ORGANOPHOSPHATE INSECTICIDE (FAMPHUR) TOPICALLY APPLIED TO CATTLE KILLS MAGPIES AND HAWKS

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Abstract: A systematic field study of a black-billed magpie (*Pica pica*) population revealed that magpies and red-tailed hawks (*Buteo jamaicensis*) were killed by famphur (=famophos, Warbex®) used as a pour-on to control cattle warbles (*Hypoderma* sp.). Magpie mortality began on treatment day and continued for more than 3 months (38 found dead); mortality peaked between Day 5 and Day 13. Estimates of magpie density (based on transects) decreased in both the control and treatment areas, but the decrease was greater in the treatment area. A red-tailed hawk found dead on Day 10 had eaten a famphur-contaminated magpie. Another red-tailed hawk was found alive but immobilized, and a third died outside the study area. Brain cholinesterase (ChE) activity was 70–92% depressed in all dead birds examined; famphur residues were detected in all 17 magpies and the 2 hawks analyzed. The amount of famphur obtained by the dead magpies was estimated at 5.2–6.1 mg/kg (based on residue concentrations in the gizzard), which was above the acute oral LD_{50} for several bird species. The cow hair portion (12%) of the pooled gizzard contents from 13 other dead magpies produced extremely high famphur residues (4,600 ppm). The residues persisted on cattle hair for more than 90 days post-treatment. Magpie populations in the far western states declined between 1968 and 1979, which corresponds with widespread use of famphur, although other factors may be involved.

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Organophosphate (OP) insecticides are now used extensively in agriculture. The topical use of famphur (O,O-dimethyl O-[p-(dimethylsulfamoyl)phenyl] phosphorothioate) in the autumn as a systemic insecticide for control of warbles in cattle was recommended in 1970 (Every et al. 1970). Famphur can be administered to livestock dermally as a pour-on (the only method we observed), orally (mixed with feed), or by intramuscular injection (Ivey et al. 1976). The larvae are killed within the animal during the autumn before they develop into grubs the following year. Grubs emerging on the backs of untreated cattle during the spring may be eaten by magpies (Bishopp et al. 1926), but this is not an adequate control.

Observations of magpies dying after famphur use on cattle were reported by ranchers as early as 1973 (unpubl. data, Oreg. Dep. Fish and Wildl., La Grande). Magpies and other species of birds were found dead after cattle were treated with famphur in the United Kingdom (Felton et al. 1981). Magpie brain ChE activity was severely depressed and famphur was identified in the gizzard contents. Another organophosphate (fenthion), also used as a pour-on to control *Hypoderma* larvae in cattle, was implicated in magpie mortality in Canada (Hanson and Howell 1981). Despite relatively rapid degradation in the environment and tissues of homeotherms, some OP insecticides are highly toxic to wildlife for varying periods of time after application (Zinkl et al. 1978, White et al. 1979). The degree of exposure of nontarget wildlife species to OP insecticides can be assessed by measuring ChE activity in tissues and blood (Bunyan et al. 1968, Ludke et al. 1975, Hill and Fleming 1982). The depression of brain ChE activity by 20% or a decrease of 2 SD in wild birds (relative to species baseline data or concurrent controls) has been used as a conservative criterion to indicate absorption of OP chemicals. Depression of brain ChE activity by ≥50% and confirmation of suspected OP residues in tissues or ingesta are criteria for cause-effect diagnosis of death in birds exposed to anti-ChE chemicals.

We studied a magpie population that lived on or near seven ranches where 535 cattle were treated with Warbex® (13.2% famphur). Warbex® was poured along the back line of the cattle at the recommended rate of 0.326 ml/kg body weight, not to exceed 118 ml/animal. The field study was prompted by: (1) reported magpie mortality in Oregon and the United Kingdom; (2) a magpie population decline in the far

western states between 1968 a
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METHODS AND MATERI

Black-billed magpie habit
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western states between 1968 and 1979 (Robbins et al. 1985); and (3) laboratory experiments showing potential secondary poisoning of predatory birds from eating prey poisoned by famphur (Hill and Mendenhall 1980).

We acknowledge the late R. S. Rohweder for bringing to our attention the potential magpie problem in the Pacific Northwest. J. Downs-Berg provided extensive field assistance. R. A. Grove, D. J. Lenhart, and J. A. Nee helped with laboratory and field work. R. C. Laybourne, U.S. Fish and Wildl. Serv. Div. of Law Enfor., verified the composition of the hawk crop contents, and E. F. Hill provided technical advice for the ChE analysis. C. H. Trost trapped control magpies for plasma ChE assays, and B. G. Marcot performed the computer analyses of the census data. Battelle Pacific Northwest Lab. provided office and laboratory space near the study area. We thank the seven participating ranchers for allowing us access to their land and cattle. D. G. Paullin provided the birds from Malheur Natl. Wildl. Refuge (NWR). The manuscript was improved by the comments of L. C. McEwen, D. J. Hoffman, and J. G. Zinkl.

METHODS AND MATERIALS

Black-billed magpie habitat is characterized by thickets or riparian areas associated with open meadows, grassland, or sagebrush stands (Linsdale 1937, Bock and Lepthien 1975). Our study area was located in such prime magpie habitat. The cattle treatment area was located along the Yakima River near Benton City, Benton County, Washington, with a control area (for magpie census) about 15 km away near Richland in habitat along the same river. No cattle were present in the control area, but small herds were located throughout the treatment area. The river bottomland consisted of small farms ranging in size from 1 to 50 ha. Pastureland was interspersed among fruit and cereal grain farms. Cattle on these small ranches were seldom treated with warble-control materials in the past. We supplied the Warbex® to seven ranchers and observed/assisted with its applications to ensure that recommended rates were used. The insecticide was applied between 2 and 24 October 1982 to cattle restrained in squeeze chutes. Treatment dates were as follows: 2–3 October (105 cattle), 12–16 October (190), and 23–24 October (240). After treatment, the cattle were immediately released into pastures ranging from 5 to 50 ha. The number of cattle treated at each ranch ranged from 25 to 140.

Cattle (140) were treated with Warbex® at two ranches again in 1983 (between 12 and 14 Oct) to evaluate the persistence of famphur on cow hair. Hair samples were pulled from their backs at about weekly intervals up to 91 days following treatment. Hair samples were pulled from the backs of Hereford bulls (118 ml application rate), smaller Hereford steers (about 60 ml), and Angus yearlings (about 30 ml).

Field Procedures

Ten days before cattle treatment began in 1982, roadside transects were established in treatment and control areas. Magpies were highly visible in each area with 1,958 magpies counted (averaging 40 magpies on each transect surveyed). The sighting angle and distance (m) from the observer of each magpie were recorded. Control and treatment transects were each surveyed 24 times between 22 September and 18 November 1982. The routes were 6.4 and 10.9 km in length, respectively. Counts were begun early in the morning and followed the same daily sequence (control first).

Perpendicular distances to the transect were calculated by program TRANSECT (Burnham et al. 1980). Default conditions for the program runs were used with the Fourier series estimator with variable number of parameters (up to six), use of the largest perpendicular distance calculated as the cutoff value for transect width, and use of ungrouped data. Default output was generated which included estimates of Fourier series parameters, $f(0)$ values, and density estimates, with means, standard errors, and 95% confidence intervals (Laake et al. 1979). The transect surveys were divided into three approximately equal sets of runs, and estimates of $f(0)$ and bird densities were generated from each pooled set of runs. Thus, three estimates of magpie density (and variance) were available for control and treatment areas: pre-treatment (8 control, 7 treatment counts, respectively, between 22 Sep and 1 Oct), treatment (9, 10 counts between 4 and 28 Oct), and post-treatment (7, 7 counts between 1 and 18 Nov).

Carcass searches were made at 1- to 3-day intervals—usually daily on weekdays until 8 December 1982. The searches covered pastures where treated cattle were present and some adjacent fields, but they were not considered complete, e.g., some woodland areas with thick understory vegetation adjacent to pastures were never checked. Dead magpies were only found in pastures with treated cattle, or within 50 m of the pastures. Some dead magpies were scavenged by predators, but magpie feather piles were recorded as dead birds.

Magpies were livetrapped, banded, and bled at three of the ranches during the study. Blood plasma was analyzed for ChE activity, and 15 live-trapped birds (post-treatment) were killed to determine brain ChE activity. The normal ranges of blood plasma and brain ChE activity were determined from unexposed magpies shot or trapped in areas with no cattle (near Wenatchee, Wash., and Pocatello, Idaho). Control red-tailed hawks were obtained from western Oregon near Corvallis and near Wenatchee, Washington (road kills, electrocution, and illegally shot). Tissues of 17 magpies that died during the study in 1982 and 1983 were analyzed for famphur and famphur oxon. Food habits were determined by examining gizzard contents of other magpies that died in 1982. These contents were also analyzed for chemical residues. No census or systematic daily searches for dead magpies were conducted in 1983, but six freshly killed magpies were found. The primary objective the 2nd year was to record magpie activity and collect hair samples from the backs of cattle.

Chemical Analyses

Bird carcasses and blood plasma samples were stored at −50 C, whereas cow hair was stored at room temperature away from direct light, pending analysis. Plasma and brain ChE assay procedures followed the Ellman (Ellman et al. 1961) method as adapted by Hill and Fleming (1982). ChE activity was determined with a Spectronic 88 spectrophotometer (Bausch & Lomb) fitted with a water-jacketed micro flow-through cell. Optical density readings were taken every 30 seconds for 3 minutes to assure that the reaction was linear. All analyses were performed at 25 C.

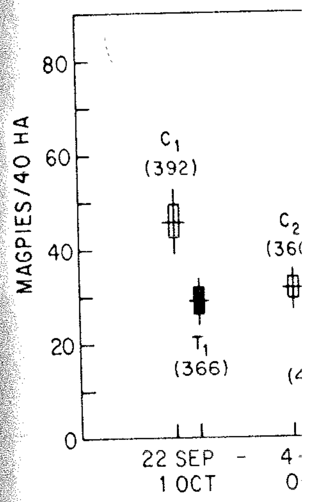
The upper gastrointestinal (GI) tract (primarily the gizzard and its contents), the lower GI tract, and remaining carcass (plucked; with bill, feet, wings, and brain removed) were analyzed for famphur and famphur oxon. Gizzard contents from additional magpies found dead were separated into cow hair, other animal matter, and vegetable matter with like materials pooled for analysis. Extraction of magpie GI tracts including pooled gizzard contents and cow hair samples, and red-tailed hawk crop and stomach contents was accomplished by soaking each sample in methylene chloride as described by White et al. (1982). No further cleanup was necessary. Magpie carcasses, cow manure samples, and the red-tailed hawk liver were homogenized, and a 10-g aliquot of each sample was obtained for extraction. These aliquots and the whole pooled insect samples were extracted three times with 50 ml methylene chloride by blending with a Tissumizer. The methylene chloride extract was cleaned up by gel permeation chromatography (R. L. Leicht et al., ABC Labs, Inc., Columbia, Mo., unpubl. data). The solvent system was methylene chloride/cyclohexane, 15/85, at a flow rate of 5 ml/min. The first 140 ml containing lipid was discarded, and the next 70 ml was collected.

The samples were analyzed by a gas chromatograph equipped with a flame photometric detector and a 3% OV-101 column at 205 C. Lower limits of reportable residue for famphur were 0.3 ppm in insect and cow hair samples and 0.1 ppm in all other samples. Lower limits of reportable residue for famphur oxon was 3.0 ppm in insect samples and 1.0 ppm in all other samples except the cow hair in which famphur oxon could not be determined due to interference from the high residues of famphur. Duck tissues fortified with famphur at the 0.2 ppm level and famphur oxon at 2.0 ppm were run in triplicate to determine the percent recovery. The average recoveries were 97% famphur and 80% famphur oxon. All residues are presented on a wet weight basis and are not corrected for recovery. The presence of famphur was confirmed by gas chromatograph/mass spectrometer (GC/MS) in two magpie upper GI tracts, a magpie lower GI tract, a red-tailed hawk crop and the other red-tailed hawk stomach, a cow manure sample, and a magpie carcass. Famphur oxon was confirmed by GC/MS in a magpie upper GI tract.

RESULTS AND DISCUSSION

Survey of Live Magpies

Density estimates (magpies/40 ha) for the control area (C_1, C_2, C_3) and the treatment area (T_1, T_2, T_3) were based on pooling the observations in each of the six time periods. The time periods corresponded to the pre-treatment, treatment, and post-treatment (Fig. 1). The



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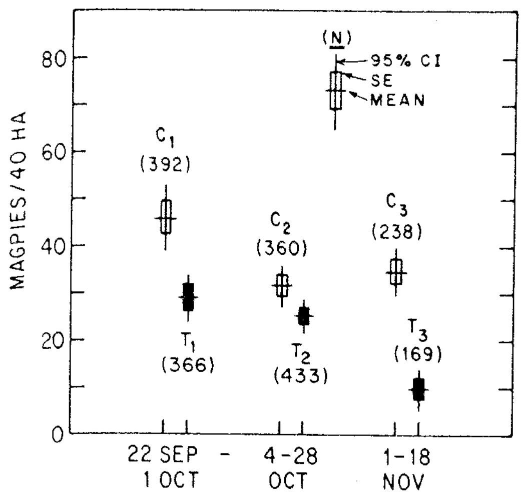

Fig. 1. Magpie density in the control (C_1, C_2, C_3) and treatment (T_1, T_2, T_3) areas in Washington, 1982. The means were estimated by pooling all observations for each period with the SE generated by program TRANSECT. Time periods correspond to pre-treatment, treatment, and post-treatment.

control area contained a higher density of magpies than the treatment area before treatment (C_1 vs. T_1) (Satterthwaite's unpaired $t = 4.24$, 721 df, $P < 0.001$); the higher density continued throughout the study. The control area contained more riparian vegetation, and we believe habitat explains the initial density differences. The control area showed no changes between the treatment and post-treatment periods (C_2 and C_3), ($t = -0.94$, 515 df, $P = 0.18$), but the population density declined from C_1 to C_3 ($t = 2.71$, 627 df, $P < 0.01$). In the treatment area, the population density declined between T_2 and T_3 ($t = 5.70$, 379 df, $P < 0.001$), and between T_1 and T_3 ($t = 5.88$, 501 df, $P < 0.001$). We prefer to survey populations at a time of the year when no movement occurs, but apparently some magpie movement occurs during autumn, usually in September (Bent 1946, Millar 1964). We believe movement accounts for general population declines in both study areas (especially from Sep to Oct). The overall magnitude of the decline during the three time periods (magpies/40 ha) was more severe in the treatment area (29.0, 25.2, 9.7) than the control area (46.1, 31.8, 35.0). Another analysis was conducted based on magpie densities calculated for individual transect surveys by applying $f(0)$ (effective detection distance) values generated from pooling observations in each time period. This second analysis provided similar results.

Table 1. Brain and plasma cholinesterase activities of control magpies and red-tailed hawks outside the treatment area (Oregon, Washington, Idaho, 1982–84).

Species	N	$\bar{x}$ ± SD (range)
Brain ChE activity, μ mol/min/g		
Black-billed magpie	10	21.76 ± 2.39 (17.81–26.13)
Red-tailed hawk	6	18.83 ± 1.66 (16.25–21.32)
Plasma ChE activity, mU/ml		
Black-billed magpie	17	1,512 ± 381 (933–2,378)
Red-tailed hawk	3	1,396 ± 331 (1,032–1,677)

Recorded Magpie Mortality, Brain ChE Activity, and Famphur Residues

Thirty-eight magpies were found dead in 1982 in or near pastures with treated cattle. The first magpie died on Day 0 (treatment day), and observed mortality continued through Day 82, peaking (58%) between Days 5 and 13. Systematic searches for dead magpies were concluded on 8 December 1982, about 45 days after the largest herd of cattle was treated. Two dead magpies (at 58 and 82 days) were brought to our attention that winter by ranchers after we had departed, but these birds were not analyzed. The limited treatments in 1983 yielded two dead magpies (fresh) that were of particular interest. One died 88 days post-treatment (10 January 1984) and the other 107 days post-treatment (29 January 1984), and both were analyzed for ChE activity.

Based on brain ChE activity in 10 control magpies (Table 1), ChE depression in the dead magpies from the treatment area ranged from 70 to 92% (Table 2). With the inclusion of the magpies found following the autumn 1983 treatment, the known period of magpie mortality and life-threatening (≥50%) ChE depression is at least 107 days post-treatment.

Famphur was found in all 17 magpies analyzed with the highest concentrations reported in the upper GI tracts, i.e., the gizzard (Table 3). The lower GI tracts contained lower concentrations and the carcass the least. Even though the magpie that died on treatment day contained no or low residues in the lower GI tract, in the carcass, and in the upper GI tract, it had severe brain ChE depression. Although brain ChE activity was severely depressed in

Table 2. Magpie and red-tailed hawk mortality in relation to treatment date with famphur. Data are a composite from the seven Washington ranches in 1982 with supplementary information from 1983.

Days after treatment	Magpies N	Magpies Brain ChE depression $\bar{x}$ (range)	Red-tailed hawk N
0–1	1 (1)[a]	82% (82–83)	0
2–4	2	86%	0
5–7	6 (2)[a]	85% (77–88)	0
8–10	9	82% (70–89)	1[b]
11–15	7	88% (83–92)	1[c]
16–20	5	85% (81–88)	0
21–25	3	89% (83–92)	0
26–30	3	NA[d]	0
32	(1)[a]	89%	0
58[e]	1	NA[d]	0
82[e]	1	NA[d]	0
88	(1)[a]	79%	0
107	(1)[a]	90%	0

[a] Magpies found dead (in fresh condition) following 1983 treatment; search effort for carcasses was not uniform over time in 1983.
[b] Brain ChE depression 87%.
[c] Sick and unable to fly, but later released.
[d] NA = not analyzed.
[e] Carcass searches terminated on 8 December 1982, after which dead magpies were reported by ranchers.

all dead magpies, there was considerable variation in famphur residue concentrations. Famphur oxon was detected in 1 of 17 magpies. Our results indicated that the parent molecule was primarily responsible for the long-term magpie mortality. The two criteria for diagnosis of famphur-induced magpie mortality were met: (1) brain ChE depression of ≥50% in birds found dead, and (2) the confirmation of famphur residues in their tissues or ingesta.

Secondary Poisoning of Red-tailed Hawks

Secondary poisoning occurs through eating disabled or dead animals. Although the major chemical source in secondary poisoning may be the tissues of the consumed animal, it usually is unabsorbed compound remaining in the GI tract of the animal that is eaten (Hayes 1975). During the peak of magpie mortality, an immature male red-tailed hawk was found dead and another immature was found unable to fly. Brain ChE activity for the dead red-tailed hawk was depressed 87% (Table 2); while plasma ChE in the sick bird was depressed 82%. The sick hawk was held and fed for 4 days and released. Blood plasma ChE at the time of release was depressed 60%.

The red-tailed hawk that died 10 days after

Table 3. Residues of famphur in black-billed magpies found dead in the Washington study area.

Days after treatment	Sex[a]	Residues of famphur (ppm wet weight): Upper G.I. tract[b]	Lower G.I. tract[b]	Carcass
0	F	2.2	nd[c]	nd
5	U, M	8.1, 30	0.31, 0.46	0.25, 0.19
5	F, F	550, [0.19][d]	2.8, [nd][d]	0.81, [nd][d]
6	U	170	1.3	1.1
9	F, M	43, 48	[e], 0.68	0.32, 0.30
11	F, F	39, 360	1.2, 4.1	0.94, 0.70
19	U, F	13, 420[f]	0.16, 24	0.40, 3.8
22	M	530	3.5	3.0
23	M, M	93, 4.2	1.9, nd	0.68, nd
32[g]	M	310	2.4	0.74
88[g]	F	290	4.3	1.4

[a] M = male, F = female, U = unknown; two letters listed for day indicates two magpies analyzed.
[b] Gastrointestinal (tract and contents).
[c] nd = not detected.
[d] [Sick bird that was killed].
[e] Sample lost.
[f] Also, famphur oxon 3.8 ppm.
[g] Found incidental to autumn 1983 study.

cattle treatment had eaten a magpie. Feathers in the hawk's crop were positively identified as black-billed magpie (R. C. Laybourne, pers. commun.). The crop contents contained 21 ppm famphur. Another dead immature red-tailed hawk was found in southeastern Oregon at Malheur NWR on 28 January 1983; 5 weeks earlier a dead magpie had also been recovered there. Brain ChE activity was depressed 83% in the magpie, and 64 ppm famphur was found in the upper GI tract. The hawk brain ChE activity was depressed 83% and the stomach contents contained 53 ppm famphur. A few feathers and a tibiotarsus in the hawk's stomach were European starling (*Sturnus vulgaris*) (R. C. Laybourne, pers. commun.).

The only birds found dead in our study area were magpies and a red-tailed hawk although several other species (e.g., killdeers [*Charadrius vociferus*] and European starlings) were common in the pastures.

Seven of the 38 magpies found dead during the 1982 test (not counting the magpie eaten by the red-tail) were already fed on by predators or scavengers indicating a rapid disappearance of carcasses.

Sublethal Exposure of Surviving Magpies to Famphur

Because magpies were dying at all seven ranches, we investigated sublethal exposure in the surviving segment of the population. Or-

amphur in black-billed magpies found
study area.

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er G.I. act[b]	Lower G.I. tract[b]	Carcass
2	nd[c]	nd
1, 30	0.31, 0.46	0.25, 0.19
[0.19][d]	2.8, [nd][d]	0.81, [nd][d]
	1.3	1.1
48	[e], 0.68	0.32, 0.30
360	1.2, 4.1	0.94, 0.70
420[f]	0.16, 24	0.40, 3.8
	3.5	3.0
4.2	1.9, nd	0.68, nd
	2.4	0.74
	4.3	1.4

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Table 4. Body weights (g) of black-billed magpies.

Male $\bar{x}$ ± SD (*N*)	Female $\bar{x}$ ± SD (*N*)	State	Source
186.6 ± 9.2 (10)	160.3 ± 11.8 (18)	NV, OR, CA	Linsdale (1937)
182.9 ± 9.0 (6)	162.4 ± 8.4 (4)	WA	Mugaas and King (1981)
187.8 ± 10.5 (41)	166.7 ± 12.4 (30)	UT	Reese and Kadlec (1982)
180.6 ± 14.1 (12)	153.5 ± 7.4 (12)	WA	This study[a]

[a] Died from famphur poisoning (some dehydration occurred in the field; occasionally birds were dead 1–2 days before found).

ganophosphate studies on forest spray projects (e.g., Zinkl et al. 1979) had shown ChE depression (30–40%) in brains of surviving birds following treatment. We trapped 15 magpies at the ranches between Day 15 and Day 19 post-treatment and analyzed brain ChE activities. All values were within the normal range (lowest value 19.37 μmol/min/g).

Blood from live-trapped magpies was also collected at the ranches. Advantages of plasma collection include non-destructive sampling of the same individuals over time, and plasma analysis can detect low-grade exposure to an anti-ChE chemical, which may depress plasma ChE and not brain ChE (Hill and Fleming 1982). Plasma ChE values are more variable; therefore to evaluate exposure, we used 50% depression (less 2 SD of controls) as the criterion. The data were grouped into four time periods: (1) Days 8–17 ($N = 14$)—7% showed exposure; (2) Days 23–28 ($N = 16$)—6% showed exposure; (3) Days 31–36 ($N = 13$)—none showed exposure; and (4) Days 45–51 ($N = 4$)—none showed exposure. The two significantly depressed plasma ChE values were 610 and 680 mU/ml, which is equivalent to 55 and 60% depression. Low plasma ChE values of 234 mU/ml (85% depression) and 137 mU/ml (91% depression) were determined for two sick magpies caught by hand and killed 5 and 9 days after treatment; brain ChE activity was depressed 77% and 83%, respectively.

Based on the ChE activity of live-trapped magpies, few live birds in the treatment areas were exposed to famphur. Thus, it appears that most magpies exposed to famphur died. This contrasts with forest studies where a wide range of ChE activity was found including many individual birds with sublethal inhibition. The forest habitat received a relatively uniform spray application by aircraft, but the degree of exposure for birds varied with their food habits, activity, and other factors. In the present study where only cattle were treated rather than the habitat, a true dichotomy of death or survival existed for the magpies. Apparently, most magpies exposed to famphur died; survivors were not exposed.

Timing of Death in Relation to Famphur Exposure

Magpies died over a prolonged period in this study (Day 0–Day 107), but the peak occurred between Day 5 and Day 13. The 5-day period before mortality peaked suggests (1) a delay in high exposure, or (2) mortality due to chronic exposure. Four points suggest acute poisoning immediately after exposure: (1) famphur residues were highest in magpie gizzards (Table 3); (2) brain ChE activity of live-trapped magpies in treatment areas was normal suggesting little or no OP exposure in live birds; (3) plasma ChE activity, although more variable, also indicated limited OP exposure for live birds; and (4) weights of magpies that died were near normal. Published mean weights for males ranged from 182.9 g to 187.8 g and for females 160.3 g to 166.7 g (Linsdale 1937, Mugaas and King 1981, Reese and Kadlec 1982, Table 4). Males and females found dead in our study averaged 180.6 g and 153.5 g, respectively. Birds dying of chronic poisoning usually undergo severe weight loss. Recurring acute poisoning over several weeks or months indicates stability of the chemical in the environment.

Field observations following the treatment of 140 cattle also suggest acute poisoning. Eight magpies were observed on the ground among the cattle 3 days after treatment, and when they flew about 200 m toward the river, one was uncoordinated and hit a tree. It fell to the ground immobilized and salivating (a sign of organophosphate poisoning [O'Brien 1967]) and died within 5 minutes.

Mode of Famphur Exposure

High concentrations of famphur in the magpie gizzards (Table 3) indicated that the ma-

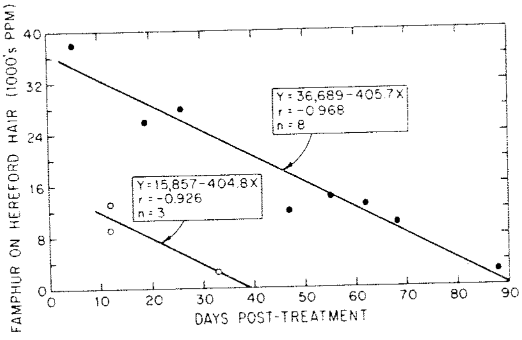


Fig. 2. The persistence of famphur on the hair of Hereford bulls (●) and steers (○) in Washington, 1983–84.

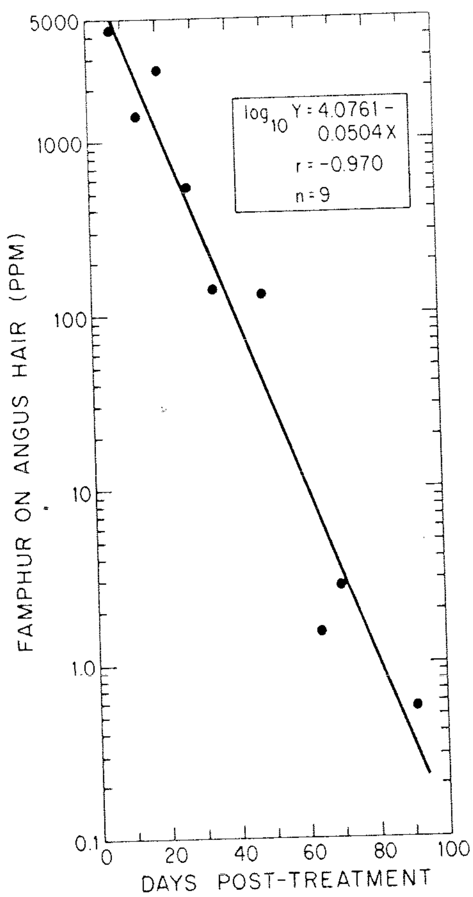


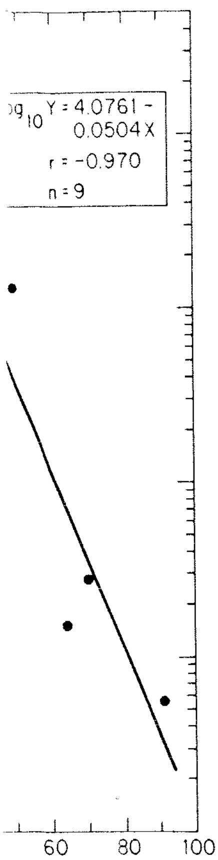
Fig. 3. The persistence of famphur on the hair of Angus yearlings in Washington, 1983–84.

terial was ingested as opposed to dermal contact or inhalation. Kalmbach (1927) reported that adult magpie food habits varied from month to month, but in October and November animal matter accounted for 54% and 37%, respectively. Gizzard contents from 13 magpies that died during this study consisted of 51% vegetable matter, 37% animal matter, and 12% cattle hair. Cattle hair was found in all gizzards except one that was empty (range <1–50% of contents). Most of the 97 arthropods found in the magpie gizzards were ground-dwelling types: Coleoptera 73 (including 71 Carabidae); Orthoptera 9; Diptera (pupa 5, adults 2); Hymenoptera 2; Lepidoptera (larva 2); Solpugida 2; and Araneida 2. Flies (Diptera) and ticks (Ixodidea) directly associated with cattle were probably not the source of the contaminant.

Famphur in Cow Manure.—Magpies frequently feed on the ground near cattle. With ground beetles and other insects present in the gizzards of dead magpies, we first hypothesized that famphur exposure resulted from magpies eating insects associated with manure. Horn fly larvae (*Haematobia irritans*) were controlled in manure of cattle fed famphur (Drummond et al. 1967). Fresh manure samples were collected at regular intervals post-treatment in 1982. Low concentrations of famphur were found in three of seven samples collected on Day 1 (0.12, 0.13, 0.14 ppm). No residues were detected in three samples on Day 4, in four samples on Day 6, or in four samples on Day 7. Later samples were not analyzed. In addition, four pools of adult and/or larval insects collected from manure in treated fields yielded no famphur residues. The manure-insect pathway of exposure was untenable.

Famphur on Cow Hair.—Gizzard contents from 13 magpies that died were pooled and analyzed for famphur and famphur oxon. Contents were first separated into cow hair, other animal matter, and plant matter. Cow hair contained 4,600 ppm famphur, the other animal matter contained 620 ppm, and plant matter contained 340 ppm. Clearly, the cow hair was the major source of famphur; most or all of the famphur on the other material may have originated from the cow hair.

Although OP's may be highly toxic, most degrade rapidly by chemical and biological processes and are considered less hazardous in the environment than more persistent organochlorine pesticides (Stoker and Seager 1977). The persistence of famphur on cattle hair was evaluated at two ranches in the autumn of 1983. Pre-treatment samples showed no famphur, but the material persisted on the hair of the Here-



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ford bulls (same two bulls sampled each time) throughout the sampling period, with residues decreasing in a linear manner with time (Fig. 2). Residues were lower initially (lower application rate) but the relationship was similar for the smaller Hereford steers. Angus yearlings (lowest application rate) showed a semi-logarithmic decline in residues over time (Fig. 3). Angus hair differs in not being as thick and coarse as Hereford hair. The persistence of famphur on cattle hair appears to be related to the initial application rate and probably the breed and age of cattle treated. The generalization of rapid inactivation of OP insecticides was not true for famphur used as a pour-on.

If we assume that the toxicity of famphur to magpies is similar to the 2–4 mg/kg median lethal oral dose (LD_{50}) reported by Schafer et al. (1983) for red-winged blackbirds (*Agelaius phoeniceus*) and European starlings, then a magpie ingesting only 8–19 mg of contaminated hair (38,000 ppm) would receive a potentially lethal dose. By 60 days post-treatment when hair of some cattle contained 12,000 ppm, a potentially lethal dose would range from 26 to 60 mg of hair.

We also calculated the dose of famphur ingested per bird derived from the residue concentrations in the gizzard contents of the 13 dead magpies analyzed. By using mean concentrations and weights for each category (hair, animal matter, plant matter) and the magpie mean body weight for each sex, we estimated that males ingested 5.2 mg/kg famphur and females 6.1 mg/kg. These values are above the LD_{50} values, but are also a minimal estimate because additional famphur was found in the lower GI tract and carcass (see Table 3).

Metabolism-Excretion Studies.—Gatterdam et al. (1967), using tritium-labeled famphur, reported marked differences in metabolism and excretion patterns depending on species and method of administration (they used intramuscular and intravenous injection). None of the famphur metabolism or excretion studies we located in the literature used pour-on treatment. In sheep treated intramuscularly, the radioactivity in both plasma and urine decreased more slowly than in the intravenous treatment, but 64% of the administered dose was recovered in excreta after 72 hours. Gatterdam et al. (1967: 849) stated that this difference may be due to a "depot effect," i.e., 72 hours after intramuscular treatment, the muscle tissues at the injection site contained about 20 times as much radioactivity as muscle taken from sites removed from the injection area. They also indicated that nearly all of the radioactivity was excreted from sheep in the urine, with fecal elimination accounting for less than 3% of the administered dose. Extensive metabolism occurred with less than 1% excreted as famphur or famphur oxon—the other excreted metabolites were of low toxicity. This agrees with the low concentrations of famphur reported 1 day after treatment in manure samples during this study.

Although we located no absorption/excretion research with a pour-on treatment of famphur, studies with ^{32}P-labeled coumaphos (=Co-Ral®) were available. It is another OP systemic used against warbles in cattle. In marked contrast to high levels of excretion (37.3% and 34.9%) 10 hours after orally treating cattle, only 3.0% was excreted by dermally-treated cattle (McDuffie 1966). Low levels of radioactivity in the blood and urine and exceptionally high levels of activity on the hair were characteristic of all dermally treated animals. Based upon the rapid metabolism of famphur to primarily nontoxic metabolites in warm-blooded animals, the reduced excretion rates of coumaphos when dermally applied to cattle, and the high residues that persist on cow hair, it becomes quite clear that unabsorbed famphur remaining on the backs causes the magpie mortality.

Magpies Need for Hair?—Magpies perch on the backs of cattle (Kalmbach 1927, Linsdale 1937, Bent 1946), although the frequency was low during this study (only observed once during 2+ months of field activities). Kalmbach (1927:13) stated that the presence of hair of horses and cattle, the wool of sheep, and the bristles of hogs in magpie stomachs indicates they will accept as food almost anything of animal origin. The hair in gizzards from our study (12% of contents overall) provides evidence that the dead magpies ingested cattle hair (i.e., hair from magpies at ranches with Angus cattle was black and hair from ranches with Herefords was red). Cattle hair is common throughout the pastures on fences, feed bunkers, rubbing posts, wheel irrigation systems, etc. Shed cattle hair collected at random from two pastures 89 and 91 days post-treatment contained low levels of famphur (3.0, 3.7, 6.7, and 10 ppm). We do not know the proportion of hair ingested directly from the backs of treated cattle vs. shed hair from the other sources. Shed hair from other sources may account for the 5-day delay before mortality peaked.

Hair and feathers are almost pure crude protein (85->90%), but this keratin protein is not readily digestible in the natural state. Moran et al. (1967) developed a theory that cystine destruction (they used steam cooking under pressure) was necessary before hair proteins could be digested by chickens. Thus, we concluded that the nutrient value of hair ingested by magpies is low, at best, and perhaps nonexistent. Chickens on low protein diets sometimes crave feathers and will injure other chickens to obtain them (Fischer 1973), although no nutrients are gained from their ingestion. Another explanation for ingesting hair may be to aid in the formation of pellets which are cast to eliminate undigestible materials. The ejection of pellets by magpies in England was noted long ago (Cox 1864), although Linsdale (1937) observed the phenomenon only in captive magpies.

The ingestion of cattle hair by magpies (see Bock and Lepthien [1975] for distribution of magpies), which is now jeopardizing the magpies, may have first developed from the symbiotic relationship reported by Bent (1946:149) between magpies and wild ungulates (mule deer [*Odocoileus hemionus*], elk [*Cervus elaphus*], buffalo [*Bison bison*], and mountain sheep [*Ovis canadensis*]). Thus, the cow hair may be performing the function (unknown at this time) originally provided by wild ungulate hair.

Famphur-induced mortality of magpies can be eliminated by changing the insecticide application from the present pour-on method, which would eliminate residues from the cow hair. Drummond (1964, 1966, 1984) lists several systemic insecticides (including famphur) that are effective against cattle grubs when mixed with feed, given in capsule form, or applied by injection.

In conclusion, famphur applied at the recommended rate as a pour-on to control cattle warbles killed magpies. Magpie surveys provided a measure of population loss through mid-November, but we know additional magpies died in December and January. Although the magnitude of the population loss was not precisely known, the loss was substantial.

The magpie population decline that occurred throughout much of the West (Robbins et al. 1985) was temporally correlated with the appearance of famphur as a cattle grub treatment. However, the roles of habitat changes and other pesticides (including other pour-on treatments for grub control, e.g., fenthion [Hanson and Howell 1981]) cannot be totally discounted in the region-wide population decline. Some magpies were killed by heptachlor in the Columbia Basin in the late 1970's (Blus et al. 1979). Only low concentrations of DDE were reported in magpie eggs from Oregon in 1978 (up to 1.4 ppm fresh wet weight), and no eggshell thinning was observed from Oregon or Idaho in 1978 (Findholt and Trost 1983; C. J. Henny, unpubl. data).

We report a bird of prey killed by secondary poisoning after a legal application of an OP insecticide. Famphur secondary hazard work with common barn-owls (*Tyto alba*) (Hill and Mendenhall 1980) was initiated after a captive great horned owl (*Bubo virginianus*) died in Oregon when fed a famphur-killed magpie (Oreg. Dep. Fish and Wildl., unpubl. data). Laboratory work with barn-owls previously demonstrated famphur had potential for secondary poisoning. Our field study verifies such. Illegal poisoning of red-winged blackbirds, common grackles (*Quiscalus quiscula*), and European starlings with parathion-poisoned corn and rye in New York resulted in the deaths of two red-tailed hawks, a Cooper's hawk (*Accipiter cooperii*), and an American kestral (*Falco sparverius*) that consumed poisoned icterids (Stone et al. 1984). Perhaps the most severe OP case of secondary poisoning involving birds of prey occurred in Israel where about 400 raptors died from eating voles (*Microtus guentheri*) and birds that were poisoned with monocrotophos (=Azodrin®) (Mendelssohn and Paz 1977). Other OP mortality includes a harrier hawk (*Circus approximans*) killed by parathion and 42 by fensulfothion (=Dansanit®) in New Zealand (Mills 1973). The lack of OP secondary poisoning reports for birds of prey in North America may be due to the limited number of dead raptors being analyzed for ChE depression and OP residues.

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ACCESSING ACCURACY OF A RADIOTELEMETRY SYSTEM FOR ESTIMATING ANIMAL LOCATIONS

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Abstract: Accuracy of a radiotelemetry triangulation system for estimating locations of mule deer (*Odocoileus hemionus*) in northwestern Colorado was quantified using five fixed towers, each with a stacked, dual-Yagi antenna array and a null detection system. Replicate bearings were taken on radio transmitters placed at surveyed points. Bearings with absolute error >10° were considered signal bounce and excluded from bias and precision calculations. Remaining bearings were corrected for tower orientation bias. System precision was measured by the standard deviation of bearing errors. Bearing arcs ranged in size from 7.0 to 20.6° at $P = 0.05$. There was no difference in precision ($P = 0.38$) between observers, but there was a difference in precision ($P = 0.02$) of bearings to non-modulating and modulating signals by the same observer. Isopleths of error polygon area are displayed. Results are discussed with respect to system and study design.

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Radiotelemetry triangulation has become an increasingly popular technique for locating individual animals through time. This method involves attaching a frequency-specific radio transmitter to the animal and then estimating its location by intersection of two or more directional bearings. At any instant in time, bearings from receiving points to free-ranging animals are discrete, but bearings determined by radiotelemetry are estimates (Springer 1979). Too often investigators have treated radiotelemetry bearings, and subsequent locations, as exact and have failed to adequately test and report the accuracy of their techniques (Springer 1979, Hupp and Ratti 1983).

Accuracy of bearings estimated using radiotelemetry is a measure of discrepancy between true bearing and estimated bearing and has two components: error and precision. Error (e) is the difference between the true bearing (θ) and the estimated bearing ($\hat{\theta}$) defined as

$$e_{ij} = \theta_i - \hat{\theta}_{ij}$$

for each bearing i and replicate j. An error of a consistent nature is termed bias and is the average difference between estimated bearing and true bearing. One estimate of bias can be defined as

$$\bar{e} = \sum_{i=1}^{n} \sum_{j=1}^{r} e_{ij}/nr,$$

where n is the number of reference transmitter locations and r is the number of bearing replicates.

Precision is the repeatability or amount of variation of estimated bearings. One measure

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