effective response to pocket gophers.

1.2 Issue Statement

The northern pocket gopher has been identified, by forage producers, as having serious negative impacts on their operations in Manitoba. Losses incurred by forage producers are estimated to be $15-22 million dollars annually. The soil mounds that gophers produce cause damage to machinery and reduce the yield of the stand itself. The magnitude of the losses indicates that refined additional management techniques need to be developed, including a rapid and reliable method of assessing pocket gopher populations, as well as a more efficient method of control. Currently, control decisions are made based on crude estimations of infestation levels, and control methods are used that may be ineffective and costly compared to other techniques. A census method could be used in combination with a formula giving known losses per 2.5 ha, and an effective control method, that would allow producers to readily determine cost threshold levels with a reasonable degree of precision.

1.3 Objectives

The objective of this study was to refine control techniques for the northern pocket gopher in Agro-Manitoba.

The specific objectives of the research were:

1. to develop a census method for northern pocket gophers in Manitoba alfalfa fields;
2. to study burrow ranges and movements of northern pocket gophers;
3. to evaluate the effectiveness of zinc phosphide rodenticide, B.O.B® on northern pocket gopher control;
4. to report the performance of two artificial burrow builders in Manitoba alfalfa fields; and
5. to make management recommendations to Manitoba forage producers to deal with northern pocket gophers more effectively.

Chapter 2

2.0 Burrow Construction and Associated Behaviors

The pocket gopher has a unique life history that challenges conventional techniques for studying small mammals. A number of techniques have been developed to control rodents, however, the fossorial life style negates their applicability to the pocket gopher. Burrowing is one of the most important behaviors displayed by the pocket gopher. The construction of the burrow system and its variations in spacing, architecture and uses, makes it central to any discussion on the ecology or development of any management techniques, including a census method, for the pocket gopher. Through an enhanced understanding of the construction of the burrow, strategies for controlling the gopher can be developed.

This fossorial herbivore uses tunnels to locate and gain access to food items as well as to secure shelter, to disperse and to obtain mates (Thorne and Andersen, 1990). The burrow system construction results in the formation of surface mounds. It is these mounds which hold the key to determining populations.

2.1 Burrow Construction

The fossorial life style of pocket gophers make it difficult to estimate their abundance. Pocket gophers are rarely seen above-ground and evidence of their above-ground activities is limited to anecdotal reports, owl pellets, and predator scats (J. Dubois, personal communication). Therefore, it is important to understand how the subsurface fulfills the gophers habitat requirements so completely. The most important aspects of habitat for a pocket gopher include the depth and texture of the soil, and availability of food resources (Case 1988). The ideal habitat has abundant food, and light textured, porous soils with good drainage which allow for firm tunnels, and gas exchange. The burrow system of a pocket gopher is generally made up of shallow feeding tunnels (constituting >80% of the total length) and deeper food-storage and nesting chambers (Vleck, 1981). The construction of feeding tunnels is the focus of all foraging activity by the pocket gopher and these feeding tunnels run parallel to the surface of the ground (Vleck, 1981). The feeding tunnels are constructed at an energy cost to the gopher that includes the cost of digging a segment of the desired length, and the associated laterals, as well as the cost of pushing the generated soil against gravity to the surface (Vleck, 1981). Laterals are used for surface feeding and for pushing out excavated soil.

The total area of a pocket gopher burrow system is determined by a variety of factors. Different species have been found to maintain different-sized burrows, *Geomys bursarius* may have open tunnels exceeding 100 m in length, whereas *Thomomys* systems can be up to 75 m (Cameron et al, 1988). Plant productivity also effects overall length (though all other parameters stay the same), average burrow lengths in areas of high productivity have been shown to be significantly shorter than those burrows in areas of low productivity (Reichman et al, 1982).

Extensive studies have been done on the relationship between the patterns, rates of excavation and structure of burrows and on how they relate to the food resources in the area. These relationships are very important when trying to determine how many mounds will be formed by a gopher in a given area. Andersen and MacMahon (1981) looked at the bioenergetics of *Thomomys* burrowing and how it relates to burrow dynamics. The metabolic costs associated with a fossorial life history dictate that the method by which the burrow is constructed is very important (Andersen, 1988). Vleck (1979) found that the energetic costs associated with moving below-ground (burrowing), are many orders of magnitude greater than those associated with moving above-ground (may be 360-3400 greater). Andersen and MacMohan (1981) found that *Thomomys* burrowing takes place at an average rate of 2.0 cm/min.

2.2 Behavioral Influences on Burrowing

Optimal foraging theory looks at the behavior patterns which are associated with foraging. This theory can be studied readily in the pocket gopher because the burrow system provides a long-lasting record of past foraging (Vleck, 1981). Andersen (1988) cites that the logic of optimal foraging theory dictates that the pocket gopher will burrow in the most energy efficient manner in order to minimize burrowing costs in relation to the benefits. Andersen (1988) developed a number of simple rules that may describe what the gopher does in order to maximize search efficiency and minimize costs. These consisted of: random selection left or right for direction of the segment, starting the segment at the base of the last lateral segment, making the angle of elevation as small as possible and taking advantage of either local soil conditions or forage presence by the position of the next lateral. Branch angles, due to symmetry in the use of the foreclaws during shearing were found to generally be around 90° (Andersen, 1988). An area-restricted search in the presence of a clump of food will lead to the increase in number of branch-origination sites at the clumps (Andersen, 1988). The general attributes of the placement of branches off of tunnels for the northern pocket gopher are due to a combination of random choices in direction and the physical constraints associated with burrowing (Andersen, 1988). *Thomomys* was found to have a linear burrow system with numerous lateral branches off the main tunnel (Vleck, 1981).

Andersen (1988) looked at what effect plant density would have on the overall architecture of the burrow systems of *Geomys bursarius*. It has always been believed that food resources are the definitive factor in the construction of the burrow system, however, Andersen (1988) found that the density had no effect on architecture. The energetic cost of constructing a tunnel system is offset by the fact that the gopher can travel back to profitable areas without having to repeat the entire search process or rely on spatial memory (Andersen, 1990).

2.4 Burrow Spatial Patterns

The pressures for gophers to efficiently utilize space in relation to neighbors and resources is enormous due to the high costs of burrowing . It is important to look at the way in which gophers space themselves in relation to others of their own species to develop a census method that will estimate how many individuals are in a given area.

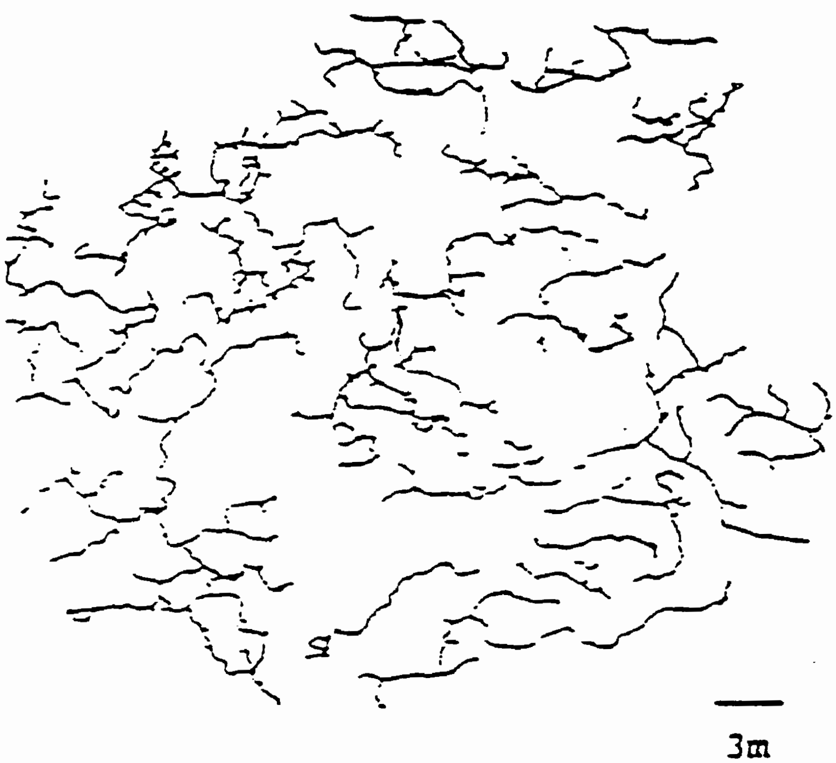
In non-fossorial species, home ranges tend to overlap somewhat, as well as shift periodically. However, pocket gopher burrows represent a great deal of energy output and they will maintain, and rigorously defend one discrete system for the duration of their adult life. Each individual burrow system is an entity unto itself which can be influenced by the food resources available, as well as the size of the individual and the soil type. The spacing within and between burrow systems is remarkably constant for all sizes and both sexes of pocket gopher (Reichman et al, 1982). The patterns of burrow placement in relation to other burrows are very complex but are not random because none of the burrows intersect each other at any time (Reichman et al, 1982). Extreme uniformity of burrow spacing, shape and configuration was found with each population (Reichman et al 1982). Figure (4) shows an aerial view of a population of pocket gophers. The line drawing demonstrates the placement of the burrow systems that were dug open and lined with white marking lime and photographer from the air.

A difference in burrow length, home range area, perimeter and number of adjacent neighbors was seen when comparing reproductive males to non-reproductive males and females (Reichman et al., 1982). A larger absolute burrow size and linearity was shown by reproductive males. This difference in burrowing behaviour may function to increase their potential for encountering a receptive female (Reichman et al., 1982).

It is not known how pocket gophers detect each other. The high cost of burrowing rules out any possibility that the gopher will dig until they find another burrow, then plug that tunnel and burrow the other direction (nor has any evidence of this occurring found)

(Reichman et al, 1982). Also, Andersen (1990) determined that even the detection of food without physically running into it, is limited by lack of light and poor air movement below-ground. Andersen (1990) showed that a pocket gopher could pass as close as 10 cm from a food item without detecting it. However, pocket gophers must be consciously aware of their neighbors, because a burrow system recently abandoned due to trap removal of the

Figure 4. Aerial line drawings of the burrows of a population of pocket gophers (*Thomomys bottae*) (Reichman et al., 1982).



occupant, will be quickly taken over by another gopher within a very short period of time (Reichman et al, 1982).

2.4 Foraging Strategy Influence on Burrowing

Foraging strategies vary widely between species of mammals and are a determining factor in the search path an animal will follow. Therefore, understanding the foraging strategies of the gopher can further explain why gophers burrows are structured as they are. The efficiency of a foraging path under certain conditions, is largely dependent on how well the animal uses, obtains, and updates information used to detect resources, while maintaining a positive benefit-to-cost ratio (benefit being the food obtained and the cost being the energy expended to obtain that food). The path an animal takes during foraging is determined by a variety of behavioral decisions, as well as by the surrounding environment.

Andersen (1987) looked at food patch structure, and how it influences pocket gopher foraging. It was found that below-ground plant biomass density did not alter burrowing behavior (Andersen, 1987). Andersen (1987) hypothesized that burrowing is instinctively continued at a high level set by internal energy stores, regardless of plant density. High burrowing rates would provide a great deal of information on habitat quality and would increase the chances of encountering a food item (Andersen, 1987). The foraging path of the pocket gopher was found to be consistent with a search path predicted for a harvesting animal (as was the linear geometry stated earlier) which minimizes the energy costs of burrowing (Andersen, 1988). Andersen's (1988) findings show gophers display behaviors consistent with area-restricted search theory. This is displayed through intensified searching by the gopher when it finds an area with a clump of food. The search path of the pocket gopher was unaffected by habitat patchiness or the density of palatable plants (Andersen, 1988). Results from many studies indicate that perhaps the behavioral drive for the pocket gopher to dig may not hinge directly on food availability (Andersen, 1987). Burrowing may be necessary to wear down the rapidly ever-growing incisors, as well as fulfill an exploratory, information-gathering drive (Andersen, 1987).

2.5 Influences of Food on Burrowing

The nature of the food which an animal searches for is very important in understanding why they search in a particular manner. Pocket gophers were thought to be generalist herbivores, due mainly to the high cost involved in foraging by burrowing. However, species of gophers that are very similar in life history and morphology, differ in food preferences and available resources.

Growth rates in fossorial mammals are subject to the constraints of burrowing energetics and the amount of effort that must be put forth to obtain food (Andersen, 1978). Smith and Patton (1980), hypothesized that differences in food resources will cause variations in body size by influencing growth rates. Relatively high levels of effort in nutrient-poor sites represents poor return on energy invested in foraging. Therefore, differences in habitat will modify overall size attained due to variation in returns on energy expenditures (Patton and Brylski, 1987).

As availability or presence of appropriate food items decreases, pocket gophers must move greater distances to obtain sufficient food. Pocket gopher populations are thought to be food limited (Andersen and MacMohan, 1981). This has been supported by the results of other studies. In examination of diet when there is a shift in plant species, *Geomys* shows a distinct seasonal change in the species of plants preferred from forbs to grasses, however, *Thomomys* shows no shift (Myers and Vaughan, 1964). The shift in *Geomys* is thought to reflect the abundance of available plant species, with March through August having forbs most abundant and September through February abundant in grasses (Myers and Vaughan, 1964). *Thomomys* preference seems to be independent of plant species composition or availability. In an area which was made up of 50% grass, 42% forbs and 8% shrubs, their diet was comprised of 93% forbs (Ward and Keith, 1962). This makes *Thomomys* highly dependent on forbs for food (Myers and Vaughan, 1964). When faced with a shift in plant species composition (in this example, due to the spraying of a herbicide), where forbs dropped from 67% of species composition to 30%, *Thomomys* population dropped 87% (Ward and Keith, 1962).

Food habit differ somewhat between adult and juveniles (Myers and Vaughan, 1964). Adults tend to eat significantly less aboveground vegetation in comparison to young gophers, which probably reflects more experience on the part of the adult in avoiding predation (Myers and Vaughan, 1964).

2.6 Activity Patterns

A interesting characteristic of the pocket gopher is that it does not hibernate, even though it is a rodent that lives in temperate climates. Pocket gophers show a four hour activity cycle averaging out to two hours of rest and two hours of movement (Gettinger, 1984). The 24-hr activity cycle is punctuated to a small degree by a peak of activity occurring during the late afternoon early evening (Gettinger, 1984). Sites of activity are particularly found in the shallow feeding tunnels located close to the surface, with resting periods centred exclusively in the single nest chamber (Gettinger, 1984). The amount of time spent active or resting is not effected by either body mass of the individual or the size of its burrow system (Cameron et al, 1988). Also, activity levels are not related to the above-ground or within-burrow temperature (Cameron et al, 1988). Surface activity is rarely if ever observed, however, surface activity does take place during dispersal. One radio-collared juvenile female was observed in this study to move 133 m overnight, which would be impossible to accomplish through burrowing.

The mechanics and theory behind the construction of the tunnels was discussed earlier, in order to complete the picture, seasonal patterns related to temperature and moisture changes, as well as reproductive periods must be overlain. Miller (1948) showed that tunneling correlates closely with soil moisture, and that mound production is at its highest level when soil moisture reached 9-19%. The importance of soil moisture was identified by Anderson and MacMohan (1981) as one of the key factors in the burrowing rates of *Thomomys talpoides*. Over saturation of the soil limits mound production. Overall increases in the tunnel system are closely linked to a combination of sexual behavior and availability of food (Cox and Hunt, 1992). Bandoli (1981) indicates that mate seeking may be more important than precipitation. To introduce another factor, Criddle (1930) demonstrated that the observed drop in mound production is correlated with the gophers' timing of reproduction and rearing of the young. The resurgence of mound production in the fall could then be explained by the dispersal of the young and their establishment of home ranges (Moore and Reid 1951, in Cox and Hunt 1992). Not all tunneling results in the production of mounds, with a variable amount of the loose soil being used to back-fill old and unused tunnels. These fluctuations in mound building are very important when trying to use their formation in estimations of abundance with a predetermined mathematical equation.

2.7 Summary

The aspects of the pocket gophers life history discussed above make this a difficult animal to census. To briefly summarize these:

- Pocket gophers are rarely seen above-ground, therefore counts can not be made through sightings.
- Surface soil mounds produced by tunneling are the only obvious signs of gophers, however, many factors other than the absolute number of gophers cause fluctuations in the number of mounds present.
- Fluctuations in mound production can be a result of; density of forbs in the area, sex and reproductive status of the individual, total number of gophers in the area, soil moisture and texture, amount of tunnel back-filling, and time of the year.

Therefore, for a census method to be used effectively on the pocket gopher it must either take into account all of these variables or be specifically designed for use under certain circumstances (i.e. for use in forage fields at a specified time of year).

Chapter Three

3.0 Census Methods

Census counts are used to determine the abundance of an organism. The information generated by the census counts can be used in a variety of ways including to increase or decrease harvest levels, or as in the species under study to determine the most cost effective method of population control.

3.1 Statistical Considerations

The methods available to estimate the abundance of pocket gopher populations are controlled by ecological, economical and statistical factors. The ecological factors are the constraints due to the biology of the animal and its habitat. The extensive exploration of the gopher's life history above, has provided ample background into the unique constraints that must be given consideration in developing the census method. The economical factors include such things as the cost and effort required of the method, and whether or not the cost is justified by the accuracy that can be achieved. The statistical constraints are such things as sample size, the variances in the data and meeting assumptions that allow for statistical significance to be measured.

Krebs (1989) outlines a sequence of decisions through which one can choose a technique to estimate population. Using this method with the pocket gopher shows quadrat counts to be the most applicable techniques. The assumptions of these techniques require that the area of the count must be known, and the animals must be moderately immobile during the sampling period, which fit well with the biology of the gopher (Krebs, 1989). Difficulty is encountered when trying to determine the size and shape of the quadrat which is required. What is required to ensure statistical significance and that which is possible (in relation to time and money constraints in the field) are often two very different things.

Krebs (1989) suggests that the same size and shape quadrat used in previous studies can be used. However, previous studies indicate that the chosen size of the quadrat for pocket gophers can vary widely dependent on soil type, vegetation and population densities. Therefore, quadrat size is highly dependent on the population in question. The shape of the plots has generally been square, because of the regular spacing and linear configuration of pocket gopher burrows (which will minimize edge effect without compromising area). It is at this point, once a size and shape has been chosen, that the sampling design becomes important. A census or estimation of abundance constitutes a measurative experiment during which no treatment is applied to the plot, therefore, no control is needed (Krebs, 1989). As a result, there are less restrictions on the design required, though as many replications possible is recommended. Repeated sampling over time and space (on the field) bolsters the significance of the generated data by mitigating variables introduced through variations in population fluctuations and localized habitat characteristics.

The estimates generated by the study census method are confirmed by trapping-out the gophers found within the study plot. Trapping constitutes a treatment and must be treated as such statistically. Repeated measures (census counts) on the same treated (trapped-out) plots would not be independent and would be considered temporal pseudoreplication, and should be subject to ANOVA (Krebs, 1989). A simple solution to this problem is to abandon the plot after one trap-out and move to a new plot which has not been acted upon.

3.2 Sign Counts

It has been the goal of many researchers to prove statistically, that there is a linear mathematical relationship between the number of gophers in an area and the number of mounds which they produce through burrow construction (Ried et al., 1966, Engeman et al., 1993, Proulx et al., 1992). The discussion of burrowing in the previous section outlines that there are a number of factors influencing burrowing, however that burrowing follows a logical, and maybe quantifiable pattern. The mounds are the only visible signs of the gophers and are therefore the only sign used to make an index of the population. Richens (1965) found a positive relationship between the number of mounds and the number of pocket gophers, with the highest correlation found after performing periodic and cumulative counts, confirming the logical structure of the burrowing process.

Another important reference that is used as a model for gopher census methods, confirmed a mathematical correlation (Reid, Hansen, and Ward, 1966). The described method involved the flattening of all mounds in a predetermined area, which is returned to 48 hours later, at which time all fresh mounds are counted. The plots in the original study were then trapped-out to allow for statistical evaluation of the accuracy of the method. An equation was generated to describe the relationship (valid for a 2 day interval on 54, 1-

2.5 ha plots), $\acute{Y} = (0.6582)(\times x)(\log(x + 1)$ into which the number of new mounds after 48 hours becomes (x) (Reid et al., 1966).

Example: number of mounds counted = 80

number of gophers = (0.6582) (×80)(log (80 ÷ 1)

number of gophers = (0.6582) (8.944) (1.9085)

number of gophers = 11.2 ⇧ 4

This method is complicated by fluctuations in burrowing activity, and analysis showed that the number and area of the plots sampled, are dependent on the size of the existing population. Reid et al. (1966) found that in order to obtain results in a time period of 24-48 hr., that were statistically significant, a large number of large plots had to be sampled (55, 1-2.5 ha plots when the population was 11, and 7, 1-2.5 ha plots when the population was 22). The high labour and monetary cost entailed in this effort makes it impractical for use at a field level. To further undermine the only technique generated so far to assess gopher populations, Gettinger (1984) points out that in counting mounds not all burrowing activity is considered because not all burrowing creates mounds, due to gophers using some of the soil to back-fill abandoned tunnels. However, this is still the most promising method because the mounds are the only sign that can be used, and back filling could be assumed to be in relatively constant proportion to surface mound building. Intuitively, it would seem that further refinement of the technique, either through a nested quadrat design (to determine if the area required could be reduced), or limiting its application to areas of high population, could allow it to remain useful. Therefore, this techniques will be used as the basis for this study, with modifications being made to minimize some of the problems outlined above.

3.3 Other Techniques

Other techniques have been tried in place of the mound counts with limited success. Anderson and MacMohan (1981) tried to use mark and recapture to count the gophers, basing densities on individuals live-trapped within plots in early summer (to represent breeding population densities) and in the fall (the wintering populations). However, the characteristics of a gopher population violate a number of the assumptions that form the statistical framework of catch-and-release calculations. The Peterson Method is a simple mark-and-recapture method that involves a single period of recapturing after marking (Krebs, 1989). The assumptions of this method are violated by pocket gophers' unequal catchability, the difficulty of capture-recapture that precludes a closed population, and non-random sampling due to discreet burrow systems (Krebs, 1989). The Schnabel Method extends the recapture period to include a series of trapping episodes (Krebs, 1989). The assumptions of the Schnabel Method are the same as the Peterson Method, making it equally unusable. A final method the Jolly-Seber Method, that looks at when the individual was last captured, is for a open population, but is still not applicable because sampling can not be random, (a crucial assumption), due to the nature of the burrow system (Krebs, 1989).

Proulx et al. (1992) looked to the remote sensing to see if it could be used in censusing populations. It was found that colour aerial photographs could be used to confirm the presence of pocket gophers (limited to areas with dry soils and short vegetation), and black and white infrared photos were useful to outline areas disturbed by activity.

However, neither could be used to count individual gopher mounds. Proulx et al. (1992) suggested that remote sensing could play a role in determining areas of concentration and expansion. Currently, Proulx is working on a census method which involves the opening of tunnels and assessing activity by observing the rate at which these holes are plugged. The open hole method was investigated previously by Engeman et al. (1993), and was found to be more sensitive than the mound-count method, and less labour intensive. However, this study also found that there was a potential for bias when less-experienced observers were used to count fresh mounds. Engeman et al. (1993) acknowledge that there were many factors influencing the accuracy of each method, and that each must be tested under different conditions to provide a definitive answer.

Chapter Four

4.0 Control Methods

In order for a control method to achieve widespread and repeated use, Witmar et al. (1995) detail conditions that it must meet. The method must be safe, effective, inexpensive, legal, environmentally safe, and socially acceptable. To date no control that meets all criteria has been developed for the pocket gopher. However, different methods of control for pocket gophers has been practiced by producers for generations. The three methods most commonly used include; baiting with toxicants (rodenticides), removal trapping, and premature cultivation of the effected field. These methods have a variety of advantages, disadvantages, and costs associated with them.

4.1 Rodenticides

Poisons are under continuous investigation and development by manufacturers. The use of these chemicals has changed over time as environmental standards have changed and awareness of the damage to non-target species has increased. There is a push to increase regulation of control activities, to reduce the available tools and materials to control pests (because of safety and health concerns), and pressure to use methods of control that reflect societies requirement for the humane treatment of animals (Timm, 1997). The poisons that have been developed to control rodents can be differentiated from each other by the method of application, and the toxicant or active agent.

The poisons used to target pocket gophers share a common method of application but vary in the carrier and effective agent. The rodenticide is deposited directly into the burrow system through the use of a mechanical burrow builder or a hand probe. The burrow builder is pulled behind a tractor and is useful for large scale application of the poisoned bait. The function of the burrow builder is to create an artificial feeding tunnel just under the surface, into which poisoned bait is deposited via a modified seeder calibrated to deposit the prescribed dosage. The hand probe is useful for small-scale application of the poison, and is used to deposit bait into the pre-existing tunnels of individual gophers.

There are a number of toxicants that are used as the active agent in rodenticides. These toxicants are subject to strict regulations, and some are being phased out of the market in response to safety or environmental concerns. They can be grouped into two broad categories based on their mode of action, anticoagulants and non-anticoagulants.

4.1.1 Anticoagulants

Anticoagulants, as the name suggests, causes massive hemorrhage in the animal. This can be accomplished in a single dose or multiple doses, depending on the formulation. These poisons are available for sale under different names and have been evaluated by numerous studies. Deniset (1993) evaluated Maki® and Contrac®, both of which are single-dose anticoagulants, based on bromadiolone. Bromadiolone was evaluated by Sullins (1997), who reported a reduction in activity of only 8.5-17.4%. Deniset (1993) had positive results with Maki®, but not with Contrac®. Sullins (1997) and Proulx (1994) tested two types of multi-dose anticoagulants, chlorophacinone and diphacinone and achieved completely different results. Sullin (1997) found a reduction of 77.5-95.5% with chlorophacinone, and 70.7% with diphacinone, whereas Proulx (1994) had a 0% reduction in activity with both rodenticides. Proulx explained these results (and other negative results) with the finding that the antidote to anticoagulants is vitamin K, that is found in extremely high doses in alfalfa. Proulx went so far as to state that none of the available toxins available on the market could be recommended due to similar flaws in the formulations, and the high doses required to be effective.

4.1.2 Non-Anticoagulants

Toxicants classified as non-anticoagulants include; strychnine, zinc phosphide, bromethalin, cholecalciferol, sodium fluoroacetate (Compound 1080) and fumigants such as liquid anhydrous ammonia. Strychnine is a poison that has had wide spread use in the past, however, every effort is being made to remove this product from the market due to its potent effect on non-target species, and the large potential for secondary and tertiary poisoning. Deniset (1993) tested a new formulation, Gophacide®, and noted a reduction in activity, however, Proulx (1994) achieved only a 0-30% control and would not recommend it. Deniset tested a poison based on the chemical cholecalciferol, Quintox®, that functions to produce an extremely high level of calcium in the blood stream that causes hypercalcemia, resulting in a heart attack. This poison yielded good results and is recommended as a method of control. Zinc phosphide was also investigated by Proulx (1994), who rejected it due to a reduction in population of only 20%. However, O'Brien

(1997) found that its limitations could be over come if the bait was made acceptable to the target species through pre-baiting with non-toxic bait.

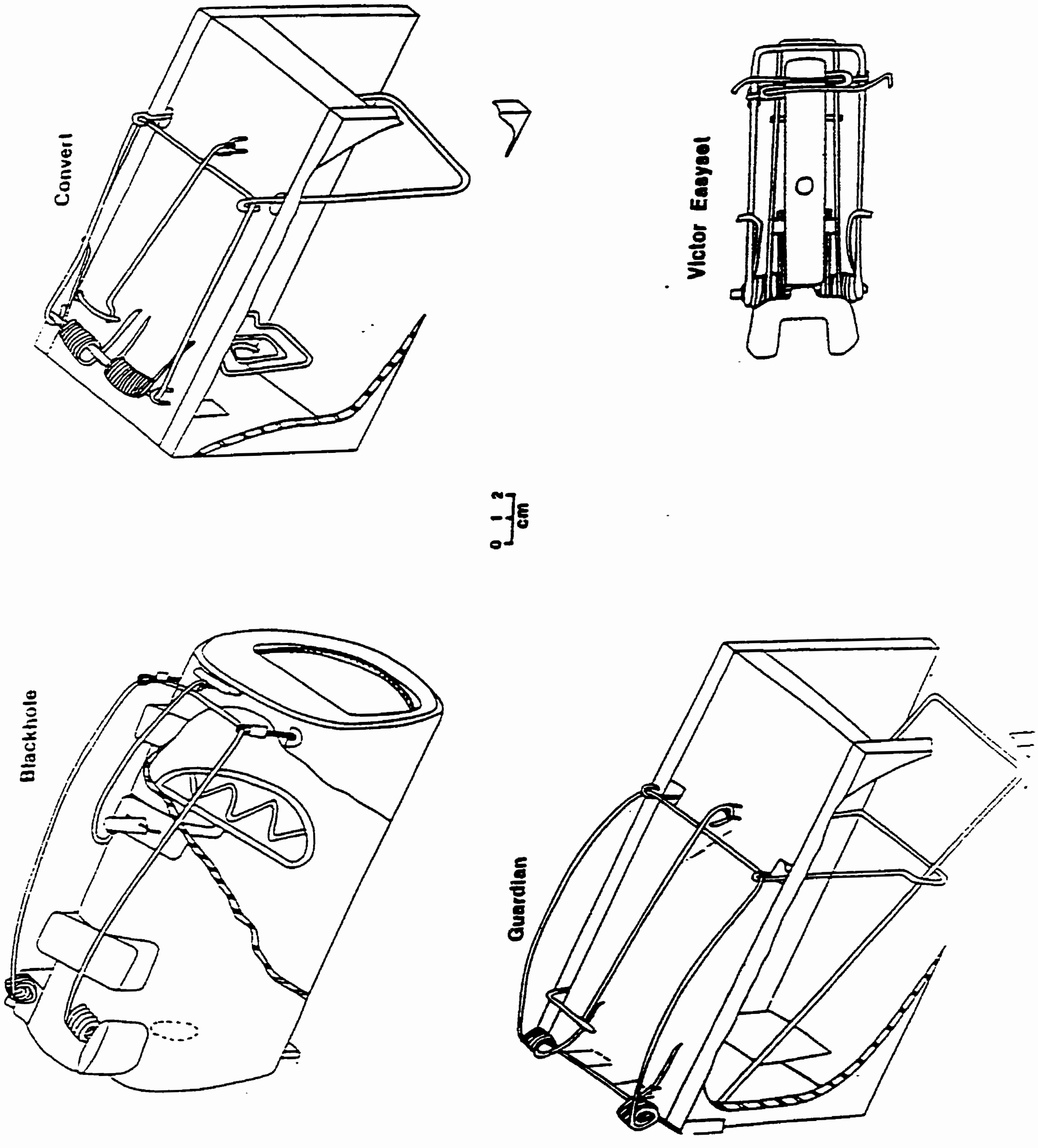
4.2 Trapping

Trapping is a common method of control for rodents. There are two main types of traps, impalement types, and snare types (Figure 5). These have been modified by various companies to give the producer a choice of trap. The impalement trap is activated when pressure is placed on a floor mounted trigger, causing spikes from each side of the trap to pinch together, impaling the pocket gopher. The snare trap is set inside a container with the trigger hanging down and the body of the snare resting on the ground at the entrance. When pressure is placed on the trigger the snare is raised to the ceiling, trapping the animal.

Deniset (1993) did an extensive three year evaluation of the efficiencies of four types of traps. The results showed an overall efficacy of 44.25%, and a catch effort of 35 minutes per gopher trapped. The most efficient trap was an impalement trap, the Macabee®, at 51.5%. This was followed by the snare type, the Wooden Box , 46.8%, another snare, the Black Hole®, 42.8%, and lastly an impalement trap, the Easy Set®, 42.8%.

Proulx (1997), over two nights of study found that the most efficient trap was a snare type identical to the Wooden Box, the Convert. This was followed by the Black Hole® and the Easyset ®, (the Macabee® was not part of the study).

Figure 5. Impalement and Snare Traps (Proulx et al., 1992).



The purchase price of the individual trap varies from $4.95 for the Easy Set to $15.00 for the Black Hole. Another option for producers is to hire a professional trapper who can charge $2.00 - $7.00 per gopher trapped depending on current market prices.

Chapter 5

5.0 Methodology

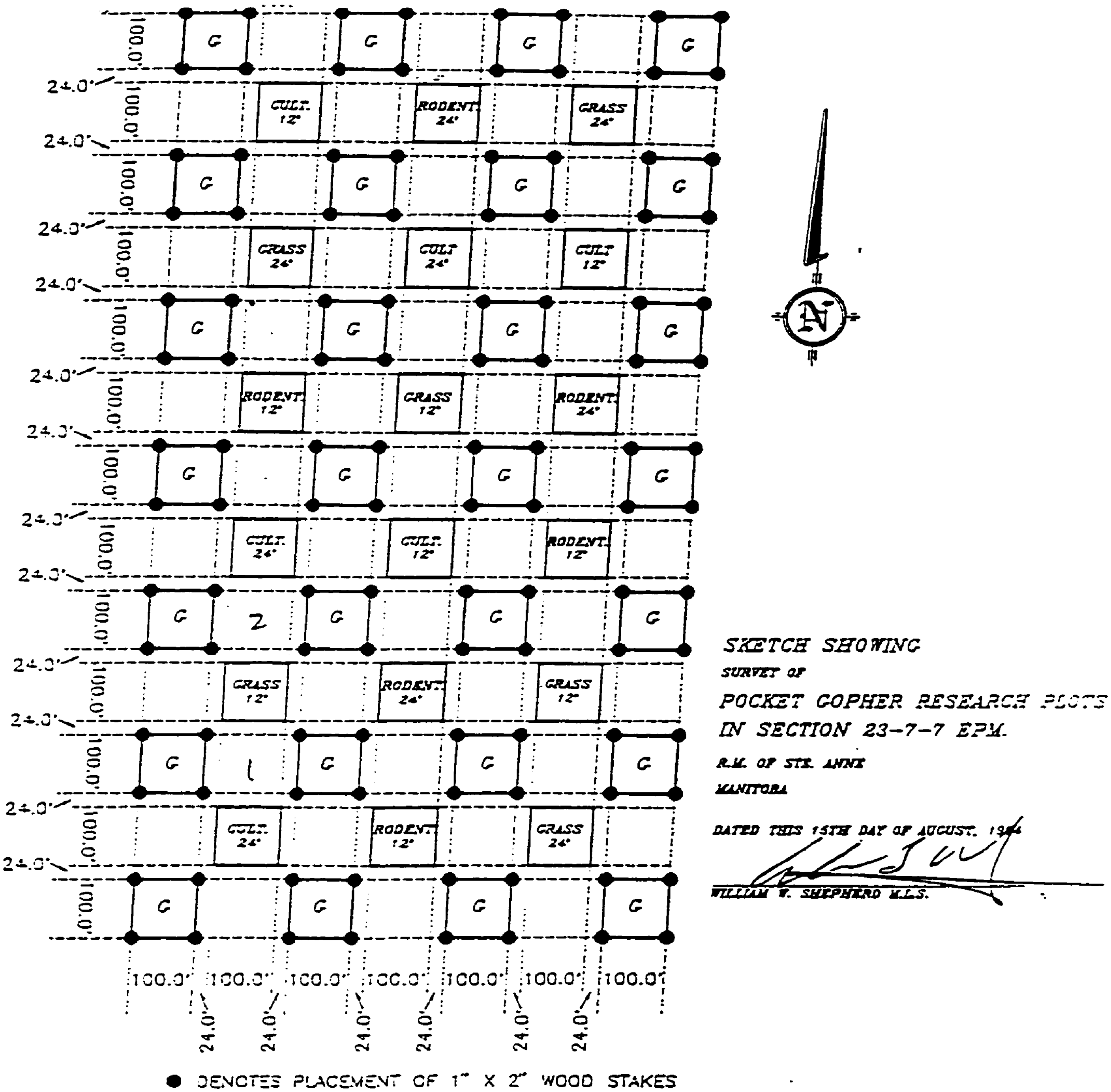
A range of methodologies were developed to reach the objectives outlined previously.

5.1 Study Site

The data collection for the census method and the radio-collaring trials took place on two sites in Manitoba. The study was conducted in the municipality of St. Anne, on a 32 hectare alfalfa field, 1.6 km east of Giroux (23 -7-7 EPM) , during the summers of 1994, 1995, and 1996. The study site shifted to the municipality of Erikson during August of 1996, when the field previously used was no longer available.

The St. Anne site was established in the summer of 1994, and was surveyed by a professional company to ensure accuracy. The section under study was 484 m x 258 m, and was further divided into plots 30.3 m x 30.3 m (Figure 6). These dimensions yielded a large number of identical plots, each with an assigned purpose. The study area was used by another project at the same time (DeWandel, 1997), and plot selection was modified to avoid using the plots under study by the other project.

Figure 6 Study Site



5.2 Objective 1: Census Method Development

The census methods trials consisted of periodic and cumulative counts followed by a trapping-out of each plot.

In all trials, the first stage consisted of flattening all mounds contained within the plot. Then all fresh mounds were counted daily over a number of days. At the completion of the period of counting, traps were set in the plot for an average of three days or until there was no fresh mound activity.

Modification of the number of days of mound counting occurred over the duration of the study. During the first full field season (1995) mounds were counted two days after the mounds were initially flattened. During the final field season (1996), the time period was expanded to counts every day for seven days. Pocket gophers were trapped for three days after the seven day period was completed. The data was analyzed using Systat®. Multivariate general linear regression was done on each to determine the sampling period with the shortest length of time and the highest correlation.

5.3 Objective 2: Burrow Range and Movements

Radio equipment was obtained from AVM Radio Telemetry Equipment and Techniques. The collar that was used was the SM1-H. This external neck collar was designed to have a large range to transmit through the soil, and to be attached easily in the field. It had a whip antenna built into the collar, to avoid interfering with the pocket gophers burrowing motion. The pocket gophers were trapped using a modified live trap, and the collars were affixed in the field to the pocket gophers.

The radio-collared pocket gopher was monitored for as long as time allowed or until the collar was removed by the animal. Transmission relocation points were established every 30 minutes and plotted on a map in meters and in degrees from the point of capture.

5.4 Objective 3 & 4: Rodenticide Evaluation and Burrow Builder Comparison

The rodenticide, provided by United Agri-Products for further testing, was the Clean Crop Burrow Oat Bait® (B.O.B.®), Registration No. 24795 under the Pest Control Poisons Act. The price of the poison at the time of testing was listed at $136.00(CAN) for a 20 kg bag. At the recommended rate it would cost $10.20/2.5 ha(CAN), at the experimental rate (11 kg/2.5 ha) the cost would be $17.00/2.5 ha(CAN). It is a toasted oat groat, infused with a zinc phosphide poison (2% concentration). The poison reacts with the stomach acids of the rodent, gas is produced in the blood, and is exhaled through the lungs, suffocating the gopher.

The rodenticide was applied with an artificial burrow builder. This machine is pulled behind a tractor on a three point hitch, and creates a tunnel below-ground, while dispensing the rodenticide-impregnated bait into the tunnel at a set rate. Two different machines were used for the purpose of comparison (objective 5), the Bob Kentch-Gofer® (Figure 7) and the Western Alfalfa Burrow Builder® (Figure 8) .

The study sites were situated in three different regions, as determined by the participation of three producer groups.

Three trials were applied in the spring (May - June) on the following fields:

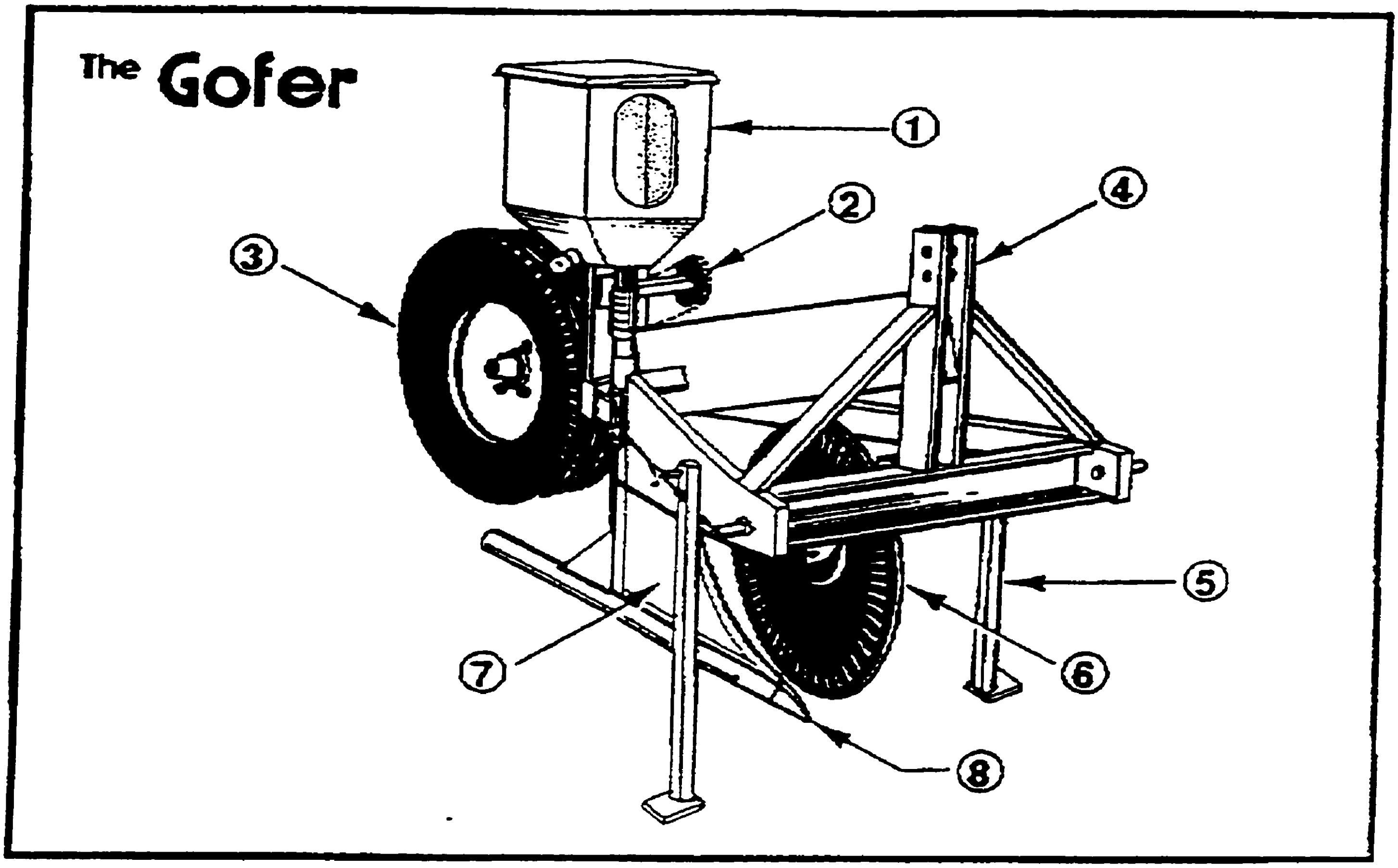
- Mr. Raynald Chappellaz, St. Claude, Manitoba, location SW 33-8-7
- Mr. George Lefloch, Haywood, Manitoba, location SW 27-8-6
- Mr. Raynald Theroux, St. Claude, Manitoba, : location SE 14-8-9

Four trials were applied in the fall (August - October) on the following fields:

- Mr. Ken Wright, MacGregor, Manitoba, location:
- Mr. Roger Bruneau, St. Claude, Manitoba, location SE 11-8-7
- Mr. John Dion, St. Claude, Manitoba, location NE 35-7-8
- Mr. Lawrence Lacoste, Giroux, Manitoba, location SE 4-8-70

Each field contained four study plots that were 0.4 ha^2 (63.6m x 63.6m), with a 20m area around each plot, treated as a buffer zone. One of the study plots was used as a control, with tunnels made, but no rodenticide applied. One plot received rodenticide at 6.6 kg/2.5 ha, applied with the Gofer®; one at 6.6 kg/2.5 ha with the Western Alfalfa Burrow Builder®; and the remaining plot was treated with B.O.B.® at 11 kg/2.5 ha with the Gofer®. The rodenticide was applied every 6m, with passes made in two directions perpendicular to each through the field.

Figure 7. Bob Kentch Gofer® Artificial Burrow Builder.



1. **BAIT CONTAINER**
   Divided, holds two different gopher baits.
2. **BAIT DISPENSER**
   with twin feeder alternates baits or feeds one bait only.
3. **GROUND DRIVE WHEEL**
4. **MAIN FRAME**
5. **PARKING STAND**
6. **SPRING LOADED COULTER**
7. **CHROME-PLATED BLADE**
8. **REPLACEABLE CAST POINT** - chrome alloy.

In order to monitor the efficacy of the applied rodenticide on gopher populations, the census method previously used in similar studies was used (Deniset, 1993). The procedure involved the flattening of all surface mounds, then returning 48 hours later and counting the new mounds. This was performed prior to the application of the rodenticide, to assess the activity levels, and counts were performed three days and ten days post-treatment

The collected data was examined to compare the percent change in mound production within each plot. The average number of mound counts was calculated and the percent change was determined. The percent change was modified to reflect 'background' events (seen as the amount of change in activity in the control plots on each field). These changes represented fluctuations in activity which would have occurred in the plots if the rodenticide was not applied. Through the modification of the treatment results , the true effects of the poison are clear.

Comparisons were made between the efficacy of the Gofer® at 6.6 kg/2.5 ha and the Western Alfalfa Burrow Builder® at 6.6 kg/2.5 ha. Anecdotal observations were made on ease of use and the machine's ability to make good tunnels, and speculations were made on the differences seen.

5.5 Objective 5: Management Recommendations

The results from the census method and the rodenticide trials were combined with the findings of previous studies (Deniset, 1994 and DeWandel, 1997) to develop a management decision worksheet. The yield losses determined by DeWandel (1997) were combined with the census method equation to find the dollar value of losses per gopher. This value was used in the worksheet to allow producers to calculate their individual losses per ha. The known losses per hectare could then be compared to the cost of different methods of control per hectare. The results of the rodenticide evaluation and burrow builder comparison were incorporated into the worksheet. This worksheet is intended for use by forage producers.

Chapter Six

6.0 Results

6.1 Objective 1: Census Method Development

The investigation into the census method determined that an accurate mathematical relationship could be determined between the number of gophers in an area and the number of mounds produced in that same area. The data violated the assumption of constant variance of error, necessary for regression and correlation analysis, therefore the data was logged, normalizing the variance (Krebs, 1989). The data was grouped by sampling day, with all plots being pooled. An adjusted squared multiple R correlation value was generated for each sampling period. This value indicates the percentage of the variance in the number of gophers that is predicted by the variance in the number of mounds.

Day 7 showed the highest correlation of 0.934 or 93.4%. The equation generated by this sampling period is;

$$-2.555 + 1.137(\log \text{mounds}) = \log \text{gophers}$$

This has a p value of <0.0001 and a confidence interval of 1.137 +/- 0.195.

Day 3 showed the highest correlation in the shortest number of days, with an adjusted squared multiple R or a correlation of 0.923, (92.3%). This can be translated to mean that 92.3% of the variance in the number of gophers can be predicted by the mounds. This has a p-value of <0.0001 and a confidence interval of 0.934 +/- 0.174. The equation that describes the relationship is;

$$-0.980 + 0.934 \text{ (log mounds)} = \text{log gophers}$$

Day	*p-Value*	*f-Statistic*	*Adjusted R^2*
one	<0.0001	45.427	0.774
two	<0.0001	54.344	0.781
three	<0.0001	192.487	0.923
four	<0.0001	153.009	0.905
five	<0.0001	145.970	0.901
six	<0.0001	164.146	0.911
seven	<0.0001	227.750	0.934

Table 1. Census Count Statistics

6.2 Objective 2: Burrow Ranges and Movements

The investigation into the above-ground movements and dispersal of the northern pocket gopher was limited by the time-consuming nature of live trapping study animals, however, some interesting anecdotal information was gathered. A total of nine gophers were collared, and data collected on each (appendix 1) (Figure 9).

The first gopher shed its collar 1 1/2 hr. after release, yielding only three stationary relocation's, and the collar was retrieved. The collar was found in a burrow system 133.35 m south, 19.8 m west of the point of release. This juvenile female was trapped in a burrow system containing an adult female, assumed to be its mother. The collar was retrieved in a burrow containing a juvenile female of the same dimensions, assumed to be the original collared gopher. The second gopher (male juvenile) was accidentally kill-trapped immediately after collaring when it moved into a control plot of the other project and only two relocation's were obtained. The animal was trapped 22.7 m south and 14.5 m west from the point of release after collaring. The third and fourth pocket gophers shed their collars immediately upon release and the collars were recovered at the point of release.

The final pocket gopher collared at this location was successfully collared and generated a total of 89 relocation points over 46 hours of monitoring. The mapping of these points revealed a defined area of movement with a range measuring 471.50m^2 (Figure 10).

The project was moved to Erickson and the final four gophers were collared. Gopher number six retained its collar for a short time, generating 30 relocation's over 15 hours of monitoring, however only 5 were at locations other than the spot where the collar eventually remained stationary. The seventh collaring was the most successful, yielding 125 relocation's over 62.5 hours of monitoring before the gopher shed its collar. This pocket gopher was consistently found in the area shown in Figure 11 . This area measured

209.25 m^2. The gopher spent 40% (40/102) of the relocation's in a spot assumed to be its nest before the transmissions became stationary in this location.

The total area where gopher #5 was relocated was double the size of the area in which gopher #7 was found. The range of gopher #5 was more spread out than #7 and included a number of tunnels of up to 12 m in length. The range of gopher #7 was more compact and the longest distance measured from the point of capture was one relocation at 12.5 m.

The final two gophers collared did not retain their collars, and the collars were retrieved at the point of the gophers release.

Figure 8. Northern pocket gopher with radio collar.

Figure 9. Relocation Points, gopher #5.

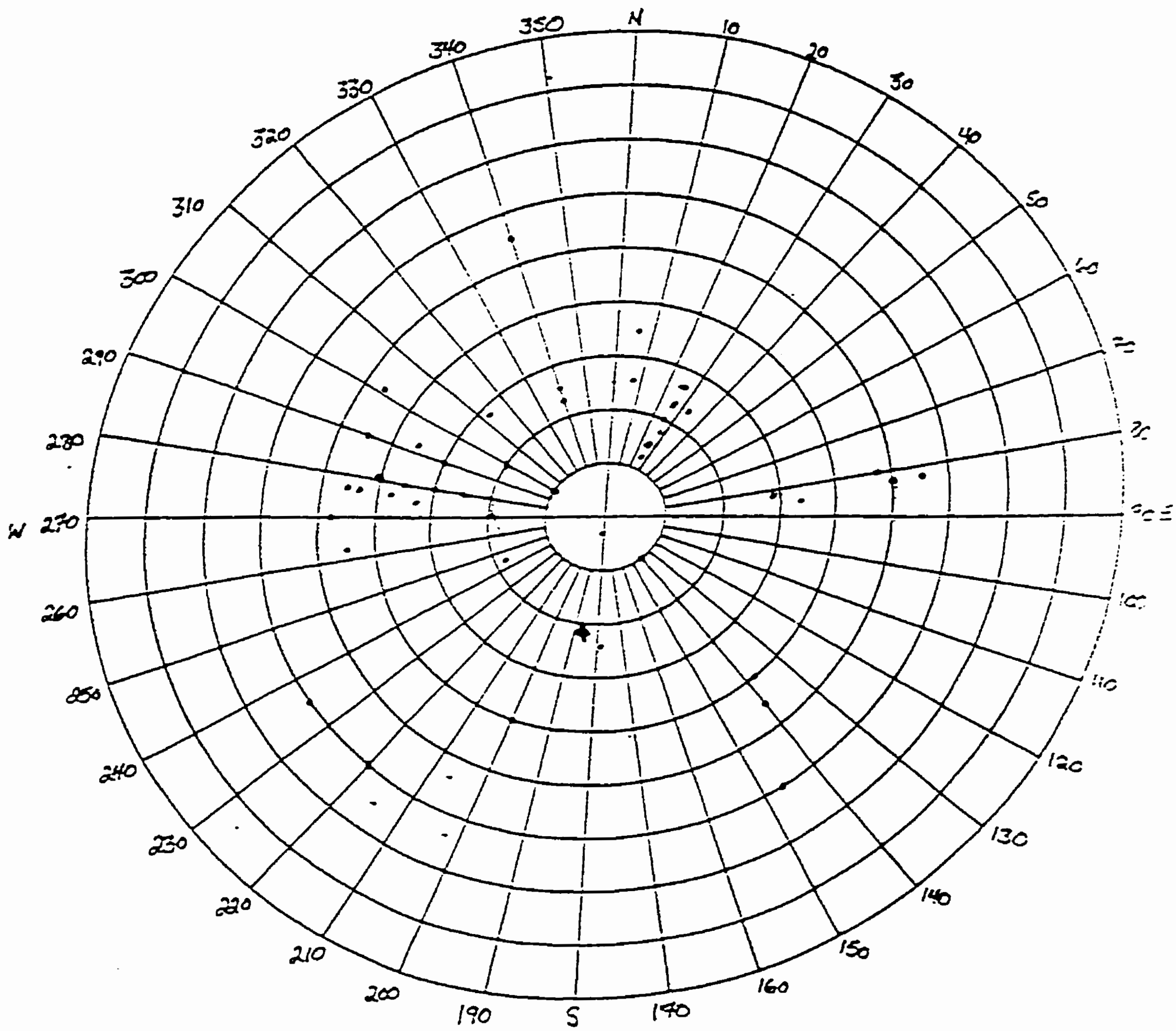
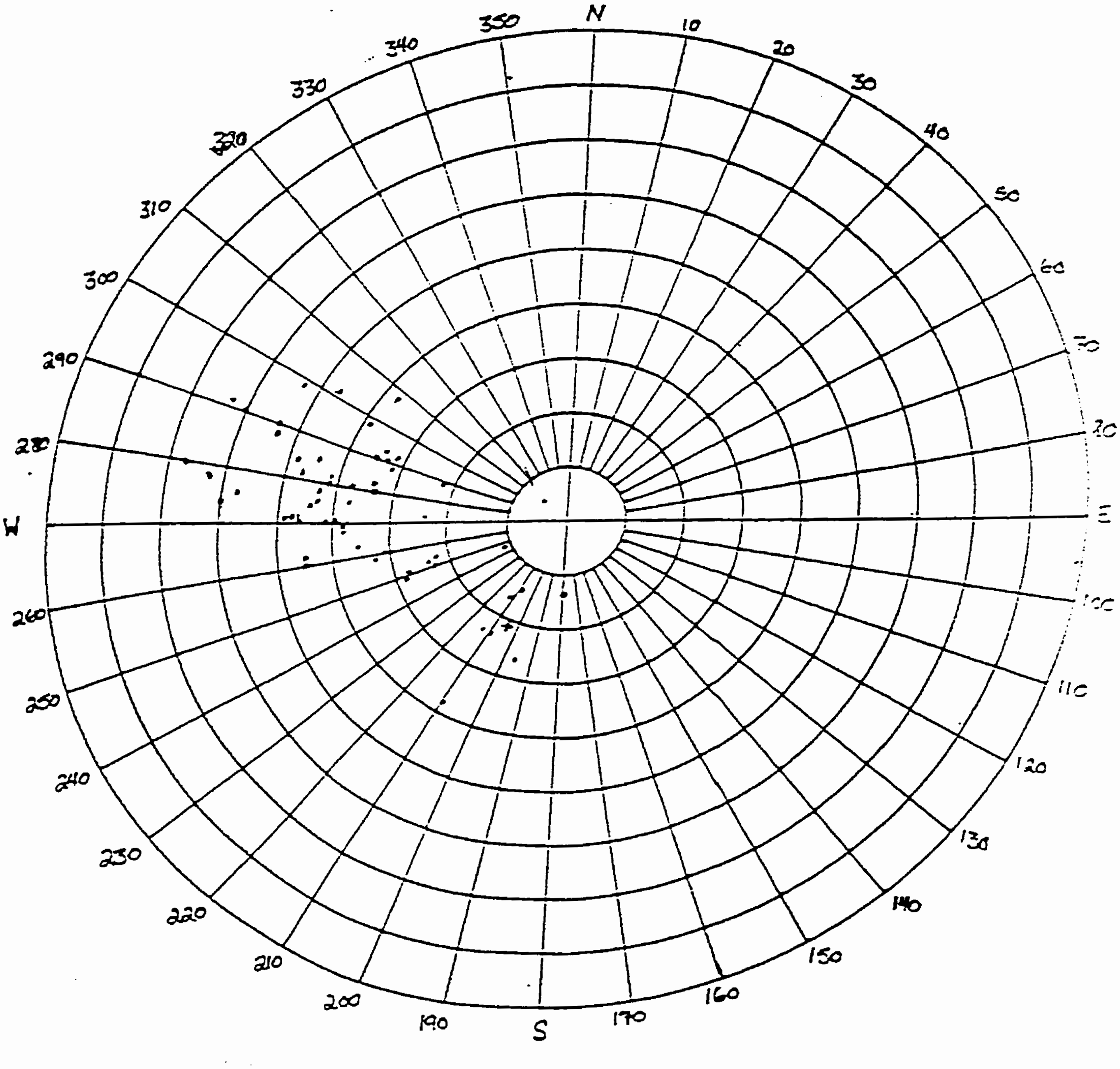


Figure 10. Relocation Points, gopher #7.



6.3 Objective 3: Rodenticide Evaluation

A control plot was established on each field to allow for comparisons between the change in the number of mounds in plot that had been treated and the change in activity in a plot that had not been treated. The spring control plots showed a decrease in activity of 18% over the ten days after application of the rodenticide to adjacent plots. Fall control plots showed a decrease of 24% over the ten-day period.

6.3.1 The Gofer® at 6.6 kg/2.5 ha

Spring Application

The B.O.B.® was applied to three fields in the spring at a rate of 6.6 kg/2.5 ha with the Gofer®. The results showed a decrease in surface mound activity of 52% after ten days.

Fall Application

The B.O.B.® was applied to four fields in the fall at a rate of 6.6 kg/2.5 ha with the Gofer®. The results were a decrease in mounding activity of 57%.

6.3.2 The Western Alfalfa Burrow Builder® at 6.6 kg/2.5 ha

Spring Application

B.O.B.® was applied to three fields in the spring using a rate of 6.6 kg/2.5 ha, with the Western Alfalfa Burrow Builder®. Mound counts showed a decrease of 55% over the ten-day period.

Fall Application

B.O.B.® was applied to three fields in the fall at a rate of 6.6 kg/2.5 ha with the Western Alfalfa Burrow Builder®. Counts of surface mound showed a decrease of 38% after ten days.

6.3.3 The Gofer® at 11 kg/2.5 ha

Spring Application

The rodenticide was applied at a rate of 11 kg/2.5 ha with the Gofer® on three fields in the spring. The results were a decrease in mound activity of 68% over ten days.

Fall Application

B.O.B.® was applied in the fall on four fields at a rate of 11 kg/2.5 ha, using the Gofer®. Mound counts showed a decrease of 61% after ten days.

Machine Used	*Amount of Bait*	*Time of Year*	*Change in Activity*	*Change in Control*	*Actual Change*
Gofer®	6.6 kg/2.5 ha	spring	-72%	-20%	-52%
Western®	6.6 kg/2.5 ha	spring	-75%	-20%	-55%
Gofer®	11 kg/2.5 ha	spring	-88%	-20%	-68%
Gofer®	6.6 kg/2.5 ha	fall	-80%	-23%	-57%
Western®	6.6 kg/2.5 ha	fall	-62%	-23%	-38%
Gofer®	11 kg/2.5 ha	fall	-84%	-23%	-61%

Table 2. Changes in Activity Levels Post-Rodenticide Application

6.4 Objective 4: Burrow Builder Comparison

The efficacy of the rodenticide was better when using the Gofer® compared to the Western Alfalfa Burrow Builder®. There was a 3% difference in the efficacy of the rodenticide in the spring, when comparing the plots applied with the two different machines. A larger difference was observed in the fall, when the difference in the efficacy of the rodenticide was 19% higher in the plots applied with the Gofer®.

Chapter Seven

7.0 Discussion and Observations

7.1 Objective 1: Census Method

The census method can be used with accuracy in fall in Manitoba alfalfa fields. The most efficient time period between flattening the mounds and counting the new ones is three days. The most accurate time interval is seven days, achieving an increase in accuracy of one percent over the three day period. Three days is recommended because waiting until the seventh day would increase the chance that the producer will run into problems with the weather (i.e. rain). When mounds are rained on it is difficult to distinguish between fresh mounds and old mounds. Also, the seven day interval would require a commitment of four additional days of waiting, which could be problematic in a busy season. The increase in waiting time is not warranted by the small increase in accuracy.

The best method consists of flattening all mounds in an area 30.3 m by 30.3 m, waiting three days and counting the number of fresh mounds. The number of mounds can be inserted into the equation s -0.980 + 0.934(log mounds) = log gopher. This method and the numbers generated should be used with the results of rodenticide testing and the losses in yield found by DeWandel (1997) to make decisions on control. The use of this equation to make management decisions is outline in the Worksheet (Table 2).

The study used as a model for this project (Reid et al., 1966) used a period of two days but found that the accuracy was insufficient. Richens (1965) also found a counting interval of three days to produce insufficiently accurate results. Unfortunately no reason could be found for the difference in results between those studies and this projects findings.

7.2 Objective 2: Burrow Range and Movements

This portion of the study was hampered by the difficulty in catching gophers and by the gophers shedding the collars soon after the animals were released. However, collaring showed the discrete ranges of two individual gophers, and gave insights into their daily activity patterns.

The difference in size between the ranges of the radio-collared gophers may be due to the fact that gopher #5 was a male, who are known to have larger burrow systems than females. The range of gopher #5 was more spread out than #7, which could not be explained by plant density or density of population because both factors were very similar. Range sizes are comparable to what is reported in the literature.

The nesting area of the gophers was clearly indicated by the long periods of time the gophers spent in one location. Monitored movements away from this area are assumed to be foraging or burrowing activities. The activities did not show any obvious pattern. The seventh gopher collared did show an increased number of inactive periods in the nest area leading up to the collar remaining stationary.

Observations of mound building in an area where one of the gophers was known to live could have provided information as to the number of mounds that gopher produced over time. Unfortunately there was little to no surface mound building during the monitoring of either gopher. This may be due to the fact that collaring took place at the time of year that is characterized by low mound production. The ranges of the collared gophers were of similar area, which could be due to a similar density of gophers and a similar density of alfalfa on both fields.

The two gophers observed to move large distances above-ground added to anecdotal reports of such movements. The juvenile female that moved a long distance was initially trapped in what was assumed to be the maternal burrow system and left it immediately after collaring. The disturbance of being collared combined with the physical presence of the collar may have caused the juvenile to be forced out by the adult or to disperse on its own. The juvenile male that moved above-ground was originally caught by hand on the surface, while he was trying to dig into a fresh mound. After being collared, a hole was dug into that mound and the gopher placed in that tunnel. It is possible that this gopher was in the process of dispersing and was inadvertently placed in the burrow system of another gopher. This intruding gopher would be forced out by the original inhabitant, explaining the immediate movement into another area. However, the disturbance of being collared could have caused it to move as well.

Greater success could have been achieved if the live traps were more effective and if the collars were easier to secure. The traps had been used in previous studies and required approximately 24 hours to catch a gopher, compared to 1/2 hour to catch one in a removal trap. The collar used was specifically designed for pocket gophers however, they were extremely difficult to secure on the animal. The collar itself was made of a single piece of thermoplastic-coated wire that acts as the collar and the antenna. To make the collar snug to the animal's neck, a loop of the wire had to be folded back and then secured by a piece of heat-shrink tubing. The instructions recommended attaching the collar by holding the animal upside down and carefully raising a small open flame from a butane lighter or a wooden match up towards the tubing. These instructions were not given in the order booklet and only were revealed upon receipt of the collars. The inefficiency and mechanical difficulties of this system are considerable. Every method was tried to pinch the collar as tight as possible and melt the heat shrink plastic without harming the gopher, however, it was a challenge. Four of the nine gophers collared were able to almost immediately remove their collars. This could have been a direct result of the difficulties in achieving a secure fit.

7.3 Objective 3: Rodenticide Evaluation

The results indicate a reduction in pocket gopher mound activity after the application of Clean Crop Burrow Oat Bait® rodenticide, in spring and fall.

7.3.1 Comparisons of Rates

The reduction in gopher activity after seven trial applications of B.O.B® at the recommended rate averaged 51%. Mound production was reduced by 65% when the application rate was increased to 11 kg/2.5 ha. This was a 14% increase over the efficacy at 6.6 kg/2.5 ha. The amount of product applied could be further increased, however, there will be a point at which the return on money spent will not be cost effective. The 14% increase in efficacy seen here would come at an increase of 60% in the cost (from $10.20/2.5 ha to $17.00/2.5 ha). The producer must decide if the increased price is cost effective.

This projects findings indicate a higher success rate for the zinc phosphide treated bait than was indicated by Proulx et al. (1997). That study determined a success rate of only 20%, compared to the range of 38% to 68% found in this study.

7.3.2 Comparison of Time of Year

There was a small difference in efficacy seen between spring and fall. Spring application resulted in a drop of 58% (average of 6.6 kg and 11 kg per 2.5 ha), and fall saw a drop of 52% (average of 6.6 kg and 11 kg). This small difference could be explained by a number of factors. The spring is always the optimal time to apply rodenticide (from a biological perspective) because it will remove breeding adults before they can add to the population. Also, the greater abundance of fresh foodstuffs in the fall may result in the gopher ignoring the bait. Finally, the drier conditions experienced in the fall can hamper the artificial burrow builder's ability to make a good, clean tunnel. If the soil lacks the moisture to hold together, the bait may be contaminated with soil or even buried. The fall application in this study was hampered by dry soil conditions to a small degree, and poor tunnels may have caused the slightly lower reduction in the fall.

7.4 Objective 4: Burrow Builder Comparison

A difference in efficacy was seen in the rodenticide results when comparing plots in which the only variable was the machine used for application.

The differences seen in the same field where two machines applied the identical product on plots side by side could be attributed to three basic things: the amount of poison being deposited, the uniformity of the distribution, and presentation of the bait. Common sense would suggest that the machine that distributes the most precise dosage in the cleanest form, at the most uniform rate will give the best results. The Gofer® was more successful in achieving these performance goals.

Both machines deposit bait using a hopper regulated by a gear mechanism triggered by a wheel running along the ground. On uneven ground or adverse soil conditions, obstacles can cause the wheel to lift, stopping the flow of bait through the machine. This can alter the amount per 2.5 ha, or the uniformity of deposition in the tunnels. This problem was seen to occur more often with the Western Alfalfa Burrow Builder®, due to the lighter construction and smaller wheel, though slowing down the tractor lessened this problem. The addition of weighted plates to the machine was also necessary to apply the rodenticide over the treated area.

The Gofer® has a better ability to create clean, round tunnels in a variety of adverse soil conditions. The longer torpedo length of the Gofer® may be the reason for this. Also, the Gofer® has a torpedo shaft with a more gradual slope up to the feeder mechanism, as a result vegetation did not wrap around the knife as often as with the other machine. The Western Alfalfa Burrow Builder's® up-right knife blade causes vegetation to wrap-around it, causing tunnels to collapse. This slows down the application of the rodenticide because the operator is forced to lift the torpedo out of the soil, then dismount from the tractor to clear the vegetation. The lifting of the torpedo also leaves portions of the tunnel untreated.

The main advantage of the Western Alfalfa Burrow Builder® is its mobility. This machine is smaller, and lighter, and much easier to get out to the field. The large size and weight of the Gofer® is a draw back when evaluating the ease of use of the machines. The Western Alfalfa® was significantly easier to load on and off of a truck, and onto a three-point hitch.

7.5 Objective 5: Management Recommendations

The findings of this study can now be used to provide producers with a method of determining the most cost effective method of managing northern pocket gophers in alfalfa fields in Manitoba. The decision process recommended is as described in Figure 12.

7.5.1 Cost Threshold Determination Worksheet

This Worksheet is to be performed in the fall.

Step 1. Determine the species present is the northern pocket gopher.

- Are mounds present with no open tunnels?
- Is the animal gray, with small eyes and a naked tail?
- If yes to these questions, continue

Step 2. Performing the census count

- set up counting plot, a square measuring 30.3 m X 30.3 m
- flatten all mounds in the plot
- come back to the plot after three days and count the fresh mounds (if it rained in the interim, you must start over by flattening all mounds)

Step 3. Use Number of mounds counted in the worksheet (table 3).

In order to use this worksheet the producer must have a calculator that has a log and anti-log function key. In order to normalize the errors in the data the numbers where logged, therefore without this crucial step the numbers generated would be useless.

The first step is to divide the number of mounds in the plot by 0.091809, converting the number into gophers per hectare. The producer would then key into his/her calculator the number of gophers per hectare and they would then press the LOG key on the calculator. They would then multiply this number by 0.0934 and then add -0.98 (these are constant values generated by the computer analysis). This number would then be inputted into the calculator and the ANTI -LOG key pressed.

Figure 11. Decision Flowchart.

DETERMINE THAT THE SPECIES PRESENT IS THE NORTHERN POCKET GOPHER
(is the animal gray with a naked pink tail)

IF NO, LOOK TO OTHER RESOURCES
IF YES, CONTINUE
←

PERFORM CENSUS COUNT

←

INSERT NUMBER INTO EQUATION
OBTAIN NUMBER OF GOPHERS / HA

←

CALCULATE DOLLAR LOSS / HA

←

COMPARE COST OF CONTROL METHODS
CHOOSE BEST METHOD

Management Worksheet

Example	*Producer's Numbers*
1. Count Mounds in Plot	
Number of Mounds / Plot = 69	Number of Mounds / Plot =____
2. Convert to Mounds / ha	
69 ÷ 0.091809 = 751.56 mounds / ha	___ ÷ 0.091809 = ___ mounds / ha
3. Convert to Number of Gophers / ha	***(-0.980 + 0.934 (log of mounds)***
-0.980 + 0.934 (log of 751.56) = log of gophers	-0.980 + 0.934 (log of ___) = log of gophers
-0.980 + 0.934 (2.876) = 1.70615	-0.0980 + 0.934 (___) = ___
4. Convert Log Gophers to Gophers	
anti log of 1.70615 = 50.83 gophers / ha	anti log of ___ = ___ gophers / ha
5. Convert Gophers / ha to Losses / ha	***Losses = $2.893 / gopher***
50.83 X $2.893 = $147.06 / ha	___ X $2.893 = $___ / ha
6. Compare Cost of Control / ha ***to Losses / ha***	
No Control = $147.06 / ha	No Control = $___ / ha
Rodenticide: Quintox® $229.72 / ha >$147.06 / ha Gophacide® $29.64 / ha < $147.06 / ha B.O.B.® $10.20 / ha < $147.06 / ha	Rodenticide: Quintox® $229.72 / ha __ $___ / ha Gophacide® $29.64 / ha __ $___ / ha B.O.B.® $10.20 / ha __ $___ / ha

Re-establishment of Alfalfa Stand: $527. 18 / ha > $147.06 / ha	Re-establishment of Alfalfa Stand: $527. 18 / ha __ $___ / ha
Trapping @ $2.00 / gopher = $102.00 / ha	Trapping @ $2.00 / gopher = $___ / ha
7. Choose Method of Control	
Gophacide®, B.O.B®, or trapping	________________

Table 3. Management Decision Worksheet

This worksheet can be used by producers to make decisions on management of northern pocket gophers, however, the losses per gopher used in the calculations include only the dollar value of losses to the yield as measured by DeWandel (1997). It is important to note that the losses per gopher do not include damage to machinery which is considered by producers to be the greatest source of loss associated with infestations of pocket gophers (Deniset, 1994).

Chapter Eight

8.0 Conclusions and Recommendations

8.1 Summary

The value of the research done is shown in its practical use in management decisions. The information generated by this project must be linked to the northern pocket gopher management projects that proceeded it. A multi-step process can be recommended to producers to determine the most effective way to manage the northern pocket gophers in their forage fields.

8.2 Objective 1: Census Method Development

- The producer should use the census method in the fall with a waiting period of three days between flattening and counting. This will give producers an accurate population assessment for their fields.
- The numbers generated by the census count should then be used with the total loss in yield as calculated in DeWandel (1997) (using up to date dollar values), to determine the dollar value of the losses the producer is incurring.
- The dollar value of the losses should then be compared to the cost of controlling the pocket gophers through cultivation, trapping or the use of rodenticide.
- The census method should be tested at different times of the year (spring and summer) to expand its use and accuracy.

8.3 Objective 2: Burrow Ranges and Movements

- Radio collaring showed that the pocket gophers under study had range sizes similar to those described in the literature.
- Longer distances of above-ground movements were observed in collared gophers in this study than noted in the literature.
- Additional radio collaring with a larger sample size and a different collar design is needed . These could be used to track the number of mounds produced by individual pocket gophers, enhancing the accuracy of the census method.

8.4 Objective 3: Rodenticide Evaluation

- The Clean Crop Burrow Oat Bait® (B.O.B®) is effective in reducing the amount of surface mounding activity observed over a ten-day period post application.
- It can be recommended for use at the rate of 6.6 kg/2.5 ha in the spring.
- Further testing of rodenticides should be on-going as new products come on the market to achieve greater control, as well as permitting cost/efficiency comparisons.

8.5 Objective 4: Burrow Builder Comparison

- The Gofer® artificial burrow builder is recommended for use

- Further product development is needed to design a machine that is easier to transport and use than the models currently available

8.6 Objective 5: Management Recommendations

- The management decision worksheet developed by this project is a powerful and practical tool that should be made available to forage producers.
- It is important that the management decision worksheet be further improved by the inclusion of the losses incurred as a result of the damage to machinery in pocket gopher infested fields.

Chapter Nine

9.0 Appendix

9.1 Radio Collaring Data

Collar Specifications:

Transmitter SM1 - H

Current Drain: 0.050 mA

Power Source: Li008

Custom Application: BR Collar

Neck Circumference Max.: 9 cm

Collar Material: Plastic-coated brass

Antenna Length: 9 cm tuned loop

Unit Weight: 4.5 g

Expected Life: 2.3 months

St. Anne's Pocket Gophers

1. Date of Collaring: July 4, 1995

   Sex: female

   Measurements: total length: 204 mm

   tail length: 67 mm

   hind foot: 6 mm

   ear: 6 mm

   Number of Relocation's: 3

Total Hours of Monitoring: 14

2. Date of Collaring: Aug. 5, 1995

Sex: male

Measurements: total length: 208 mm

tail length: 70 mm

hind foot: 30 mm

ear: 6 mm

Number of Relocation's: 2

Total Hours of Monitoring: 1

3. Date of Collaring: Aug. 8, 1995

Sex: male

Measurements: total length: 243 mm

tail length: 79 mm

hind foot: 34 mm

ear: 7 mm

Number of Relocation's: 0

Total Hours of Monitoring: 0

4. Date of Collaring: Aug. 1, 1995

Sex: female

Measurements: total length: 196 mm

tail length: 69 mm

hind foot: 31 mm

ear: 7 mm

Number of Relocation's: 0

Total Hours of Monitoring: 0

5. Date of Collaring: Aug. 10 - 13, 1995

Sex: male

Measurements: total length: 217 mm

tail length: 74 mm

hind foot:: 31 mm

ear: 7 mm

Number of Relocation's: 89

Total Hours of Monitoring: 46

Erikson Pocket Gophers

6. Date of Collaring: Aug. 20 - Aug. 21, 1995

Sex: female

Measurements: total length: 234 mm

tail length: 53 mm

hind foot: 33 mm

ear: 9 mm

Number of Relocation's: 30

Total Hours of Monitoring: 15

7. Date of Collaring: Aug. 21 - Aug. 30, 1995

Sex: female

Measurements: total length: 230 mm

tail length: 67

hind foot: 31 mm

ear: 8 mm

Number of Relocation's: 125

Total Hours of Monitoring: 62.5

8. Date of Collaring: Aug. 23, 1995

Sex: female

Measurements: total length: 234 mm

tail length: 72 mm

hind foot: 30

ear: 8

Number of Relocation's: 0

Total Hours of Monitoring: 0

9. Date of Collaring: Aug. 29, 1995

Sex: female

Measurements: total length: 228 mm

tail length: 70 mm

hind foot: 32 mm

ear: 8 mm

Number of Relocation's: 0

Total Hours of Monitoring: 0

Table: Activity Pattern of Gopher #7

Day	Time	Activity
Aug. 22	9:30 - 12:30	moving
	12:30 - 2:00	stationary at nest
	2:00 - 3:00	moving
	3:00 - 4:30	stationary
	4:30 - 8:15	moving
Aug. 23	8:45 - 9:30	stationary at nest
	9:30 - 10:30	moving
	10:30 - 12:30	stationary at nest
	12:30 - 3:30	moving
	3:30 - 4:00	stationary at nest
	4:00 - 5:00	moving
Aug. 24	11:00 - 12:00	stationary at nest
	12:00 - 3:00	moving
	3:00 - 4:00	stationary at nest
	4:00 - 5:00	moving
	5:00 - 7:00	stationary at nest
	7:00	moving
Aug. 28	8:00 - 9:30	moving
	9:30 - 10:30	stationary at nest
	10:30 - 11:00	moving
	11:00 - 1:00	stationary at nest
	1:00 - 4:00	moving
	4:00 - 6:00	stationary at nest
	6:00 - 7:30	moving
	7:30 - 8:00	stationary at nest
Aug. 29	8:00 - 10:30	moving
	10:30 - 11:30	stationary at nest
	11:30 - 12:00	moving
	12:00 - 1:00	stationary at nest

	1:00 - 1:30	moving
	1:30 - 2:00	stationary at nest
	2:00 - 3:00	moving
	3:00 - 3:30	stationary at nest
	3:30 - 4:00	moving
	4:00 - 6:00	stationary at nest
	6:00 - 8:00	moving
Aug. 30	8:00 - 7:00	stationary at nest
assume collar removed		

Table 4. Activity of Gopher #7

9.2 B.O.B® Evaluation

9.2.1 The Gofer® at 6.6 kg/2.5 ha

Spring

table 1

Day	Chappellaz	Theroux	Lefloch	Average	Change	Actual Change
pre-treatment	8	8	4	7		
3	10	0	2	4		
10	3	1	1	2	-72%	-52%

Fall

table 2

Day	Wright	Bruneau	Dion	Lacost	Average	Change	Actual Change
pre-treatment	78	24	4	47	38		
3	51	8	1	18	20		
10	17	4	1	9	8	-80%	-57%

9.2.2 The Western Alfalfa Burrow Builder® at 6.6 kg/2.5 ha

Spring

table 3

Day	Chappellaz	Theroux	Lefloch	Average	Change	Actual Change
pre-treatment	10	3	12	8		
3	7	4	6	6		
10	4	3	0	2	-75%	-55%

Fall

table 4

Day	Wright	Bruneau	Dion	Lacost	Average	Change	Actual Change
pre-	89	31	N/A	40	53		

treatment							
3	55	22	N/A	15	30		
10	32	18	N/A	10	20	-62%	-38%

9.2.3 The Gofer® at 11 kg/2.5 ha

Spring

table 5

Day	**Chappellaz**	**Theroux**	**Lefloch**	**Average**	**Change**	**Actual Change**
pre-treatment	7	7	10	8		
3	2	0	1	1		
10	0	0	1	1	-88%	-68%

Fall

table 6

Day	**Wright**	**Bruneau**	**Dion**	**Lacost**	**Average**	**Change**	**Actual Change**
pre-treatment	114	26	14	23	44		
3	10	5	3	13	8		
10	15	7	0	7	7	-84%	-61%

9.2.4 Control Plots

Spring

table 7

Day	Chappellaz	Theroux	Lefloch	Average	Change
pre-treatment	5	5	6	5	
3	4	3	3	3	
10	6	4	3	4	-20%

Fall

table 8

Day	Wright	Bruneau	Dion	Lacost	Average	Change
pre-treatment	134	33	7	35	52	
3	82	18	4	27	33	
10	97	24	6	31	40	-23%

Chapter Ten

10.0 Literature Cited

Andersen, D. C. 1987. *Geomys bursarius* burrowing patterns: influence of season and food patch structure. Ecology 68 (5): 1306-1318.

Andersen, D. C. 1988. Tunnel construction methods and foraging path of a fossorial herbivore, *Geomys bursarius*. J. Mamm. 69(3): 565-582.

Andersen, D. C. 1990. Search path of a fossorial herbivore, *Geomys bursarius,* foraging in structurally complex plant communities. J. Mamm. 71 (2): 177-187.

Andersen, D. L., and J. A. MacMohan. 1981. Population dynamics and bioenergenics of a herbivore, *Thomomys talpoides* (*rodentia: geomyidae*), in a spruce-fir sere. Ecol. Monog. 51 (2): 179-202.

Bandoli, R. 1981. Factors influencing seasonal burrowing activity in the pocket gopher *Thomomys bottae*. J. Mamm. 62:293-303.

Banfield, A.W.E. 1974. The Mammals of Canada. University of Toronto Press. Toronto, Ontario. 438 pp.

Cameron, G. N., S. R. Spencer, B. D. Eshelman, L. R. Williams, and M. J. Gregory. 1988. Activity and burrow structure of Attwater's pocket gopher (*Geomys attwateri*). J. Mamm. 69(4): 667-677.

Case, R. M. 1988. Pocket Gophers: prevention and control of wildlife damage. Great Plains Agricultural Council submitted to Wildlife Research Council: B-13-B-25.

Cox, G. W., and J. Hunt. 1992. Relation of seasonal activity patterns of Valley pocket gophers to temperature, rainfall, and food availability. J. Mamm. 73(1): 123-134.

Criddle, S. 1930. The prairie pocket gopher *Thomomys talpoides rufescens*. J. Mamm. 11:265-280.

DeWandel, M. 1997. Management Strategies for the Control of Northern Pocket Gophers (*Thomomys talpoides*) in Agro-Manitoba. MNRM Practicum. Natural Resources Institute, University of Manitoba. Winnipeg, Manitoba.

Deniset, Y. 1993. Northern Pocket Gopher (*Thomomys talpoides*) control in Agro-Manitoba. MNRM Practicum. Natural Resources Institute, University of Manitoba. Winnipeg, Manitoba.

Dubois, M. J. 1995. Diet related morphometric variation in the northern pocket gopher (*Thomomys talpoides rufescens*). B.Sc. (4 yr.) thesis, University of Winnipeg, Winnipeg, Manitoba, 31 pp.

Engeman, R., D. Campbell, and J. Evans. 1993. A Comparison of 2 Activity Measures for Northern Pocket Gophers. Wildl. Soc. Bull. 21:70-73.

Gettinger, R. D. 1984. A field study of activity patterns of *Thomomys bottae*. J. Mamm. 65(1): 76-84.

Krebs, C. J. 1989. Ecological Methodology. Harper Collins, NY, NY.

Miller, L. 1948. Seasonal trends in burrowing of pocket gophers *Thomomys talpoides*. J. Mamm. 29:38-44.

Mupondwa, F. K. 1993. A survey of forage crop production practices and the role of forages in crop rotations in Manitoba and Eastern Saskatchewan. P. 143 - 149. In Manitoba Agri-Forum and Water in Agriculture: An International Symposium. Manitoba Institute of Agrologists. Winnipeg, MB.

Myers, and Vaughan. 1964. Pocket gopher food habits. J. Mamm. 45 (4): 582-597.

O'Brian, J. 1997. Evaluation and Performance of Acute Toxicants for Ground Squirrel Damage Control. p 34-37. In Proceedings: Burrowing Rodent Damage Control Workshop, Alberta Agriculture, Food and Rural Development.

Patton, J. L., and P. V. Brylski. 1987. Pocket gophers in alfalfa fields: causes and consequences of habitat-related body size variation. Amer. Nat. 130 (4): 493-506.

Pawlina, I.M> Proulx, G., A.J. Kolenosky, P.J. Cole, R.K. Drescher, and M.J. Badry. 1993. Fall bait selection by northern pocket gophers (Thomomys talpoides) in captivity. Wildlife Section, Forestry Department, Alberta Research Council. Edmonton, Alberta. 9pp.

Proulx, G. 1994. Summary of Pocket Gopher Research in Alberta. In Minutes of the Three Province Pocket Gopher Meeting, Dec. 20, 1994. Regina, Sask. Saskatchewan Department of Agriculture.

Proulx, G., A. Kolenosky, I. Pawlina, P. Cole, and R. Drescher. 1992. Application of Remote Sensing to Northern Pocket Gopher Management and Evaluation of Four Killing Traps in Alfalfa Fields. Alberta Research Council, PFRA Agriculture Canada Report. pp. 30.

Reichamn, O. J., G. Whitham, and G. A. Ruffner. 1982. Adaptive geometry of burrow spacing in two pocket gopher populations. Ecology 63 (3): 687-695.

Reid, A. H., L. M. Hansen, and N. Ward. 1966 Counting mounds and earth plugs to census mountain pocket gophers. J. Wildl. Mgmt. 30(2):327-334.

Richens, V. B. 1965. An evaluation of control on the Wasatch pocket gopher. J. Wildl. Mgmt. 29(3):413-425.

Smith , M. F., and J. L. Patton. 1980. Relationships of pocket gophers *Thomomys talpoides* of the lower Colorado River. J. Mamm. 61:733-756.

Sullins, M. 1997. Summary of Field Rodent Control and Rodenticide Testing in Montana. p 57-61. In Proceedings: Burrowing Rodent Damage Control Workshop, Alberta Agriculture, Food and Rural Development.

Thorne, D. H. and D. C. Anderson. 1990. Long-term soil-disturbance pattern by a pocket gopher *Geomys bursarius*. J. Mamm. 71(1): 84-89.

Timm, R. 1997a. Effective Rodenticides and Their Modes of Action. p 3. In Proceedings: Burrowing Rodent Damage Control Workshop, Alberta Agriculture, Food and Rural Development.

Timm, R. 1997b. The future of burrowing rodent damage control: a prospectus for researchers, managers and land custodians. p 9-11. In Proceedings: Burrowing Rodent Damage Control Workshop, Alberta Agriculture, Food and Rural Development.

Vleck, D. 1981. Burrow structure and foraging costs in the fossorial rodent, *Thomomys bottae*. Oecologica (Berlin) 49: 391-396.

Vleck, D. 1979. The energy cost of burrowing by the pocket gopher *Thomomys bottae*. Physio. Zoo. 52:122-136.

Ward A. L., and J. O. Keith. 1962. Feeding habits of pocket gophers on mountain grasslands, Black Mesa, Colorado. Ecology 43 (4): 746-749.

Witmar, G. W., M. W. Fall, and L. A. Fielder. 1995. Rodent Control, Research Needs, and Technology Transfer. p.693-697. In Integrating People and Wildlife for a Sustainable Future. The Wildlife Society.