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HAZARDS TO WILDLIFE ASSOCIATED WITH 1080 BAITING FOR CALIFORNIA GROUND SQUIRRELS

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Monofluoroacetic acid was first prepared in Belgium in 1896 (Atzert 1971), but was not seriously investigated as a pesticide in the United States until World War II eliminated major sources of raw materials for red squill, thallium, and strychnine. Studies by the U.S. Fish and Wildlife Service showed that sodium monofluoroacetate (1080) was an effective rodenticide, predacide, and insecticide, and resulted in its widespread use from the late 1940s through the 1960s.

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Although laboratory studies have repeatedly shown that 1080 theoretically poses hazards to nontarget wildlife through both primary poisoning (the toxic bait is ingested directly) and secondary poisoning (the result of consuming an animal killed by primary poisoning), few field data are available to assess the effects of 1080 on nontarget populations. The objective of this study was to evaluate the primary and secondary effects on nontarget wildlife of an operational program using 1080-treated grain bait to control ground squirrels. Specific objectives were to determine efficacy of 1080 for control of California ground squirrels (*Spermophilus beecheyi*); primary hazards to other rodents, rabbits, and seed-eating birds; and secondary hazards to raptors and mammalian predators.

METHODS

Study Area

The study area was near Exeter, Tulare County, California, on the east side of the San Joaquin Valley in the foothills of the Sierra Nevada mountains. Elevations ranged from 125–1,100 m. Vegetation included annual range grasses and associated forbs under open stands of oak (*Quercus* spp.), with Fremont cottonwood (*Populus fremontii*), California sycamore (*Platanus racemosa*), and California buckeye (*Aesculus californica*) along stream bottoms.

Treatment

The 1080 baiting was conducted between 7 and 9 June 1977 by aerial application as authorized by the Tulare County Agricultural Commissioner. The Commissioner's Office formulated the bait with crimped oat groats, 0.075% 1080, and 0.03% Auramine O concentrate (a brilliant yellow dye applied to repel birds). About 25,000 ha on several ranches encompassing 90,000 ha were treated with 1080; only about 3.4% of the 25,000-ha area was covered with bait because bait was spot-broadcast over ground squirrel colonies at a rate of about 6.7 kg/ha (Marsh 1967, 1968). About 5,700 kg of bait were applied.

Effect of 1080 Treatment on Ground Squirrels

We used 4 methods to evaluate the efficacy of 1080 grain bait on California ground squirrels: closed-hole, marked population survival, total population survival, and radiotelemetry. For the closed-hole method, we selected 12 treated plots ranging from 0.3–2.2 ha ($\bar{x}$ = 1.2 ha) and 4 control plots ranging from 0.4–2.0 ha ($\bar{x}$ = 1.1 ha). Pretreatment activity was measured by closing ground squirrel burrow entrances and counting the number of holes reopened 7 days later (immediately before treatment). One week post-treatment, we repeated the procedure. The difference between numbers of holes opened pretreatment vs. those opened post-treatment was used to calculate the change in ground squirrel activity. Data were analyzed by paired *t*-tests.

For the marked survival and total survival methods, we live-trapped and marked 115 ground squirrels with colored ear tags and rhodamine B dye on 5 treated plots beginning 1 month before treatment. During the week before treatment, ground squirrels were counted from 1 side of each plot during 3 to 6 15-min morning or evening observation periods in which several sweeps of a plot were made with a 20X spotting scope. The count with the highest number of ground squirrels was recorded and populations were estimated by a Lincoln Index, using the ratio of marked : unmarked. We used the mean of the population estimates for each plot as the pretreatment population. To estimate the total and marked populations that survived treatment, we trapped and shot surviving ground squirrels between 2 and 6 weeks post-treatment. Treatment effect was calculated by comparing the total population that survived treatment with pretreatment population estimates and by comparing the marked population surviving treatment with the population originally marked on each plot.

For the radiotelemetry method, we trapped 10 ground squirrels during the week before treatment, tranquilized them using ketamine hydrochloride, attached ear tags, and fitted each with a 30-MHz neck-collar transmitter. Each ground squirrel was released at the point of capture and its movement followed for 5 days post-treatment using hand-held loop antennas and Johnson Messenger 3 receivers. (Reference to trade names does not imply government endorsement.)

Hazards of 1080 Treatment to Nontarget Wildlife

We used radiotelemetry to determine movement of radio-equipped animals in and around treated areas and to determine the location of animal carcasses. During the month prior to treatment, transmitters were attached to 66 nontarget animals. Additional animals were radio-equipped but we lost contact with them prior to treatment. Those data are not included in this report. We used a 164-MHz radio-tracking system (Hegdal and Gatz 1978) with a beacon transmitter, numbered tracking stations, and mobile radio-tracking vehicles equipped with dual yagi antennas and voice radio communication systems. Animal locations were determined by triangulation. After capture, we attempted to locate each radio-equipped animal daily before treatment and for 2 months after treatment or until the transmitter failed.

Death of animals equipped with motion-sensitive mortality transmitters (coyotes [*Canis latrans*], bobcats [*Felis rufus*], and badgers [*Taxidea taxus*]) was detected by an increase in the pulse rate of the transmitter. Dead animals were located on foot using AVM model LA-12 receivers and hand-held loop and yagi antennas. Mortality of other radio-equipped animals was detected by lack of movement of the transmitter signal. We attempted to check the status of each animal daily by locating the animal with hand-held yagi antennas and getting a visual sighting. Radio-equipped animals found dead were necropsied if the condition of the carcass permitted, and tissue samples were preserved for chemical analysis.

Mourning Doves and Quail.—We captured 21 mourning doves (*Zenaida macroura*) and 3 California quail (*Callipepla californica*) using a variety of traps and mist nets. Each bird was radio-equipped and fitted with a colored, numbered leg streamer (Guarino 1968) to facilitate field identification during the monitoring period. Transmitters were glued to a 3 × 3-cm patch of latex rubber. The rubber and transmitter were attached to the bird's back by trimming feathers to about 1 cm and glueing it to the trimmed surface with cyanoacrylate-base glue.

Mammalian Predators.—Mammalian predators including 6 coyotes, 10 bobcats, 2 raccoons (*Procyon lotor*), 3 badgers, and 4 striped skunks (*Mephitis mephitis*) were captured, ear-tagged, radio-equipped, and their movements monitored pre- and post-treatment. Coyotes, bobcats, raccoons, and badgers were trapped using No. 3 offset traps with tranquilizer tabs (Balser 1965). Skunks were netted (Adams et al. 1964). Ketamine hydrochloride was used to immobilize all but coyotes during radio instrumentation; coyotes were manually restrained. Some badger transmitters were attached with a harness, and other transmitters were attached with collars. Animals were held until they recovered from the tranquilizer before release at the capture site. We conducted 3 predator scent-post surveys and 4 coyote siren surveys (Hegdal et al. 1981).

Raptors and Carrion-eating Birds.—Raptors were trapped using bal-chatri (Berger and Mueller 1959) and Verbail traps (Stewart et al. 1945) and mist and cannon nets. Vet-wrap (3M Co., Minneapolis, Minn.) was used to restrain raptors while fitting transmitters and bands (Fuller 1975). We banded, radio-equipped, and monitored movements of 3 red-tailed hawks (*Buteo jamaicensis*), 1 golden eagle (*Aquila chrysaetos*), 1 great horned owl (*Bubo virginianus*), 2 turkey vultures (*Cathartes aura*), and 2 common ravens (*Corvus corax*). A harness transmitter attachment was used for all raptors.

Some raptors were feeding nestlings during the treatment period; we checked active nests weekly to determine impact on nesting success. To prevent nest abandonment, our activities were kept to a minimum during critical periods, particularly during the 2 weeks after hatching (Fyfe and Olendorff 1976).

Carcass Searches

Intensive carcass searches began the day of treatment and continued for 2 weeks post-treatment. A 10-m distance was maintained between searchers who walked in parallel lines across designated areas; searched areas were plotted on aerial photographs. We searched 381.1 ha in treated areas (about 2% of the treated area), including open rangeland (56.2 ha), oak savannah (240.1 ha), stream bottoms (74.4 ha), and brushy areas (10.4 ha). All live animals observed were recorded. The plots used for estimating 1080 efficacy against ground squirrels were searched on days 1, 7, and 14 post-treatment to determine numbers of ground squirrels and other animals dead on the surface.

Residue Analysis

Bait and samples from animals were analyzed for 1080 residue by 2 gas chromatographic procedures, 1 requiring samples of about 100 g (Peterson 1975) and the other samples of 1–10 g (Okuno and Meeker 1980). Most samples were analyzed by the latter technique.

Untreated oat groats, oat groats with 0.075% (750 ppm) 1080, and oat groats with dye only were prepared by the Tulare County Agricultural Commissioner's Office and analyzed to test the accuracy of the analytical techniques. Bait samples were collected from bait sacks before treatment and from the ground starting the day of treatment and periodically up to 185 days after treatment.

Samples from animals consisted of stomach contents from mammals and crop and gizzard contents from birds. Samples were analyzed from animals collected both before and after the 1080 treatment. Field personnel coded all samples with randomly assigned numbers to eliminate bias in the analysis.

To establish the most probable cause of death for mammalian predators, we integrated several criteria including time of death, radiotelemetry data, necropsy, residue analysis of tissue, and other pertinent information. None of these criteria used singly is diagnostic for establishing secondary 1080 poisoning as the cause of death. However, when evaluated separately and then integrated into a composite, we can establish a most probable cause of death.

RESULTS

Bait Residues

Gas chromatographic analysis of samples containing known amounts of 1080 yielded no false positive results; all bait samples known to contain 1080 showed high levels while none

Table 1. Percentage reduction of California ground squirrel populations on 5 plots treated with 1080 baits as determined from marked survival estimates, total survival estimates, and closed-hole activity indices, 1977 (n = number of surveys/plot).

No. marked	Plot size (ha)	n	Pretreatment population[a]		Survival		Population decline (%)		
			$\bar{x}$	SE	Marked	Total	Marked[b]	Total[c]	Closed-hole[d]
24	1.1	3	38.7	4.8	0	1	−100.0	−97.4	−84.4
23	0.8	4	54.2	5.4	4	10	−84.6	−81.5	−40.0
33	1.6	6	82.9	14.0	4	24	−87.9	−71.1	−70.3
19	1.1	5	46.5	6.5	1	9	−94.7	−80.4	−61.2
16	1.1	6	50.2	8.7	1	5	−93.8	−90.0	−67.1

[a] Total observed × Total marked/Marked observed.
[b] [1 − (Marked survived/Total marked)] × 100.
[c] [1 − (Total survived/Population estimate)] × 100.
[d] [(Burrows pretreatment − Burrows post-treatment)/Burrows pretreatment] × 100.

was detected in untreated bait and animal tissue samples collected before treatment. However, the average recovery rate for 1080 residue is only 25% (Okuno and Meeker 1980) so false negative results may have occurred at levels near the limit of detection of the procedure. All reported levels are corrected for recovery rate.

Concentrations of 1080 were highest in bait taken directly from the bait sack ($n = 6$; $\bar{x} = 327 \pm 76$ ppm SE). Bait taken from the ground immediately post-treatment averaged slightly less ($n = 2$; $\bar{x} = 275 \pm 35$ ppm), and that taken between 2 and 7 days post-treatment showed still less ($n = 4$; $\bar{x} = 174 \pm 15$ ppm). The 1080 concentrations declined in bait collected 2–10 weeks after field exposure ($n = 5$; $\bar{x} = 71 \pm 29$ ppm); after 135 days, no 1080 was present ($n = 3$).

Effect of 1080 Treatment on Ground Squirrels

Efficacy Estimates.—Based on the closed-hole activity index, the efficacy of 1080 varied from 40.0% to −91.6% ($\bar{x} = -74.0 \pm 4.4$) after treatment on the 12 treated plots. On the 4 untreated plots post-treatment activity varied from 20.8% to −34.8% with a mean of −8.1% (±14.1). Paired t-tests showed a significant ($P < 0.0002$) reduction in activity on treated plots and no significant ($P > 0.6$) difference on untreated plots.

On 5 treated plots mean ground squirrel reduction was 92.2% using marked ground squirrel survival, 84.1% using total ground squirrel survival, and 64.6% using closed-hole activity indices (Table 1).

Nine of 10 radio-equipped ground squirrels died. We found 2 dead on the surface about 12 hours post-treatment; both contained 1080 residue in their stomachs ($\bar{x} = 13.5 \pm 2.5$ ppm). We trapped 1 live radio-equipped ground squirrel 22 days post-treatment. The remainder probably died in their burrows because the radio signal sources did not change, burrow entrances remained closed, and they were not trapped post-treatment.

Carcass Searches.—After treatment, 38 ground squirrels (2.8/ha) were found dead on the surface of treated plots: 29 on day 1 post-treatment, 9 on day 7, and none on day 14. None was found dead on untreated plots. Eleven of the 115 marked ground squirrels (9.0%) were found dead on the surface. During off-plot carcass searches, we found 294 ground squirrels dead on the surface of 381.1 ha searched. Twenty ground squirrel carcasses were collected for residue analysis. All other carcasses were left undisturbed to provide the means for assessing secondary poisoning hazards. Fifteen of the 20 were collected during carcass searches conducted between 8 hours and 5 days after treatment and showed a mean 1080 content of 23.3 ppm (±10.5). A carcass being consumed by a raccoon 12 hours after treatment contained 13 ppm 1080; a carcass found under a raptor nest 3 days after treatment contained 1.6 ppm, and a carcass dropped by a red-tailed hawk 9 days after treatment contained 1.7 ppm. The remaining 2 carcasses did not contain 1080 residues: 1 was being consumed by a rattlesnake (*Crotalus viridis*) 3 days after treatment, and 1 was found dead 22 days after treatment.

Primary Hazards of 1080 Treatment to Nontarget Wildlife

Rodents and Rabbits.—During searches of the 12 treated ground squirrel plots, 8 Heermann's kangaroo rats (*Dipodomys heermanni*), 1 little pocket mouse (*Perognathus longimembris*), and 1 desert woodrat (*Neotoma lepida*) were found dead. We found 22 other rodents during off-plot carcass searches on 381 ha, including 7 kangaroo rats, 7 pocket mice, 3 woodrats, 4 deermice (*Peromyscus* spp.), and 1 western harvest mouse (*Reithrodontomys megalotis*). Each of these species contained 1080 residues: 4 of 10 kangaroo rats analyzed ($\bar{x} = 5.2 \pm 1.3$ ppm); 5 of 9 pocket mice (26.7 ± 13.3 ppm); 2 of 3 woodrats (14.0 ± 1.0 ppm); 3 of 3 deermice (23.1 ± 11.8 ppm); and 1 harvest mouse (17.2 ppm).

Ten dead desert cottontails (*Sylvilagus audubonii*) were found during carcass searches and 1 during radiotracking. All but 2 were found in rock piles or heavy brush. Four of the 11 carcasses contained 1080 residue in the stomach contents ($\bar{x} = 8.2 \pm 3.9$ ppm).

Seed-eating Birds.—We found few bird carcasses. A Brewer's blackbird (*Euphagus cyanocephalus*) found 7 days after treatment contained 2 ppm 1080. A scrub jay (*Aphelocoma coerulescens*), found convulsing 19 days after treatment, died the next day; no 1080 residue was detected. A plain titmouse (*Parus inornatus*) found dead 10 days after treatment also contained no detectable 1080 residue.

Twenty-one radio-equipped mourning doves were tracked after treatment for between 6–51 days. These doves visited treated areas and some were observed picking up 1080-treated bait. All radio-equipped doves apparently survived the baiting. Later, we lost radio contact with 3, 8 lost the transmitter, and 10 were killed by predators or hunters. Only 1 relatively intact carcass was available for analysis and it contained no detectable 1080 residue.

No dead mourning doves were found during carcass searches around feeding and roosting areas, and doves remained numerous after treatment. We shot 10 doves after treatment to determine if they consumed sublethal doses of 1080, but residue analysis and examination of crop and stomach contents indicated they did not feed on bait.

Two of 3 radio-equipped California quail tracked after treatment survived; 1 was killed by a predator. None was found during thorough searches of brush piles and gooseberry (*Ribes* spp.) patches where quail roosted. Quail did not eat the grain (milo, millet, and corn) put out to trap them. Residue analysis and examination of crop and stomach contents of 9 California quail shot after treatment indicated they were not feeding on 1080 bait.

Secondary Hazards of 1080 Treatment to Nontarget Wildlife

Insectivorous Birds.—Insectivorous birds may have died after eating poisoned ants (*Veromessor andrei* and *Liometopum occidentale*). An acorn woodpecker (*Melanerpes formicivorus*) found plucked under a Cooper's hawk (*Accipiter cooperii*) nest 14 days after treatment contained 4.4 ppm 1080. We found 2 dead white-breasted nuthatches (*Sitta carolinensis*) 2 days after treatment. One contained 1 ppm 1080; the other contained no detectable residue but was found near an ant mound with large numbers of bait kernels and dead ants. An ash-throated flycatcher (*Myiarchus cinerascens*), found dead 4 days after treatment, also near an ant mound, contained no detectable 1080 residue.

Raptors and Carrion-eating Birds.—Of the 9 radio-equipped raptors and carrion-eating birds tracked during the 1080 baiting operation, 8 survived. The great horned owl and 3 red-tailed hawks were radio-tracked for ≥73 days after treatment. The golden eagle, 1 common raven, and 1 turkey vulture were tracked 6–17 days after treatment and apparently left the area. One common raven was tracked only 2 days after treatment but was captured alive 8 months later. A turkey vulture found dead 42 days after treatment contained no detectable 1080 residue; cause of death could not be determined. We found a convulsing American kestrel (*Falco sparverius*) 7 days after treatment that died 1 day later. A dead western screech-owl (*Otus kennicottii*) was found 11 days after treatment, and a dead turkey vulture was picked up 135 days after treatment. No 1080 residues were detected in any of these birds and the cause of death was not established, although convulsions are a sign of 1080 poisoning (Kun 1982).

We located 58 active raptor nests. All raptor nests active post-treatment successfully fledged young: 30 red-tailed hawks fledged from 15 nests, 14 great horned owls from 6 nests, 3 golden eagles from 2 nests, and 4 Cooper's hawks from 1 nest.

Mammalian Predators.—General results of 1080 baiting on mammalian predators were reported by Hegdal et al. (1981) and will be only briefly summarized here. Five of six radio-equipped coyotes and 3 of 10 radio-equipped bobcats died following 1080 treatment for ground squirrels. Other radio-equipped mammalian predators (2 raccoons, 3 badgers, and 3 of 4 striped skunks) survived treatment. One skunk was consumed by a predator. We found 3 other dead skunks that were possibly killed by 1080. Necropsies were not conducted on 2 coyotes and 3 skunks because of advanced decomposition. Necropsies of other animals showed lesions consistent with 1080 intoxication, including lung edema and hemorrhage, petechial cardiac hemorrhage, and gastrointestinal purpura (Cottral et al. 1947). However, chemical analysis of stomach contents did not indicate 1080 residue except for a juvenile skunk that contained 1.5 ppm of 1080.

In addition to those predators discussed in Hegdal et al. (1981), a domestic dog and a domestic cat died 8 days and 10 days post-treatment within 450 m of a treated area. Both showed 1080 poisoning signs (extreme nervousness, excessive running and convulsions [Casper et al. 1983, Kun 1982]) for 2–3 days before death; necropsy indicated 1080-like lesions for both animals but chemical analysis did not show residue.

DISCUSSION

Residue Analysis

While the presence of 1080 residue is diagnostic of 1080 poisoning, the absence of 1080 residue does not mean that 1080 was not involved in the death of an animal. We found 1080 residues in 90% of ground squirrels killed by primary poisoning; 1080 residues were detectable in 50% of the nontarget rodents presumably killed by 1080. Some of the carcasses recovered were in an advanced state of decomposition. State of putrefaction and size of sample affected detection limits for 1080 analysis, which is reflected in the variation that occurred in the lower limit of detection (I. Okuno, Denver Wildl. Res. Center, unpubl. data). Detection of 1080 residues in animals killed by secondary poisoning is further complicated by the fact that 1080 exerts an emetic action, especially on canids (Atzert 1971), and levels remaining in the stomach at death are low. Hegdal et al. (1981) reported that in a laboratory study, 1080 residues present in coyotes killed secondarily by consuming 1080-

killed ground squirrels could not be reliably detected in coyote carcasses with current techniques.

Target Wildlife

The 1080 baiting reduced ground squirrel populations from 71.7% to 92.2%. We feel that monitoring of radio-equipped animals gave the most accurate estimate of efficacy (90%) by revealing the actual number of survivors rather than an estimate. However, the sample size was low (10 animals). Efficacy estimates based on marked ground squirrel survival (92.2%) are maximum estimates, as a portion of the marked population may not have been recoverable because of emigration, predation, or estivation. Estimates based on total population survival (84.1%) are also influenced by these factors, but are more conservative because of possible immigration onto the plots. The closed-hole indices gave the lowest (and probably least precise) estimates (71.7% on 12 plots and 64.6% on 5 plots). These estimates were poor because the number of opened holes/squirrel changed from 1.3 ± 0.1 pretreatment to 3.8 ± 0.9 post-treatment based on the 5 plots where pre- and post-treatment estimates were made using both closed-hole and Lincoln indices.

Some ground squirrels died on the surface and were available to scavengers. The best estimate of surface mortality (2.8 ground squirrels/ha) came from the ground squirrel plots, where we conducted regular searches for carcasses. The best estimates of the percentage of ground squirrels that died on the surface were based on recovery of marked ground squirrels (9%) and radiotelemetry (20%).

Primary Hazards to Nontarget Wildlife

Rodents and Rabbits.—It is not surprising that 1080 killed other rodents in addition to ground squirrels. In the past, 1080 has been used to control many of these species and their LD_{50}'s are relatively low (Denver Wildl. Res. Center, unpubl. data): woodrat—1.5 mg/kg, kangaroo rat—0.33 mg/kg, and deermouse—4.0 to 5.5 mg/kg. As in this study, Marsh (1968) found that aerial 1080 baiting for California ground squirrels reduced populations of deermice and killed kangaroo rats and woodrats. Keyes (1945) found dead deermice, kangaroo rats, woodrats, and pocket mice during hand baiting operations with 1080 for controlling California ground squirrels.

Cottontail rabbits were killed by 1080 bait in this study but we feel that populations were probably not drastically reduced, as 55 live rabbits were observed during post-treatment carcass searches. The LD_{50} for cottontail rabbits is not known but is presumably in the range of those for other lagomorphs: 0.8 mg/kg for European rabbits (*Oryctolagus cuniculus*) and 5.5 mg/kg for black-tailed jack rabbits (*Lepus californicus*) (Atzert 1971). Baits treated with 1080 have been used to poison rabbits in Australia and New Zealand for many years (Rowley 1963, Poole 1963). Keyes (1945) and Marsh (1968) reported mortality of cottontail rabbits and jack rabbits during 1080 baiting. However, McNeill (1977) felt that rabbits were less vulnerable than rodents to aerial 1080 baiting because of the widely scattered grain distribution pattern.

Seed-eating Birds.—Although our study indicated that surface baiting with dyed 1080-treated oat groats presented little hazard to mourning doves, the LD_{50} for 1080 to mourning doves is low enough—7.8 mg/kg (Tucker and Crabtree 1970)—that mourning doves could theoretically be killed by consuming 1080 bait. Spencer (1945) reported finding a few dead mourning doves after 1080 baiting. However, Keyes (1945) noted no reduction in their numbers after 1080 hand-baiting. Spencer (1945) observed that 1080 often acted as an emetic to mourning doves; only 2 of 18 offered 1080 bait for 24 hours died.

None of the 3 radio-equipped quail died as a result of 1080 treatment, none was found dead in post-treatment carcass searches, and we observed no post-treatment change in numbers of quail in frequently observed coveys. Quail fed heavily on gooseberries during the treatment period and fed little if any on bait. These data indicated that surface baiting with dyed 1080-treated oat groats presented little hazard to California quail. Other studies suggest that quail ignore 1080-treated oat groats (R. Dana, Calif. Dep. Food and Agric., unpubl. data). Spencer (1945) and D. Green (U.S. Fish and Wildl. Serv., unpubl. data) reported that Gambel's quail (*C. gambellii*) had to be force-fed because they refused lethal doses of 1080 under voluntary feeding. Keyes (1945) stated that no California quail were killed in pen tests even when offered 1080 baits from which the dye had faded. Despite a low LD_{50} for California quail—2.6 mg/kg (Calif. Dep. Fish and Game 1962) and 4.6 mg/kg (R. K. Tucker, U.S. Fish and Wildl. Serv., unpubl. data)—Keyes (1945), Spencer (1945), and Marsh (1968) noted no detectable hazard to California quail during 1080 hand-baiting programs for California ground squirrels.

While we found only 3 carcasses of other seed-eating bird species during intensive searches of roosting and feeding areas, this may be a low assessment of mortality rates. At near minimum lethal doses, 1080 acts slowly to produce death in birds, allowing them to seek cover or travel considerable distances from treated areas (Spencer 1945). Other researchers reported some seed-eating birds killed by 1080, including sparrows, blackbirds, and towhees (*Pipilo* spp.) (Spencer 1945; R. E. Marsh, Univ. Calif., Davis, unpubl. data), horned larks (*Eremophila lapestris*), McCown's longspurs (*Calcarius mccownii*), chestnut-collared longspurs (*C. ornatus*), and western meadowlarks (*Sturnella neglecta*) (H. Fish, U.S. Fish and Wildl. Serv., unpubl. data).

Secondary Hazards to Nontarget Wildlife

Insectivorous Birds.—Ants killed by 1080 may present a secondary hazard to insectivorous birds. Ants carried 1080 bait to their nests and left bait concentrated on the ground (several hundred to 2,000 kernels/m^2). Although we did not quantify ant mortality, our observations indicated that almost every anthill in the treated area had hundreds of dead ants on the surface. Residue analysis of dead ants showed 1.4 ppm 1080 in 1 sample and none in another. We found 3 insectivorous bird species (acorn woodpecker, white-breasted nuthatch, and ash-throated flycatcher) that were susceptible to 1080 poisoning. The insecticidal activity of 1080 has been recognized since the 1940s (Spencer 1945). Marsh (1968) reported that harvester ants (*Pogonomyrmex* spp.) and darkling ground beetles (Tentyridae) removed and consumed 1080 bait, leaving bait and dead ants concentrated on the ground near the nest. In addition, F. C. Sibley (U.S. Fish and Wildl. Serv., unpubl. data) in 1966 found 2 dead white-breasted nuthatches during a 1080 ground squirrel baiting operation.

Raptors.—Although raptors were exposed to 1080-poisoned carcasses, secondary hazards appeared low. Only 1 raptor (American kestrel) was located during carcass searches with signs (convulsions) that indicated probable secondary poisoning. Telemetry data revealed no 1080-related mortalities despite the fact that raptors were frequently observed feeding on ground squirrels and other rodents after treatment. Some of these carcasses fed upon by raptors contained 1080, including a ground squirrel dropped by a red-tailed hawk and another found under a red-tailed hawk nest from which all 3 young fledged. A kangaroo rat dropped by an American kestrel contained no detectable residue, and an acorn woodpecker found plucked under a Cooper's hawk nest contained 4.4 ppm 1080 residue; all 4 young fledged from this nest. The average number of red-tailed hawks fledged/nest (1.73) exceeded that reported by Fitch et al. (1946) (0.84), Brown and Amadon (1968) (1.4), and Wiley (1975) (1.64). The number of great horned owls fledged (2.3) was higher than reported by Olendorff (1972) (2.0).

Most other investigators reported little or no secondary hazards to raptors from 1080 ground squirrel baiting programs. Rough-legged hawks (*Buteo lagopus*), northern harriers (*Circus cyaneus*), Swainson's hawks (*B. swainsoni*), red-tailed hawks, Cooper's hawks, golden eagles, common ravens, turkey vultures, and California condors (*Gymnogyps californianus*) have all been observed feeding on rodents and rabbits killed by 1080 without apparent adverse effects (Spencer 1945, Welch 1945, Keyes 1945, Koford 1953). Vultures and condors are considered relatively immune to 1080 (Spencer 1945, Hagen 1972); vultures weighing 3 kg required 30 mg of 1080 to produce poisoning signs. Spencer (1945) and Koford (1953) suggested that vultures could not consume enough rodents in 1 day to obtain a lethal dose. However, owls may be somewhat more susceptible to 1080. H. Coulombe (cited in Zarn [1974]), Keyes (1945), and Spencer (1945) mentioned burrowing owls (*Athene cunicularia*) killed by 1080 bait. Spencer (1945) also found 1 dead and 3 sick "barred" owls (probably barn owls [*Tyto alba*]) in Camp Roberts, California; 2 of the owls later recovered.

Raptors may be less susceptible to secondary poisoning by 1080 than mammalian predators for several reasons. First, they have higher LD_{50}'s. With the exception of golden eagles, with an LD_{50} between 1.25 and 5.0 mg/kg (Tucker and Crabtree 1970), the LD_{50} to most raptors is between 10 and 20 mg/kg, higher than most mammals and seed-eating birds (Atzert 1971). Second, R. Dana (unpubl. data) found that captive raptors refused to eat large amounts of 1080-poisoned meats. Third, Spencer (1945) hypothesized that 1080 caused emesis before lethal amounts were absorbed; hawks force-fed poisoned mice that had received a dose of 25 mg/kg of 1080 survived by regurgitating partially digested mice, and owls regurgitated 1080-poisoned rats. Fourth, hawks and vultures eviscerated poisoned carcasses before consuming them in this study and in studies conducted by Spencer (1945) and Welch (1945).

Mammalian Predators.—We found that 1080 caused mortalities in domestic dogs and cats. In addition, Hegdal et al. (1981) demonstrated that 1080 baiting for ground squirrels caused mortalities in coyotes, bobcats, and skunks. Although chemical analysis failed to show 1080 residue in the stomach contents of dead predators because of limitations in detection of 1080, we have concluded that 1080 was the most likely cause of death: most deaths occurred in the first week after treatment, necropsies showed signs consistent with 1080 intoxication, rodent remains were found in the predator's stomachs, and the predators were located in treated areas post-treatment.

Mammalian predators have been reported killed during earlier 1080 baiting programs as well, particularly during periods of food stress when they ate poisoned ground squirrels and dug out desiccated carcasses. Dead farm dogs, coyotes, and kit foxes (*Vulpes macrotis*) were reported by Keyes (1945), Spencer (1945), and R. E. Marsh (unpubl. data) after 1080 bait applications. Spencer (1945) concluded that 1 or more 1080-poisoned rodents may kill a coyote. Spencer (1945) and Marsh (1967) both reported finding dead skunks following 1080 baiting programs.

R. E. Marsh (unpubl. data) theorized that aerial application of bait might decrease the secondary hazards of 1080 because individual rodents would consume less scattered bait. However, our results indicated that hazards to mammalian predators still exist.

SUMMARY AND MANAGEMENT IMPLICATIONS

We evaluated the primary and secondary hazards to wildlife associated with aerial application of 1080-treated grain bait to control California ground squirrels. Populations of ground squirrels were reduced 85%. Primary hazards to other rodent species and to desert cottontail rabbits were found. Primary hazards to radio-equipped mourning doves and California quail appeared minimal. Samples of dead ants contained 1080 residue and secondary hazards to insectivorous birds were recorded. No treatment-related mortalities were observed while monitoring radio-equipped raptors, specifically the red-tailed hawk, golden eagle, great horned owl, turkey vulture, and common raven, or while monitoring 58 active raptor nests. Secondary hazards to mammalian predators were evaluated by attaching transmitters to bobcats, coyotes, badgers, striped skunks, and raccoons. Radio-equipped coyotes and bobcats were found dead after treatment and striped skunks were found dead during carcass searches. Because 1080 is converted during the metabolic processes of primary poisoning, residues could not be reliably detected by current analytical methods in animals probably killed by secondary exposure.

The 1080 bait presented primary poisoning hazards to nontarget rodents and rabbits and should not be applied in areas where this is of concern. When applied in late spring, incidences of primary poisoning of seed-eating birds were few and the 1080 baiting did not affect mourning dove or California quail populations. In other situations where alternate foods are scarce, hazards to seed-eating birds may be different.

In the past, the potential for secondary poisoning by 1080 when used for rodent control has been considered minimal because it was assumed that rodents died underground in their burrows. However, in this study 9% of marked and 20% of radio-equipped ground squirrels (almost 3/ha) died on the surface and were available for scavengers. Despite the availability of poisoned ground squirrels, raptors were not affected by 1080, and may be relatively immune to 1080 poisoning because of their high LD_{50}'s. However, the 1080 baiting caused secondary mortalities to mammalian predators (particularly to canines and felids) and to some insectivorous birds. Its use should be carefully monitored where these sensitive species occur.

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