HAZARDS TO BIRDS FROM ZINC PHOSPHIDE RAT BAIT IN A MACADAMIA ORCHARD

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Oat groat baits, containing 1.88% zinc phosphide (Pank 1976), have been broadcast into sugarcane fields in Hawaii since 1970 to control damage by Polynesian (Rattus exulans), Norway (R. norvegicus), and black (R. rattus) rats. No avian mortality related to zinc phosphide baits has been documented, although Hilton et al. (1972) demonstrated that several bird species consume the bait in sugarcane fields. Previous studies (Glahn and Lamper 1983) suggested that acute hazards to birds were prevented where bait was dispersed in thick vegetation and by physiological or behavioral traits of granivorous birds, such as shyness toward new food items or regurgitation before absorption of a lethal dose.

The same bait is registered for use in macadamia orchards in Hawaii to control crop loss to black rats. Among other uses, the registration allows broadcast baiting of orchards and adjoining areas. Pank et al. (1978) detected no evidence of bird mortality when the bait was broadcast in vegetated windbreaks and wasteland adjacent to macadamia orchards. However, lack of ground cover in mature orchards greatly increases accessibility of bait to birds and might be expected to increase hazards to nontarget organisms. We undertook this study to assess acute hazards to nontarget birds posed by a worst-case application of zinc phosphide baits in a bare ground orchard.

METHODS

Study Design

We conducted the study from 16 June through 1 July 1981 in a low-elevation orchard near Keau, Hawai'i Island. Nearly complete canopy cover and cultural practices in this orchard excluded most understory vegetation. We defined 3 blocks, each consisting of a 14.2-18.2-ha treatment field and a paired control field. Trees were ≥30 years old and planted in a 7.6-m grid pattern. Control fields were paired with treatment fields based on surrounding habitat, projected orchard work patterns, tree condition, and general field configuration. Mean minimum distance between treatment and respective control fields was 1,128 m. All fields had little ground cover. Leaf litter and other debris were removed mechanically 7-10 days before the study began. Orchard activity was suspended in the 6 fields during the study, but continued in surrounding fields.

The avian community, comprised primarily of the northern cardinal (Cardinalis cardinalis), spotted dove (Streptopelia chinensis), zebra dove (Geopelia striata), common mynah (Acridotheres tristis), and the largely insectivorous Japanese white-eye (Zosterops japonica), was representative of avifauna in other bare ground orchards. Other than the Hawaiian hawk (Buteo solitarius), no indigenous Hawaiian birds were observed, although the short-eared owl (Asio flammeus sandwichensis) may have been present. Hazards to hawks and owls were not assessed because available data indicate little secondary risk from zinc phosphide (Evans et al. 1970, Hood 1972, Bell and Dimmick 1975, Tietjen 1976).

Bait consisted of 1.88% active ingredient zinc phosphide adhered to slightly crimped oat groats with 2% Alcolec-S. (Use of trade names does not imply endorsement by the federal government.) Tracerite, an inert UV fluorescent tracer, was added at 0.1% with the zinc phosphide to label birds that consumed bait. We applied the maximum permitted application of bait, 5.62 kg/ha, using a truck-mounted blower unit to treatment fields between 0700 and 1330 on 20 June 1981. Control areas received no bait because application of nontoxic oats might have acted as prebait, artificially increasing the hazard from the toxic bait.

Evaluation

Population Impact.—We estimated density of seed-eating birds by line transect surveys and indexed bird activity with mist nets. We surveyed each field for 5 days before (days -5 to -1) and 5 days after (days
+1 to +5) treatment. Survey lines terminated 38–76 m short of the mist net area in each field. Fields were not surveyed or netted on the treatment day (day 0).

Results of preliminary surveys indicated that 1,676 m of transect line in each field had to be walked daily to record 40 bird observations. We recorded the perpendicular distance from transect lines for each visual observation of a seed-eating bird. Each of 3 observers surveyed only fields within 1 block and the survey order (treated vs. control) was reversed daily. Other activity within the survey areas was discontinued ≤2.5 hours before surveys. We ran surveys between 1100 and 1200 because our preliminary studies indicated that bird densities peaked and remained relatively stable at that time.

Estimated densities were calculated with the Fourier series estimators used in program TRANSECT (Laake et al. 1979, Burnham et al. 1980). We analyzed the estimated daily density of seed-eating birds in each field for 5 days before and 5 days after treatment in a 2-factor (treatment × period) repeated-measures analysis of variance (ANOVA) (Winer 1971).

We operated 4 mist nets/field, with 2 teams raising and lowering nets in the same order in each field beginning at about 0700 and 1700, respectively. Nets were checked at 45–60-minute intervals. Captured birds were identified, sexed, aged, weighed, banded, tagged on the tarsus, and released at the capture site.

Cardinals and spotted doves together constituted >95% of birds captured, but captures of cardinals dropped rapidly after day −4, whereas captures of spotted doves fluctuated randomly throughout the study. Therefore, we conducted separate analyses for cardinals and spotted doves. We calculated daily net capture rates (birds per net hour) for each species in each field and analyzed these data using the ANOVA design described above.

Mortality and Survival.—We searched for bird carcasses on predetermined tree rows spaced uniformly throughout each treated field and in windbreaks adjacent to each treated field from 0700 to 0830 daily for 5 days before and after treatment. This search pattern provided representative coverage of about 25% of the treated area in each field. Mortality was attributed to poisoned bait if tracerite was present in gastrointestinal tracts.

Mist Net Captures.—Species composition from birds captured after treatment for tracerite at 60X magnification under UV light to estimate the percentage of birds consuming bait. Nineteen pretreatment samples were examined in the same manner to assure absence of tracerite mimics in the study area. Fisher’s exact test was used to compare daily percentages of tracerite-marked cardinals and spotted doves in the treatment fields.

We assessed persistence of bait and removal by birds on 10 randomly located pairs of 0.42-m² plots in each treated field. Each pair consisted of an exposed plot and a plot screened with 2.5- × 5.1-cm hardware cloth to exclude birds but admit insects and rodents. Members of each pair were placed 7.6 m apart and equidistant from tree rows. Immediately after treatment, each plot was standardized to contain 12 toxic oats corresponding to expected density of bait applied at 5.62 kg/ha. The amount of bait remaining was recorded daily from 0700 to 0830 hours on days +1 through +5 and analyzed as a 3-factor, repeated-measures ANOVA with repeated observations on 2 factors (Winer 1971). That is, of the 3 factors in the design (fields, exposure, days), each experimental unit (paired plots in a field) was observed at both exposure levels on each of the 5 days.

Sublethal Effects.—Weights of mature spotted doves (sexes combined) captured before and after treatment in treated and control fields were pooled across blocks. We analyzed these data as a 2 × 2 (treatment × period) ANOVA with unequal sample sizes (Helwig and Counsil 1979, PROC GLM) to detect short-term weight losses associated with bait consumption. Weights of adult male northern cardinals were analyzed similarly. Female cardinals were not analyzed because we could not accurately distinguish immature males from adult females.

RESULTS

Population Impacts

Density.—Mean daily density of birds in the 6 fields declined from 2.48 birds/ha before treatment to 2.24 birds/ha after treatment (Table 1). The decline was equal in the treated and control fields (10.87 and 10.90%, respectively). Differences were detected only among blocks ($F = 21.38; 2,16 df; P < 0.001$) and daily ($F = 3.04; 8,16 df; P = 0.028$) means. The effect of period and the treatment × period interaction were not significant ($P > 0.20$). Lack of a significant treatment × period interaction indicates treatment had no discernible impact on the total population of seed-eating birds.

Mist Net Captures.—Species composition of 286 birds captured on days −5 through
Table 2. Percentage of birds marked before treatment that were recaptured after treatment with zinc phosphide bait in macadamia orchards in Hawaii, 1981.

<table>
<thead>
<tr>
<th></th>
<th>Northern cardinal</th>
<th>Spotted dove</th>
<th>Total birds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment</td>
<td>Control</td>
<td>Treatment</td>
</tr>
<tr>
<td>Block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14.8</td>
<td>16.7</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>7.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( \bar{x} )</td>
<td>7.5</td>
<td>5.6</td>
<td>6.7</td>
</tr>
</tbody>
</table>

+5 (55.2% spotted dove, 39.9% northern cardinal, 4.9% zebra dove and common mynah combined) was similar to that observed during the density surveys (62.2, 35.9, and 1.9%, respectively, \( n = 1,789 \)). Capture rates for the spotted dove (Table 2) fluctuated without discernible pattern, increasing slightly in treated fields and decreasing in control fields after treatment, but the difference was not significant \((P > 0.15)\).

Capture rates of cardinals tended to be high on day \(-5\), but dropped rapidly thereafter (Table 3) \((F = 5.34; 8,16 \text{ df}; P = 0.002)\), suggesting that cardinal populations either became net shy or were adversely affected by mist netting. Mean daily capture rates for this species declined about 60% post-treatment in both treated and control fields, but the period difference was not detected statistically. An interaction of treatment with period could not be detected for either species, indicating that a treatment effect, if any existed, was not substantial.

**Mortality and Survival**

**Mortality Surveys.**—We found 1 dead nestling spotted dove and 1 dead adult Japanese white-eye before treatments. Three dead adult spotted doves were found after baiting; one contained tracerite, but only wings remained from the others. No labeled carcasses were found elsewhere in the orchard, although orchard personnel were requested to collect dead birds during the study period. Mongooses
Table 3. Ratios of spotted doves and northern cardinals testing positive for tracerite used to mark zinc phosphide bait in macadamia orchards in Hawaii, 1981.

<table>
<thead>
<tr>
<th>Species</th>
<th>Baited field</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Spotted dove</td>
<td>F</td>
<td>1:2</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>2:3</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>3:4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6:9</td>
</tr>
<tr>
<td>Northern cardinal</td>
<td>F</td>
<td>4:6</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>1:1</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2:2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7:9</td>
</tr>
</tbody>
</table>

* No. positive: No. captured.

(Herpestes auropunctatus) may have scavenged dead birds between searches, but mist net and survey crews found no carcasses or other evidence of mortality.

Capture-Recapture.—Eight cardinals, 16 spotted doves, and 1 common mynah were killed in the nets by mongooses and Hawaiian hawks. Of the 261 birds tagged and released, only 24 (9.23%) were subsequently recaptured. Proportionately more cardinals (15.1%) than spotted doves (4.9%) were recaptured. All recaptured birds were caught in the field of initial capture. Overall, a greater percentage of pretreatment tagged cardinals, spotted doves, and total birds were recaptured after baiting in the treated than in the control fields (Table 2), but differences were not significant in any category.

Bait Consumption

Tracerite.—Fecal samples from 56% of birds captured in nets after treatment in the baited fields were tracerite-positive. None of 50 post-treatment control or 19 pretreatment fecal samples tested positive for tracerite.

Proportionately more cardinals than spotted doves tested positive for tracerite in all fields (Table 3). Small sample size and the fact that no cardinals were captured on days +3 through +5 precluded interspecific comparison of labeling rates in 2 fields, G and H. However, in the third baited field, field F, interspecific differences in the ratio of marked : unmarked birds did not differ significantly. No zebra doves (n = 3) tested positive for tracerite. No mynahs were captured after treatment in baited fields.

We could not determine when the labeled birds consumed bait because of prolonged retention of tracerite (>48 hr in cage tests), but the overall pattern, based on limited sample size, suggested high initial consumption by both species. The general decline in consumption of zinc phosphide baits over time in other studies (Glahn and Lamper 1983, Nicolaus et al. 1983) was consistent with development of sublethal aversion. In our study the bait apparently remained in acceptable condition throughout the test period, and the rate of consumption in field F suggested that bait availability was adequate to expose birds through day +5 (Fig. 1).

None of the birds testing positive for tracerite appeared sick. We did not observe diarrhea, common among geese suffering sublethal zinc phosphide poisoning (Glahn and Lamper 1983). Survival was confirmed for only 2 cardinals, both strongly tracerite-positive when first captured. One was weakly labeled when recaptured 24 hours later (day +2); the other was recaptured 7 days later (+9), but was not checked for tracerite.

Bait-Removal Plots.—Although presence of tracerite confirmed that birds consumed bait,
bait disappearance over time was similar on covered and exposed plots within each field ($P > 0.30$ for exposure and the exposure interaction effects) (Fig. 1). Lack of treatment separation suggested that variation in bait loss resulting from extraneous factors obscured loss of the small quantities of bait consumed by birds.

In all fields, bait was lost rapidly at first, followed by slow attrition through day +5. Overall means of about 35 and 50% of the bait were missing on days +1 and +4, respectively. Atypically dry weather during the monitoring period (1.02-mm total rainfall) likely extended bait persistence and maximized potential for avian hazards. Ants may have caused much of the bait loss observed during the monitoring period. In all fields we observed ants making caches of $\geq 50$ oats under rocks and in rat burrows in the vicinity of ant colonies. We assume the rapid bait loss in field F was caused by ants.

**Weight Loss**

The bait treatments had no detectable impact on weights of exposed birds. Treatment, period, and period $\times$ treatment effects were insignificant for both the cardinal ($P > 0.40$ for all effects) and the spotted dove ($P > 0.30$ for all effects). Mean weights of tracerite-positive cardinals, 41.5 g ($n = 5$), and spotted doves, 152.6 g ($n = 16$), were similar to pre-treatment weights, 40.7 g ($n = 33$) and 155.5 g ($n = 65$), respectively.

**DISCUSSION AND CONCLUSIONS**

For northern cardinals, no acute lethal risk from exposure to zinc phosphide bait was demonstrated. Although $>70\%$ of cardinals netted in treated fields had consumed bait, no carcasses were found, and no significant changes in density were detected during the study period. The 2 cardinals recaptured after consuming bait recovered. Treatment-related weight changes were not apparent.

Results for spotted doves were less conclusive. Papaya seeds in gizzards of many of the spotted doves killed during mist netting demonstrated that this species commonly fed in papaya groves outside the orchard. Given their high mobility, spotted doves may have died outside the carcass search area and been replaced by nonresident birds. Against this possibility, no carcasses were recovered elsewhere in the orchard and limited field interchange was suggested by the fact that all recaptured spotted doves were netted in the field of initial capture, and no tracerite was detected in control field birds. Thus, other than the single positive carcass, we found no evidence of acute treatment hazard to spotted doves.

Spotted doves and northern cardinals together accounted for about 98% of seed-eating birds observed during the study. Sample sizes of other species were inadequate for analysis, but no impacts were evident. Although bait was available throughout the post-treatment period, the percentage of tracerite-labeled birds declined after 3 days of exposure, suggesting development of sublethal aversion. Our study was conducted under conditions when maxi-
mum bait was available, when dry weather maximized bait longevity and toxicity, and when there had been no prior baiting to produce sublethal aversion. Thus, our lack of evidence of hazards suggests that the tested zinc phosphide bait should pose minimal acute hazard to similar avifauna in other orchards.

No indigenous seed-eating birds presently occur in orchards anywhere in Hawaii. Continued expansion of the macadamia industry and successful endangered species recovery efforts might eventually lead to use of orchards by native birds. In particular, orchards adjoining wetlands on Kauai might be visited by the endangered Hawaiian duck (Anas wyvilliana). Widespread acceptance of bait and limited mortality documented in this study indicate that orchards should not be baited if indigenous seed-eating birds are present.

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LITERATURE CITED


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