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ZINC PHOSPHIDE: IMPLICATIONS OF OPTIMAL FORAGING THEORY AND PARTICLE-DOSE ANALYSES TO EFFICACY, ACCEPTANCE, BAIT SHYNESS, AND NON-TARGET HAZARDS

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NON-TARGET HAZARDS

PARTICLE-DOSE ANALYSES TO EFFICACY, ACCEPTANCE, BAIT SHYNESS, AND ZINC PHOSPHIDE: IMPLICATIONS OF OPTIMAL FORAGING THEORY AND NON-TARGET HAZARDS

ABSTRACT: The U.S. Department of Agriculture (USDA), Animal Plant and Health Inspection Service (APHIS) maintains six federal registrations for zinc phosphate (Zn₃P₂), three of these address the control of eight rodent species using steam-rolled oats (SRO) or wheat grains in diverse applications. Optimal foraging theory (OFT) and "particle-dose analysis" (PDA) afford predictions relevant to the efficacy, acceptance, bait shyness, and non-target hazards of these Zn₃P₂ baits. For PDA, numbers of SRO groats or whole wheat grains associated with acute oral median lethal (LD₅₀) or approximate lethal (ALD) doses of Zn₃P₂ were compared among nine target rodent and eleven non-target avian species. Key outcomes were: 1) mean (±S.D.) SRO groats and wheat grains weighed 23 (±9) and 18 (±9) mg, respectively; 2) published acute oral LD₅₀ values for Zn₃P₂ baits. For PDA, numbers of SRO groats or whole wheat grains associated with acute oral median lethal (LD₅₀) or approximate lethal (ALD) doses of Zn₃P₂ were compared among nine target rodent and eleven non-target avian species. Key outcomes were: 1) mean (±S.D.) SRO groats and wheat grains weighed 23 (±9) and 18 (±9) mg, respectively; 2) published acute oral LD₅₀ values for Zn₃P₂ baits. For PDA, numbers of SRO groats or whole wheat grains associated with acute oral median lethal (LD₅₀) or approximate lethal (ALD) doses of Zn₃P₂ were compared among nine target rodent and eleven non-target avian species. Theoretical implications of OFT and PDA to efficacy, acceptance, bait shyness (i.e., high reacceptance after ingestion of a sub-lethal dose); and 4) high specificity (i.e., high target species relative to nontarget species toxicity).

Zinc phosphate (Zn₃P₂, CAS # 1314-84-7) is an acute rodenticide used in agriculture, e.g., reduce vole populations to prevent "girdling" of orchard trees, reduce prairie dog populations to prevent range destruction in the Western U.S. (Hood 1972, Marsh 1988). Although used in rodent control for *80 years (Marsh 1988), efficacy, acceptance, bait shyness, and non-target hazards issues continue to impact the registration and use of the compound. In this paper, I present: 1) an overview of USDA/APHIS Zn₃P₂ registrations; 2) a PDA procedure for estimating consumed doses of Zn₃P₂ by target/nontarget species; 3) a synopsis of OFT relevant to the control of rodents with Zn₃P₂ SRO groat/grain baits; 4) theoretical particle-dose comparisons of 2% SRO groat and 1.82 % wheat grain baits for eight rodent (target) and eleven avian (nontarget) species; and 5) OFT and PDA implications to the efficacy, acceptance, bait shyness, and non-target hazard of these baits.

Zn₃P₂ REGISTRATIONS

FIFRA Section 3

Table 1 lists the products/target species/applications of the six Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 3 Registrations for Zn₃P₂ maintained by USDA/APHIS. Altogether, these registrations target 12 species in 15 agricultural applications. Three specify use patterns for either a Zn₃P₂ 2% SRO or 1.82% wheat bait to control meadow (Microtus pennsylvanicus), prairie (M. ochrogaster), pine (Pitymys pinetorum), and mountain voles (M. montanus), white-footed mice (P. maniculatus), black-tailed (Cynomys ludovicianus), white-tailed (C. leucurus), and Gunnison's prairie dogs (C. gunnisoni) (see No. 2, 3, and 5 in Table 1). The remaining three registrations target seven species using various Zn₃P₂ concentrate mixtures with apples, carrots, sweet potatoes, or meat-based baits (see No. 1, 4, and 6, plus Footnote 2, in Table 1).

Prohibitions for use of these products within the ranges of eight endangered species (ES) of birds or rodents are stated on the "use labels;" species are: whooping crane (Grus americana), Attwater's greater prairie chicken (Tympanuchus cupider attwater), yellow-shouldered blackbird (Agelaius xanthomus), Puerto Rican plain pigeon (Columba inorata weemore), Utah prairie dog (Cynomys parvidens), salt marsh harvest mouse (Reithrodontomys raviennis), Morro Bay kangaroo rat (Dipodomys leermannii), and Aleutian Canada goose (Branta canadensis leucopareia). All ES are cited for Registrations 1, 2, 3, 4, and 6, but only six are included on Registration 5 (depending upon identified geographical ranges of the ES and Zn₃P₂ application pattern or region of use). Certified Pesticide Applicators are also required to check/adhere to "county-by-county precautions" for other ES not specifically listed on the labels.

FIFRA Section 24(C)

Three FIFRA Section 24(C) Registrations to meet specific state applications of Zn₃P₂ are also held by APHIS (not shown in Table 1). These are: 1) Zn₃P₂ Concentrate for Marmot (Marmota flaviventris) and Black-tailed Jack Rabbit (Lepus californicus) Control
Table 1. Summary of six USD A/APHIS Zn₃P₂ Registrations (FIFRA Section 3) for rodent control; registration titles, target species, and applications cited on the "use labels" are provided.¹

<table>
<thead>
<tr>
<th>Product and Number</th>
<th>Target Species</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Zinc Phosphide Concentrate (63.2%) for Mouse Control (EPA Reg. No. 56228-6)²</td>
<td>Meadow and Pine Vole (<em>Microtus</em> spp.), White-footed mouse (<em>Peromyscus</em> spp.)</td>
<td>Orchards/groves (non-bearing phase)</td>
</tr>
<tr>
<td>2. Zinc Phosphide (1.82%) on Wheat for Mouse Control (EPA Reg. No. 56228-3)</td>
<td>Meadow, Prairie, Mountain, and Pine Voles (<em>Microtus</em> spp.), White-footed mouse (<em>Peromyscus</em> spp.)</td>
<td>Ornamentals, orchards/groves (non-bearing phase), vineyards, rangelands, forests, lawns, golf courses, parks, nurseries, and highway medians</td>
</tr>
<tr>
<td>3. Zinc Phosphide (2.0%) on Steam-Rolled Oats for Mouse Control (EPA Reg. No. 56228-5)</td>
<td>(Same as #1.)</td>
<td>(Same as #1.)</td>
</tr>
<tr>
<td>4. Zinc Phosphide Concentrate (63.2%) for Rat Control (EPA Reg. No. 56228-7)²</td>
<td>Norway (<em>Rattus norvegicus</em>) and Roof Rat (<em>R. rattus</em>)</td>
<td>Rat burrows and infested areas around homes, industrial, commercial, agricultural, and public buildings (CA, NV, OR only)</td>
</tr>
<tr>
<td>5. Zinc Phosphide (2.0%) on Steam-Rolled Oats for Prairie Dog Control (EPA Reg. No. 56228-14)</td>
<td>Black-tailed (<em>Cynomys ludovicianus</em>), White-tailed (<em>C. leucurus</em>), and Gunnison's Prairie Dog (<em>C. gunnisoni</em>)</td>
<td>Rangeland--Western U.S. (ND, SD, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY only)</td>
</tr>
<tr>
<td>6. Zinc Phosphide Concentrate (63.2%) for Muskrat and Nutria Control (EPA Reg. No. 56228-9)²</td>
<td>Muskrat (<em>Ondatra zibethicus</em>) and Nutria (<em>Myocaster coypus</em>)</td>
<td>Floating rafts and around active burrows adjacent to sugarcane or rice fields</td>
</tr>
</tbody>
</table>

¹USDA/APHIS may consolidate these registrations; the "concentrate" and "specific bait" labels will be merged into one (overall) or three (steam-rolled-oat, wheat, and concentrate) registration(s).
²The three "concentrate-type" products allow use of the technical product (63.2% A.l.) in bait preparations that promote efficacy of Zn₃P₂ during field operations. No. 1 mixes 6.4 g (level teaspoon) Zn₃P₂ per 1.101 l (1 qt.) of 1.27 cm (0.5 in.) apple cubes; No. 4 mixes 28.35 g (1 oz.) Zn₃P₂ per 1.82 kg (4 lbs.) of fresh meat (e.g., hamburger, canned dog/cat food); and, No. 7 mixes 48 g (7.5 level teaspoons) Zn₃P₂ per 4.54 kg (10 lbs.) of apple eights or 5.08 cm (2 in.) pieces of carrots/sweet potatoes, plus 30 ml (1 oz.) of corn oil.
One additional ES is specifically mentioned on the 24(C) labels; precaution for the black-footed ferret (Mustela nigripes) occurs on NM-810014.

Zn\textsubscript{3}P\textsubscript{2} TOXICITY

The toxicity of Zn\textsubscript{3}P\textsubscript{2} is attributed to the release of phosphine (PH\textsubscript{3}) gas as a result of hydrolysis with stomach acids. Death results from reduced electron transport due to cytochrome oxidase interactions in cell mitochondria causing a cessation of cellular respiration (Murphy 1986, Hazardous Substance Databank 1994).

Minimum-maximum LD\textsuperscript{50}/ALD doses cited for some mammalian and avian groups are: rodents 6.8 to 40.0 mg/kg, canids 40.0(ALD) to 93.0 mg/kg, gallinaceous birds 8.8 to 26.7 mg/kg, passerines 23.7 to 178.0 mg/kg, raptors \textgreater 20.0 mg/kg, and waterfowl 7.5 to 67.4 mg/kg (see Johnson and Fagerstone in press). Doses differ and vary greatly between/within species or studies. Primary hazards of grain baits are a main concern for gallinaceous birds, passerines, and waterfowl; whereas, indirect primary hazards via undigested Zn\textsubscript{3}P\textsubscript{2} loads in gastrointestinal (GI) tracts of target species (carcasses) can be a concern for canids, felids, and raptors (see Marsh 1988, Tkadlec and Rychnovsky 1990). A key attribute of the rodenticide’s toxicity is the illness effect associated with relatively small species or extremely toxic specific; still, single-/few-particle-lethal baits should be associated with relatively small species or extremely toxic rodenticides.

OPTIMAL FORAGING THEORY (OFT)

Assumptions

OFT affords numerous predictions for the effectiveness of acute rodenticide applications, especially hypotheses about granivorous rodents and grain baits (see Kamil and Sargent 1981, Kamil et al. 1987). The key assumption of OFT states that a foraging animal is motivated to maximize net energy gained per unit time feeding (Schoener 1987). Other relevant assumptions include: 1) animals make probabilistic-type decisions about the availability of foods in the environment (i.e., "patches" of food resources must afford sufficient energy returns during feeding or else "search behaviors" are initiated); 2) "switches" to alternative foods (baits) by animals are based upon declines in energy yields from preferred foods; 3) local predation factors (e.g., predator densities, predator-rodent encounters) are inversely related to the time expended by rodents in food-search and above-ground activities; and 4) handling times of specific food items affect ingestion rates and energy yields.

Derivations to Acute Rodenticides

OFT offers numerous hypotheses relevant to efficacy, acceptance, bait shyness, and non-target hazard issues surrounding Zn\textsubscript{3}P\textsubscript{2} bait applications. Bait formulation/delivery and rodent foraging behavior must be examined relative to rodent-control methods.

That olfaction, search rate, bait distribution, and habitat density affect bait pick up by rodents has been discussed (Reidinger and Mason 1983); however, other factors also must be considered. Highly odor-sensitive, fast-searching rodents have greater likelihoods of discovering dispersed bait particles than odor-insensitive, slow-searching rodents. This alludes to the need for highly palatable, energy laden, alternative bait products. Under conditions of high bait density (e.g., 10 lbs/acre broadcast), target/nontarget species should find, handle, and consume larger numbers of individual bait particles than under low bait density applications (e.g., 2 lbs./acre broadcast)—the formulation/distribution of baits impacts the probability of bait encounters by target/nontarget species. Behaviorally, encounters with predators or predator signs have been shown to decrease the number of food-search bouts, but to increase rates or gaits of above-ground ambulation, by granivorous desert rodents (Reichman 1981).

The toxicity of individual baits to the target/nontarget species affects efficacy/hazard. Use of "single-/few-particle-lethal baits" reduces the foraging time and particle ingestions needed to deliver a cumulative lethal dose to given animals; whereas, use of "multiple-particle-lethal baits" increases the required foraging time, bait-handling time, and particle ingestions needed for lethal dose delivery. These dose characteristics are specific; still, single-/few-particle-lethal baits should be associated with relatively small species or extremely toxic rodenticides. I contend that multiple-particle-lethal baits increase the probability for onset of hydrolysis-induced GI effects in rodents via intermittent, small quantity intakes and lead to bait shyness. Interruptions of feeding bouts are more likely for rodent species (and individual animals) that require multiple particles for receipt of a cumulative lethal dose.

PARTICLE-DOSE ANALYSIS (PDA)

Assumptions

For current purposes, PDA is a theoretical approach to investigating the "particle toxicity" of a rodenticide. It involves estimates of specific numbers of treated grains needed for ingestion of LD\textsuperscript{50} or ALD doses by target/nontarget species. Present analyses are limited to the 2.0% Zn\textsubscript{3}P\textsubscript{2} SRO and 1.82% Zn\textsubscript{3}P\textsubscript{2} wheat grain baits cited under the Section 3 Registrations (see No. 2, 3, and 5 in Table 1). Assumptions of PDA are that: 1) a sufficient number of toxic bait particles for delivery of lethal doses are available to the target/nontarget animals as a result of baiting schemes; 2) acute oral LD\textsubscript{50} and ALD doses are directly related to lethal concentration (LC) doses under conditions of uninterrupted feeding; and 3) accurate nominal formulation and homogeneous adherence of Zn\textsubscript{3}P\textsubscript{2} (technical product) to each bait particle occurs.
Formulas
To conduct the present analyses, 100 SRO groats and 100 wheat grains were weighed. Although SRO groats is not the actual registered product (groats refer to the hulled SRO), weights of these products are essentially equal. Mean (±S.D.) weights of groat and wheat particles were 23 (±9) and 18 (±9) mg, respectively. Assuming homogeneous distribution of Zn₃P₂ on groats/grains, the general particle-dose formula is:

Particle Zn₃P₂ = [Mean Particle Weight (mg) X ZnP₂ Concentration (96)].

Substituting the 23 and 18 mg mean weights for the registered 2% SRO groat and 1.82% wheat baits, mean particle Zn₃P₂ is estimated at 0.46 and 0.33 mg, respectively.

The theoretical LD₅₀/ALD particle-dose formula is:

Particles to LD₅₀/ALD = Species LD₅₀ or ALD (mg/kg) X body weight (kg)
Mean Particle Zn₃P₂ (mg)

where the mean amounts of Zn₃P₂ are 0.46 mg/SRO groat and 0.33 mg/wheat grain, respectively. For example, consider the hypothetical case of a 0.5 kg rodent species found to have an LD₅₀ of 10 mg/kg and baited with 2% SRO groats; computation yields [(10 mg/kg X 0.5 kg) - r 0.46 mg] or that 10.9 groats must be ingested by each rodent to lethally dose < 50 % of the rodents.

THEORETICAL EFFICACY AND ACCEPTANCE
Some Definitions
"Theoretical particle efficacy" refers to the calculated number of groat/grain particles associated with ingestion of lethal acute oral doses of Zn₃P₂ by target species. This differs greatly from "actual particle efficacy" which refers to the numbers of grains ingested during the natural foraging bouts of particular species and from "product performance efficacy" which refers to the field reduction in rodent activity following bait application(s). For the latter term, Pesticide Assessment Guidelines (PAGs) for Subdivision G, Product Performance Tests (§ 96-12) set a minimum 70% reduction-in-rodent-activity criterion for registration of agricultural rodenticides (Schneider 1982). PDA Comparison for Target Species: Efficacy and Acceptance
Table 2 presents typical body weights, reported LD₅₀/ALD values, and computed theoretical numbers of 2% SRO groat or 1.82% wheat grains associated with acute oral doses of Zn₃P₂ for the nine target species listed in these three bait registrations. Zn₃P₂ is highly toxic to these species. Published minimum-maximum LD₅₀ values are 16.2 to 18.0 mg/kg (i.e., prairie vole vs. meadow vole and black-tailed prairie dog), while a lone ALD of 42.0 mg/kg was found for white-footed mouse. For the two rodents listed on both SRO and wheat labels (meadow vole and white-footed mouse), more of the lighter/less-toxic wheat grains are required to attain LD₅₀/ALD doses than the heavier/more-toxic SRO groats; however, body weight interacts with toxicity to determine number of particles associated with the published doses. Whereas short-term intake of <1-3 and <2-4 particles of SRO groats and wheat grains should prove lethal to <50% of target voles and <100% (ALD) of white-footed mice (deer mice), respectively, short-term consumption of >40 SRO groats is expected to cause death in =»50% of prairie dogs.

OFT and PDA Implications: Efficacy and Acceptance
OFT and PDA offer several implications to the efficacy and acceptance of Zn₃P₂ groat/grain baits:
1) Specific forms of Zn₃P₂ baits are "best viewed" as a case of diet selection rather than an optimal energy source; palatable, preferred formulations of baits are essential to cause target rodents to "switch" to alternative foods.
2) Timing of bait applications should coincide with non-crop cycles because acceptance of alternative foods should occur more readily at times when the preferred forage is depleted/harvested.
3) Zn₃P₂ is expected to be most efficacious for voles and mice, rodents for which the groats/grains are 1 to 4 particle lethal.
4) Aerial or mechanical broadcast which distributes particles widely should also prove effective for voles and mice (<4 particles lethal); whereas, localized dense applications (e.g., site baiting at burrow openings) with small amounts of bait (e.g., »10 g equals 435 SRO groats or 556 wheat grains) should be more effective with prairie dogs that require >38 particles for median lethality. Interestingly, many of these implications characterize current baiting techniques.

THEORETICAL BAIT SHYNESS
Historical Background
The term "bait shyness" was coined by Rzoska (1953). In a set of five experiments with white and brown rats, he noted that survivors of initial presentations of arsenic, red squill, and barium carbonate baits developed "a cautious attitude towards food (and poison bait) experienced previously with harmful effects". Rzoska (1953) stated four main results:
1) An identical poison bait was refused on successive occasions.
2) A new poison in a base harmfully experienced was rejected.
3) An experienced poison in a new base was accepted.
4) A new poison in a new base was accepted.

Rodent Feeding Patterns
Laboratory studies have characterized the food-ingestion patterns of rodents (e.g., Le Magnen 1971, Sterner 1982). For example, data indicate that the majority of rats eat <70% of their daily food intake as 8 to 12 "meals" during the nocturnal portion of the diurnal cycle. In addition, several investigators have reported a positive correlation between the size of a meal and the length of the subsequent inter-meal interval (Le Magnen 1972, Panksepp 1973). Such evidence has implications to Zn₃P₂-particle baits.
Table 2. Theoretical particles of Zn₃P₂ SRO groats and wheat grains associated with LDS₉₀/ALD doses for eight target rodents cited on use labels.¹

<table>
<thead>
<tr>
<th>Species</th>
<th>Typical Body Weight (kg)</th>
<th>Zn₃P₂ LD₉₀ or ALD (mg/kg)</th>
<th>SRO Groats (2.0%)</th>
<th>Wheat Grains (1.82%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine Vole²</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Meadow Vole</td>
<td>0.04</td>
<td>18.0</td>
<td>1.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Prairie Vole</td>
<td>0.035</td>
<td>16.2</td>
<td>2.7 (ALD)</td>
<td>3.8 (ALD)</td>
</tr>
<tr>
<td>Mountain Vole²</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>White-footed Mouse</td>
<td>0.03</td>
<td>42.0 (ALD)</td>
<td>2.7 (ALD)</td>
<td>3.8 (ALD)</td>
</tr>
<tr>
<td>Black-tailed Prairie Dog</td>
<td>1.0</td>
<td>18.0</td>
<td>39.1</td>
<td></td>
</tr>
<tr>
<td>White-tailed Prairie Dog²</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gunnison’s Prairie Dog²</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

¹LD₉₀/ALD values from Johnson and Fagerstone (in press); dual values for the same species reflect multiple reports of acute oral toxicity cited in the literature. Mean Zn₃P₂/SRO groat is 0.46 mg (2.0%), and mean Zn₃P₂/wheat grain is 0.33 mg (1.82%).
²Published LD₅₀/ALD values not found or not available. (Note—Blanks indicate that the species is not listed as a target for that bait.

Figure 1 is a plot of the three-day, minute-by-minute, single-choice (ground chow) food intake measurements obtained for eight albino rats using a computerized food-intake measurement system (Sterner 1982). Note the distinctive patterns evident for the various animals. The top four records show that these rats ate larger, less frequent meals followed by pronounced "non-feeding bouts". In contrast, the bottom four records indicate that these rats ate smaller, more frequent, more intermittent amounts of chow. I call these "meal-eater patterns" and "nibbler patterns," respectively. Whether these were acquired from feeding experiences or genetically-transmitted behaviors is uncertain; nevertheless, the implication is clear. Certain rodents within target species appear more likely than others to ingest multiple particles of Zn₃P₂ groats/grains than others. "Meal-eaters" should ingest lethal doses of rodenticides frequently, with "nibblers" being likely candidates for bait shyness. Prebaiting is viewed to enhance meal characteristics.

PDA Comparison for Target Species: Bait shyness

Although Zn₃P₂ is often described as a "single-dose" rodenticide (Gratz 1973), this term requires careful definition. It refers to the one-time ingestion of a lethal dose by rodents, not the single-particle-lethal attribute sought for some acute rodenticides.

Data in Table 2 suggest that bait-handling times and particle-ingestion rates differ among the target species. A hierarchy of particles needed for lethality is evident. More groat/grain particles are required for lethal dose ingestions by prairie dogs than by white-footed mice and voles. This relates to the onset of bait shyness. Essentially, longer bait-ingestion sessions and greater food-handling times associated with multiple-particle-dose ingestions are expected to correlate with greater frequencies of bait shyness in and prairie dogs (38 to 58 particle lethal doses) than in mice and voles (2 to 4 particle lethal doses). This would be aggravated by broadcast applications for prairie dog control where foraging for large numbers of particles would allow ample time for onset of Zn₃P₂ hydrolysis in the GI tract before fatal doses had been ingested by rodents.

OFT and PDA Implications: Bait shyness

A number of theoretical implications concerning Zn₃P₂-induced bait shyness effects can be derived from OFT and PDA:

1) Species that require more or longer bait-particle handling are predicted to display greater frequency of bait shyness due to greater chances for interruptions of feeding and onset of GI disturbance.

2) Increased predation is predicted to increase the frequency of bait shyness of target rodents by causing shorter, faster above-ground food searches and reduced meal size (nibbling).

3) Social dominance relationships affecting specific rodent species are predicted to increase bait...
Figure 1. (A) Minute-by-minute food-intake patterns of eight albino rats during continuous three-day ad libitum, single-choice feeding tests (Rat 1 = top...Rat 8 = bottom). (Note: The dashed portion of each abscissa refers to a one-hour maintenance period between 0800-0859 hours daily; no food measurements were recorded during this period.) (B) Enlargement of the consumption by Rat 1 between 2200 and 0130 hours of Day 1. (Reprinted courtesy of The Psychonomic Society from Sterner 1982.)

4) Aerial or mechanical broadcast should prove effective for voles and mice (widely dispersed particles, but _<.4 particles lethal); however, these bait applications would be expected to increase the frequency of bait shyness for prairie dogs because of the increased likelihood for spaced, interrupted intakes during foraging for _>39 particles.

THEORETICAL NONTARGET HAZARDS
PDA Comparison for Nontarget Species: Primary Hazards

Table 3 presents LD10/ALD values and PDA calculations of the SRO groat and wheat grain baits for 11 nontarget avian species. Two features of these data are obvious: the wide variability in particle-dose estimates both within and between species and the high toxicity of Zn3P2 to these species. The first feature mirrors the large range in LD10/ALD values reported by different investigators for the same or different species (Johnson and Fagerstone in press). The second feature reflects the relatively non-specific action of Zn3P2 (Gratz 1973, Hood 1982, Marsh 1988, Johnson and Fagerstone in press).

With nontarget avian species, foraging behavior is probably a more important consideration than either LD50/ALD or body weight. For example, certain species of gallinaceous birds may not forage or spend much time in habitats listed on the "use labels" (e.g., rangelands). Thus, the current comparison must be treated cautiously. Nevertheless, as for the target rodents, more of the lighter, less-toxic wheat grains than the heavier/more-toxic SRO groats are required to produce mortality in nontarget species; but, as before, body weight determines particle to lethal dose within species. Fewest particles are estimated to produce mortality for the house sparrow, with _<1 to 3 and _>2 to 5 groats and grains estimated to cause _>100% mortality in adults of this species, respectively. Minimum and maximum SRO groat particles for _=50% lethality of the remaining bird species varied from 3.6 (red-winged blackbird) to 175.8 (mallard duck), depending upon which published LDM was utilized. Similar estimates involving wheat grains vary from 5.0 (red-winged blackbird) to 245.1 (mallard duck). Noteworthy, are particle estimates for bobwhite and California quail (_<5 and _>7 SRO groats and wheat grains, respectively), and ring-necked pheasant (_<19-58 and _>27-79 SRO groats and wheat grains, respectively); these species yield very low particle estimates and have been cited as at risk of primary hazards from Zn3P2 groat/grain bait applications (see Johnson and Fagerstone In Press). The PDA values for waterfowl (i.e., Canada goose, snow goose, and mallard duck) range between _>34 particles (SRO groats, mallard duck) to _<245 (wheat grains, mallard duck), and waterfowl have been historically cited as species at risk of greatest primary hazard (Marsh 1988, Johnson and Fagerstone in press).
Table 3. Theoretical particles of SRO groats and wheat grains to LD₉₀/ALD for 11 selected non-target avian species (primary hazard).

<table>
<thead>
<tr>
<th>Species</th>
<th>Typical Body Weight (kg)</th>
<th>Zn₃P₂ LD₉₀ (mg/kg)</th>
<th>SRO Groats (2.0%)</th>
<th>Wheat Grains (1.82%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada Goose</td>
<td>5.0</td>
<td>12.0</td>
<td>130.4</td>
<td>181.8</td>
</tr>
<tr>
<td>Snow Goose</td>
<td>3.0</td>
<td>8.8</td>
<td>57.4</td>
<td>80.0</td>
</tr>
<tr>
<td>Mallard Duck</td>
<td>1.2</td>
<td>13.0-67.4</td>
<td>33.9-175.8</td>
<td>47.3-245.1</td>
</tr>
<tr>
<td>Northern Bobwhite Quail</td>
<td>0.17</td>
<td>12.9</td>
<td>4.8</td>
<td>6.6</td>
</tr>
<tr>
<td>California Quail</td>
<td>0.17</td>
<td>13.5</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Ring-necked Pheasant</td>
<td>1.0</td>
<td>8.8-26.7</td>
<td>19.1-58.0</td>
<td>26.7-78.8</td>
</tr>
<tr>
<td>Domestic Chicken</td>
<td>1.5</td>
<td>24.0-26.0</td>
<td>78.3-84.8</td>
<td>109.1-118.2</td>
</tr>
<tr>
<td>Mourning Dove</td>
<td>0.13</td>
<td>34.2</td>
<td>9.7</td>
<td>13.5</td>
</tr>
<tr>
<td>House Sparrow</td>
<td>0.03</td>
<td>20-50 (ALD)</td>
<td>1.3-3.3 (ALD)</td>
<td>1.8-4.5 (ALD)</td>
</tr>
<tr>
<td>Red-winged Blackbird</td>
<td>0.07</td>
<td>23.7-178.0</td>
<td>3.6-27.1</td>
<td>5.0-37.8</td>
</tr>
<tr>
<td>Horned Lark</td>
<td>0.07</td>
<td>47.2</td>
<td>7.2</td>
<td>10.0</td>
</tr>
</tbody>
</table>

1LD₉₀/ALD values from Johnson and Fagerstone (in press); dual values for the same species reflect multiple reports of acute oral toxicity cited in the literature. Mean Zn₃P₂/SRO groat is 0.46 mg (2.0% of 23 mg), and mean Zn₃P₂/wheat grain is 0.33 mg (1.82% of 18 mg).

2The scientific names for the listed nontarget species are: Canada goose (Branta canadensis), snow goose (Chen caerulescens), mallard duck (Anas platyrhynchos), northern bobwhite quail (Colinus virginianus), California quail (Callipepla californica), ring-necked pheasant (Phasianus colchicus), domestic chicken (Gallus gallus), mourning dove (Zenaida macroura), house sparrow (Passer domesticus), red-winged blackbird (Agelaius phoeniceus), and horned lark (Eremophila alpestris).

OFT and PDA Implications: Nontarget Hazards

OFT and PDA results imply that the high, non-specific toxicity of Zn₃P₂ to avian species warrants detailed studies/analyses of specific nontarget avian foraging patterns related to the registered applications. Mitigations to limit bait-application times, exposure patterns, and local use must be carefully devised and followed to reduce nontarget primary hazards of groat/grain particles in all Zn₃P₂ applications.

CONCLUSIONS

Zn₃P₂ is an acute rodenticide that has been used safely for years. Recent outbreaks of Hantavirus Pulmonary Syndrome (HPS) have demonstrated the often unexpected need for acute rodenticides (Childs 1994). Published acute oral toxicity values coupled with PDA comparisons confirm that Zn₃P₂ groat/grain baits are highly toxic to the target species—attribute 1 of an effective acute rodenticide (Gratz 1973). OFT and PDA suggest that Zn₃P₂ will be most efficacious for voles/mice species requiring <4 particles to ingest a lethal dose. Aerial or mechanical broadcast bait application which distributes particles widely should prove effective for these rodents; whereas, localized, site baits at burrow openings with small amounts of bait (<10 g; 435 SRO groats) should be more effective with prairie dogs—a species requiring >39 particles for <50% lethality.

Avoidance of Zn₃P₂-induced bait shyness depends upon rodent consumption of sufficient lethal groats/grains in a relatively short feeding bout-attributes 2 and 3 of Gratz (1973). PDA suggests that bait shyness is less probable in voles/mice that require only two to four particles of bait but more likely in prairie dogs that must ingest >39 particles, probably over a longer time span. OFT implies that rodents which can forage uninterrupted (absence of predators, lack of social dominance hierarchies, etc.) have greater chances for consuming larger, grain-bait meals (lethal doses of Zn₃P₂).

Finally, a review of reported LD₉₀/ALD values for nontarget species indicates that Zn₃P₂ is not highly specific—attribute 4 of Gratz (1973). Safe use relies heavily upon selective, mitigation procedures linked with appropriate baiting techniques. Studies of the foraging patterns of nontarget species in relation to groat/grain preference and consumption are needed to further improve the selectivity of these techniques.
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LITERATURE CITED