POTENTIAL EFFECTS OF PESTICIDE APPLICATIONS ON PREBLE'S MEADOW JUMPING MOUSE (*Zapus hudsonius preblei*) AND MOUNTAIN PLOVER (*Charadrius montanus*) IN SOUTHEAST WYOMING

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INTRODUCTION

Grasshoppers are a native component of rangeland in western North America, and their high protein content makes them a valuable food resource for free-ranging mammals, birds, and other vertebrates. Certain weather conditions and other environmental factors often interact to cause dramatic grasshopper irruptions. Such irruptions are natural phenomena in the sense that they have likely occurred throughout the evolution of modern grasslands and exert substantial selective forces shaping the adaptations and life histories of grassland biota. From an economic perspective, grasshopper irruptions can cause major damage to rangeland vegetation and croplands (McEwen 1982, Johnson et al. 1996). Once grasshopper populations reach certain densities, lethal control may be deemed necessary to protect the agricultural economy of a region.

Since the 1930s the USDA-Animal and Plant Health Inspection Service (APHIS) has had the responsibility of managing grasshoppers on federal rangeland. Their cooperative control programs for rangeland grasshoppers are undertaken almost every year in affected parts of the west. Controlling rangeland grasshopper irruptions via insecticide has occurred in eastern Wyoming for at least 45 years (S. Schell, personal communication). Much of this has occurred on land surface managed by the USDI Bureau of Land Management (hereafter BLM), primarily in the Casper Field Office Region.

The highly toxic compounds used before the mid-1960s were effective against grasshoppers but caused unintended damage to rangeland ecosystems, primarily by killing nontarget organisms. Those chemicals were replaced with compounds that break down more rapidly, have fewer environmental risks, and are less toxic to nontarget taxa (McEwen 1982, Stromborg et al. 1984). However, there is still concern about the possible side effects of modern insecticides on rangeland ecosystems (Fair et al. 1995, McEwen 2001, Foster 2001, Johnson et al. 1996; see also Martin et al. 1998, 2000).

Preble's meadow jumping mouse (*Zapus hudsonius preble*; hereafter Preble's) and mountain plover (*Charadrius montanus*) are 2 vertebrates of management concern that occupy rangelands subjected to grasshopper control treatments in Wyoming. Both species are rare, and both are thought to have suffered substantial declines in both numbers and distribution over the past several decades (e.g., U.S. Fish and Wildlife Service 2002a, Knopf 1996). Preble's was listed as Threatened under the U.S. Endangered Species Act in 1998 (U.S. Fish and Wildlife

Service 1998), and the mountain plover will probably receive a similar listing under the Act within the next 2 years (U.S. Fish and Wildlife Service 2002b). The habitats of these 2 vertebrates will continue to be treated with insecticides as grasshopper irruptions occur in the future.

Because of the high degree of management concern afforded to both Preble's and mountain plover, and because of the importance and imminence of continued grasshopper control, it is necessary to explore the potential for negative effects of insecticide application on these 2 vertebrates. To this end the BLM Wyoming State Office established a research project (Task Order 17 tiered to Cooperative Agreement KAA010012) with the Wyoming Natural Diversity Database at the University of Wyoming to review the available literature concerning the possible effects of grasshopper pesticide application on Preble's and mountain plover in Wyoming. The results of that review make up this report.

STUDY AREA

The study area consists of all Wyoming BLM lands within Platte and Goshen counties and those parts of Converse and Natrona counties south of Interstate Highway 25 and north of the drainage divide of the Laramie Mountains. This is a diverse landscape supporting conifer (e.g., *Pinus contorta, Pinus ponderosa*) forests and woodlands at higher elevations, shrub-dominated (e.g., *Artemesia tridentata*, *Cercocarpus montanus*) vegetation on lower mountain slopes and escarpments, and true grasslands at the lowest elevations. Riparian areas embedded within these upland zones change similarly with elevation; conifer and aspen (*Populus tremuloides*) dominance at higher elevations gives way to cottonwood (*P. angustifolia*, *P. deltoides*) and herbaceous communities at lower elevations. Willows (*Salix* spp.) are common in riparian zones throughout the study area, with particular species preferring different combinations of elevation and soil type.

The low elevation grasslands are the primary focus of grasshopper control treatments. Livestock grazing is pervasive on almost all grasslands within this area, and is the primary economic use of dry uplands here. Floodplains, irrigated meadows, and riparian zones are also commonly used for hay and crop production.

HISTORY OF GRASSHOPPER CONTROL IN THE REGION

Grasshopper irruptions are a regular occurrence in eastern Wyoming. In the late 1940s and early 1950s, chlorinated hydrocarbons, or organochlorines, were developed and used successfully against these irruptions (S. Schell, personal communication). These fast-acting, long-residual compounds were applied aerially as liquid sprays or baits (Foster 2001). At least chlordane, toxaphene, aldrin, endrin, and dieldrin were used in the early 1960s in Wyoming in large-scale APHIS control projects (J. Lockwood, personal communication).

However, it soon became apparent that the longevity of these compounds allowed residues to accumulate in the environment, wildlife, and human food. Non-target organisms were often poisoned and killed; for example, chlordane and toxaphene caused direct mortality to sage grouse (*Centrocercus urophasianus*), sharp-tailed grouse (*Pedioecetes phasianellus*), and ring-necked pheasants (*Phasianus colchicus*) in Wyoming (Post 1951, as cited in Johnson 1987). Because of these problems, in 1962 organochlorines were withdrawn from use in large-scale APHIS control projects (Foster 2001, McEwen 1982).

Organochlorines were replaced with organophosphates, insecticides that are less persistent in the environment and less harmful to nontarget organisms. One of these, a form of carbaryl known as Sevin 80 S (trademarked name; such names are not specifically indicated in this report) spray, was introduced in 1962, but delivered less grasshopper lethality and reliability than was desired. Furthermore, it often caused trouble with aerial spray equipment. By 1972 carbaryl spray had been greatly improved with the Sevin-4-Oil formulation. This petroleum oil-based insecticide became a standard treatment in rangeland grasshopper programs elsewhere (Foster 2001), but was rarely used in Wyoming. Instead, aerial application of Sevin XLR Plus, a water-based emulsifiable concentrate formulation, was used more often. Sevin XLR Plus continues to be favored over the oil formulation in Wyoming. Carbaryl in the form of carbaryl bran bait was also sprayed aerially in Wyoming, but its use was limited because existing spray equipment could not efficiently handle the large volumes of bait required (J. Lockwood, personal communication).

Widespread use of the organophosphate malathion was made possible by the development in the early 1960s of ultralow volume (ULV) aerial spray application, defined as less than 0.5 gal/ acre (Maas 1971). By 1964, and continuing through the 1980s, Malathion ULV Concentrate was the most commonly used spray for grasshopper control in all states in cooperative rangeland programs (Foster 2001). Malathion has been the pesticide most often used in Wyoming's grasshopper control programs during the past 20 years. Up until the last 5 years, about 90% of Wyoming's cooperative control programs used ULV malathion (J. Lockwood, personal communication).

A pathogen, *Nosema locustae*, has been studied as a microbial biological control agent of grasshoppers since the 1960s. It was tested in Wyoming in the late 1980s and early1990s, but was considered a failure by some researchers because of its inconsistent effects on grasshoppers (Streett 2001) and because it was expensive, slow-acting, and inefficient (J. Lockwood, personal communication).

CURRENT AND POTENTIAL FUTURE EFFORTS AT INSECT CONTROL IN THE REGION

Current compounds used and application techniques

Carbaryl - Carbaryl is a broad-spectrum carbamate insecticide with the chemical name of 1-naphthyl N-methylcarbamate. It was developed by Union Carbide in 1956 and is registered for control of many species of insects on rangelands, forests, pastures, agricultural sites, poultry sheds, horses, dogs, cats, and landscape and indoor plants (Foster and Onsager 2001a).

Carbaryl's acute oral LD_{50} of 270 mg/ kg of body weight for rats shows it to be moderately toxic to mammals (USDA 2002). Carbaryl is slightly toxic to birds and moderately toxic to fish, but extremely toxic to aquatic invertebrates and many insects, including bees and all species of grasshoppers. Grasshoppers are killed through both contact and ingestion, with ingestion causing most of the mortality (Lloyd et al. 1974).

Carbaryl is relatively short-lived in the environment. Its residual activity against grasshoppers lasts 14 - 21 days. Carbaryl performs best at temperatures in the 60° - 80° F range, killing more slowly at lower temperatures (Foster and Onsager 2001a). Depending on conditions, grasshopper mortality during the first 2 days after treatment may range from 30 - 80%. Under especially good application conditions, mortality may reach 90% (Foster and Onsager 2001b).

Carbaryl is used by APHIS-managed cooperative grasshopper control programs in Wyoming most often in the water-based Sevin XLR Plus formulation. For controlling grasshoppers on rangeland, it is typically sprayed aerially at 16 fluid oz (0.50 lb of active ingredient)/ acre. Reduced Agent Area Treatments (RAATs), in which sprayed swaths of rangeland are alternated with unsprayed swaths, uses 8 fluid oz (0.25 lbs of active ingredient)/ acre (USDA 2002). This system has been shown to reduce the amount of chemical used, reduce costs, and conserve nontarget organisms (Lockwood and Schell 1997). When carbaryl bait is used, it is at the conventional rate of 10 lbs (0.50 lb of active ingredient) of 5% carbaryl bait/ acre, or at the RAATs rate of 10 lbs (0.20 lb of active ingredient) of 2% carbaryl bait/ acre (USDA 2002).

Malathion - Malathion, an organophosphate which is the 0,0-dimethyl phosphorodithioate ester of diethyl mercaptosuccinate, was developed by American Cyanamid in 1950. This broad-spectrum insecticide-acaricide is registered for control of a wide variety of insects on crops, forests, rangelands, pastures, agricultural sites, farm animals, stored grains, and in homes and gardens.

Malathion's acute oral LD_{50} of 1,375 mg/ kg of body weight for rats indicates it is very slightly to moderately toxic to mammals (Foster and Onsager 2001a). The compound shows slight to moderate toxicity to birds and is highly toxic to fish and aquatic invertebrates (McEwen 1971). It is highly toxic to most insects, including bees and all grasshopper species. Malathion kills through both direct contact and ingestion, although ingestion causes most of the mortality (Pfadt et al. 1970).

Malathion is less persistent in soil, water, plants, and animals than organochlorine pesticides. Malathion is quick acting, usually producing high levels of control during the first and second days after application. Residual control against grasshoppers can be seen for 2 - 5 days after treatment. Malathion works best when the air is dry, the expected daytime high temperature is >80° F, and no rain is expected. With especially good application conditions, control can range from 92 - 96% (Foster and Onsager 2001b).

There are several formulations of malathion; only Cythion ULV, Fyfanon ULV, and Malathion ULV Concentrate have been used in APHIS managed cooperative programs. The typical conventional spray rate is 8 fluid oz (0.62 lb)/ acre; the RAATs rate is 4 fluid oz (0.31 lb)/ acre (USDA 2002).

Diflubenzuron - Diflubenzuron (1-(4-chlorophenyl)-3-(2,6 difluorobenzoyl)-urea) is an insect growth regulator. It works differently than most broad-spectrum insecticides, interfering with the synthesis and deposition of chitin, the chemical responsible for hardening an insect's exoskeleton during molting. This interruption of the molting process can lead to the death of the insect (Foster and Reuter 2001). Diflubenzuron is effective against immature stages of several insect pests including crop and forest pests, mosquito larvae, and grasshopper larvae. It can also kill eggs and newly-hatched larvae (USDA 2002).

Diflubenzuron has been shown to be practically nontoxic to mammals, wild birds, and fish. The acute LD_{50} for diflubenzuron for deer mice is 4,640 mg/ kg of body weight, indicating a slight to very slight toxicity to mammals. While it is considered to have fewer side effects to nontarget species and to the environment, it does affect organisms that contain chitin and are still undergoing molting processes (Catangui et al. 2001). Therefore it is highly toxic to immature insects and to larval stages of aquatic arthropods (USDA 2002).

Diflubenzuron binds quickly to the soil and thus has low mobility (J. Lockwood, personal communication). It persists only a few days in water. Because it is effective against immature insects, diflubenzuron can be used earlier in the treatment season than either malathion or carbaryl (USDA 2002).

Dimilin, a brand of diflubenzuron, has been registered for use on grasshoppers since the spring of 2001 and is now part of the APHIS grasshopper control program (J. Lockwood, personal communication). It is available as a suspension concentrate, wettable powder, or as granules. The conventional ULV spray rate is 1 fluid oz (0.016 lb of active ingredient)/ acre, while the RAATs strategy uses 0.75 fluid oz (0.012 lb of active ingredient)/ acre (USDA 2002).

Future use

Carbaryl, malathion, and diflubenzuron are the 3 insecticides currently approved by APHIS for grasshopper suppression on rangeland. The use of Sevin XLR Plus carbaryl spray for grasshopper control has been successful in Wyoming and its use is expected to increase. Similarly, malathion has provided successful grasshopper control and will continue to play a large part in cooperative control programs in the future. Because malathion is sensitive to high temperatures and evaporation, an encapsulated form is being tested which should resist heat and have a longer residual in the field. Diflubenzuron has performed well during its 2 seasons of use in Wyoming and is expected to be used on a much larger scale in the future (USDA 2002, J. Lockwood, personal communication).

One strain of the fungus, *Beauveria bassiana*, has proven virulent to some species of grasshoppers. A commercial product was registered by the Environmental Protection Agency against rangeland grasshoppers in 1995, and technology has been developed for mass production of the agent. Some researchers expect *B. bassiana* to become competitive with current chemical insecticides and be very useful in future grasshopper integrated pest management programs (Hostetter and Streett 2001). However, at this time, the use of *B. bassiana* is prohibitively expensive (J. Lockwood, personal communication).

POTENTIAL NEGATIVE EFFECTS OF GRASSHOPPER CONTROL EFFORTS ON PREBLE'S MEADOW JUMPING MOUSE

Meadow jumping mouse ecology

General - Preble's is considered a distinct subspecies of meadow jumping mouse that diverged from other forms via geographic isolation following the Pleistocene - Holocene transition. During this transition the climate in the Rocky Mountains warmed and dried, causing the range of meadow jumping mice to contract to the north and east of Wyoming as the species tracked cooler and moister conditions. However, a pocket of suitably mesic habitat remained at the foot of the Rocky Mountain Front Range. Meadow jumping mice persisted here and eventually were described as Preble's by Krutzsch (1954; see also Jones 1981, Hafner et al. 1981, Morrison 1992).

Preble's strongly prefers heavy vegetation immediately adjacent to flowing streams. Individuals will make brief forays into dry uplands, but spend about 90% of their time in riparian corridors. Irrigation ditches, flooded hay meadows, wetlands, and ponds with heavily vegetated borders may also be occupied (U.S. Fish and Wildlife Service 1998, 2002a).

In Wyoming, Preble's are thought to occupy riparian areas in the South Platte and lower North Platte river basins. This includes Platte, western Laramie, southern Converse, and northern and eastern Albany counties (Figure 1). Trapping efforts in Goshen County have failed to record Preble's; this area, along with eastern Laramie County, may be too warm and dry to support the taxon (Beauvais 2001, Keinath 2001). To the north, Preble's range is probably bounded by the arid drainage divide separating the North Platte basin from the Niobrara, Cheyenne, and Powder river basins.

The western boundary of Preble's range is still in question. Surveys performed in summers 2000 and 2002 documented *Zapus* spp. along the Little Laramie and Laramie rivers in central and south-central Albany County (Wyoming Natural Diversity Database - University of Wyoming, unpublished data). These specimens are currently being analyzed for specific and subspecific identity. Also, there is no apparent ecological barrier between currently presumed Preble's range and Natrona County, and northern and eastern Carbon County.

Ecological overlap with insects - Like most rodents, meadow jumping mice are thought to feed primarily on seeds and vegetation, with only occasional and opportunistic predation on insects (Whitaker 1972). However, the relative rarity of insects in Preble's diet may not directly reflect their importance. Insects are high-quality packages of food, with especially high contents of fat and protein, and as such may be crucial supplements to rodent diets. When nutritional demands in general, and protein demands in particular, are unusually high (i.e., gestation, lactation, juvenile growth), insects may be rare but extremely important food items.

Temporal overlap with insect control efforts - Preble's are active from mid May - mid October, and hibernate for the remainder of the year. Like most rodents of this size, Preble's are active mostly at night, and occupy nest-like structures during most of the day. These nests range in form from simple piles of vegetation on the ground surface to sub-surface burrows (Whitaker 1972, U.S. Fish and Wildlife Service 2002a).

Spatial overlap with insect control efforts - As stated above, the distribution of Preble's is strongly tied to riparian features, and they are only rarely found far from surface water. Present USDA (2002) guidelines state that liquid ULV sprays should not be applied within 500 ft (152 m) of aquatic habitats (e.g., reservoirs, lakes, ponds, seasonal pools, springs, streams, rivers, swamps, bogs, marshes, and potholes) or where leaching or surface runoff is likely, or when precipitation seems imminent. There is unresolved discussion about the precise definition of wetlands in this context, and whether or not dry intermittent creek beds, wet meadows, and seasonally dry potholes qualify under the definition. The motivation for restricting spraying around riparian features is primarily to avoid killing aquatic organisms, which are extremely sensitive to modern grasshopper control chemicals; even low-level exposure is lethal to certain aquatic invertebrates (Beyers et al. 1995). Such restrictions will also obviously help protect terrestrial species occupying riparian margins, like Preble's, from exposure.

Potential for intoxication

Organochlorine pesticides formerly used for range grasshopper control (e.g., dieldrin, chlordane, toxaphene) caused mortality of nontarget wildlife by direct toxicity, but modern grasshopper control chemicals usually do not kill wildlife by such a direct mode (McEwen et al. 2001a). While lethal exposure of Preble's to modern grasshopper insecticides is unlikely, sublethal exposure is highly probable for almost all wildlife in sprayed rangeland. Sublethal exposure may be dermal from being directly sprayed or by moving through sprayed vegetation, ingestion in food or drinking water, and inhalation.

In general, the effects of sublethal exposure can range from insignificant to convulsions and near death followed by recovery. The sublethal effects of carbaryl and malathion take the form of acetylcholinesterase (AChE) inhibition. In vertebrates, AChE is an enzyme necessary for the normal functioning of the nervous system. Moderately severe inhibition (40 - 60%) affects coordination, behavior, and foraging ability, while severe inhibition (>60%) can lead to death from exposure to other stresses of the wild, such as weather or predators (McEwen et al. 2001a).

Preble's avoids significant sublethal exposure by its almost complete restriction to riparian zones that are avoided during insecticide application, and also by its relative inactivity in day-nests during insecticide application. Thus, chemicals usually have some time to dissipate before individuals emerge and are exposed (McEwen et al. 2001a). However, some degree of sublethal exposure is likely as a result of accidental spraying of riparian zones, spray drift, movement of exposed prey into riparian zones, occasional diurnal activity by Preble's, and occasional upland forays by Preble's.

In addition to minimizing major sublethal exposure by patterns of habitat use and behavior, Preble's is likely physiologically resistant to the 3 major grasshopper control chemicals. Many small mammals are inherently resistant to these chemicals (Nimmo and McEwen 1994). Carbaryl, malathion, and diflubenzuron are considered only moderately, slightly/ moderately, and very slightly/ slightly toxic to mammals, respectively (Foster and Onsager 2001a, USDA 2002). Malathion applied at the ULV application rate of 8 fluid oz/ acre resulted in no toxicity-caused mortality of mammals (Beyers et al. 1995). Similarly, McEwen (1982) observed no severe toxic symptoms in terrestrial wildlife following grasshopper control treatments using both carbaryl and malathion, and George et al. (1992) found no evidence of

AChE inhibition in the deer mouse (*Peromyscus maniculatus)* following application of carbaryl bran bait for grasshopper control. In samples of birds and mammals from areas treated with carbaryl and malathion, Fair et al. (1995) found no animals with >40% (moderately severe) brain AChE inhibition, and only a few individuals with >20% inhibition.

Habitat degradation

Although lethal and substantial nonlethal intoxication of Preble's by modern grasshopper insecticides is unlikely, the species could still be negatively affected by indirect pathways. The most obvious of these pathways is a reduction in insect prey abundance (see Johnson et al. 1996, Martin et al. 1998, 2000), which could possibly lower survival and reproduction of Preble's as nutritional resources are decreased and individuals are forced to forage more widely and often, increasing their exposure to predation.

Such habitat degradation should be expressed at the population level as decreased abundance, density, survival, or reproductive output following pesticide application. Most existing studies of other small mammal taxa have failed to document substantial population changes in response to pesticides. Malathion applied at the ULV application rate of 8 fluid oz/ acre had no short term (i.e., same season) effect on small mammal abundance (Erwin and Sharpe 1978). Limited live trapping studies on malathion-sprayed areas in North Dakota, and studies of carbaryl-sprayed areas at other locations, showed no post-treatment decreases in abundant populations, primarily deer mice (McEwen et al., unpublished data). On a Canadian prairie, deer mice populations showed little response to pesticide-induced reductions in grasshoppers (Johnson et al. 1996).

In an Appalachian forest, Seidel and Whitmore (1995) found no significant difference in estimates of white-footed mice (*P. leucopus*) density, body dimensions, weight, and fat content between diflubenzuron treated areas and untreated areas. The total amount of food consumed per individual mouse was not significantly different between treated and untreated areas; however, mice on treated areas consumed less lepidopteran prey than did mice on untreated areas, suggesting that mice in treated areas relied more heavily on alternative prey to compensate for loss of grasshoppers. Diflubenzuron affects mostly immature insects, leaving adult insects in the treatment area unharmed and available for consumption. Insects that burrow before spraying or are nocturnal would most likely not be exposed to the insecticide, and would probably become available as prey in a matter of days (USDA 2002). Seidel and Whitmore (1995) also documented a lower juvenile/ adult female ratio on their treated areas relative to their untreated areas. This was interpreted as evidence of a potential impact of diflubenzuron on mouse populations through emigration, infanticide, and reduced survival of young. These processes usually occur in response to food shortage, which was apparently not the case in this study, and the authors could not explain the lower ratios. They concluded that the application of diflubenzuron did not affect the physical condition or densities of white-footed mice.

House mice (*Mus musculus)* and deer mice are known to avoid contact with carbaryl bran bait placed in their cages (Gregory et al. 1993). Carbaryl bait did not appear to affect either species of mouse, possibly because of the avoidance of contact or because of the reversible nature of AChE inhibition induced by carbamate insecticides. This avoidance suggests the possibility of local emigration (at least temporarily) of small mammals in response to carbaryl bait application.

POTENTIAL NEGATIVE EFFECTS OF GRASSHOPPER CONTROL EFFORTS ON MOUNTAIN PLOVER

Mountain plover ecology

General - Mountain plovers are endemic to western North America where they breed only in the shortgrass prairie and adjacent shrub-steppe. Historically, the center of mountain plover breeding range extended from the western Dakotas south through western Nebraska, Kansas, and Oklahoma into northwestern Texas. As native prairie in this area was increasingly converted to human uses (primarily cultivated agriculture), the center of mountain plover breeding range shifted west into eastern Montana, Wyoming, and Colorado. These 3 areas now support the remaining breeding concentrations of mountain plovers (Knopf 1996).

In contrast to most other Charadriformes, mountain plovers avoid surface water and moist sites in favor of dry uplands. Furthermore, mountain plovers strongly prefer flat sites with low and sparse vegetation in which to place their nests. Heavily grazed sites, including prairie dog (*Cynomys ludovicanus*, *C. leucurus*) colonies, on broad flats or the tops of rims and mesas appear to be preferred nesting grounds (Knopf 1996, Beauvais and Smith 2003; see also Beauvais and Smith 1999).

Mountain plovers have been documented in almost every county in Wyoming (Figure 2). Although Wyoming formed the western periphery of historic mountain plover breeding range, it is the core of current breeding range. Substantial breeding concentrations are currently not known from Laramie, Platte, Goshen, or Converse counties, but this is likely an artifact of the relatively few surveys that have been performed in this area. It is very likely that these counties support many breeding pairs.

Ecological overlap with insects - Mountain plovers are almost entirely insectivorous for their entire lives. Like most grassland birds, large quantities of insect protein are especially crucial for juvenile growth (Knopf 1996, Johnson et al. 1996). Abundant populations of large insects are crucial for positive rates of survival and reproduction. A wide variety of terrestrial invertebrates, and winged invertebrates perched on the ground, are taken by mountain plovers. Grasshoppers are a primary food item (Knopf 1996).

Temporal overlap with insect control efforts - Mountain plovers arrive on Wyoming breeding grounds in April, and remain through late July and early August. This species is diurnal, with foraging activity increasingly concentrated towards morning and evening as daytime temperatures increase. Nests and foraging sites are relatively exposed to the elements, as mountain plovers prefer sites with low and sparse vegetation (Knopf 1996, Beauvais and Smith 1999, 2003).

Spatial overlap with insect control efforts - As stated above, mountain plovers prefer sparsely vegetated and dry uplands within grassland and shrub-dominated landscapes. In general, this distribution places them in the direct coincidence with grasshopper control treatments.

Potential for intoxication

Again, modern grasshopper pesticides usually do not kill wildlife through direct toxicity as did the organochlorines of the past (McEwen et al. 2001a), but sublethal exposure, possibly extending to AChE inhibition, of almost all vertebrates in sprayed rangeland is likely. In contrast to Preble's, mountain plover habitat use, food habits, and activity patterns do not insulate them from sublethal exposure. Indeed, because they prefer dry rangeland and are almost completely insectivorous and diurnal, mountain plovers are very likely to come into direct contact with insecticides used for grasshopper control.

Evidence from field studies suggests that mountain plovers probably suffer little intoxication from modern grasshopper control chemicals (McEwen 1982). Malathion, carbaryl, and diflubenzuron are considered only slightly/ moderately, slightly, and very slightly toxic to birds, respectively. In 1 study (Stromborg et al. 1984) surviving grasshoppers captured in rangeland that had been sprayed with 8 oz/ acre ULV malathion contained pesticide residues lower than the dietary levels required to cause effects on birds in the laboratory. In North Dakota, Beyers et al. (1995) found that malathion applied at the ULV rate of 8 fluid oz/ acre and carbaryl at the Sevin-4-Oil formulation rate of 20 fluid oz/ acre produced no toxicity-related mortality of upland birds. Similarly, Howe et al. (1996) found no direct effects of malathion on Brewer's sparrow (*Spizella breweri*) and sage thrasher (*Oreoscoptes montanus*), and Fair et al. (1995) observed no toxic signs in killdeer (*Charadrius vociferous*; a species closely related to mountain plover) after spraying rangeland with Sevin-4-Oil sprays at 16 and 20 fluid oz/ acre. This latter study also showed normal brain AChE activity at 2, 8, and 21 days after spraying, and that body lipid content (a common indicator of body condition) did not differ between killdeer from sprayed and unsprayed sites.

It is important to note that the above studies of the effects of carbaryl on birds rely on the Sevin-4-Oil formulation. No studies have focused on Sevin XLR Plus, which is a different, water-based formulation now preferred for grasshopper control in Wyoming (J. Lockwood, personal communication). Furadan, a different carbamate insecticide, significantly depressed brain AChE activity in chestnut-collared longspurs (*Calcarius ornatus*) in Canada, but this did not appear to increase mortality or ultimately reduce reproductive output (Johnson et al. 1996).

Diflubenzuron is often applied with an oil carrier, usually food-grade canola or a heavier paraffin oil. In observations of oil spills or exposures of birds to application rates higher than APHIS recommendations, paraffin oils have been shown to decrease egg hatching rates of birds. For this reason, the USDA (2002) recommends against the use of paraffin oils in some habitats with nesting birds, especially those with endangered or threatened species.

Habitat degradation

It is assumed that a significant reduction in the insect food base and subsequent increases in foraging movements would negatively affect populations of mountain plovers and other upland birds to a greater degree than small mammals. The USDA (2002) recognizes that insectivorous vertebrates will be required to increase foraging ranges following treatments, but that such increases are likely temporary as insects recolonize treated areas (see also Johnson et al. 1996, Martin et al. 1998, 2000).

On North Dakota rangeland treated with Sevin-4-Oil at 16 or 20 oz per acre, killdeer maintained adequate diets by capturing invertebrate prey at significantly higher rates than did birds on control areas at 2 and 8 days after spraying. This higher capture rate was presumably due to the increased availability of dead and dying insects (Fair et al. 1995). No other differences in food habits were detected.

A 3-year investigation (Howe et al. 1996, 2000) of indirect effects of malathion on nesting birds in Idaho involved 2 areas sprayed with the standard 8 fluid oz/ acre ULV formulation of malathion. Insect populations and survival and growth of Brewer's sparrow *(Spizella breweri)* and sage thrasher *(Oreoscoptes montanus)* were monitored following application. Although total invertebrate availability was significantly reduced, nesting birds switched their diets to remaining insects and reproduced as successfully as birds on untreated comparison plots. Although adults foraged longer on sprayed plots, and nestlings on sprayed plots showed a higher rate of infestation by parasitic blowfly *(Protocalliphora braueri),* neither effect was statistically significant. Pre-spray grasshopper densities were low (1 - 4 individuals/ m^2) on all plots, which probably made the test of food availability more rigorous than an operational grasshopper control program where pre-spray grasshopper densities are much higher, and postspray densities usually exceed even 1 - 2/ m^2.

Johnson et al (1996; see also Martin et al. 1998, 2000) carefully studied the effects of grasshopper pesticides on chestnut-collared longspurs on a Canadian prairie. They documented larger foraging ranges for adults and, predictably, a reduction in the prevalence of grasshoppers in bird diets following pesticide application. Of 4 reproductive parameters analyzed, only egg success differed significantly between sprayed and control plots; it was lower in sprayed plots in the post-spraying period.

George et al. (1995; see also George et al. 1992) monitored rangeland bird communities before and after application of Sevin-4-Oil, malathion, and carbaryl bait in both treated and untreated plots. The total number of individuals of all observed bird species did not change between pre- and post-treatment. Populations of 1 highly insectivorous species, western meadowlark *(Sturnella neglecta),* consistently decreased at 10 and 21 days post-treatment. This was presumed to be due to reduced food availability; there was no evidence of toxic signs in the remaining meadowlarks and no dead meadowlarks were found. Adams et al. (1994) found no effects of carbaryl bait application on survival, growth, and fledging rates of vesper sparrows (*Pooecetes gramineus*).

A recent study by Nicolaus and Lee (1999) suggested a formerly unrecognized effect of organophosphates on habitat quality for birds. Birds that fed on poisoned insects developed a strong aversion to those insect species and would no longer capture them for food, even after the insects were free of contamination. If this effect is strong enough, and if it extends to mountain plover and other species of rangeland birds, it could represent an important reduction in vertebrate habitat quality as a result of pesticide application.

When diflubenzuron is sprayed for grasshopper control it affects mostly immature insects, leaving adult insects in the treatment area unharmed and available for consumption. Insects that burrow before spraying or that are nocturnal most likely would not be exposed to the insecticide, and probably would become available as prey in a matter of days (USDA 2002).

CONCLUSIONS

Current information suggests that pesticide application intended for grasshopper control in eastern Wyoming has few negative effects on Preble's under current conditions and guidelines. Preble's, like most small mammals, probably has a high degree of natural resistance to pesticide intoxication. In addition, there is minimal ecological, temporal, and spatial overlap between Preble's and grasshopper control efforts. Although it is likely intended to protect sensitive aquatic organisms, the explicit avoidance of riparian areas during pesticide application helps protect Preble's from negative interactions with pesticides.

Current information suggests that pesticides used to control rangeland grasshoppers in Wyoming may have some negative effects on mountain plovers, but these effects may be minimal. Although the potential for direct intoxication appears to be low, the high degree of ecological, spatial, and temporal overlap between mountain plovers and grasshopper control efforts indicates a relatively high probability of negative indirect effects. Several field studies have documented altered feeding behaviors of upland birds following pesticide application, and although most fail to show substantial harm, some (e.g., Howe et al. 1996, 2000; George et al.

1992, 1995; Johnson et al. 1996; Nicolaus and Lee 1999) suggest at least low levels of interference with survival and reproduction**.**

It is important to note the complete lack of field research that directly addresses the effects of grasshopper control on Preble's and mountain plover in Wyoming; i.e., at this time conclusions are necessarily tentative and extrapolated from research on similar species and areas. Although this extrapolated information can inform management actions to some degree, managers would clearly benefit from research that directly addresses the physiological and population-level effects of grasshopper treatments in Wyoming on these 2 vertebrates.

In addition to such direct studies, there are several other research questions whose answers would help integrate the management of Preble's, mountain plover, and grasshopper irruptions:

--- What are the effects of the water based Sevin XLR Plus formulation of carbaryl on small mammals and upland birds? Almost all studies in the current literature focus on the effects of the Sevin-4-Oil formulation, and Sevin XLR Plus is favored for control efforts in Wyoming.

--- What density of grasshoppers provides an adequate forage base for mountain plovers? Complete grasshopper mortality is not only difficult to achieve, but also expensive and ecologically damaging (Johnson et al. 1996). Some experts suggest that only 0.5 - 15 grasshoppers/ m^2 are needed to maintain most ecosystem processes (J. Lockwood, personal communication). Mountain plovers may be able to maintain high levels of survival and reproduction at relatively low densities of grasshoppers. If such densities were known it might be possible to modulate control efforts to benefit agricultural production while maintaining habitat quality for mountain plovers.

--- What is the relative importance of invertebrate prey in the diet of Preble's? It is difficult to evaluate the effects of pesticide application on Preble's until the degree to which the taxon relies on invertebrates in general, and grasshoppers in particular, is known.

--- Can the prey-avoidance results of Nicolaus and Lee (1999) be generalized? If upland birds, including mountain plovers, avoid uncontaminated prey items following consumption of poisoned prey items, grasshopper control efforts may be reducing habitat quality over large areas.

--- Do carbaryl bran baits have fewer negative effects than sprays on birds and small mammals? Dry bait formulations use less active chemical per area and limit the route of exposure primarily to ingestion of affected insects. In contrast, liquid sprays result in multiple exposure routes (dermal, inhalation, ingestion of coated vegetation as well as insects). Baits are also easier to direct toward a target area and do not drift as much as sprays. However, some rangeland grasshoppers will not consume baits, baits generally produce lower grasshopper mortality than do sprays, and can be more costly to apply (Foster 2001). George et al. (1995) and McEwen et al. (2001a, 2001b) recommend using baits to minimize negative effects of pesticides on upland birds; however, Gregory et al. (1993) found that some small mammals may avoid baits, possibly to the extent of temporarily leaving a baited area. More studies comparing the responses of non-target organisms to sprays and baits may be warranted.

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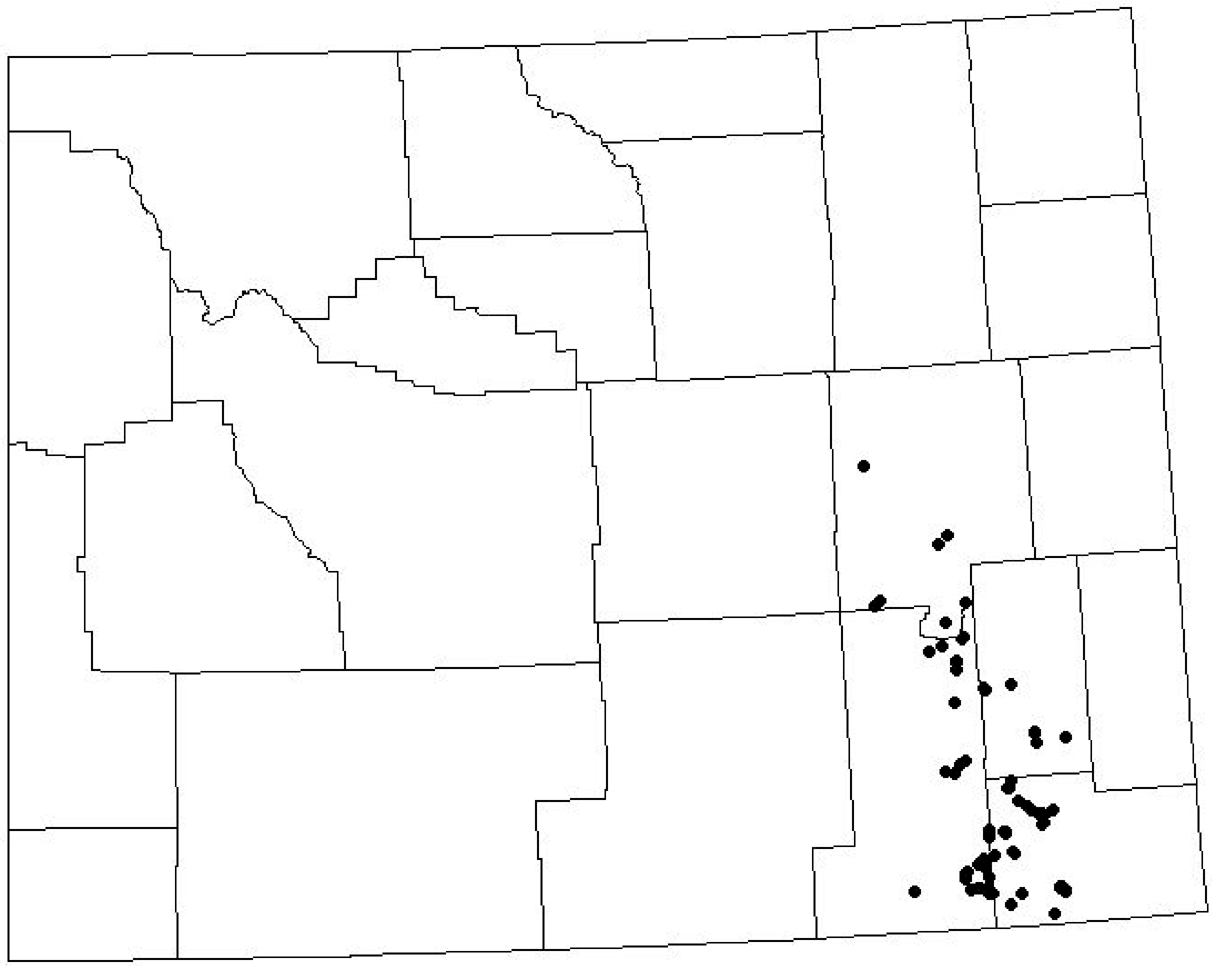

Figure 1. Suspected distribution of Preble's meadow jumping mouse (*Zapus hudsonius preblei*) in Wyoming. Black dots represent capture locations of animals suspected to be Preble's mouse; conclusive identification is currently not possible due to unresolved taxonomic uncertainty. Lines show boundaries of Wyoming counties. All data on file at the Wyoming Natural Diversity Database (University of Wyoming, Laramie, Wyoming).

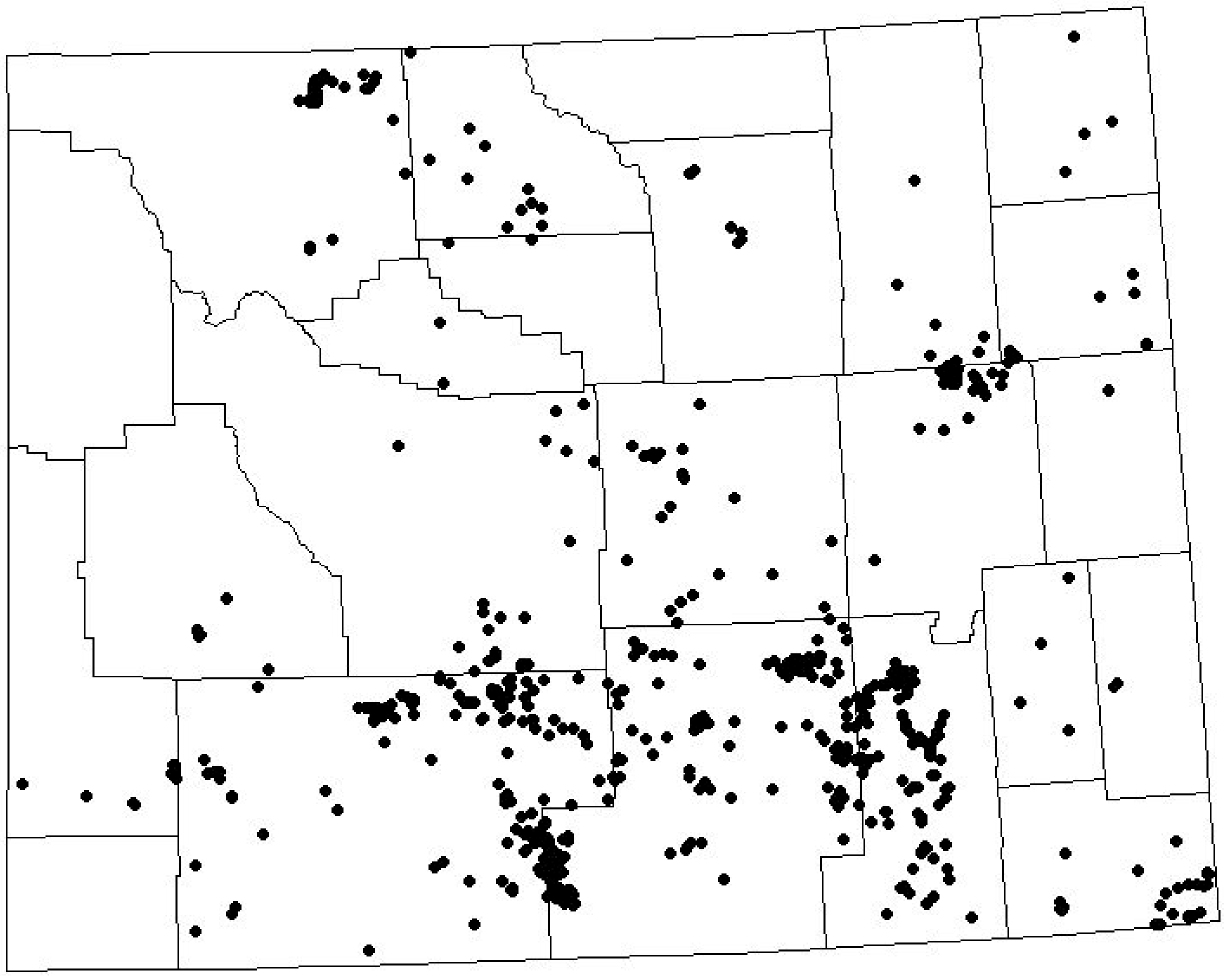

Figure 2. Known distribution of mountain plover (*Charadrius montanus*) in Wyoming. Black dots represent locations where mountain plovers have been observed; lines show boundaries of Wyoming counties. All data on file at the Wyoming Natural Diversity Database (University of Wyoming, Laramie, Wyoming).