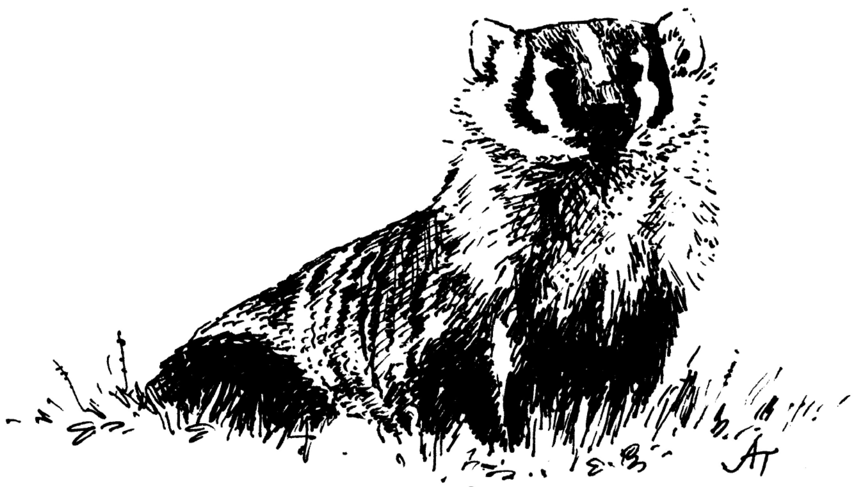
BADGER PREY ECOLOGY:
THE ECOLOGY OF SIX SMALL MAMMALS FOUND IN BRITISH COLUMBIA



by

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EXECUTIVE SUMMARY

Badgers in British Columbia are ranked as Endangered by COSEWIC and are continuing to decline in numbers (Newhouse and Kinley 2000). The availability and abundance of prey have been identified as primary factors limiting Badger populations, but there is a lack of knowledge on the ecology of these prey species in British Columbia. The purpose of this report is to help recovery of Badger populations by synthesizing information on Badger prey that will assist in "ensuring adequate prey for Badgers" (Adams et al. 2003). The report synthesizes existing information on Badger prey ecology and its influence on Badger distribution, abundance, productivity, and survival. The ecology of six main prey species for Badgers in B.C. is reviewed: the Columbian Ground Squirrel (*Spermophilus columbianus*), Yellow-bellied Marmot (*Marmota flaviventris*), Northern Pocket Gopher (*Thomomys talpoides*), Muskrat (*Ondatra zibethicus*), Red-backed Vole (*Clethrionomys gapperi*), and Meadow Vole (*Microtus pennsylvanicus*). The distribution of prey affects the range of Badgers and especially their use of non-grassland habitats. Survival of Badgers may not be directly linked to lack of food but rather low prey availability. Decreased prey availability may lead to larger home range sizes, longer distance movements, and increased risk of mortality, especially on roads. Large home range sizes also may be leading to lower productivity of females by restricting breeding, and ultimately limiting the abundance of Badgers. Future research should identify important prey species for Badgers locally and the influence these have on regulating populations. The effects of disturbance on prey abundance and its role on the use of non-grassland habitats by Badgers should also be explored. Finally, management techniques that promote habitat for prey are encouraged.

ACKNOWLEDGEMENTS

Funding for this report was provided by the Habitat Conservation Trust Fund (HCTF) to assist efforts to conserve Badgers in British Columbia. The need for a summary of prey ecology and its relationship to Badgers was first suggested by the *jeffersonii* Badger Recovery Team, and Eric Lofroth of the Ministry of Environment (formerly Water, Land and Air Protection) acted on this request. The report incorporates ideas from discussions held during Recovery Team meetings, and with Nancy Newhouse (Sylvan Consulting Ltd.) and Roger Packham (Ministry of Environment (formerly Water, Land and Air Protection). Gratefully, the report was reviewed and edited by Eric Lofroth, and Andrea Toth is the artist responsible for the cover picture.

1. INTRODUCTION

The American Badger, *jeffersonii* subspecies (*Taxidea taxus jeffersonii*), is federally listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Newhouse and Kinley 2000) and is Red-listed in British Columbia (Cannings et al. 1999). The most current status report estimates the provincial population at less than 200 adults (Newhouse and Kinley 2000) and declining (Newhouse and Kinley 2001; Adams et al. 2003). This decline has caused Badgers to be extirpated from the upper Columbia Valley of the East Kootenay region (Newhouse and Kinley 2000). Threats to the British Columbia Badger population include highway mortality (Newhouse and Kinley 2001; Weir and Hoodicoff 2002), habitat loss and degradation (Adams et al. 2003), trapping, persecution, and loss of prey species (Newhouse and Kinley 2000; Adams et al. 2003).

The loss of prey is considered to be one of the primary factors limiting Badger populations in British Columbia (Newhouse and Kinley 2000). The extent to which Badgers are food-limited is not directly known but is speculated to be substantial. Prey is recognized as an important component in mustelid ecology (Powell 1994). Sometimes prey availability can describe habitat suitability for mustelids better than any vegetation association or ecological classification (Lofroth et al. 2000). Because Badgers are opportunistic predators, there are a number of prey species that influence Badger ecology.

The primary prey species of the Badger is thought to be Columbian Ground Squirrel (*Spermophilus columbianus*). Yellow-bellied Marmots (*Marmota flaviventris)*, Northern Pocket Gophers (*Thomomys talpoides*), and arvicolid rodents (voles) also may be important prey species. Most of these species are at the northern limit of their range in British Columbia, but are locally common to abundant (Adams et al. 2003). The ecology of these prey species, as it relates to Badgers, is not well understood in British Columbia. Recent work in the Cariboo region indicates that Muskrats (*Ondatra zibethicus*) may also be an important prey species.

The National Recovery Strategy for the American Badger, *jeffersonii* subspecies (Adams et al. 2003) has listed "ensuring the Badger food supply," as one of the short-term recovery objectives. This requires an increased knowledge of Badger's diet, an increased knowledge of the prey population dynamics and requirements, and an increased public acceptance of the importance of these prey species. The recovery team has suggested that a thorough review of relevant literature on ground squirrels and other prey species be completed before initiating any research on Columbia Ground Squirrels (Adams et al. 2003). Without this knowledge, recovery efforts will have difficulty addressing the underlying causes of Badger declines, thus limiting their ability to halt further declines.

The primary objective of this report is to compile and synthesize existing information on the ecology of Badger prey in an effort to better understand Badger distribution, abundance, productivity and survival. This synthesis will also identify critical gaps in knowledge of prey species and will suggest future research and management needs. Ultimately this will be used to direct future critical ecological research on Badger prey and Badger foraging ecology.

2. BADGER FEEDING ECOLOGY

2.1 Diet

Badgers are carnivores that specialize in hunting fossorial or semi-fossorial prey (Messick 1987). In British Columbia, the main prey is ground-dwelling squirrels (*Sciuridae*), pocket gophers (*Geomyidae*), voles (*Microtinae*), and mice (***Cricetinae***) (Newhouse and Kinley 2000). Columbian Ground Squirrels (*Spermophilus columbianus*) are a main component of most Badger diets (Rahme et al. 1995; Newhouse and Kinley 2001; Hoodicoff 2003). Rahme et al. (1995) also reported that up to 75% of Badger sightings in the Northern Thompson Upland were associated with Yellow-bellied Marmots (*Marmota flaviventris*). However, some of these prey species do not occur throughout Badger ranges. Pocket Gophers (*Thomomys talpoides*) may be a main component of Badger diets south of the Thompson River (Hoodicoff 2003). In the Cariboo, where pocket gophers do not occur and ground squirrels are not abundant, Muskrats (*Ondatra zibethicus*) may be the primary source of prey (Roger Packham, pers. comm.). Voles (*Clethrionomys gapperi* and *Microtus* spp.) and mice (*Peromyscus maniculatus*) also are consistently found in diets of Badgers across the province.

Badgers supplement their diets with many other small mammals, reptiles, amphibians, birds and eggs, and fish (Newhouse and Kinley 2000; Newhouse and Kinley 2001; Hoodicoff 2003). The Great Basin Pocket Mouse (*Perognathus parvus*) was found in one sample taken from the Thompson region (Hoodicoff 2003). It is the only heteromyid that occurs in B.C. and is limited to the extreme southeast of the region (Nagorsen 1990). Arthropods are found in diets of Badgers, including beetles (Coleoptera, Newhouse and Kinley 2001) and crickets (*Cyphoderris* spp.; Robert Cannings, Royal BC Museum, pers. comm.). Saskatoon berries (*Amelanchier alnifolia*) also were eaten in the Thompson region (Hoodicoff 2003). A comprehensive list of diet items found in diets of Badgers in British Columbia is summarized in Table 1.

Badgers may specialize in fossorial prey, but they will take advantage of other species that are more abundant and readily available. In Idaho, after a population collapse of Townsend's Ground Squirrels (*Spermophilus townsendii*), Badgers relied more on lagomorphs and other rodents (Messick and Hornocker 1981). This may

Table 1. Frequency of diet items that occurred in scats and gastrointestinal tracts of Badgers collected from the East Kootenay (Newhouse and Kinley 2001), Okanagan, and Thompson (Hoodicoff 2003) regions of British Columbia.

Diet items identified	Region			Total (n=40)
	East Kootenay	Okanagan	Thompson	
	(n=13)	(n=5)	(n=22)	**90% (36)**
Mammals				
Sciuridae				-
Spermophilus columbianus	38% (5)	-	-	45% (18)
Unidentified -	-	100% (5)	36% (8)	
Microtinae				-
Clethrionomys gapperi	31% (4)	-	-	33% (13)
Unidentified		40% (2)	50% (11)	
Geomyidae				5% (2)
Thomomys talpoides	-	-	9% (2)	
Cricetinae				5% (2)
Peromyscus maniculatus	-	-	9% (2)	
Heteromyidae				3% (1)
Perognathus parvus	-	-	5% (1)	**25% (10)**
Arthropods				
Coleoptera	23% (3)	-	-	
Unidentified	-	20% (1)	27% (6)	**15% (6)**
Birds				
Sparrows or similar sp.	15% (2)	-	-	
Gavia immer	15% (2)	-	-	
Unidentified	-	-	9% (2)	**15% (6)**
Vegetation				
Amelanchier alnifolia	-	-	27% (6)	**3% (1)**
Amphibians				
Bufo boreus	-	20% (1)	-	3% (1)
Reptiles				
Thamnophis sp.	-	-	5% (1)	**1% (3)**
Fish				
Catostomus sp.	8% (1)	-	-	
Salmonidae	8% (1)	-	-	
Unidentified	-	20% (1)		

explain the many different species that are minor components of Badger diets.

Differences in diet have been reported between juvenile and adult Badgers (Errington 1937; Messick and Hornocker 1981). Juveniles in south-western Idaho ate more arthropods and birds, and fewer mammals and reptiles than adults (Messick and Hornocker 1981). This was attributed to unfamiliarity with the landscape during dispersal, and the undeveloped predatory skills of juveniles. Juveniles also moved through farmed areas that probably supported larger populations of insects and ground-nesting birds. There have been no reports of dietary differences between male and female Badgers (Sovada et al. 1999).

The number of species in Badger diets varies seasonally; the greatest diversity of prey is eaten in the summer. In east-central Minnesota, analysis of scat and the contents of gastrointestinal tracts confirmed that at least 11 species were eaten in summer, 6 species in spring, and 9 species in fall (Lampe 1976). This may be related to the diversity of potential prey species and vegetation and fruit available in the summer, and long-distance movements made by Badgers across many habitat types. Badgers decrease their movements in fall and winter, focusing foraging activities in local areas. As a result, there may be less diversity of prey available to an individual.

2.2 Behaviour

Badgers forage alone and primarily at night. Rather than digging up entire prey burrow systems, Badgers penetrate the burrow at several key points using olfactory clues to pinpoint prey (Lampe 1976). Badgers may plug all entrances except one, and then excavate the open entrance (Lindzey 1982). Balph (1961) also described Badgers concealing themselves underground to prey on ground squirrels exiting a burrow system. Badgers usually consume their prey underground. Michener (2000) reported that, of 26 radiocollars recovered from Richardson's Ground Squirrels (*S. richardsonii*) preyed on by Badgers, only two radiocollars were found above ground, whereas 24 were recovered underground. Minta et al. (1992) also observed that Badgers normally consumed Uinta Ground Squirrels (*S. armatus*) without surfacing.

Food caching by Badgers has been reported in the literature, but there are few documented cases of this behaviour. Badgers cache food over short periods of time in the autumn, presumably to increase weight rather than to store food for use during the winter. In southern Alberta, Michener (2000) found that Badgers (n = 5) hoarded ground squirrels (*S. richardsonii*) in caches from early September to the end of November. Badgers cached 46% of the prey caught and the rest was consumed on the night of capture (n = 35 ground squirrels). Single, intact ground squirrels were cached either above ground covered with 10 to 15 cm of loose soil, or below ground in Badger burrows or ground squirrel dens. Carcasses were always retrieved in the order they were cached, and retrieval occurred up to 55 days after caching into early December. Caches were located 4 to 150 m apart (mean 35 ± 38 m, n = 26). Caching does occur at other times of the year. A mother Badger with two kits also was observed caching three carcasses in June (Michener 2000). In Iowa, Snead and Hendrickson (1942) located Thirteen-lined Ground Squirrels (*S. tridecemlineatus*) cached by Badgers above ground in April and May.

Caching behaviour may be difficult to detect, since in most cases hunting and caching occurs at night (Michener 2000).

3. PREY ECOLOGY

Prey is recognized as an important component in mustelid ecology (Powell 1994). Sometimes prey availability can describe habitat suitability for mustelids better than any vegetation association or ecological classification (e.g., Lofroth et al. 2000). Because Badgers are opportunistic predators, many prey species influence Badger ecology. The main mammalian species found in diets of Badgers in British Columbia are Columbian Ground Squirrels and marmots in Family Sciuridae; Northern Pocket Gophers in Family Geomyidae; and Red-backed Voles, Meadow Voles, and Muskrats in Family Muridae. The ecology of these species as it relates to Badgers is reviewed in the following section. Table 2, at the end of this section, summarizes the information for each prey species.

3.1 Family Sciuridae: Ground-Dwelling Squirrels

Two main species of Family Sciuridae are reported in diets of Badgers across British Columbia: the Columbian Ground Squirrel and the Yellow-bellied Marmot. Ground-dwelling sciurids also were the main prey species of Badgers in Iowa (Errington 1937; Snead and Hendrickson 1942), South Dakota (Jense 1968), and Wyoming (Goodrich and Buskirk 1998). Other species that may occur in Badger diets in B.C. but are not reported include the Golden-mantled Ground Squirrel (*S. lateralis*) and the Woodchuck (*Marmota monax*). Woodchucks are reported in diets of Badgers in Ontario (Newhouse and Kinley 2000).

Columbian Ground Squirrel (*Spermophilus columbianus*)

Columbian Ground Squirrels have robust bodies with short legs and ears and a moderately bushy tail (Banfield 1974). Their hair is short, fine, and tawny-coloured, and the guard hairs are tipped in black, giving a dappled effect to their dorsal side. This species is one of the largest members of the Genus *Spermophilus*, and average lengths of adults range from 327 to 377 mm, and weights of adult males in hibernation range from 435 to 571 g (Banfield 1974). Columbian Ground Squirrels are a colonial species. Territorial boundaries are defended by both males and females, and core areas are defended more than other parts of the range (Elliott and Flinders 1991). Territories of male ground squirrels may overlap, and territories of females surround the nest burrow up to 1000 m^2. Ground squirrels are diurnal, but daily patterns of activity depend on season and temperature. Individuals are more active in warmer weather but avoid the heat of the day during mid-summer (Elliott and Flinders 1991).

In B.C., Columbian Ground Squirrels inhabit the Rocky, Purcell, Selkirk, Monashee, and Cascade mountain ranges, and parts of the dry Interior as far west as the Fraser River (Nagorsen 1990). These ground squirrels occur in intermontane valleys, forest edges, open woodlands, tundra, prairie, meadows, and grasslands from 215 m to 2400 m in elevation (Banfield 1974). In alpine areas of the Pacific Northwest, ground squirrels are found in wet meadows and grasslands and less often in rock, heather, and herb field habitats. Ground squirrels also readily use modified habitats such as clearcut forests and pastures. In certain parts of southwestern Alberta, ground squirrels were concentrated on well-drained, south-facing slopes, perhaps because these areas become snow-free earlier in spring and allow squirrels to emerge from hibernation earlier (Boag and Murie 1981). These sites consistently gained population over the years.

Ground squirrels may be a reliable source of prey for Badgers, particularly in modified environments where colonies are persistent. Average densities of Columbian Ground Squirrels on agricultural lands were reported at 4.2 per hectare, and may be as high as 14.8 per hectare (Banfield 1974). In agricultural land in Washington, population densities were as high as 24.7 squirrels per hectare on wheat fields, and 61.7 per hectare on agricultural bottomlands (Elliott and Flinders 1991). Ground squirrels were found at densities of 32 animals per hectare on subalpine rangeland in central Idaho (Elliott and Flinders 1991). Messick and Hornocker (1981) estimated that an 8 kg Badger in captivity would need to consume only 1.2–1.4 Townsend's Ground Squirrels (*S. townsendii*) per day and that a free-ranging Badger would require 1.8 times more energy (approximately 2.3 ground squirrels per day).

Badgers mainly prey on ground squirrels by excavating their burrows. The hunting methods of Badgers are precise and minimize excavation. In one observation, the Badger covered entrances of ground squirrel burrows and dug 1 to 4 holes up to 5 m from entrance (Murie 1992). There was no obvious pattern to the sequence in which burrows were dug, except that digging at the periphery of the colony was more common than at the centre. The distance between nests dug up ranged from 20 to 200 m. Autopsies of ground squirrels killed by Badgers indicated that Badgers grasped their prey around the thorax causing multiple internal injuries, including subcutaneous and thoracic hematomas, ruptured intercostal tissue, broken ribs, and hemorrhages in the thoracic cavity. This was usually accomplished without puncturing the skin (Michener and Iwaniuk 2001).

Placement of ground squirrel burrows is influenced by soil moisture, aspect, drainage, slope, and social or historical factors (e.g., presence of conspecifics or burrowing sites). Burrows are located on open ground or in banks usually under boulders, stumps, or logs (Banfield 1974). Burrows are up to 1 m below the surface and 3 to

18 m in length. An individual may bring 25 to 50 kg of soil to the surface, and 4 to 7 m of tunnel may be added to burrow systems annually (Elliott and Flinders 1991). On average, there are 11 burrow entrances (2–35) that are small and round (7–10 cm in diameter), or large and funnel-shaped (Banfield 1974). Often, entrances have soil berms, but others are well-hidden and may be plugged at night as a protection from other adult male ground squirrels. Summer dens often are used as brood dens, and may have a small separate tunnel connecting the brood den to outside. A separate summer den may be used and then joined to a hibernation den deeper (up to 2 m) in the soil (Banfield 1974). The hibernation den is a circular cavity that is proportional to the size of the animal. It is lined with shredded grass and has a drain to keep water from entering the nest. Before hibernation, the entrance is covered with a soil plug about two feet long and tamped into place with the squirrel's forehead (Banfield 1974). Hibernation dens of adult males often have a food cache to be used in spring when they emerge and the ground is still covered in snow (Elliott and Flinders 1991). At high elevations, ground squirrels use larger and shallower hibernacula than at lower elevation (Elliott and Flinders 1991). Ground squirrel burrows may be used by pocket gophers, Deer Mice, or Meadow Voles.

Ground squirrels are always vigilant of predators when active above ground. Individuals use the highest rocks near burrow openings as observation posts, especially for terrestrial predators (Machutchon and Harestad 1990). Macwhirter (1992) reported that ground squirrels that were not near a burrow ran away from a simulated Badger attack. The Squirrel did not usually enter the nearest burrow but ran to a vantage point farther away from the approaching predator. This behaviour was attributed to the probability of Badgers making repeated attacks and their ability to pursue prey into burrows. In the North Thompson River valley, the main predators of ground squirrels were Coyotes and Badgers (Machutchon and Harestad 1990). Grizzly Bears, Coyotes, Marten, Lynx, weasels, Mountain Lions, Golden Eagles, and hawks are other predators of ground squirrels (Elliott and Flinders 1991).

Ground squirrel densities are highest in areas of abundant food resources. Columbian Ground Squirrels eat a variety of flowers, seeds, bulbs and fruits, grain crops, and vegetables (Banfield 1974). Preferred vegetation includes silky lupine (*Lupinus sericeus*), yarrow (*Achillea milefolium*), balsamroot (*Balsamorrhiza sagitatta*), and bluebunch wheatgrass (*Pseudoroegnaria spicata*). They may also eat insects and animal matter, and are infrequently cannibalistic (Elliott and Flinders 1991). In fields that were grazed by cattle in B.C., ground squirrels ate clover (*Trifolium* spp.) and dandelion (*Taraxacum officinale*) (Harestad 1986). Ground squirrels may only feed for 130 days each year and consume approximately 17.2% of their body weight in one day. Changes in food supply and food quality can affect reproductive success of females, and survival of juvenile ground squirrels in particular (Bennett 1999). Ground squirrel populations that were supplemented with food increased 48–74% per year in one study (Dobson and Oli 2001). After food supplementation ended, populations declined slowly at a rate of 12–15% per year over the next 3 years. The declines were attributed to an increase in age of maturity of females and a decrease in survival, age at last reproduction, and fertility.

Columbian Ground Squirrels are active for only 90–100 days per year before hibernation begins in late summer or early autumn. In eastern Washington, the average hibernation period for ground squirrels was 208 days for males (range 192–220 days) (Banfield 1974). Adult males enter hibernation first, followed by adult females, yearlings, and juveniles. During hibernation, individuals may rise to urinate then return to their burrows. This occurs at least every 19 days (Banfield 1974), but the frequency of this behaviour depends on environmental temperature (Elliott and Flinders 1991). Adult males are the first to emerge in April followed by females and then yearlings 1 to 2 weeks after adult emergence. Emergence occurs later in the season with increasing altitude and latitude (Elliott and Flinders 1991). In the North Thompson River valley of B.C., adult Columbian Ground Squirrels emerged in mid-April and juveniles emerged by the first week of June (Machutchon and Harestad 1990).

Breeding occurs shortly after the adult females emerge from hibernation and lasts for about 3 weeks (Elliott and Flinders 1991). Ground squirrels reach their full body mass in their fourth summer (3 years old), and adult males are heavier than females. Males in Alberta did not breed until they were 3 years old (Murie and

Harris 1978). Females may breed during their first year and continue to have one litter per year (Elliott and Flinders 1991). Gestation takes 24 days, and an average of 2.7 to 7.0 young is born. Heavier females can have larger litters. Neonates weigh 6.8 to 11.4 g on average. Dispersal occurs immediately after juveniles emerge from hibernation in the spring. Juvenile males travel farther from natal burrow, have larger home ranges, and shift activity centres more than juvenile females. Juvenile females remain close to the natal burrows and may inherit the nest burrow of their mother when they breed (Elliott and Flinders 1991). Excursions or temporary absences from home ranges also are common by yearling females.

Badgers prey on juvenile ground squirrels in spring and hibernating ground squirrels in autumn. Michener (2000) found that predation on Richardson Ground Squirrels (*S. richardsonii*) was most intense when ground squirrels were immobile and particularly vulnerable to underground capture (i.e., infants or during hibernation). She also suggested that ground squirrels are fatter when they enter hibernation because they rely on fat stores to meet metabolic costs, and therefore provide more energy for predators. In eastern Washington, Badgers dug up the nest burrows of female ground squirrels each year over 6 years (Murie 1992). Most of the attempts were directed at lactating female ground squirrels during a 30-day window between birth and emergence (most within a 2 week period). Some predation was associated with non-nest burrows both before litters were born and after parturition. The pre-emergent juveniles were the most vulnerable to predation, but non-juvenile ground squirrels usually survived attacks. After the nest burrows were dug up, females did not move their nests to a new location, but remained in the same area. Most surviving offspring emerged within 10 to 20 m of the original nest burrow entrances. Knopf and Balph (1969) reported that Badgers prey on family groups of Uinta Ground Squirrels (*S. armatus*) and leave adjacent burrows containing a single ground squirrel.

Predation is more prevalent during years when populations of ground squirrels peak. Michener (2000) found that Badgers did not hunt for Ground Squirrels (*S. richardsonii*) regularly on her study site until August in a year when the population of ground squirrels was at its peak. Predation continued until the adult population of ground squirrels had declined to less than 20% of its peak size. Murie (1992) suggested that there were no notable declines in the population the year after Badger predation at his study site, but the growth of the colony may have been constrained. Ground squirrels also develop the plague, Yersinia pestis, which may reduce colony size. Badgers may develop only transient symptoms of the disease caught from ground squirrels (Messick 1987).

Ground squirrels generally respond positively to minor habitat disturbance. On deferred grazing pastures in Alberta, the biomass of Richardson's Ground Squirrels (*S. richardsonii*) was estimated to be more than 73 times the biomass of mice and voles (Skinner et al. 1996). On these sites, more Badger burrows were counted where ground squirrels were abundant than in pastures that had more mice and voles. Ground squirrel populations also increase after stand-replacing fires (Ream 1981). Habitat created by clearcutting forests may encourage temporal colonization by ground squirrels, especially if areas are seeded for livestock forage or road stabilization.

Ground squirrel populations may decline as a result of extermination programs on private lands. Their burrows are seen as a hazard to livestock, and animals are viewed as competition for forage although this effect may be overstated. Shaw (1916) reported that 385 ground squirrels consumed as much forage as one cow, and 96 ground squirrels consumed only as much as one sheep. Control efforts for ground squirrel populations include using sodium floroacetate, which is more effective than zinc phosphide, gas cartridges, or strychnine (Elliott and Flinders 1991). Also, the anti-coagulant rodenticides chlorophacinone and bromadiolone applied in mid- and late-season have been found to achieve 70–80% and 100% mortality, respectively (Elliott and Flinders 1991).

Yellow-bellied Marmot (*Marmota flaviventris*)

Yellow-bellied Marmots have stout bodies, short legs, and a short bushy tail. The hair on the dorsal side of these marmots appears grizzled, the hair on the ventral sides of the neck, hips, and belly are buffy-yellow, and there is a cream-coloured bar across the bridge of their noses and around the lips (Banfield 1974). Mean adult weights are reported to be 3.9 kg for males and 2.8 kg for females (Frase and Hoffmann 1980). Yellow-bellied Marmots live as a harem of an adult male with several females and their offspring, but they also may live as singles or paired animals (Frase and Hoffmann 1980). Marmots are a diurnal species and their peak activity hours occur in the morning from sunrise, and in the late afternoon until 30 minutes after sunset (Banfield 1974). Marmots maintain home ranges that overlap but contact between colonies is avoided (Banfield 1974).

Yellow-bellied Marmots are common in the dry interior of British Columbia and occur in the western Cordillera as far north as Williams Lake (Nagorsen 1990). In the northern part of their range, Yellow-bellied Marmots are restricted to lower elevations. Yellow–bellied Marmots are found in pastures, meadows, and old fields that are close to wooded areas, and often are associated with rocks or slashpiles (Frase and Hoffmann 1980). They prefer meadows where vegetation is low, allowing for detection of predators. Yellow-bellied Marmots are semi-fossorial and typically inhabit vegetated talus slopes and rock outcrops that support burrows and serve as sunning and observation posts.

Badgers dig marmots out of their burrows using techniques similar to those used when preying on ground squirrels. Verbeek (1965) observed a Badger preying on a Yellow-bellied Marmot in July at a snowfield in Wyoming. The Badger dug a fresh burrow at the base of a large boulder and, a short time later, had a small marmot in its mouth at the entrance to the burrow. The Badger took the marmot inside the burrow and filled the entrance behind it. Van Vuren (2001) found whole or parts of marmots killed by Badgers buried with their radio-transmitter under more than 10 cm of loose soil inside burrows. On two occasions, an entire marmot carcass was found buried in an apparent cache and uneaten 7 to 10 days after death. Van Vuren reported that 5 of 10 marmot predations by Badgers occurred in shallow burrows used temporarily to escape threatening situations.

Marmots maintain nest, flight, and hibernating burrows (Armitage 1991). Flight burrows tend to have only one opening and nest burrows may have several entrances (Armitage 1991). Burrows are usually located in well-drained slopes at depths from 0.6 m. The main passageway of a burrow extends 3.8 to 4.4 m horizontally into a hillside and several short blind tunnels branch from the main passageway. The nest chamber is located at the end of the burrow beneath a large rock (Frase and Hoffmann 1980). The burrow located at the centre of the home range usually is preferred (Banfield 1974). Obvious above-ground trails connect burrows within a colony. Burrows serve as nurseries, refuges from predators and conspecifics, and hibernacula (Armitage et al. 1976). Burrow availability may be a limiting resource that partly explains marmot distribution (Frase and Hoffmann 1980).

Marmots do not exhibit sentinel behaviour, but give alarm calls to the rest of the colony when they feel threatened (Frase and Hoffmann 1980). Marmots rarely range farther than 20 m from a burrow and will run to the nearest flight or home burrow when alarmed (Armitage 1962). The entrances of these burrows lacked rocks or other barriers to prevent Badgers from enlarging the entrance, but other burrows that Badgers successfully dug out did have rocks protecting the entrance.

Yellow-bellied Marmots are herbivorous rodents that eat mainly grasses, flowers, and forbs. In the late summer, seeds, caterpillars, and moths also have been identified in their diets (Banfield 1974). Stallman and Holmes (2002) reported that marmots in California ate forbs, especially clover (*Trifolium andersonii*), despite its relative rarity, over grasses, sedges, and rushes. This behaviour may be related to the higher nutritional value or water content of forbs over other plants. Marmots will consume 0.8 to 3.1% of the above-ground primary production (Armitage 1991). Moderate grazing may provide more food resources for marmots because it inhibits or prevents growth of perennial grasses that are not favoured by marmots. However, heavy grazing (>40% of the standing crop) may reduce food supply during the period when marmots are accumulating fat before hibernation (Frase and Hoffmann 1980).

Yellow-bellied Marmots generally hibernate for approximately 8 months of the year, starting the second week of August (Banfield 1974). Adult males emerge first in late April or early May, followed by adult females, yearling males, and yearling females (Armitage 1991). Adults will emerge spontaneously, but young will not emerge until fed or emaciated (French 1990). Reproductive behaviour is concentrated in the first two weeks after emergence and most copulation occurs underground (Frase and Hoffmann 1980). The length of the active season may affect reproduction and local marmot densities. Reproduction of females, survival of young, and litter sizes are larger in years with shorter winters (Armitage 1991). Reproduction must occur as early after emergence as possible since survival of young weaned late in the season is less than 10% (Armitage et al. 1976). Females are reproductive after their first year and males are reproductive in their second year. Gestation takes 30 days and litter sizes range from 3 to 8 (average, 4–5) (Frase and Hoffmann 1980). Neonates weigh 33.8 g and remain in the burrow for 20 to 30 days until they are weaned when food resources are nearly maximized (Armitage et al. 1976). All males and some female offspring disperse after their first year in May to July (Armitage 1991). Dispersal may take individuals up to several kilometres (15.5 km) away from their natal burrow.

Predation is a dominant cause of mortality for Yellow-bellied Marmots especially during the active season. Van Vuren (2001) investigated the predation of Yellow-bellied Marmots in Colorado. Of all mortalities in the summer, 47% of the marmots were preyed on by Coyotes, 10% by Badgers, 7% by American Martens, 7% by Black Bears, and 6% by raptors. Other predators of Yellow-bellied Marmots include Gray Wolves, Bobcats, owls, and Golden Eagles. Weasels and Marten also may prey on emergent young (Banfield 1974). Van Vuren (2001) reported that some marmot colonies in his study experienced higher predation rates. These were either larger colonies, sites where residents or dispersing animals were funnelled down corridors (e.g., a narrow canyon), or sites that allowed predators some degree of concealment (e.g., tall vegetation).

3.2 Family Geomyidae: Pocket Gophers

The Northern Pocket Gopher is the only geomyid that occurs in British Columbia. Pocket gophers were the major prey items of Badgers in south-central Idaho (Todd 1980), east-central Minnesota (Lampe 1982), west-central Minnesota, and south-eastern North Dakota (Sovada et al. 1999).

Northern Pocket Gopher (*Thomomys talpoides*)

Northern Pocket Gophers (*Thomomys talpoides*) have heavily muscled heads and shoulders tapering to relatively narrow hips, short legs, small eyes, and pinnae. The pelage is soft and dense, ranging from dark brown to pale gray, and animals may have irregular white blotches at the throat and chest. Toes on the forelegs have long claws for digging. Pocket gophers are named for their fur-lined cheek pouches that open externally to the mouth, and the lips can close behind the incisors to prevent soil from entering the mouth. Adult body masses range from 64.3 to 99.7 g in Oregon, 75.1 to 131.4 g in Nevada, and 75 to 180 g in Wyoming (Verts and Carraway 1999). Pocket gophers aggressively defend territory boundaries and maintain exclusive burrow systems except during the breeding season (Banfield 1974). Home ranges are only 125 to 167 m^2 (Banfield 1974). Populations tend to be spatially aggregated because individuals use patches of vegetation or plant species (Huntly and Inouye 1988). Activity above ground is limited but may occur at night.

The Northern Pocket Gopher is found in the dry southern interior of B.C. from the southern Kootenays as far north as the South Thompson River (Johnstone 1954). They are found up to 2225 m in Alberta, and up to 3500 m in Colorado (Burns 1987). Pocket gophers occur in a variety of ecosystems, including natural grasslands, cultivated fields, roadsides, and riverbanks (Banfield 1974), up to Engelmann spruce (*Picea engelmannii*) subalpine fir (*Abies lasiocarpa*) ecosystems (Andersen 1978). Pocket gophers avoid dense forests, wet, fine-textured, rocky soils, and cold areas. The availability of suitable soils limits range expansion, and major rivers are a barrier to immigration (Burns 1987).

Pocket gophers are fossorial mammals that maintain both living galleries and feeding tunnels. Individuals have approximately 45 to 60 m of tunnels that are usually 30 to 40 cm below the surface (Verts and Carraway 1999). Living galleries are located 1.8 to 2.7 m below the surface and consist of several nesting chambers and storage chambers about 20 to 25 cm in diameter. Nests are lined with finely shredded grasses and have only one entrance from the main tunnel. Shallow feeding tunnels are 13 to 45 cm below the surface and approximately 5 cm in diameter, and radiate from the main chamber (Banfield 1974). Pocket gophers dig special chambers or use abandoned tunnels to store waste such as old nesting materials, cached food, or feces (Verts and Carraway 1999). Soil dug from tunnels is pushed to the surface to produce fan-shaped spoil mounds that are characteristic of pocket gophers, and the entrance to the side of the mound is plugged. In the winter, excavated soils and waste materials are packed into subnivean tunnels that form soil casts on the ground after the snow melts.

Suitable soils for pocket gophers are finer textured and have moderate moisture (not extremely dry or wet). An individual can excavate nearly 0.5 m of tunnels in approximately 15 minutes. In Utah, 11.5 metric tonnes of earth per hectare was excavated and mounds covered 3.5% of the surface in an area where pocket gophers were found in densities of 10.2 to 40.6 animals per hectare (Ellison 1946). Relative numbers of pocket gophers may be correlated with mounds and earth plugs (Verts and Carraway 1999). Excavation peaks in late summer and autumn when soil moisture is moderate (9–18%) and juveniles are dispersing and need to construct their own burrow systems (Verts and Carraway 1999). Soils are softer and looser where pocket gophers are present, which affects soil aeration, moisture content, and fertility (Verts and Carraway 1999). Badgers forage for pocket gophers under the soil. Lampe (1976) found that Badgers penetrated burrows where gophers may be located, successfully capturing gophers in 73% of the attempts. On average, more than 180 litres of soil were displaced at each predation site.

Pocket gophers eat mostly forbs in the summer and roots in the winter, as well as some seeds and arthropods (Cox 1989). Cox (1989) found that pocket gophers in north central Oregon ate more forbs (97%) than grasses (2.4%), and particularly selected leaves of lupines (*Lupinus caudatus*). Gophers also can select plants with higher levels of protein and fat than other species available (Verts and Carraway 1999). Feeding occurs during night-time forays or by tunnelling under plants, cutting the roots and pulling the plants into the burrow. Gophers will cache food materials to consume during the winter, and may also eat parts of trees and shrubs depending on the depth of snow (Verts and Carraway 1999).

Pocket gophers are active year-round. Breeding season for pocket gophers occurs from April to early May, but may be delayed to July and early August in mountainous regions (Banfield 1974). Females become reproductive after their first year and may produce more than one litter per season (Verts and Carraway 1999). The natal chamber is stocked with green forage so the pregnant female will not have to leave the burrow. Gestation takes approximately 18 days (Andersen 1978). Litter sizes vary from 2 to 7 young and neonate weights range, but average litter weights are 17.65 g (±0.46 g, n = 6 litters). There was no significant difference between weights of litters of 5 or 6 young (Andersen 1978). Dispersal occurs 6 to 8 weeks later in August (Banfield 1974). Juveniles travel above ground before they dig temporary burrows of their own, and mortality due to predation is high during this time. Young pocket gophers probably reach adult weight by early to mid-October (Andersen 1978).

The life expectancy of pocket gophers is 2.9 years, but an individual as old as 4 years was recorded during one monitoring program (Banfield 1974). Gopher populations experience rapid turnover during the breeding season and only a small proportion of yearlings live until their second year. (Banfield 1974).

Badgers may be attracted to areas dense with pocket gophers. Sargeant and Warner (1972) reported that the area used by a female Badger during the fall appeared to have one of the densest populations of pocket gophers (*Geomys bursarius*) in the Badger's home range. In Utah, pocket gopher counts in autumn were highest in meadow habitat (12.5 to 62.5 per hectare), but were much lower in aspen (2.1 to 33.3 per hectare), fir (0 to 10.4 per hectare), and spruce (0–1.0 per hectare) habitats (Andersen and MacMahon 1981). Pocket gophers amounted to 81 to 83% of the fauna biomass (excluding ungulates) in meadows, 67 to 70% in aspen, 5 to 20% in fir, and 2 to 7% in spruce habitats in 1976 and 1977 (Andersen et al. 1980). Dispersion of pocket gophers at low densities may be clumped in optimal habitats, and become more uniform at high densities (Hansen and Remmenga 1961).

Badgers may target pocket gophers when they are most active and the young are most vulnerable. Salt (1976) reported that in east-central Alberta, pocket gophers were the major food items from late March to early July. Live-trapping indicated that 80% of pocket gophers that were active in June (19–21) were immature. This corresponded to the gopher breeding season and the time when young feed above-ground. Activity levels of pocket gophers declined in late July. During this time, Badgers switched to target Richardson's Ground Squirrels (66% of all food) although pocket gophers were more numerous and broadly distributed than Richardson's Ground Squirrels. At least one and usually two pocket gophers were confirmed per scat sample (Salt 1976). Lampe (1976) estimated that a daily energy requirement for a Badger, excluding energy cost for pursuit of prey, to be at least 1.7 pocket gophers per day. Other predators of pocket gophers include Gopher Snakes (*Pituophis catenifer*), Coyotes (*Canis latrans*), Bobcats (*Lynx rufus*), Marten (*Martes americana*), and owls, including Burrowing Owls (*Athene cunicularia*) (Banfield 1974).

Pocket gophers respond favourably to habitat alteration. Gophers often increase in areas that have been logged, exposed to silvicultural site preparation, or after other activities that open tree canopies and disturb the soil (Teipner et al. 1983). Pocket gophers are reported to have expanded their range after road construction in the south-western United States (Huey 1941). Burns (1987) found that pocket gophers have extended their range into the Rocky Mountains of southern Alberta (in at least five locations) and suggested that the effects of livestock grazing contributed to the spread. Pocket gophers have also been known to increase after fire (Teipner et al. 1983).

Pocket gophers have negative impacts on range and agricultural lands and as such are often the target of population control programs. Pocket gophers can limit forbs available to livestock. During feeding trials, pocket gophers ate 83 g of dandelion and 80 g of peavine each day, amounting to approximately 1636 kg per hectare for an average population of 54 gophers on one hectare of land (Banfield 1974). This may have a large effect on the landscape. Plains Pocket Gophers (*Geomys bursarius*) in western Nebraska reduced forage production by 18 to 49% (Foster and Stubbendieck 1980). Another study in California found that gophers at densities of 25 animals per hectare on rangeland would destroy 284 kg per hectare of vegetation (Foster and Stubbendieck 1980). Pocket gopher control has been shown to be effective for increasing range resources available to livestock. In Grand Mesa, Colorado, herbage available to livestock increased by 218 kg per hectare after 1 year of gopher control, and crown cover of plants commonly eaten by gophers increased (Foster and Stubbendieck 1980). Pocket gophers may also increase the abundance of grasshoppers, compounding forage competition. Gopher tunnelling and mound-building exposes soil where most grasshoppers oviposit and where the probability of survival of eggs and nymphs is greatest (Huntly and Inouye 1988).

Pocket gopher populations may be reduced after the use of herbicides to control weeds in agricultural areas. Cox (1989) reported that pocket gopher populations decreased by 87% in a field that had been treated with the herbicide 2,4–D to reduce weedy forbs and favour grasses. Since pocket gophers prefer forbs, herbicides may cause a reduction in food and limit populations.

Barnes et al. (1985) examined the hazards to Grizzly Bears of strychnine baiting to control pocket gophers. Pocket gophers were baited using steam-rolled oats containing 0.5% strychnine alkaloid dispensed by hand in clearcuts and in a 20- to 30-m-wide border around each clearcut (1.2–2.2 kg per hectare). Also, 3 to 5 g of bait was deposited directly inside gopher burrows. During the study, 65% of the pocket gophers included in the study died from strychnine poisoning; 50% died within 1 day after bait exposure and the rest died within 4 days. Researchers found from 0.1 to 18.3 g of bait stored in both alive and dead gopher burrows. Dead gophers were usually found alone in their nest but some were found in groups, such as a mother with her young. Sixty percent of the carcasses were found more than 40 cm (10–152 cm) below the surface, and almost half were within 10 cm of a nest. Mean strychnine content in carcasses was 0.23 mg and 0.11 mg at two different sites. The largest amount of strychnine found in a dead pocket gopher carcass was 0.4 g with 1.3 mg stored in its cheek pouch. Residual strychnine was concentrated (69%) in gastrointestinal tracts. Little or no strychnine (<0.01 to 0.20 mg) was found in carcasses of other animals that were collected after the treatment. These included a Yellow-pine Chipmunk (*Tamias amoenus*), a Deer Mouse (*Peromyscus maniculatus*), and a Blue Grouse (*Dendragapus obscurus*). The authors concluded that a 45 kg Grizzly Bear would need to ingest 94 pocket gopher carcasses with an average of 0.16 mg of strychnine to reach a lethal dose of 0.33 mg/kg.

Converting these figures, a small 8 kg Badger (assuming a similar lethal dose) would have to eat 17 carcasses. This likely is more than a Badger could eat at one time. Because strychnine is fast-acting, prolonged consumption would lead to sublethal effects rather than death (Crabtree 1962, cited in Barnes et al. 1985). However, negative health effects could inhibit other Badger activities, such as mate-searching or foraging, and affect the fitness of an animal.

3.3 Family Muridae: Muskrats and Voles

This section focuses on the murid species that commonly occur in grassland areas and are reported in Badger diets. These species include the Muskrat (*Ondatra zibethicus*), Southern Red-backed Vole (*Clethrionomys gapperi*), and Meadow Vole (*Microtus pennsylvanicus*). The Montane Vole (*M. montanus*) has not been identified in diets, but may be a source of prey for Badgers. These voles are found in the southern Interior from the Okanagan Valley to Williams Lake (Nagorsen 1990).

Murid species may be particularly important components of Badger diets west of the Fraser River where sciurids are not available, or north of the South Thompson River where pocket gophers do not occur. In the Cariboo region, evidence suggests that Muskrats may be an important component of Badger diets (Roger Packham, Ecosystem Section, MOE (MWLAP 2005), pers. comm.). Rahme et al. (1985) suggested that marmots and microtines could also be important. Microtines also were a large component of the diets of Badgers studied across the province (Newhouse and Kinley 2001; Hoodicoff 2003). Microtine and cricetine rodents were the major prey source for Badgers in Utah and Idaho, followed by lagomorphs that may have been eaten as carrion (Lindzey 1971).

Muskrat (*Ondatra zibethicus*)

The Muskrat is a large Vole that is adapted for living in water. It has a large body with short legs, small eyes, and short ears hidden under its glossy chestnut brown fur. Muskrats have webbed hind feet, and a flattened and nearly hairless tail that they use for swimming. Their lips close behind the incisors to allow animals to eat under water without getting water in their mouths. Adults are approximately 60 cm long, and weigh from 700 g to more than 1800 g (Banfield 1974). Muskrats are primarily nocturnal, but may be seen during the day in spring and autumn (Boutin and Birkenholz 1987). Activity peaks are reported 1600 to 1700 h and 2200 to 2300 h, but they may be active earlier on rainy days (Willner et al. 1980).

Muskrats are found near sloughs, lakes, marshes, and manmade water channels such as farm ponds at lower elevations across the province (Willner et al. 1980). Muskrats prefer wetlands of fresh or brackish (occasionally alkali) water with abundant emergent vegetation, but generally do not inhabit open expanses of water (Errington 1963). Ideal ratios of vegetation to water are 75:25 to 80:20 (Allen and Hoffman 1984). Areas of dense vegetation (>50% cover) of cattails, bulrushes, and other edible marsh plants are preferred (Allen and Hoffman 1984). Muskrats are not usually found along forested riverbanks. Even within a large marsh with available habitat, Muskrats are attracted to areas where conspecifics are dwelling (Errington 1963). They will start to colonize nearest the other animals before occupying uninhabited sites. Muskrats rarely range farther than 15 m from their burrows or lodges, but may travel farther when populations are declining in poorer habitats (Willner et al. 1980). Home ranges are reported to be anywhere from 1 to 101 m from the central dwelling, and as large as 1112 m^2 for Muskrats in Ontario (Boutin and Birkenholz 1987).

Water levels and velocities affect Muskrat habitat (Perry 1982). Streams with gradients more than 6.1 m/km and less than 9.0 m/km support Muskrats; however, habitat is scoured if flow of water exceeds 28 m^3/sec. Depth of water is generally less than 3.7 m to allow submerged vegetation to thrive. Extreme water level fluctuations also may disturb Muskrat activity or displace individuals from their home ranges (Allen and Hoffman 1984). During low water, Muskrats dig canals from lodges and burrows to deeper water (Willner et al. 1980). Winter temperatures may freeze the water at entrances, especially if water levels are lower than 1.2 m (Banfield 1974). If water levels rise more than 0.6 m, Muskrats may be forced out of burrows and lodges. Most displaced Muskrats return to their home ranges (Willner et al. 1980).

Depending on their environment, Muskrats build several types of structures for resting and feeding. Muskrats build feeding platforms or lodges to get out of the water to eat and as protection from weather and predators (Perry 1982). The platforms begin from a floating rush raft or mud bar with a solid foundation. Vegetative material is heaped onto the substrate surface from 1.8 to 3.5 m in diameter (Errington 1963). An inner chamber and passage is hollowed out from beneath. Several entrances from under the water surface lead to the inner chambers. In the winter during drought, individuals may not come out of their burrows unless there are moderate daytime temperatures (Errington 1963). Most lodge-building activity occurs in the late summer and early fall by subadults preparing for the winter (Errington 1963). Feeding lodges are smaller and simpler in design than overwintering lodges. Up to 12 individuals can be found huddling inside the larger lodges for warmth. Other species that use Muskrat lodges include snakes, turtles, toads, and Canada Geese (Perry 1982).

Transient and resident Muskrats build burrows into banks in areas that are not too rocky or too friable, preferably with clay substrates (Errington 1963). Roots or other objects provide support for the burrow. Optimum sites for bank burrows are on slopes of more than 30 degrees with a minimum height of 0.5 m (Allen and Hoffman 1984). During the summer on the Mackenzie River Delta in the NWT, Muskrats burrowed closer to shallow water, on gentler slopes with greater cover, and nearer to *Equisetum fluviatile* than in winter (Jelinski 1989). In the winter, Muskrats burrowed less in areas with *Carex aquatilus* and *E. fluviatile*, and used more steep-sided cutbank sites. Entrances to burrows start below the surface of the water and extend as far as 15 m before meeting the shoreline. Burrows may be shallow and spread laterally along the shore or perpendicular to the shore and extend 18 to 91 m up a low-gradient slope (Errington 1963). Inside are one or more nest chambers lined with fresh plant material (Willner et al. 1980). In firm soils, burrows may be elaborate and occupied regularly for decades even where there is considerable disturbance (Errington 1963). Burrows in areas with overhead obstacles such as vegetation may decrease the risk of predation by terrestrial predators (Jelinski 1989).

Badgers have been reported to hunt Muskrats in their burrows in the Sand Hills of Nebraska (Errington 1963). Muskrats were burrowed into primarily sandy soils with thin sod that was broken by livestock. Badgers had dug out the upper parts of Muskrat burrow systems along the banks. In some cases, young Muskrats were pulled out of the burrows. It was thought that Muskrats would be able to relocate because there was suitable habitat nearby, but some Muskrat burrows remained active and individuals plugged their burrows with vegetation or sand after Badgers dug them up. Similar sign has been observed in the Cariboo region (Roger Packham, pers. comm.), but has not been observed in the Thompson or East Kootenay regions of B.C. (Nancy Newhouse, East Kootenay Badger Project, Invermere, pers. comm.).

Badgers may be eating Muskrats where other prey items are limited. Errington (1963) reported an inverse occurrence of Meadow Voles and Muskrats, and supposed Coyotes and Badgers were eating Muskrats as an alternative food source. Coyotes may also eat Muskrats when Meadow Voles are less abundant. Raccoons (*Procyon lotor*), Mink (*Mustela vison*), Red Foxes (*Vulpes vulpes*), hawks, and owls are other predators of Muskrats (Willner et al. 1980).

Muskrats eat basal portions, rhizomes, and leaves of aquatic emergent vegetation, such as horsetail (*Equisetum fluviatile*), *Potamogeton*, cattail, bulrush, sedge, arrowhead (*Sagittaria* spp.), clover (*Trifolium* spp.), and willow (*Salix* spp.) (Willner et al. 1980, Jelinski 1989). Some fish, crustaceans, dead birds, and frogs also have been reported in diets of Muskrats (Perry 1982). Muskrats increase their fat levels in early winter and probably use these stores in spring and early summer when metabolic costs are likely highest, rather than for insulation during the winter (Jelinski 1989). Muskrats usually remain within 15 m of their lodges while foraging, but may range as far as 183 m (Willner et al. 1980). Over-foraging by Muskrats, especially when populations are high, can impact riparian ecology and result in large pools of open water (Willner et al. 1980). Population collapses generally occur as food resources are depleted. In the Mackenzie River District, pelt return surveys indicate that populations peak every 10 years (Boutin and Birkenholz 1987). These population cycles are linked to “eat out” conditions where low populations lead to abundant food supplies, then the population booms and food resources are depleted leading to a subsequent population crash (Willner et al. 1980).

Local Muskrat densities vary annually, seasonally, and in different habitats (Boutin and Birkenholz 1987). Breeding density of Muskrats may range from 2.5 to 5 pairs per hectare (Perry 1982). Populations are reported to follow a 6- to 14-year cycle (Willner et al. 1980). If densities grow too high, Muskrats become cannibalistic and kill young of other Muskrats (Willner et al. 1980). Muskrat population densities can be estimated by counting dwellings and multiplying the number of animals per house. Counts may underestimate population size as burrows are not always detected.

Breeding season of Muskrats is determined by geographic and climatological conditions (Willner et al. 1980). In the southern United States, Muskrats breed year-round, peaking in winter (Boutin and Birkenholz 1987). In Canada, the breeding season for Muskrats occurs between March and September (Banfield 1974). Female Muskrats are seasonally polyestrous, with estrous cycles range from 2 to 22 days (average, 6.1). Males are reproductive between March and late August (Banfield 1974). Litter sizes may be associated with a latitudinal gradient where larger litters occur in the north (Willner et al. 1980). There are two or sometimes three or four litters per season. Fewer and smaller litters occur in poorer quality habitats (Willner et al. 1980), and larger litters occur in more northern habitats (Boutin and Birkenholz 1987). First litters of females are smaller, and young females may have only one litter during that season (Banfield 1974).

First litters are born late in April or early in May, and subsequent litters may be born monthly up to November (Willner et al. 1980). Gestation lasts for 25 to 30 days (1974). Mean litter sizes range from 4 to 8 (average 6 or 7) (Willner et al. 1980). Neonates weigh approximately 22 g and are independent after 30 days (Banfield 1974). Young become active and can swim within 14 days of birth (Willner et al. 1980). Juvenile dispersal over land occurs from March to May (Willner et al. 1980). Juveniles establish breeding territories, colonize vacant territories (Willner et al. 1980), or they remain within the parents' home ranges (Boutin and Birkenholz 1987). Juveniles are mature after a year in the northern part of their range and are reproductive in mid-May, usually later than the adults (Banfield 1974). Juvenile survival ranges from 18% to 85% across their range, but 50% survival from birth to autumn is considered relatively good (Errington 1963). Winter survival of Muskrats in all age classes ranges from 19% to 68% (Boutin and Birkenholz 1987).

Muskrats are trapped heavily for their pelts, and this may affect the availability to Badgers and other predators. Harvest rates of Badgers have been reported at 7 to 20 Muskrats per hectare in Maryland, and 7 to 9 Muskrats per hectare in South Dakota (Boutin and Birkenholz 1987). In North America in 1982/1983, 7.4 million Muskrats were harvested (Boutin and Birkenholz 1987). Proportions of Muskrats trapped are estimated from 50 to 90% of the autumn population (Boutin and Birkenholz 1987). In New Brunswick, populations were harvested at 60%, but did not show any long-term population declines if the harvest was confined to the spring or summer only (Parker and Maxwell 1984).

Various management techniques have been used to maintain high populations of Muskrats. Manipulation of the habitat can keep marshes in early seral conditions favourable for Muskrats and waterfowl (Boutin and Birkenholz 1987). Marshes already dominated by emergent vegetation can be burned or kept at high water levels (Willner et al. 1980; Boutin and Birkenholz 1987). Dikes to control water fluctuations in marshes can increase Muskrat populations by 3 to 5 times. Ditching may also increase Muskrat populations by opening water and providing bank habitat for burrowing (Willner et al. 1980). Temporary draw-down of marshes may stimulate the germination of vegetation and increase nutrients. Muskrat densities reached peak levels 3 to 4 years after this practice, but declined afterward (Boutin and Birkenholz 1987).

Because burrowing activities cause damage to river banks and agricultural areas, efforts have been made to control or eliminate Muskrats (Willner et al. 1980). Those include extermination by trapping, gassing, poisoning, and shooting individuals, or changing habitat by manipulating water level or covering banks with large crushed stones (Willner et al. 1980). Muskrats also may be affected by practices that degrade marsh habitat such as dredging, diking, and urban sprawl (Willner et al. 1980). Grazing of riparian vegetation by cattle can reduce cover for Muskrats, and trampling can damage Muskrat dens and potentially reduce populations.

Southern Red-backed Vole (*Clethrionomys gapperi*)
The Southern Red-backed Vole is a small, slender vole with small eyes, prominent ears, and a moderately short, slim tail. The species has a chestnut dorsal stripe that extends from the forehead to the base of the tail, with pale grey sides and ventral surface. Lengths range from 120 to 164 mm and mean adult weights range from 6 to 42 g, but sizes vary considerably throughout their range (Merritt 1981). Red-backed Voles are solitary in the

summer and congregate in family groups in the winter (Banfield 1974). They are primarily nocturnal but are sometimes active during the daytime, and are active all year long (Banfield 1974). Females are territorial (Bondrup-Nielsen 1987), although home ranges may overlap. Home range sizes vary from 0.01 to 1.4 ha (Allen 1983), and may depend on habitat characteristics rather than population density (Bondrup-Nielsen 1987).

The Southern Red-backed Vole has a very large range in B.C. and inhabits a variety of habitats, including damp conifer forests, bogs, swampy areas, and drier aspen forests (Eder and Pattie 2001). Red-backed Voles were found in aspen (*Populous tremuloides*) stands that had a closed tree canopy and an understorey of shrubs and herbs (Merritt 1981). In Idaho, ungrazed riparian vegetation with forb understories supported the highest number of voles (Uresk et al. 1982). Voles tend to avoid fields and forest clearings where there is no protective ground cover (Allen 1983). Red-backed Voles may inhabit grassland habitats particularly in winter (Iverson and Turner 1972). Voles may use logged areas where some protective cover remains. In Wyoming, more Red-backed Voles were found in selectively cut and in mesic unlogged forests than in other sites (Campbell and Clark 1981). However, voles become rare within 2 to 3 years after harvest due to reduction in availability of lichens and fungi (Martell 1981). Approximately 2 ha of suitable habitat must be present before Red-backed Voles will occupy a site (Allen 1983). Availability of water also is important and individuals generally are not found far from it (Banfield 1974).

Red-backed Voles require dense understorey, mossy rotten logs, stumps, and brush for cover (Banfield 1974). This species does not construct runways, but uses those made by other animals (e.g., Meadow Vole). Tunnels in soft litter under fallen logs or through sphagnum moss are used most often (Banfield 1974). Red-backed Voles construct round nests of grass, moss, lichen, or shredded leaves in holes in trees or on branches up to 6 m off the ground (Banfield 1974). They also may use abandoned burrows of other rodents or make dens under the snow during winter.

Red-backed Voles are omnivorous, but rely heavily on fungi (Maser et al. 1978). In the spring, voles eat new shoots of plants. In the summer, berries and petioles of broad-leafed forbs and shrubs are their main food source, and piles of these can be found near their dens (Banfield 1974). In the autumn, voles mainly eat seeds of conifers. They do not store food for winter, but eat petioles, twigs and winter buds, and green plants they find under the snow. Voles also may eat mouse carcasses and insects in minor amounts (Banfield 1974).

Voles are very prolific and can have 3 to 4 litters per year. Females are polyestrous and breed from April to early October with three peaks times occurring in May, July, and September. Gestation takes between 17 and 19 days. Average litter sizes are 5.47 young (range, 1–8), but litter size varies year to year, and is lower when vole population density is high. Young are born in grass-lined nests and weigh 1.9 g (range, 1.7–2.3 g). Juveniles can move out of the den at 5 days holding on to their mothers' nipples, and are weaned at 17 to 21 days when they are on their own. Juveniles of the spring litter mature and bear young at 4 months old (Banfield 1974). Red-backed Voles live at least 20 months in the wild (Banfield 1974).

Populations fluctuate widely between years, but there is no known association with these fluctuations (Banfield 1974). Populations do not exhibit 3- to 4-year cycles as do many other small mammals (Bondrup-Nielsen 1987). Red-backed Vole densities vary from 0.42 to 10.9 animals per hectare (0.17 to 4.42 per acre) (Banfield 1974).

Little is reported of Badgers foraging on voles. Hawks, owls, raccoons, weasels, foxes, coyotes, skunks, marten, mink, black bears, and red squirrels are other predators that prey on voles.

Some management practices lower densities of Red-backed Vole populations. Livestock grazing may contribute to the isolation of Red-backed Vole habitat by reducing cover, and may lead to low populations in isolated forest patches (Witt and Huntly 2001). Application of the herbicide glyphosate resulted in a decline of Red-backed Voles (Sullivan and Sullivan 2003). Voles also are controlled on forest plantations because they girdle young forest trees.

Meadow Vole (*Microtus pennsylvanicus*)

The Meadow Vole is a stout, medium-sized vole with a short tail (Banfield 1974). In summer, Meadow Vole hair is short and rough with a rusty tinge, and is longer and greyer in the winter. Size of adults varies depending on geography, food, and population structure. Mean adult weights are 44.2 g (±6.29 g) for males, and 44.0 (±10.25 g) for females (Reich 1981). Meadow Voles are active all year round, and are mostly crepuscular. They form extensive colonies and use communal latrine areas (Banfield 1974). Home ranges are estimated to be 0.03 to 0.9 ha (Banfield 1974). Home ranges are larger in summer than in the winter but smaller where densities are high (Reich 1981). Individuals, especially females, defend territories around their nests.

The Meadow Vole is a common species in grassy areas of B.C. and occupies the mainland east of the Coast Mountain ranges (Nagorsen 1990). Typical Meadow Vole habitat occurs in moist, dense grasslands with substantial plant litter. In Virginia, suitable habitat included vegetation cover of 20 to 41cm and a presence of litter (Conley et al. 1976). Habitat selection is influenced by relative ground cover of grasses and forbs, soil temperature, soil moisture, humidity, and interspecific competition (Birney et al. 1976; Snyder and Best 1988).

Meadow Voles are abundant on sites with abundant overhead cover. Typical densities of Meadow Voles in old field habitat are 37 to 111 voles per hectare, and may reach 370 per hectare in marsh habitat (Banfield 1974). Densities fluctuate dramatically and peak populations occur every 3 or 4 years (Banfield 1974). Factors that affect densities include food quality, predation, climatic events, density-related physiological stress, and behavioural variants among dispersing individuals. In Iowa, populations of Meadow Voles increased during initial vegetation succession, and reached peak populations when perennial grasses established tallgrass prairie (Schwartz and Whitson 1986).

Meadow Voles dig shallow burrows and nests are constructed inside enlarged chambers (Banfield 1974). Nests are used as nurseries, resting areas, and protection against weather. Nests are made of woven grasses and may be constructed under a cover object (e.g. boards, rocks, brush piles, grassy tussocks, etc.). In winter, nests are constructed on the ground surface under snow cover, usually against a natural barrier such as a rock or log. Meadow Voles also form runways or paths in dense vegetation or under snow that lead between burrows, latrines, or cover objects.

Meadow Voles typically feed on grasses, sedges and forbs, and agricultural plants (Reich 1981). Other diet items include leaves, flowers, fruit, fungi (*Endogone* spp. mostly), and occasionally insects and snails. In a field community in Quebec, Meadow Voles preferred quackgrass (*Elymus repens*), sedges, fescues, wild strawberry, timothy (*Phleum pratense*), bluegrasses (*Poa* spp.) and bird vetch (*Vicia cracca*). Early-successional plants may provide better quality forage for voles than late successional plants (Bucyanayandi and Bergeron 1990). In the summer and fall, voles cut grasses into sections to reach succulent leaves and seed heads. Meadow Voles occasionally scavenge carrion, and cannibalism is frequent when population density is high. During the winter, voles eat basal portions of grass plants found under the snow, seeds, roots, and bulbs, and strip bark from woody plants. Some food such as seeds and tubers are stored in the nests (Banfield 1974).

Meadow Voles are extremely prolific. The breeding season begins in April when new vegetation emerges, and finishes in October when vegetative growth stops (Banfield 1974). Breeding may even continue until February when there is food, such as unharvested grain, and enough snow for insulation. Reproduction may be slower in hot summers. Gestation takes 20 to 21 days and neonates weigh 2.1 g (range, 1.6–2.9 g). Up to 11 young (average 6.3) are born. Litters become larger as the summer progresses, food becomes more available, and as mothers get older (Banfield 1974). Females enter oestrous immediately after giving birth and have an average of 3.5 litters per year (Banfield 1974). The young are weaned on the 12th day when they weigh approximately 14 g. A young female can mate at 25 days of age, and bear young at 45 days old. Males do not mature until their first year. Meadow Voles have a very short life span of approximately 16 months (Banfield 1974). In a field study in Michigan, 88% of mortality during the year occurred during the first month after birth (Banfield 1974). Populations fluctuate annually, peaking at 2- to 5-year intervals (Banfield 1974).

Meadow Voles may be a consistent source of food for Badgers, especially when ground squirrels are not active and energy requirements are high. In east-central Alberta, Badgers preferred Meadow Voles late in October (Salt 1976). Meadow Voles were found in 68% of scat samples, despite the fact that *Microtus*, *Peromyscus*, and *Clethrionomys* species were all documented at the site using snap-trap methods. Insects (grasshoppers and beetles) accounted for 50–90% of the items in scat samples. Voles represented a smaller proportion of diets by weight, however, and no more than two individuals were found in any sample. Most predators eat microtines, including hawks, owls, mammalian carnivores, some snakes, and even fish (Reich 1981). Meadow Voles are less vulnerable to predators than Deer Mice because they spend more time under the snow.

Voles tend to respond negatively to practices that reduce vegetative cover and forage (Birney et al. 1976; Jones 1990). Vole species generally avoid areas affected by stand-replacing fires, but slash burning may not affect Meadow Vole numbers (Ream 1981). Grazing by livestock will contribute to habitat fragmentation and may affect the ability of a population to establish (Witt and Huntly 2001). Herbicide application may impact vole populations. After application of the herbicide glyphosate to reduce vegetative cover, *Microtus* populations increased in abundance. However, management of orchard floor vegetation with multiple applications of glyphosate effectively altered habitat and reduced Montane Vole (*M. montanus*) populations (Sullivan and Sullivan 2003). Clearcut strips in conifer swamp areas of Michigan resulted in the increased relative abundance of Meadow Voles (Verme and Ozoga 1981). Most *Microtus* species are dependent on cover, and this may have explained their preference for dense vegetation along interstate highways (Adams and Geis 1983). In another study, Meadow Voles were documented to use right-of-way habitat along an interstate highway and its connecting roads to expand their range by 90 km (Getz et al. 1978).

Meadow Voles are considered pests on agricultural land (Uresk et al. 1982). It is estimated that a moderate population can eat as much as a ton of hay from one hundred acres of alfalfa (Banfield 1974). They also will eat crops of bulbs and vegetables. Meadow Voles are known to girdle fruit trees and seedlings under the snow or when populations are high (Reich 1981). This activity may be so significant that Meadow Voles may impact the growing ability of new tree plantations (Sullivan and Krebs 1981). In some cases, voles may prevent forest ingrowth onto grasslands. In central New York, voles substantially reduced tree and shrub colonization of old fields (Gill and Marks 1991).

4. INFLUENCE OF PREY ON BADGER POPULATIONS

Increased prey may lead to higher densities and larger populations of Badgers. Predators respond to high prey densities by increasing migration into these areas and by increasing their reproductive rates (Mallory 1987). Thus, prey availability could influence the health, distribution, survival, and abundance of Badgers in British Columbia.

4.1 Distribution

Local Badger habitat may be best described as sites of abundant, diverse prey in areas with suitable burrowing habitat. Weir et al. (2003) detected considerable patch-scale selection for sites with abundant prey. In Wyoming, Badgers were associated with deep, silty soils in areas with an abundance of prey (Minta 1993). Badger burrows were correlated with prey holes in Idaho as well (Todd 1980). In another study, Badger activity was positively correlated with the size and number of burrow openings in prairie dog (*Cynomys* spp.) colonies (Clark et al. 1982). If Badgers are attracted to prey locally, it is reasonable to suggest that prey may determine the distribution of Badgers across the landscape.

Practices that increase the ranges of prey may contribute to Badgers using "non-traditional" or non-grassland ecosystems such as clearcuts and alpine meadows (Adams et al. 2003). Disturbances such as logging and grazing increase the range of many prey species. Pocket gophers are reported to expand their ranges in response to road construction and grazing (Huey 1941; Burns 1987). Other species that respond positively to disturbance, such as ground squirrels and perhaps Deer Mice, may also draw Badgers into new areas. For example, in the Pend d'Oreille Valley southeast of Trail, B.C., local biologists believe that Badgers from Washington followed Yellow-bellied Marmots as they emigrated along the new dam road and rocky roadsides (Rahme et al. 1995). Badgers readily use roadsides as burrowing and foraging habitat and may use right-of-ways as dispersal corridors. Roads are considered movement facilitators for many other species of animals and plants (Underhill and Angold 2000).

Table 2. Summary of each species of Badger prey indicating their distribution in B.C., important habitat characteristics, and population densities.

Prey species	Mean weight	Distribution in B.C.	General habitat	Important habitat features	Density	Factors Affecting Density
Columbian Ground Squirrel	435-571 g in hibernation	Most of southern B.C., east of Fraser River	Valley to alpine, meadows, grasslands, fields, clearcuts	Soil moisture, drainage, aspect, slope, proximity to rocks for observation posts	4.2-61.7 per ha on agricultural lands	Food resources, plague, predation extermination
Yellow-bellied Marmots	2.8 kg females 3.9 kg males	South-central B.C., east of Coastal Mountains to Rocky Mountain trench	Lower elevations, talus slopes, meadows, pastures	Burrowing sites, well-drained slopes, rock outcrops, slashpiles	Patchy distribution	Predation, duration of winter, burrowing habitat availability
Northern Pocket Gophers	64.3-180 g	Southern interior of B.C., south of Thompson River	Grasslands, cultivated fields, roadsides, riverbanks, forests	Moderate moisture, fine-textured soils; avoids dense forests, wet or rocky sites	1-10 per ha in fir and spruce forests, 62 per ha in meadows	Juvenile mortality, extermination, herbicides, predation
Muskrats	700-1,800 g	Widespread across B.C., may be important to Badgers in Cariboo	Lower elevations near standing water or slow streams	Emergent riparian vegetation, burrows built in friable soils, steep banks	Max 10 per ha	Food resources, cannibalism, juvenile survival, trapping, water level
Southern Red-backed Voles	6-42 g	Widespread across most of southern B.C.	Conifer forests, bogs, swamps, dry aspen forests, dense understorey	Woody debris, brush, litter for cover, proximity to water	0.42-10.9 per ha	Predation, livestock grazing, herbicides, population fluctuation
Meadow Voles	34.0 g females 44.2 g males	Widespread across B.C., east of Coastal Mountains	Moist, dense grassland, meadows	Abundant litter and vegetation coverage (>20 cm)	37-111 per ha in old fields, 370 per ha marsh habitat	Juvenile mortality, livestock grazing, herbicide, population fluctuation 2-5 yrs

4.2 Survival

Badgers may be affected by a lack of food directly but reports of malnourished Badgers in B.C. are rare (Newhouse and Kinley 2001; Weir et al. 2003). Energetic demands of Badgers are high during lactation in the early spring and in the summer when Badgers are actively searching for mates and foraging. Lampe (1976) determined the energy costs of various activities, and found that the energy costs for an active Badger were 25.2 kcal/hour, 0.55 kcal/litre to move soil while digging, and only 7.2 kcal/hour while resting under ground. In other studies, daily energy costs of active Badgers were between 45 kcal/kg (Jense 1968) and 52.25 kcal/kg (Lampe 1976). For example, an 8.3 kg Badger would require approximately 22% of an adult rabbit (82.6 g dry weight), or 16% of an adult ground squirrel (72.3 g) per day (Jense 1968). Juveniles were estimated to need as much as 62% more than adult Badgers.

Badgers are physiologically and behaviourally adapted to deal with food shortages, especially during the winter months. Harlow (1979) monitored the responses of Badgers during 30-day periods of fasting and found that total metabolism decreased by 54%. He also observed that during cold weather (below –15ºC), Badgers limit their activity and reduce heat loss by remaining inside burrows and are able to go into torpor during very cold weather. Periods of inactivity inside of burrows are reported for Badgers up to 38 days (Messick and Hornocker 1981). It is estimated that an average of 24% of a Badger's fat reserve is depleted during winter months when they remain within their burrows (Harlow 1981). Therefore, Badgers may be food-limited in the autumn when they require fat reserves to survive through the winter while they are less active and food may be difficult to obtain. Adult Badgers are likely meeting these requirements, but effects of prey declines may be more indirect.

Loss of prey may result in increased home range sizes of Badgers particularly during spring and summer when Badgers are most active and energetic demands are high. Home range sizes of Badgers in B.C. are up to 100 times those of Badgers in the United States (Newhouse and Kinley 2001; Weir et al. 2003). Low prey populations may result in larger home ranges because Badgers range farther in search of food (Lindzey 1982). This may be especially true for females as their home ranges are limited by food distribution (Minta 1993). Larger home ranges have been documented for a number of other predator species when prey availability is low (e.g., Ward and Krebs 1985; Litvaitis et al. 1986; Chamberlain and Leopold 2000).

Badgers must increase their movements within large home ranges and this may expose individuals to higher risk of mortality on highways (Adams et al. 2003; Weir et al. 2003). Small mammals are reported to take refuge in roadside habitats where cover is abundant and during agricultural perturbations such as harvesting and ploughing (Adams and Geis 1983; Meunier et al. 1999; Underhill and Angold 2000). The abundance and the high incidence of prey road kill attracts predators that forage and scavenge along roadsides (Underhill and Angold 2000). Badgers use highway side berms for burrowing and foraging, and these factors may contribute to the high incidence of Badger road mortality reported in the province and elsewhere (Case 1978; Messick and Hornocker 1981; Apps et al. 2002; Weir et al. 2003).

4.3 Abundance and Productivity

Large home ranges have implications on the local abundance of Badgers. Greene and Stamps (2001) suggested that understanding habitat selection at low densities is important to successfully predict the movements (e.g., dispersal and settlement) in fragmented landscapes of the few remaining individuals in a threatened population. They predicted that if animals benefit from settling near conspecifics as Badgers do (Minta 1993), then settlers will aggregate at low levels of saturation even if all habitats are equivalent. Therefore, if resident Badgers die, local extinction may occur even if habitat suitable for dispersing Badgers exists because there are no Badgers to attract others to an area.

Low population densities, in turn, limit Badger reproductive capacities. In large home range areas, it is more difficult for male Badgers to find females to breed with. Badgers also may be induced ovulators requiring multiple copulations before pregnancy can occur (Wright 1963). The difficulty in finding mates and the need to copulate often may result in fewer successful pregnancies and lower productivity of females. If Badgers are food-limited, then fecundity and survival of young may also be affected. These statements are, however, speculation because the effect of food availability on Badger reproduction is not well understood.

5. CRITICAL GAPS IN KNOWLEDGE

Although a strong association between Badgers and their prey is commonly cited, we are far from understanding this relationship. Many gaps were originally outlined in the report, *Status of the Badger in British Columbia* (Rahme et al. 1995). Since that report, some questions have been at least partially addressed with subsequent research (Apps et al. 2002; Weir et al. 2003). Most of the research was directed at the autecology of Badgers since the species was poorly understood at its northern extent. Subsequently, more questions have been raised with respect to Badger diet and their prey (Adams et al. 2003).

1. Diet information from across British Columbia
Diets of Badgers vary regionally, but this trend has not been fully explored. This is especially important for areas where Columbian Ground Squirrels and pocket gophers are not common. For example, in the Cariboo where ground squirrels are not as abundant as in other parts of B.C., Badgers may be substituting Muskrats for the primary food source (Roger Packham, pers. comm.), but this has not been observed elsewhere in the province.

The difference in diets between season, age classes, and sex has not been addressed in the province. This likely is due to the lack of samples and the ability of researchers to distinguish the animal that produced a particular scat sample. Prey availability may be limited during the winter months, and Badgers may depend for food more on hibernating ground squirrels and caches. However, other prey such as pocket gophers and voles that are active may be used when the ground is too frozen to be excavated. Females may also have special dietary requirements, especially when energetic demands peak during lactation. Finally, juvenile Badgers may depend on different prey and have higher energy requirements than adults. Juveniles are reported to eat more arthropods and birds, possibly because these are easier to capture than other species (Messick and Hornocker 1981). Therefore, there may be unique prey requirements for juvenile Badgers.

2. Baseline prey ecology and response to habitat disturbance
The relative availability of prey species in different habitat types and at different levels of disturbance should be established. Many species are known to increase after certain disturbances (e.g., ground squirrels, marmots, pocket gophers), and others may decline (e.g., voles, Muskrats). Local information could be used to develop methodologies to inventory population and establish benchmarks for prey species, and to improve management of grassland and open ecosystems.

The effects of rodenticides may lead to losses of prey, but the extent and frequency of these practices are not well documented. Rodent-control programs may also affect Badgers that ingest bait or poisoned prey. However, in a review of the effects of rodenticides on mammalian carnivores, Hegdal et al. (1981) found that secondary poisoning of Badgers by 1080 (sodium monofluoroacetate), strychnine, anticoagulants, and zinc phosphide caused limited mortality of Badgers.

3. The relationship between Badger abundance and prey availability
The influence of prey on Badgers is documented in the literature (Minta 1993), but poorly understood in British Columbia. The range extensions of many prey species may be attracting Badgers to non-grassland habitats, and could influence the distribution of Badgers in the province. Also, the availability and the dispersion of prey across the landscape may contribute to the large home ranges that Badgers use in B.C. (Newhouse and Kinley 2001; Adams et al. 2003; Weir et al. 2003). This, in turn, may influence the ability of males to find estrous females, and may limit the productivity of the population. Finally, the relationship between food resources and pregnancy success may affect local population densities.

6. SUGGESTIONS FOR FUTURE RESEARCH

1. How do the diets of Badgers vary in British Columbia?
The diet of Badgers has been reported only in the East Kootenay and the Thompson regions. Diet samples should be collected from other parts of the province to be analyzed to identify other food sources particularly where ground squirrels and pocket gophers do not

occur. Nondestructive techniques for collecting scat from burrows should be developed, especially to differentiate Badger scat from other species that may be deposited outside of burrows (e.g., fox, Coyote). Gastrointestinal tracts from all Badger mortalities should be included in these analyses. These samples should be analyzed in a standardized manner where both the hair and bones are identified to corroborate results. Data should be synthesized to identify diets across the province and how diets vary seasonally, by age and sex, to direct conservation goals for prey.

2. What limits or regulates prey populations in British Columbia?

Although most rodent species have been extensively researched, more localized information should be collected with respect to historic, current, and future prey population trends. This includes increased knowledge about what regulates ground squirrel populations, as well as other prey populations locally. A better understanding of the variation in prey populations with respect to cycles, disease, colony establishment, and abandonment, and how these affect colony persistence, would allow for better management approaches to maintain prey populations across the landscape. Also, the effects of rodent control programs on Badgers is not clear, but has been suggested to play a role in the decline of Badger populations in British Columbia (Adams et al. 2003).

3. What role does prey availability play in Badgers' use of non-grassland habitats?

Badgers are known to use non-grassland habitat in B.C., but this is rarely recorded in other research. Badgers may be attracted to prey in these areas, and this may serve to expand the distribution of Badgers and increase the amount and quality of habitat. Human disturbance (e.g., logging, seeding, and road construction and management) may play a role in the use of these areas. This could include the responses of prey populations to disturbance and restoration after grazing, road management, and forestry activities. For example, what effect does seeding forest openings for range have on the abundance and composition of small mammals found after the treatment? Monitoring of pre- and post-treatment conditions and population densities of relevant ecosystem restoration plans would help to determine the duration of population responses and the effects of succession.

4. What is the relationship between prey availability, Badger spatial ecology, and productivity of populations?

This is a broad question but may be the most important to address if conservation efforts are to be successful. Prey may play a role in the size of Badger home ranges found in B.C., but this may be compounded by the lack of females in some areas (Weir et al. 2003). Large home ranges may decrease the abundance of Badgers directly by increasing the mortality rate of Badgers on highways, by restricting the number of successful breedings in a low-density population, and by limiting the colonization rate of vacant habitat by dispersing individuals that may be attracted to conspecifics. Finally, if prey availability is in fact limiting, this may affect the reproduction of females and the survival of juvenile Badgers. The relative fitness of the population should be studied, including the number of successfully breeding females and juvenile survivorship.

7. MANAGING FOR PREY

Badger populations in the province would benefit from measures that ensure adequate prey populations, and that protect or enhance prey habitats. Much of the grassland habitat in B.C. occurs on private lands or publicly used rangelands; therefore, conscientious management is critical to maintaining adequate prey populations. This is especially true because many of the species that Badgers prey on are considered agricultural pests, and extermination of many species is still common.

Targets should be set for managing prey densities for Badgers. Carbone and Gittleman (2002) reported that 10,000 kg of prey biomass supports approximately 90 kg of a given carnivore. They suggested that 10,000 kg of prey would support approximately 32 Red Foxes (*Vulpes vulpes*), 12 Coyotes (*Canis latrans*), or 10 Bobcats (*Lynx rufus*). Following this logic, it would require approximately 1000 kg of prey to maintain a Badger with an average mass of 10 kg. This can translate into the area a Badger would need to sustain itself based on prey density in different habitats (Table 3). Depending on prey present in an area, these figures give some density targets to strive for. This scaling also can be engineered to identify if Badgers are declining due to prey loss (Carbone and Gittleman 2002).

Table 3. Average prey masses and densities (taken from Table 2) used to estimate the area needed to support a 10 kg Badger with 1000 kg of prey biomass.

	Average prey mass (kg)	Average prey density (per ha)	Prey mass (per ha)	# ha = 1000 kg prey biomass
Columbian Ground Squirrels	0.503	33	16.6	60
Yellow-bellied Marmots	3.350	patchy		(298 marmots)
Northern Pocket Gophers	0.122	10	1.2	833
Muskrats	1.250	62	77.5	13
Red-backed Voles	0.015	11	0.2	5000
Meadow Voles	0.039	74	2.9	345

It may be important to maintain habitat for a diversity of small mammal prey for predators. Badgers will switch prey as one species becomes less available (Messick and Hornocker 1981). If there is no other prey to access, then animals may be faced with leaving their home ranges and emigrating over long distances (e.g., Ward and Krebs 1985). For example, conditions that benefit ground squirrels do not always allow sufficient vegetative coverage for other species, especially voles. Therefore, if areas were managed for a diversity of species, that is, a range of successional stages in various habitats, then Badgers would be able to access alternative food sources.

Disturbance may decrease or increase prey populations by affecting habitat quality, food availability, and reproductive success. Some of these disturbances include livestock grazing, fire and suppression, forestry, agriculture, road construction and management, and rodent control.

The following section summarizes measures to encourage prey colonization for Badgers, offers ways to deter Badgers and their prey from using roadsides, and recommends alternatives to exterminating Badger prey species. Potential effects of these recommendations on each prey species are compiled in Table 4.

7.1 Livestock Grazing

Livestock may impact small mammal populations by removing protective cover through grazing and trampling, damaging burrows, and indirectly by changing the composition of grassland communities. These may all be influenced by the intensity and timing of livestock presence and by the extent, pattern and location of grazing. Light grazing may be beneficial for some species as the nutritive quality of plants is greater in early successional stages (Bucyanayandi and Bergeron 1990). Grazing may favour some species but it reduces the overall species richness of a community (Rosenstock 1996).

The composition of small mammal communities on grasslands is determined, in part, by the structural attributes of the habitat, in particular, the above-ground plant biomass or "cover" (Grant et al. 1982). This effect may be dependent on the type of grassland habitat. Grant et al. (1982) reported that in tallgrass habitats, reduction in cover resulted in a decrease in total small mammal biomass, increase in species diversity, and shift away from litter-dwelling species with relatively high reproductive rates (e.g., microtines) to surface-dwelling species with relatively low reproductive rates (e.g., sciurids and heteromyids). In montane grasslands dominated by *Festuca idahoensis* and *Agropyron subsecundum*, reduction in cover resulted in a decrease in both small mammal biomass and species diversity, but there was a shift to species with higher reproductive rates (e.g., cricetines). The shortgrass (*Bouteloua gracilis, Buchloe dactyloides*) grasslands were dominated by cricetines and sciurids. The bunchgrass (*Agropyron spicatum*, *Stipa comata*) grasslands were dominated by sciurids and heteromyids. There was no pronounced change in response to grazing in either the shortgrass or bunchgrass sites.

Timing of grazing is also a factor to consider. Deferred grazing systems where livestock are intentionally kept off a site until the active growing season for most grass species is over provides an opportunity for those species to gain and maintain vigour, store carbohydrates, and set seed (Holecheck et al. 1998, p. 224). This may be especially helpful in typically heavily grazed sites such as riparian zones. Skinner et al. (1996) suggested that grazing management systems that defer cattle grazing until later in the season (i.e., after July 15) are beneficial to a variety of mammal species (e.g., Prairie Shrews, Richardson's Ground Squirrel, Badgers). Skinner et al. also cited that abundance and species richness of herpetofauna was greatest in deferred-grazed native grasslands and that this grazing regime increased habitat quality for songbirds that are relatively intolerant of cattle grazing (e.g., Baird's Sparrow, *Ammodramus bairdii*, and Western Meadowlark, *Sturnella neglecta*).

Although grazing may increase the overall biomass of prey on a site, the lack of effect of grazing intensity on site selection by Badgers in B.C. suggests that this may not be a major factor that affects habitat selection within a home range (Weir et al. 2003). In Idaho, Todd (1980) also looked at the effects of grazing intensity on Badger burrowing and prey and failed to detect a relationship. However, this does not necessarily suggest that grazing has no affect on habitat selection by Badgers. A relationship may exist where Badgers prefer species that increase after disturbance, or where Badgers select habitat at different scales than those studied (e.g., landscape or element scales; Weir et al. 2003).

Recommendations

Prevent overgrazing and maintain a variety of grassland structures by using rest-rotation or other appropriate grazing systems.

Maintains biodiversity and a high carrying capacity of rodents on rangeland.

- Grazing levels of less than 40% cover removal will maintain vegetation requirements for juvenile marmots (Frase and Hoffman 1980).
- Voles require 20 to 41 cm of vegetative cover and litter (Conley et al. 1976).

Defer grazing on sensitive rangeland until later in the season (after July 15).

Preserves habitat quality on grasslands and increases species richness and overall prey availability.

Maintain light grazing to ensure early successional vegetation and forb production.

Increases forage to encourage colonization of pocket gophers, ground squirrels, and Yellow-bellied Marmots. Discourages colonization of vole populations.

Create grazing exclosures to allow sites to recover from heavy grazing.

Enables small mammals to recolonize an area.

Prevent livestock congregating in riparian areas by using alternative water sources or by using mineral licks to attract livestock to other areas.

Preserves cover for vole habitat. Maintains forage for Muskrats and decreases damage to Muskrat and Badger burrows.

7.2 Prescribed Fire

Fire suppression is cited as a factor in reducing grassland habitat for Badgers (Adams et al. 2003). Fires likely have little direct effect on Badgers since animals are capable of retreating from fire or can seek refuge in underground burrows. However, Badgers may be affected by fluctuations in prey after a fire. In southwestern Idaho, wildfire reduced the abundance of small mammals in the first year after burn, and Badger burrow counts were lower on burned sites than on adjacent unburned sites (Groves and Steenhof 1988). Yensen et al. (1992) reported that Townsend's Ground Squirrel (*S. townsendii*) populations fluctuated widely on burned sites, destabilized the prey base, and potentially affected Badger populations.

Some areas may benefit from prescribed burning by increasing prey populations for Badger habitat. Species that prefer open habitats, especially Deer Mice and ground squirrels, generally recolonize after fire relatively rapidly (Ream 1981). Rahme et al. (1995) suggested that prescribed burning benefited Badgers by providing habitat for Columbian Ground Squirrels and Northern Pocket Gophers in Douglas-fir habitat types. Willner et al. (1980) suggested that fires may help to arrest marsh succession to maintain habitat for Muskrats, as long as the fire does not damage the basal parts of perennial plants.

Recommendations

Consider prescribed burning or mechanical clearing of range to limit forest ingrowth.

Increases open habitat dominated by grass and encourages rodent colonization. Burned areas may be occupied by early successional prey species (e.g., Deer Mice, ground squirrels) and later by voles as grass cover increases.

Prescribe light burning at some marsh areas, but prevent permanent vegetation damage.
Encourages production of Muskrat forage.

7.3 Forestry Activities

Prey densities may respond favourably to some forestry activities. Deer Mice in particular may be a key prey for predators after large-scale or extensive harvesting. Effects of timber harvesting on Deer Mice and Red-backed Voles are being studied in the interior of B.C. (Klenner 1997). Clearcutting and patch cuts increased the density of Deer Mice and Meadow Voles, but decreased the density of Red-backed Voles. At both sites, biomass remained high but community structures changed. Vole densities may respond to less intensive disturbance. In Wyoming, more voles were found in mesic unlogged and selectively cut forests (Campbell and Clark 1981). In Michigan, clearcut strips in conifer swamps resulted in an increase in relative abundance of Meadow Voles, and slash burning did not appear to affect population densities (Verme and Ozoga 1981). Pocket gophers often increase after logging and silvicultural site preparation activities that open tree canopies and disturb the soil (Teipner et al. 1983). Forest management may be extending the range of some prey species, attracting Badgers into areas where they were not historically recorded.

Forest management activities may cause a decline in some prey species. Decline in Red-backed Voles in northern Ontario was attributed to reduced vegetation cover, extremes in daily temperatures, and soil xerification. Logging activities were believed to affect vole populations by drying the soil contributing to the loss of ectomycorrhizal fungi for food (Maser et al. 1978). Voles became rare within 2 or 3 years after harvest due to reduction in the availability of lichens and fungi (Martell 1981).

Recommendations

Encourage cutting patterns that provide a mosaic of seral stages and maintain open areas and early seral stages. This may be particularly applicable in open forests or forests adjacent grasslands and range.
Encourages colonization of ground squirrels, pocket gophers, and voles.

- Pocket gophers and ground squirrels respond positively to activities that open forest canopy, particularly in areas dominated by forbs.
- Red-backed Voles may use logged areas where protective cover remains, but require a minimum of 2 ha before animals will inhabit an area (Allen 1983).

Maintain slash piles and coarse woody debris on cutblocks.
Provides habitat for marmots and Deer Mice.

Seed rangeland (clearcuts, fields, etc.) with a grass/legume mix of natural species.
Encourages colonization of most prey species by increasing forage available, and also increases forage for livestock and prevents further ingrowth of trees.

7.4 Agricultural Activities

Agricultural fields generally provide habitat for prey. There are plenty of grains and forbs for forage and cover, and soils are disturbed and easily dug and could support high densities of ground squirrels, marmots, and voles. Ditching for irrigation also may provide habitat for Muskrats (Willner et al. 1980). Yet, many species are negatively affected by routine agricultural activities. Populations of Common Voles (*M. arvalis*) declined after cover was removed by crop harvesting, mowing, and livestock grazing (Jacob and Hempel 2003). Application of herbicides to reduce forbs may lead to declines in species that prefer forbs, such as ground squirrels and Northern Pocket Gophers, but may also cause secondary effects in Badgers that ingest contaminated prey.

Recommendations

Rotate fields that are tilled, ploughed, or irrigated to maintain some areas with no disturbance.
Encourages colonization of small mammals and may prevent commercial crops from being infested. Fields of hay, alfalfa, or grain will have higher habitat value for small mammals.

Avoid using herbicides to reduce weed growth.
Decreases forage available to forb-eating species such as ground squirrels, marmots, and pocket gophers, and may have a secondary poisoning effect on Badgers.

Plan irrigation ditching at periphery of fields.

Encourages Muskrat colonization away from agricultural activities that may damage burrows and limits Muskrat activity in fields.

7.5 Road Construction and Management

Management practices can influence the availability and species composition near roads to deter Badgers. Reducing the attractiveness of roadsides may assist in reducing Badger road mortality. The relative abundance and richness of small mammal species tends to be higher in unmown road right-of-ways (Adams 1984; Meunier et al. 1999). Mowing practices may reduce the number of small mammals. In fact, mown median rights-of-way had very low small mammal density (0.5 captures per 100 trap nights), and half the density that was found in unmown herbaceous median strips (Adams 1984). Also, the practice of seeding banks to stabilize disturbed soil along roadsides can be replaced with other methods that would make these sites less desirable to small mammals. For example, landscaping these sites with shrubbery or placing large rock (rip-rap) along these banks would reduce the forage for small mammals, and make these banks less favourable to Badgers for digging burrows.

Recommendations

Mow roadside rights-of-way, especially those seeded with grass.

Discourages small mammals from taking refuge in these areas by reducing forage and cover.

Use alternatives to seeding for bank stabilization, such as rip-rap or shrubbery.

Deters Badgers and prey species from burrowing near roadsides.

7.6 Alternative Rodent Control

Extermination of rodents using rodenticides and kill-trapping has been a common practice on many managed lands. Badgers are an effective and natural form of rodent control, but in some cases this is not a viable option. There are many alternative methods to prevent colonization of problem animals and reduce the damage of rodents while preventing secondary poisoning and maintaining prey for predators.

Recommendations

Leave small slash piles on newly cleared land.

Attracts marmots and ground squirrels to burrow near piled wood and reduces holes in fields.

Place tarpaper or metal collars around newly established seedlings.

Decreases the damage from voles girdling trees.

Scatter used cat litter on and in pocket gopher mounds.

Deters tunnelling and mound construction by pocket gophers.

Remove protective cover by mowing grass and removing litter and brush piles in orchards, vineyards, etc.

Reduces the attractiveness of habitat for voles.

Maintain healthy range and pasture conditions.

Reduces the early successional food sources that attract pests such as ground squirrels, marmots, and pocket gophers.

Manipulate water levels in agricultural ditches.

Increased water levels (>0.6 m) can disturb Muskrats and encourages animals to temporarily abandon their burrows. Low water levels (<1.2 m) during the winter may prevent Muskrats from accessing burrows.

8. CONCLUSION

Badger populations in British Columbia are decreasing to critical levels, mostly due to human influences in habitat loss and prey declines. The loss of prey is considered to be one of the primary factors limiting Badger populations in British Columbia (Newhouse and Kinley 2000). However, the information necessary to address this problem is lacking. The National Recovery Strategy for the American Badger, *jeffersonii* subspecies, lists "ensuring the Badger food supply" as one of its main short-term recovery objectives (Adams et al. 2003). This requires a multifaceted approach. The first step is to compile existing information on the ecology of Badgers and their prey. The second step is to identify the cause behind the loss of prey in the province. Finally, measures must be put in place to mitigate these losses through changes in management practices.

The purpose of this report is to synthesize existing information on the ecology of six species of prey.

Table 4. Effects of human disturbances and corresponding responses of prey in British Columbia.

Prey species	Livestock Grazing	Fire and Suppression	Forestry Activities	Agricultural Activities	Road Construction and Management	Alternative Rodent Control
General Response	Favours some species but may reduce richness	Increases some prey; suppression reduces grassland habitat	Creates open habitat for most species but may be temporary	May reduce species richness but favours some species	Encourages range expansion; attracts Badgers to roadsides	Poisoning may result in loss of prey, or poor health for Badgers
Columbian Ground Squirrel	Light grazing encourages forage quality and provides food to support larger populations	Encourages colonization, increases forage	Encourages colonization, increases forage	Supports highest population densities	–	Healthy range condition discourages colonization
Yellow-bellied Marmots	Moderate levels may encourage forage growth	Encourages colonization, increases forage	Creates open habitat, slash piles	Old fields and pastures support high population densities	Encourages range expansion	Retain small slash piles to attract marmot colonies to localized sites
Northern Pocket Gophers	Encourages range expansion	Increase after fire	Increase after harvesting and silvicultural site preparation	Treatment with herbicide reduces forbs, populations decline	Encourages range expansion	Healthy range condition discourages colonization
Muskrats	May reduce food sources, trampling damages runs	Burning promotes food growth	–	Ditching for irrigation creates habitat	–	Manipulate water levels to temporarily displace animals
Southern Red-backed Voles	May reduce litter, protective cover	Avoid sites after stand-replacing fires	Initially increase in selective cuts, decline after loss of food	Avoid unforested sites	Attracted to unmown roadsides adjacent to fields or in urban areas	Remove grass, litter, brush to eliminate cover habitat; collar newly established seedlings to prevent girdling
Meadow Voles	May reduce litter, protective cover	May avoid sites after stand-replacing fires	Increase after opening canopy	Supports high densities, attracted to cover and food sources	Encourages range expansion	

Columbian Ground Squirrels are common in diets of Badgers across the province and are reliably found in colonies. Badgers are specialized for digging fossorial prey, but ground squirrels may not be available during the winter while they are estivating up to 2 m below the surface. Marmots are less common in diets and may be more scattered across the landscape. Pocket gophers are found only south of the Thompson River, but are more evenly dispersed than ground squirrels, are active in the winter months, and do not burrow as deeply (up to 40 cm). Muskrats may be a particularly important prey species in the Cariboo where ground squirrels are not common. The burrowing habits and high reproductive rates of Muskrats make this species readily available to Badgers. In that region, riparian habitat within grasslands may be particularly important. Voles are common and abundant especially during population booms. Voles may play an important role when other larger prey are not available, or for juvenile Badgers with less developed predatory abilities.

The availability of prey can affect the distribution, survival, abundance, and productivity of Badgers. Most of these species respond favourably to disturbances and have been known to expand their ranges as a result. The distribution of prey, in turn, affects the range of Badgers and especially their use of non-grassland habitats such as clearcuts. Survival of Badgers may not be directly linked to lack of food since evidence of starvation is rare. Low prey availability, however, may lead to larger home range sizes, longer distance movements, and an increased risk of mortality especially on roads. Large home range sizes also may be leading to lower productivity of females by restricting breeding, and ultimately limiting the abundance of Badgers in the province. This relationship is still speculative. Future research should identify the important prey species for Badgers locally, the influence these have on regulating populations, and the response of prey to disturbance and the role that this plays in use of non-grassland habitats by Badgers.

Management techniques can encourage the colonization of prey. Voles, for example, do not thrive after most disturbances because they require sufficient grass and litter cover. Muskrats may respond to low-levels of disturbance that maintain emergent forage in riparian sites. Species diversity tends to decrease after disturbance; however, some species respond favourably to disturbance such as ground squirrels, marmots, pocket gophers, and mice. Unfortunately, many of these species also are seen as pests and there are many forms of rodent control used to exterminate them. There are alternatives to using rodenticides that may have secondary effects on Badgers. With responsible management and by encouraging managers to view Badgers and other predators as effective controls for many rodents, a sustainable prey base for Badgers in B.C. can be maintained.

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