III.2 Direct and Indirect Effects of Grasshopper Integrated Pest Management Chemicals and Biologicals on Nontarget Animal Life

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NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

Initially there were 16 objectives (11 terrestrial and 5 aquatic) for the environmental monitoring studies of the Grasshopper Integrated Pest Management (GHIPM) Project. Most of the terrestrial objectives were concerned with determining effects of the grasshopper control methods and materials on birds. Studies varied from total bird population response after spray operations or bait treatments to toxicology tests with individual birds.

Small-mammal population effects and toxicology were investigated with one chemical (acephate). Some limited small-mammal observations also were obtained in areas sprayed with malathion and Sevin® 4-oil. Aquatic objectives were to investigate toxic effects of malathion and carbaryl on endangered fish in tank tests and to determine effects of grasshopper spray programs on fish and aquatic invertebrates in the field.

Other objectives included (1) evaluation of hazards to endangered species through study of related surrogate species, (2) determination of the significance of bird predation as a biological control of grasshoppers in an IPM program, and (3) wildlife tests with the candidate materials *Beauveria bassiana* (a fungal organism) and diflubenzuron (an insect growth inhibitor). More than 20 papers have been published in peer-reviewed journals on the GHIPM Project's environmental monitoring work, and other papers are in press.

Direct Effects

Direct effects on nontarget fish and wildlife of GHIPM materials may be lethal or sublethal. Unlike the organochlorine pesticides, such as dieldrin, chlordane, heptachlor, and toxaphene, formerly used for range grasshopper control (and still in use in some parts of the world) the current GHIPM chemicals do not kill wildlife by direct toxicity (McEwen 1982). There may be some rare exceptions to this statement, such as individual small nestlings of passerine (bird) species that are unusually sensitive to carbaryl or malathion being directly sprayed on an open nest. On the whole, however, GHIPM Project-funded investigators have seen only a very few such possible cases in a large number of nest observations. And none of these bird deaths could be positively attributed to chemical control materials.

At the malathion ultralow-volume (ULV) application rate of 8 fl oz/acre (0.58 kg/ha) and the Sevin 4-Oil formulation rate of 20 fl oz/acre (1.44 kg/ha) (carbaryl active ingredient [AI] rate of 0.56 kg/ha), there is very little possibility of toxicity-caused mortality of upland birds, mammals, or reptiles, and none has been observed.

However, these pesticides are more toxic to aquatic life: direct overspray of small ponds kills many aquatic invertebrates and may kill sensitive fish species. The risk is lower in flowing streams because the chemical is transported downstream and diluted more rapidly. Consequently, nonspray buffer zones around aquatic habitat must be observed (see chapter III.8). Lower-level exposure from pesticide drift or runoff (in contrast to direct overspray) does not kill fish but can be lethal to certain aquatic invertebrates (Beyers et al. 1995; also see chapter III.6).

One of our main environmental monitoring objectives was to determine effects of grasshopper control treatments on rangeland bird populations. We investigated 13 different grasshopper control treatments with GHIPM materials (malathion, Sevin 4-Oil, carbaryl bait, or *Nosema locustae).* We studied effects on total bird populations by concurrently conducting extensive line transect counts (Emlen 1977) before and after insecticide application in both treatment and control (untreated) plots. Total birds (total individuals of all species) did not change ($P > 0.05$) in the posttreatment periods (George et al. 1995). Populations of one highly insectivorous species, the western meadowlark *(Sturnella neglecta),* did consistently decrease at 10 and 21 days posttreatment. We presumed that was due to reduced food availability because there was no evidence of toxic signs in the remaining meadowlarks, and no dead ones were found. Comparative avian population response to many different pesticides used or tested for grasshopper control can be found in a report by McEwen (1982).

Sublethal Effects

Sublethal exposure to GHIPM pesticides is highly probable for wildlife inhabiting sprayed rangeland. The routes of exposure include dermal from direct hit or by moving through sprayed vegetation, ingestion in food or drinking water, and inhalation. The effects of sublethal exposure can vary from biological insignificance to convulsions and near death followed by recovery. Severe toxic signs have not been observed in terrestrial wildlife following GHIPM treatments. The potential for sublethal toxic effects can be minimized by use of bait formulations. Dry bait formulations use less actual chemical per acre or hectare and limit the route of exposure primarily to ingestion of affected insects. In comparison, liquid sprays result in multiple exposure routes (dermal, inhalation, and ingestion of coated vegetation as well as insects). Consumption of bait (bran particles) by wildlife is negligible because of the small size of bran particles and the low treatment rates used for GHIPM (2 to 5 lb/acre or 2.2 to 5.6 kg/ha of bait containing 2 percent carbaryl).

Use of bait treatments provides an environmentally safe means of obtaining some reduction of grasshopper densities in environmentally sensitive areas (such as habitat for endangered plants or animals). Vesper sparrow survival, growth, and fledging rates were not affected by carbaryl bait treatments around the nest areas (Adams et al. 1994). Total bird numbers were not reduced in a large area treated for grasshopper control with carbaryl bait (George et al. 1992a). Bait treatments at GHIPM rates reduce the potential for aquatic contamination (less drift and less chemical). Baits also appear safe for bees and pollinators of endangered plants (see chapters III.4 and III.5).

Cholinesterase Inhibition

All three of the GHIPM chemicals—carbaryl, malathion, and acephate—are cholinesterase (ChE) inhibitors. In vertebrates, acetylcholinesterase and butyrylcholinesterase are essential for normal function of the nervous system. Severe inhibition (>60 percent) often leads to death of the animal (fig. III.2–1). Moderately severe inhibition (40–60 percent) affects coordination, behavior, and foraging ability and can lead to death from other stresses of survival in the wild, such as weather or predators. Effects of lower levels of brain ChE inhibition (<40 percent) are still an open question regarding biological significance (Grue et al. 1991). In our samples of birds and mammals from areas treated with carbaryl, malathion, or acephate, we have not found any animals with >40 percent brain ChE inhibition, and only a few individuals inhibited >20 percent (Fair et al. 1995, George et al. 1995, and Petersen et al., in prep).

Figure III.2–1—Several highly toxic pesticides were field-tested to determine efficacy for grasshopper control and effects on nontarget life. Those chemicals found to be too toxic and hazardous to wildlife were not registered for use on rangeland. Most of the chemicals not registered were severe cholinesterase inhibitors and caused paralysis and death of beneficial birds, such as these Wilson's phalaropes. (Photo by G. Powell of the U.S. Fish and Wildlife Service; reproduced by permission.)

In a study of fish exposed to light drift of carbaryl (Sevin 4-Oil), Beyers et al. (1995) detected no effects on brain ChE. Blood plasma ChE also can be used as an indicator of pesticide exposure: effects of malathion on kestrels and carbaryl (Sevin 4-Oil) effects on golden eagles were reported by Taira (1994).

These results suggest that ChE inhibition is not a problem for upland wildlife when GHIPM chemicals are applied but do not mean that attention to accuracy and rigor of applications can be relaxed. Beyers et al. (1994) found that in water, concentrations of carbaryl as low as 1.3 mg/L (p/m) and of malathion as low as 9.1 mg/L were lethal to fish. Young kestrels died from malathion exposures of only 30 mg per kg of body weight (McEwen et al. 1993 unpubl.), much lower than lethal dosages for other species of birds (>100 to >400 mg/kg, Smith 1987).

A recent study by Nicolaus and Lee (1999) suggested a formerly unrecognized effect of organophosphate exposure. Birds that fed on affected 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. Thus surviving birds were indirectly denied major food sources.

Indirect Effects

The most frequently asked question about effects on wildlife of grasshopper control is, "What about the effects on birds of the loss of the insect food base?" Much of our environmental monitoring effort was directed at this problem.

A 3-year investigation of indirect effects of malathion on nesting birds was conducted in Idaho. After a year of pretreatment study, two areas of rangeland were sprayed with the standard 8 fl oz/acre (0.58 kg/ha) ULV formulation of malathion. Intensive studies were conducted to measure effects on the insect and invertebrate populations and on survival and growth of Brewer's sparrow *(Spizella breweri)* and sage thrasher *(Oreoscoptes montanus)* nestlings (Howe 1993, Howe et al. 1996 and 2000).

Although the total invertebrate availability was significantly reduced by the spray applications, nesting birds switched their diets to the remaining insects and reproduced as successfully as birds on untreated comparison plots (Howe et al. 1996 and 2000). Adults had to forage longer on sprayed plots, and nestlings showed a higher propensity for parasitic blowfly *(Protocalliphora braueri)* infestation (Howe 1991, 1992), both of which might affect survival in some situations. Those effects were not significant in this study. Prespray grasshopper densities were low (1–4 per square yard or square meter) on all plots and were significantly reduced in the postspray period. This probably made the food availability test more rigorous than an operational grasshopper control program, where prespray densities are much higher and even postspray grasshopper densities usually exceed 1 or 2 per square yard or square meter.

Effects of Sevin 4-Oil sprays on killdeer populations were investigated in North Dakota. Two large treated areas were studied. One was sprayed with the standard rate of 20 oz/acre of formulation (16 oz Sevin 4-Oil + 4 oz diesel oil), and the other area received a lower rate of 16 oz/acre (12 oz Sevin 4-Oil + 4 oz diesel oil). These rates translated to 0.56 and 0.45 kg/ha of carbaryl AI respectively. No toxic signs and no mortality were observed in the killdeer.

Effects on foraging and diet of the killdeer were examined by both direct observation and analysis of stomach contents (Fair et al. 1995a). The insect capture rate by foraging killdeer increased during the period when affected insects were easily available 2 days after treatment (Fair et al. 1995b). No other differences in food habits were detected.

A test of carbaryl bait effects on vesper sparrow *(Pooecetes gramineus)* nestling growth and survival was conducted in North Dakota. This study simulated the "hot spot" method of treating small grasshopper infestations with carbaryl bait. There was no difference in any of the productivity parameters between nests on treated and untreated sites (Adams et al. 1994). Adult sparrows on treated sites had to forage farther from the nests to obtain food but did so successfully. Grasshoppers comprised 68 percent of all food deliveries to nestlings even though grasshopper densities were <1 per square meter. The ability of birds to capture a preferred food, even when grasshopper densities are extremely low, supports the value of predation by birds as a preventive force against grasshopper increase in an IPM approach to grasshopper management (see chapter I.10, "Birds and Wildlife as Grasshopper Predators").

Biennial grasshopper infestations in southeastern Alaska provided an opportunity to examine bird population response to the extreme differences in grasshopper abundance and availability that occur naturally. Densities alternate between >25 per square yard in high years and <1 per square yard in low years. This phenomenon apparently occurs because of a synchronized 2-year life cycle of the *Melanoplus sanguinipes* grasshopper species in the population. Birds were counted on permanently marked transects in 2 high and 2 low years, and nesting success of Savannah sparrows *(Passerculus sandwichensis),* the most abundant bird species, was measured. Total bird populations did not differ among years ($P > 0.05$).

Nesting success showed a trend of lower clutch size and nestling growth rates in the low grasshopper years (1991 and 1993) but not significantly ($P > 0.05$) (Miller et al. 1994). Grasshoppers constituted >45 percent of the birds' diet numerically and an even greater proportion of biomass in the high grasshopper years (1990 and 1992)

(McEwen et al. 1993 unpubl., Miller and McEwen 1995). The birds also managed to search out and capture grasshoppers in the low years, indicating their preference for this important food source. However, the breeding birds were able to switch their main food items to other insects (beetles, Hemiptera, larvae of Lepidoptera and others) in the low grasshopper years.

Rangeland wildlife has adapted to variable food availability and environmental conditions over the long term. Evidence of this was observed in North Dakota studies. An extreme drought in 1988 resulted in avian nesting failures and population declines. The effects on bird populations did not carry over to the succeeding years, when precipitation was in the normal range (George et al. 1992b; see also chapter III.7).

Small Mammal Studies

Small mammals generally are not affected as much as birds in the same area where a pesticide application is made, probably because small mammals generally are not exposed to as much toxicant as birds are. Most small mammals are nocturnal and are often in underground burrows during and immediately after a treatment; thus there is more time for the chemical to dissipate before small mammals are exposed (fig. III.2–2). Deer mice *(Peromyscus maniculatus)* collected on a malathion-sprayed area had lower residues than birds from the same sites (McEwen et al. 1989 unpubl.). Many small-mammal species also are inherently more resistant to specific toxicants than birds (Nimmo and McEwen 1994).

Figure III.2–2—Kangaroo rat being released after capture in a live-trap for study on a rangeland-grasshopper control area. Small mammals were generally less vulnerable to pesticide effects than birds inhabiting sprayed areas. (Photo by L. C. McEwen of Colorado State University; reproduced by permission.)

Effects of acephate and methamidophos (an acephate metabolite) on small mammals were studied on short grass range in Colorado. Results have not been completely analyzed, but preliminary data indicate a decrease in populations of certain species due to a combination of greater sensitivity to chemical toxicity and reduced competitive ability with other species. Deer mice were twice as sensitive to methamidophos (the lethal dose to 50 percent, or LD_{50}, was 9 mg/kg) than the other two most common species, grasshopper mice *(Onychomys leucogaster)* and 13-lined ground squirrels *(Spermophilus tridecemlineatus)*. The LD_{50} for both the latter was 21 mg/kg (Stevens 1989). Field live-trapping studies indicated postspray decreases of deer mice but not of the grasshopper mice and ground squirrels. Data analysis and manuscripts are still in progress on these studies (Althouse et al. unpubl., McEwen et al., in prep.).

Limited live trapping studies on malathion-sprayed areas in North Dakota showed no posttreatment decreases in abundant populations, primarily deer mice, and studies of carbaryl-sprayed areas at other locations had a similar outcome (McEwen et al. unpubl. 1988). An investigation of malathion ULV (8 fl oz/acre or 0.58 kg/ha) applied in Nebraska found no effects on small-mammal populations (Erwin and Sharpe 1973).

Golden Eagle Study

Golden eagles *(Aquila chrysaetos)* are a protected species and also are designated as a “species of concern” by wildlife conservation and land management agencies. This species also has special significance for Native Americans. Golden eagles nest in remote rangeland areas and often are found on areas slated for grasshopper control. Because of these concerns and problems, a study was initiated on the Western North Dakota IPM Demonstration Area where nesting territories and spray blocks often overlap.

Active nests of golden eagles were located and randomly selected for Sevin 4-Oil treatments or left unsprayed in 1993 and 1994. Overall, 12 nest areas were sprayed with Sevin 4-Oil at 20 fl oz/acre (1.4 kg/ha) or 8 oz/acre AI

(0.56 kg/ha AI) carbaryl. Approximately 10 ha were treated around each nest. For comparison, the investigators left eight nest areas untreated. At these control nests, the spray plane flew the same pattern and length of time but did not release any spray. Some nests contained two nestlings and some, a single nestling. The total number of treated nestlings was 17, and untreated totaled 11. Treatments were made when the eaglets were 4–7 weeks of age.

When the nestlings neared fledging age (10–11 weeks) they were captured to (1) take biological measurements, (2) take a 4- to 5-mL blood sample, and (3) attach a radio transmitter for postfledging location and observations (telemetry) (O'Toole et al. 1999). Field work and data analysis are incomplete, but preliminary results can be reported.

In 1993, two untreated and three treated fledglings died from various causes unrelated to the treatments. In 1994, a better prey year, all 6 untreated and 10 treated fledglings survived. Postfledging telemetry studies indicated two behavior differences in the eagles from sprayed nest areas: "sprayed" eagles tended to perch longer and to preen more in afternoon observation periods. These results will be reported by O'Toole et al. (in prep.). All fledglings dispersed from their hatch areas by November each year (except for one, which left by December 3, 1994), and radio signals could no longer be detected in ground searches. Aerial telemetry searches were conducted in 1995 to obtain more information on movements and long-term survival rates.

Blood plasma ChE and other blood components were measured. Golden eagles were found to have a higher proportion of butyrylcholinesterase (75 percent) than acetylcholinesterase (25 percent) in plasma (Taira 1994). Blood samples from the treated nestlings had higher total ChE activity than untreated, but not significantly ($P = 0.11$). This was somewhat predictable in that blood samples were not taken until 3 to 5 weeks after exposure, and an overcompensation or "rebound effect" has been found in other species after light exposure to carbamates.

In summary, it appears that Sevin 4-Oil sprayed at the GHIPM rate offers little risk to nesting golden eagles. With global positioning system technology, spray planes could shut off and leave a small unsprayed area of a few acres or hectares around active nests, to leave the eagles completely unaffected. Similar studies of effects of malathion sprays (8 fl oz/acre or 0.58 kg/ha) for rangeland grasshopper control need to be conducted with young golden eagles.

References Cited

Adams, J. S.; Knight, R. L.; McEwen, L. C.; George, T. L. 1994. Survival and growth of nestling vesper sparrows exposed to experimental food reductions. The Condor 96: 739–748.

Beyers, D. W.; Sikoski, P. J. 1994. Acetylcholinesterase inhibition in federally endangered Colorado squawfish exposed to carbaryl and malathion. Environmental Toxicology and Chemistry 13: 935–939.

Beyers, D. W.; Keefe, T. J.; Carlson, C. A. 1994. Toxicity of carbaryl and malathion to two federally endangered fishes, as estimated by regression and ANOVA. Environmental Toxicology and Chemistry 13: 101–107.

Beyers, D. W.; Farmer, M. S.; Sikoski, P. J. 1995. Effects of rangeland aerial application of Sevin-4-oil on fish and aquatic invertebrate drift in the Little Missouri River, North Dakota. Archives of Environmental Contamination and Toxicology 28: 27–34.

Emlen, J. L. 1977. Estimating breeding season bird densities from transect counts. Auk. 94: 455–468.

Erwin, W.,J.; Sharpe, R. S. 1978. Effect of wide area ultra-low volume application of malathion on small mammal populations. Transactions of the Nebraska Academy of Science 5: 25–28.

Fair, J. M.; Kennedy, P. L.; McEwen, L. C. 1995a. Effects of carbaryl grasshopper control on nesting killdeer in North Dakota. Environmental Toxicology and Chemistry 14: 881–890.

Fair, J. M.; Kennedy, P. L.; McEwen, L. C. 1995b. Diet of nesting killdeer in North Dakota. Wilson Bulletin 107: 174–178.

George, T. L.; McEwen, L. C.; Fowler, A. C. 1992a. Effects of a carbaryl bait treatment on nontarget wildlife. Environmental Entomology 21: 1239–1247.

George, T. L.; Fowler, A. C.; Knight, R. L.; McEwen, L. C. 1992b. Impacts of a severe drought on grassland birds in western North Dakota. Ecological Applications 2(3): 275–284.

George, T. L.; McEwen, L. C.; Petersen B. E. 1995. Effects of grasshopper control programs on bird populations in western rangelands. Journal of Range Management 48: 336–342.

Grue, C. E.; Hart, A.D.M.; Mineau, P. 1991. Biological consequences of depressed brain cholinesterase activity in wildlife. In: Mineau, P., ed. Cholinesterase-inhibiting insecticides: their impact on wildlife and the environment. (Vol. 2 of the Chemicals in Agriculture series.) Amsterdam, London, New York: Elsevier: 152–209.

Howe, F. P. 1991. Two new host species for the parasitic blow fly *Protocalliphora braueri.* Wilson Bulletin 103: 520–521.

Howe, F. P. 1992. Effects of *Protocalliphora braueri* (Diptera: Calliphoridae) parasitism and inclement weather on nestling sage thrashers. Journal of Wildlife Diseases 28(1): 141–143.

Howe, F. P. 1993. Effects of a grasshopper insecticide application on diet, food delivery rates, growth, and survival of shrubsteppe passerines. Ph.D. dissertation. Fort Collins, CO: Colorado State University. 108 p.

Howe, F. P.; Knight, R. L.; McEwen, L. C.; George, T. L. 1996. Direct and indirect effects of insecticide applications on growth and survival of nestling passerines. Ecological Applications 6: 1314–1324.

Howe, F. P.; Knight, R. L.; McEwen, L. C.; George, T. L. 2000. Diet switching and food delivery by shrubsteppe passerines in response to an experimental reduction in food. Western North American Naturalist 60: 139–154.

McEwen, L. C. 1982. Review of grasshopper pesticides vs. rangeland wildlife and habitat. In: Peek, J. M.; Dalke, P. D., eds. Proceedings of the wildlife–livestock relationships symposium; 20–24 April 1981; Coeur d'Alene, ID. Moscow, ID: University of Idaho: 362–382.

Miller, C. K.; McEwen, L. C. 1995. Diet of nesting savannah sparrows in interior Alaska. Journal of Field Ornithology 66: 152–158.

Miller, C. K.; Knight, R. L.; McEwen, L. C. 1994. Responses of nesting savannah sparrows to fluctuations in grasshopper densities in interior Alaska. The Auk 111: 960–967.

Nicolaus, L. K.; Lee, H. 1999. Low acute exposure to organophosphate produces long-term changes in bird feeding behavior. Ecological Applications 9: 1039–1049.

Nimmo, D. W.; McEwen, L. C. 1994. Handbook of ecotoxicology-pesticides. In: Calow, P., ed. Handbook of ecotoxicology, vol. 2. Oxford, UK: Blackwell Scientific Publications. Chapter 8.

O'Toole, L. T.; Kennedy, P. L.; Knight, R. L.; McEwen, L. C. 1999. Postfledging behavior of golden eagles. Wilson Bulletin 111: 472–477.

Smith, G. J. 1987. Pesticide use and toxicology in relation to wildlife: organophosphorus and carbamate compounds. Resour. Publ. 170. U.S. Department of the Interior, Fish and Wildlife Service. 171 p.

Stevens, P. D. 1989. Acute toxicity and inhibition of cholinesterase activity in small mammals following exposure to methamidophos. M.S. thesis. Ft. Collins, CO: Colorado State University. 51 p.

Taira, T. 1994. Blood analysis of American kestrel and golden eagle nestlings exposed to malathion or carbaryl. M.S. thesis. Fort Collins, CO: Colorado State University. 80 p.

References Cited–Unpublished

Althouse, C. M.; McEwen, L. C.; Hoffman, L. A. Influence of prior northern grasshopper mouse *(Onychomys leucogaster)* and 13-lined ground squirrel *(Spermophilus tridecemlineatus)* live trap captures on succeeding intra and interspecific captures. Submitted to Journal of Mammalogy.

McEwen, L. C.; George, T. L.; Petersen, B. E.; Beyers, D. W.; Fowler, A. C.; Howe, F. P. 1989. Environmental monitoring. In: Cooperative Grasshopper Integrated Pest Management Project, 1988 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 82–102.

McEwen, L. C.; Petersen, B. E.; Beyers, D. W.; Althouse, C. M.; Fair, J. M.; Schleve, G. R.; Bednarski, L. T.; Taira, T. 1993. Environmental monitoring. In: Cooperative Grasshopper Integrated Pest Management Project, 1993 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 127–142.

McEwen, L. C.; Althouse, C. M.; Logan, J. A.; Stevens, P. D. (In preparation). Small mammal long-term population response to 2 rates of methamidophos spray on mixed shortgrass/*Atriplex* rangeland. Journal of Range Management or Environmental Toxicology and Chemistry.

O'Toole, L. T.; McEwen, L. C.; Knight, R. L. [In preparation.] Behavioral responses of post-fledging golden eagles *(Aquila chrysaetos)* to Sevin 4-Oil applications in the Little Missouri National Grassland, North Dakota. Environmental Toxicology and Chemistry.

Petersen, B. E.; DeWeese, L. R.; McEwen, L. C.; Palmer, D.; Ryder, R. A. Nesting success of lark buntings on rangeland treated with acephate. Submitted to Journal of Range Management.