SERIES IN ORNITHOLOGY, NO. 2

CALIFORNIA CONDORS IN THE 21ST CENTURY

EDITED BY

ALLAN MEE AND LINNEA S. HALL

PUBLISHED BY

NUTTALL ORNITHOLOGICAL CLUB
CAMBRIDGE, MASSACHUSETTS

AND

THE AMERICAN
ORNITHOLOGISTS' UNION
WASHINGTON, D.C.

2007

SERIES IN ORNITHOLOGY

The *Series in Ornithology* is published by the Nuttall Ornithological Club and the American Ornithologists' Union.

Editors of this book: Allan Mee and Linnea S. Hall

Library of Congress Control Number 2007928963

Printed by Cadmus Communications, Lancaster, PA 17601

Issued 30 June 2007

Series in Ornithology, No. 2, viii + 296 pp.

ISBN: 978-0-943610-71-1 (hard cover)
ISBN: 978-0-943610-74-0 (soft cover)

4

Movements of Introduced California Condors in Arizona in Relation to Lead Exposure

W. Grainger Hunt,[1,3] Chris N. Parish,[1] Shawn C. Farry,[1] Thom G. Lord,[1] and Ron Sieg[2]

Abstract.—The California Condor (*Gymnogyps californianus*) restoration program in Arizona has benefited by the close monitoring of movements of condors with respect to food acquisition, mortality factors, and encounters with humans and artifacts. All 69 individuals released during 1996–2004 were equipped with VHF transmitters, and 18 carried satellite-reporting GPS transmitters for varying periods since fall 2003. Tracking data revealed an evolving cycle of annual movement, with increasing predictability overall as flock members gained experience and guided the behavior of newly-released birds. Condors generally remained near the site of initial release during winter and then traveled in spring and summer to the Colorado River corridor and the Grand Canyon. Summer and fall use of the Kaibab Plateau increased each year, as did the contingent of birds summering in the Kolob region of southern Utah. Movement was more expansive in winter 2004–2005 than in previous winters, in part reflecting an increasing number of pairs establishing breeding territories. We obtained circumstantial evidence of lead sources by examining itineraries of condors on a case-by-case basis during the weeks prior to lead testing. Information supporting the hypothesis of bullet fragments in hunter-killed deer carrion as the primary cause of elevated blood lead levels in condors included (1) a recent study showing that the remains of most rifle-killed deer contain numerous lead fragments; (2) observations of condors in association with deer remains (n = 78 cases); (3) an increase of blood lead levels with increased condor use of deer hunting areas of the Kaibab Plateau in 2002; (4) spikes in blood lead levels and condor visitation to the Kaibab Plateau during and just after the 2002, 2003, and 2004 deer hunting seasons; and (5) significantly higher lead levels among condors visiting the Kaibab Plateau in the weeks prior to testing.

[1]*The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, Idaho 83709, USA.*
[2]*Arizona Game and Fish Department, 3500 South Lake Mary Road, Flagstaff, Arizona 86004, USA.*
[3]*Present address: Grainger Hunt, 552-205 James Drive, McArthur, California 96056, USA. E-mail grainger@peregrinefund.org*

Condors (*Gymnogyps* and *Vultur*), like tropical oceanic birds, are known for their longevity, delayed onset of breeding, and for the extraordinary distances they travel to forage. Wallace and Temple (1987) found breeding Andean Condors (*V. gryphus*) foraging as far as 200 km from their nests, with an overall range of up to 1,300 km^2. Meretsky and Snyder (1992) reported typical foraging distances of 50–70 km for nesting California Condors (*G. californianus*), and extremes of 180 km; the foraging range of the nonbreeders covered about 7,000 km^2.

Foraging widely means that condors visit a variety of environments, some anthropogenic, and some exposing them to mortality risks. The most prevalent of these risks has been lead (Pb) poisoning, a factor that some have invoked as a primary cause for the decline of the wild population (Meretsky et al. 2000). In California, prior to the mid-1980s when all wild condors were brought into captivity, lead ingestion was the principal recorded mortality agent based on a sample of five necropsies (Janssen et al. 1986, Wiemeyer et al. 1988). Likewise, Woods et al. (this volume) found lead poisoning the most frequently diagnosed cause of death of captive-bred condors outside their release site in northern Arizona.

The remains of animals killed by rifles and shotguns appear the most logical source of condor lead ingestion in Arizona, as suggested by the occurrence of lead shot and apparent bullet fragments in radiographs of 14 lead-poisoned condors (Parish et al. this volume). The hypothesis of rifle bullets as a principal source of lead in condors in Arizona is parsimonious because mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and other large animals known to be eaten by condors are typically killed by rifles. Because rifle bullets may pass completely through deer-sized animals, however, there was uncertainty about the extent to which bullet fragments remain in gut piles or carcasses lost to wounding. Hunt et al. (2006) addressed this question by radiographing the remains of 38 deer (*Odocoileus hemionus and O. virginianus*) killed with a variety of standard centerfire hunting bullets. Metal fragments were present in 18 of 20 offal piles (range = 2–521 fragments); five contained 0–9 fragments, five had 10–100, five had 100–199, and five showed more than 200 fragments. Five whole deer carcasses showed 416–783 fragments (mean = 551, SD ± 139). These results, together with the large amount of offal present in some regions, suggest a high potential incidence of lead exposure for scavengers. Fry and Maurer (2003) summarized, from game management statistics, the availability of shot animals to condors within the eight California counties comprising the former condor range; they reported that shooters annually left over 8,000 deer gut piles, offal from some 17,000 feral pigs (*Sus scrofa*), and carcasses of about 11,000 coyotes (*Canis latrans*).

The Peregrine Fund began its condor restoration program in the Grand Canyon region of northern Arizona (36°N, 112°W) in 1996, and continued releases brought the number of free-flying birds to about 50 by spring 2005, including two fledged from wild pairs. Frequent testing of blood lead levels of condors returning to the release site, particularly after 2002, revealed a large number of lead exposures, many at levels regarded as clinically significant and some as acutely toxic (Eisler 1988, Kramer and Redig 1997, Parish et al. this volume). The number of fatalities prevented by chelation treatment and removal of lead bodies by purging or surgery is likely substantial (Parish et al. this volume). Considering the necessity of high adult survival for population viability in this slowly reproducing species, the high incidence of lead exposure in Arizona and its potential to kill condors casts doubt upon the eventual success of establishing a self-sustaining population without the necessity of continual hands-on management (Cade et al. 2004; Mee et al., Woods et al. this volume). In this paper, we present evidence from radio-tracking and other avenues of study that pertain to sources of lead ingestion within the range of the free-flying condor population in Arizona.

Study Area

The terrain now frequented by condors in northern Arizona and southern Utah is a spectacularly rugged mix of canyons and plateaus, with elevations varying from about 600 m on the Colorado River in the Grand Canyon to about 2,800 m on the Kaibab Plateau where snow accumulates in winter (Fig. 1). Plant communities vary with elevation, from desert scrub in the lowland canyons, to semi-arid grasslands, to pinyon-juniper woodlands (1,500–2,100 m), to coniferous forests above 2,100 m. Abundant cliffs, winds, and warm summer temperatures provide updrafts upon which condors travel throughout the region. Ungulates providing carrion include mule deer, elk, big-horned sheep (*Ovis canadensis*), domestic sheep (*O. aries*), pronghorn (*Antilocapra americana*), American bison (*Bison bison*), range cattle (*Bos taurus*), and horses (*Equus caballus*) (Hoffmeister 1986).

We partitioned the general range of condor movement in northern Arizona and southern Utah into six zones (see Fig. 1). The Paria Zone contains the current release site, situated on top of the Vermilion Cliffs at the southwestern edge of a woodland plateau overlooking House Rock Canyon and the eastern slope of the Kaibab Plateau (Fig. 2). Food is continually provided at the release site in the form of dairy calf carcasses. The Colorado River Corridor Zone south of the Paria includes Marble Canyon and extends downstream from Powell Reservoir near Page, Arizona, to the confluence of the Little Colorado River in Grand Canyon National Park. The forested North Kaibab Plateau (Kaibab Zone) lies just to the west of the Paria, its western slopes becoming a juniper woodland dropping steeply into Kanab Creek where prevailing southwest winds provide updrafts for traveling

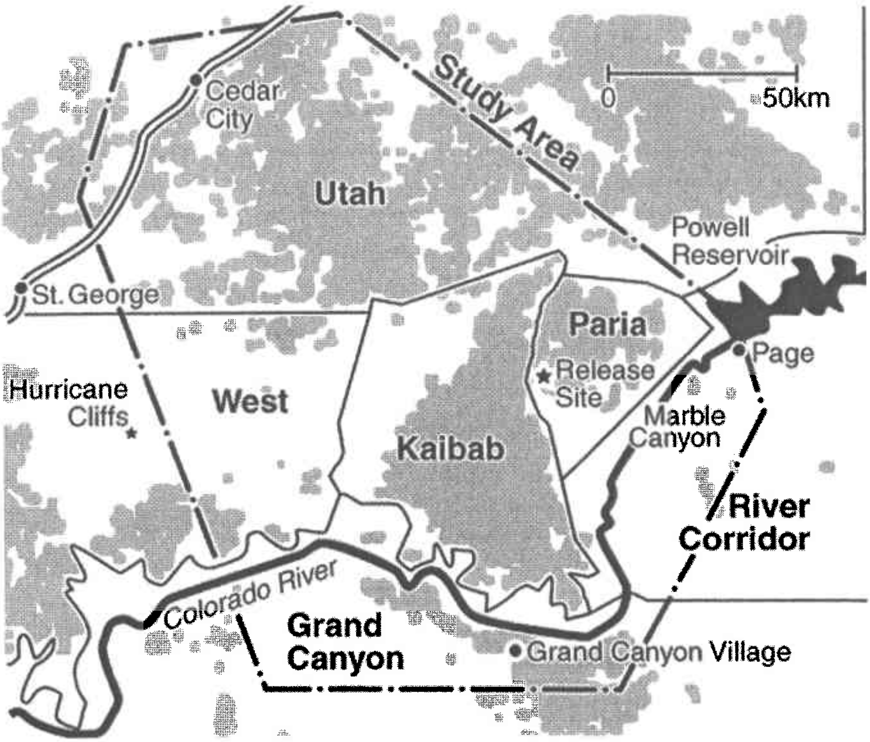

Fig. 1. The current range of California Condors in northern Arizona and southern Utah (forested areas in gray). The study area is divided into six zones of condor occurrence.

condors. Beyond Kanab Creek is the West Zone, an area of hilly woodland, with drier, open landscape to the north. The Grand Canyon National Park, south of the Kaibab Zone, comprises most of the Grand Canyon Zone, its forested rim dropping over 1,300 m through sparse woodland and desert scrub to the Colorado River (Plate 8). Grand Canyon Village on the South Rim is an area of intense human activity. The Utah Zone, to the north of the Kaibab, extends through the Kolob region northward to Cedar City, Utah; the area frequented by condors is generally composed of rugged, higher elevation coniferous forest with large, open meadows.

Tracking and Mapping

Condors released in Arizona from 1966 to 2004 were equipped with radio transmitters (≤65 g) mounted on the patagium of each wing (or occasionally on the tail), along with numbered vinyl tags for visual identification

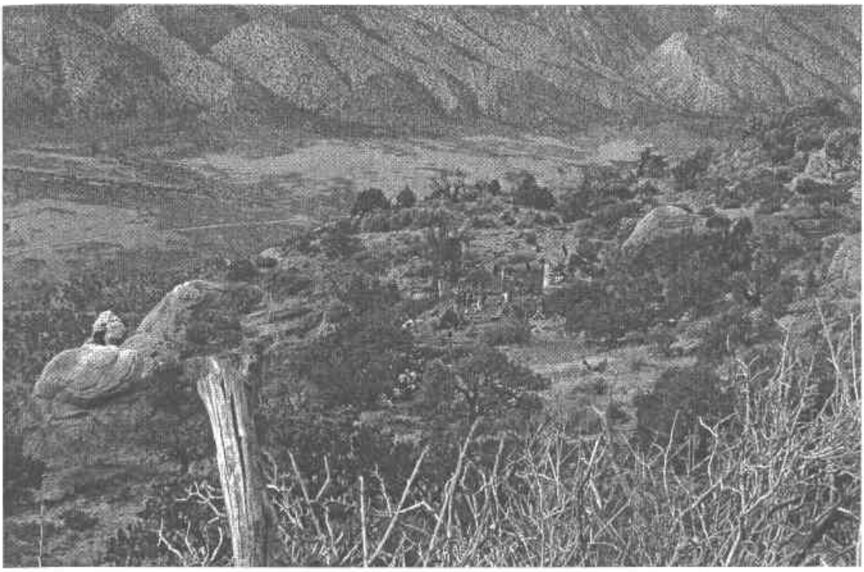

Fig. 2. The Peregrine Fund's condor release site at the Vermilion Cliffs in northern Arizona. (Photo by C. N. Parish.)

of individuals (see Wallace et al. 1994). VHF transmitters were detectable at line-of-sight distances of 100 km or more and contained "mortality sensors" designed to increase the pulse rate when the instrument was motionless for more than four hours. We captured condors in "walk-in" traps at the release site to replace failing transmitters and for other purposes, including lead testing (see Parish et al. this volume). Field crews of up to 11 individuals on foot or in road vehicles tracked VHF signals throughout the day by first situating themselves at vantage points, then following condors and maintaining visual contact when possible. A hierarchy of location codes facilitated records of sequential movement, and the last position fix of the day ("roost location") for each condor guided the next day's tracking strategy. Missing condors were occasionally sought by means of fixed-wing aircraft. Beginning in October 2003, we fitted 18 condors for various periods with GPS-equipped, satellite-reporting transmitters designed to yield hourly position fixes to within 50 m during daylight. We used ARCVIEW software to display and analyze data on topographical maps. The precise fixes provided by these transmitters together with results obtained from VFH radio-tracking led to the discovery of 196 dead animals that condors had either fed upon or closely attended. We attempted in all cases to ascertain the cause of death of these animals.

We examined seasonal changes in condor flock movements by tabulating 45,243 roost locations obtained by conventional telemetry and observation during July 2001 through June 2005, and then calculating the percentage of roost sites recorded in each zone. We tested the reliability of roost locations in predicting habitat selection by chronologically sorting the 29,756 satellite-reported GPS position fixes of individual condors (November 2003–June 2005), and randomly selecting 100 midday positions (~1,200 h) to compare with those of the last fixes of the day (~2,000 h). Condors stayed at the release site (Paria Zone) in 42 cases, moving 0–4 km during the afternoon. In the remaining 58 cases, condors traveled 0 to 65 km (mean = 18, SD ± 16), changing zones in 47% of cases. The latter outcome is consistent with ground tracking data in showing that condors visit a far greater number of locations than is apparent in the roost data alone.

Movements in the Early Years

Unpredictability characterized the initial years of the release program in northern Arizona, as there were no condors with prior experience to guide the movements and behavior of the newly-released birds. In late winter 1997, soon after the first release of six captive-bred individuals, The Peregrine Fund began placing supplemental food at several locations within about 8 km of the Vermilion Cliffs (i.e., Paria Zone) release site. These distributions were intended to encourage expansion of movement patterns in accordance with the goal of a self-sustaining population. During the first six months after release, condors ventured as far as 70 km where they found their first nonproffered carcass in the vicinity of the town of LeChee on the Navajo Reservation. The greatest distance traveled in the first year was 301 km when a female went to Arches National Park, Utah, in July 1997.

The incipient flock remained sedentary at the release site throughout the following winter, but as the weather warmed in spring 1998, condors began traveling to the river corridor (Fig. 1). Excursions that year included a 387-km trip by three condors to Grand Mesa, Colorado, and a 516-km journey by one to Flaming Gorge, Wyoming; the bird returned to the release site six days later. With fall cooling, flock movement again contracted to within the 8–15 km radius of food provisioning around the release site. The birds found several cow (*Bovus*) carcasses in the River Corridor Zone in spring 1999, and that summer, a group of condors released at Hurricane Cliffs, a second site 112 km to the east of Vermilion Cliffs, traveled 548 km to visit Mesa Verde, Colorado, briefly.

By August 1999, the birds from both the Hurricane and Vermilion Cliffs release sites had joined at the South Rim of the Grand Canyon. Inappropriate behavior involving humans and human-related structures prompted a trapping effort to remove the instigators. We held problem birds at Vermilion Cliffs to encourage remaining flock members to abandon their focus on peopled areas along the South Rim, and it was during those trappings that we began sampling blood lead levels. Two of 13 initial samples taken in July and August 1999 indicated exposure to lead. South Rim condor visitation decreased as expected that fall, and the now coalesced flock displayed its usual winter sedentary behavior at Vermilion Cliffs. We continued feeding there and along the river corridor in an attempt to retain condors within areas comparatively devoid of humans; however, a large proportion of the flock returned to the South Rim in the spring of 2000. In early summer, ingestion of shotgun pellets killed 2–4 condors and required others to be treated with chelation therapy (Woods et al. this volume), an episode that brought about the current intensive program of blood lead testing (Parish et al. this volume).

Movement Patterns 2001–2004

Condor movements became more conservative as time progressed and the succession of newly-released condors joined older, more experienced flock members. We observed very few long range movements after 1999, and none beyond 220 km from the release site. Data on the movements of condors with VHF transmitters after June 2001 showed that condors released at Vermilion Cliffs tended to remain in that vicinity for several months before venturing out to other areas: 27 young condors stayed in the area of the release site (Paria Zone) for an average of 102 days (median = 82 days, range = 25–200) before roosting in another zone for the first time. The initial zone of visitation was usually that of the river corridor in Marble Canyon, a first destination for many condors in the early months of the year.

GPS-equipped condors moved widely within the study area, with concentrations on the Kaibab Plateau, the south rim of the Grand Canyon, and in the Kolob region of southern Utah (Fig. 3). A greater tendency to travel in the warmer months was likely related to the availability of thermal updrafts, but the increase in late-winter and spring traveling apparent in 2004 may predict a trend of diminishing reliance on food subsidy at the release site (Fig. 4). Further, movements of breeders to and from their Grand Canyon nest sites in 2003 and 2004 may have encouraged the movement of other condors.

The first general flock movements outside the release area and the Marble Canyon river corridor were to the South Rim of Grand Canyon National Park (Fig. 1), an area containing numerous tourists and buildings (Plate 9). The reasons why condors continued to frequent this area in spring and summer likely relates to human-induced concentrations of Common Ravens (*Corvus corax*) and Turkey Vultures (*Cathartes aura*), both species acting as indicators of food availability. Further, condors located carrion within the canyon itself and as vehicular kills on roads into

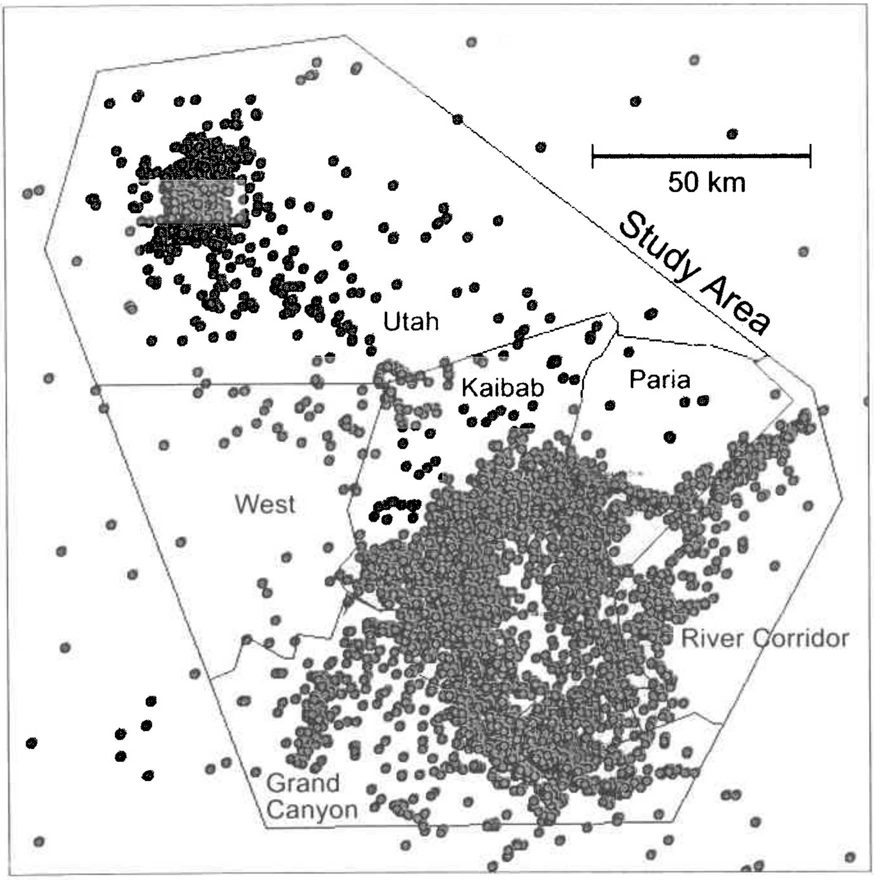

Fig. 3. Area use-pattern exhibited by 18 condors equipped for varying periods with satellite-reporting GPS transmitters during November 2003–June 2005, Arizona. Dots represent hourly GPS position fixes of individual condors during daylight (n = ~29,000 fixes).

and within the Park. These visits, particularly in the early years, resulted in encounters between condors and humans or their artifacts and prompted the development of a successful hazing program that has, together with the influence of older flock members upon the development of younger birds, tended to reduce the rate of undesirable behavior (Cade et al. 2004).

The extended use of the River Corridor Zone diminished after spring 2002 with the development of greater interest by condors in the Kaibab Plateau that summer and fall (Plate 9). Condors began visiting the Kolob region of southern Utah in the summer and fall of 2004, a pastoral area offering yet another opportunity for independent foraging.

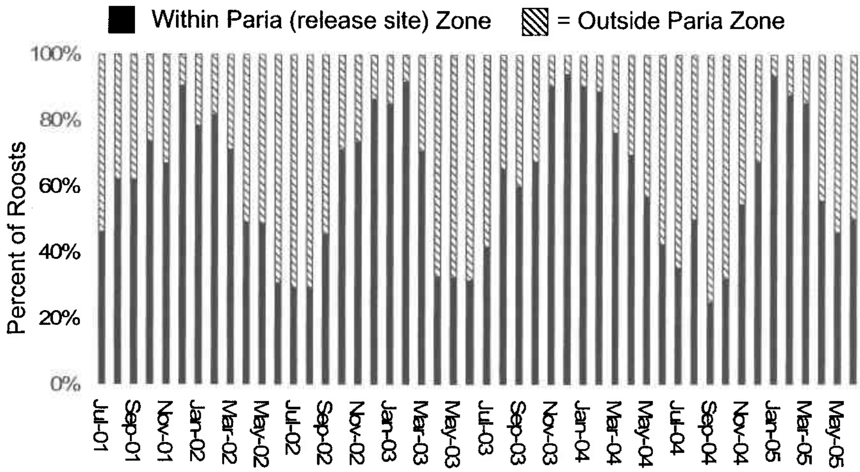

Fig. 4. Monthly roosting patterns of free-ranging condors within and outside the Paria (release site) Zone during July 2001–June 2005 (from VHF ground tracking data).

Movements in Relation to Lead Exposure

The moderately reduced numbers of condors using the Kaibab area in 2003 (Plate 9) in part reflected the longer holding of birds after testing in October and November in response to rising lead levels and those of the previous fall (Fig. 5). The many exposures recorded in November 2002 corresponded to the centerfire rifle deer seasons that extended intermittently from 18 October to 1 December on the nearby Kaibab Plateau. A total of 1,982 deer permits were issued that year compared to 975 in 2003, and 1,450 in 2004. Reported hunter success rates varied from 32–84%, meaning that an average of about 700 deer offal piles remained in the landscape each year. Data reported by Hunt et al. (2006) suggest that the majority of these would have contained bullet fragments (Fig. 6), as would an unknown number of deer carcasses lost to wounding. Observations by Peregrine Fund staff confirmed that condors fed upon deer offal and carcasses on the Kaibab Plateau and elsewhere, and suggested that ravens, which themselves may be drawn to carrion by gunshots (White 2005), attracted condors to deer carrion even in forest and woodland where visibility was restricted (see Koford 1953).

The temporal connection between lead exposure and the period of the Kaibab deer seasons (Fig. 7) led us to hypothesize that hunter-killed deer on the Kaibab Plateau could alone account for the high degree of lead exposure apparent in the fall. In a further attempt to find clarifying

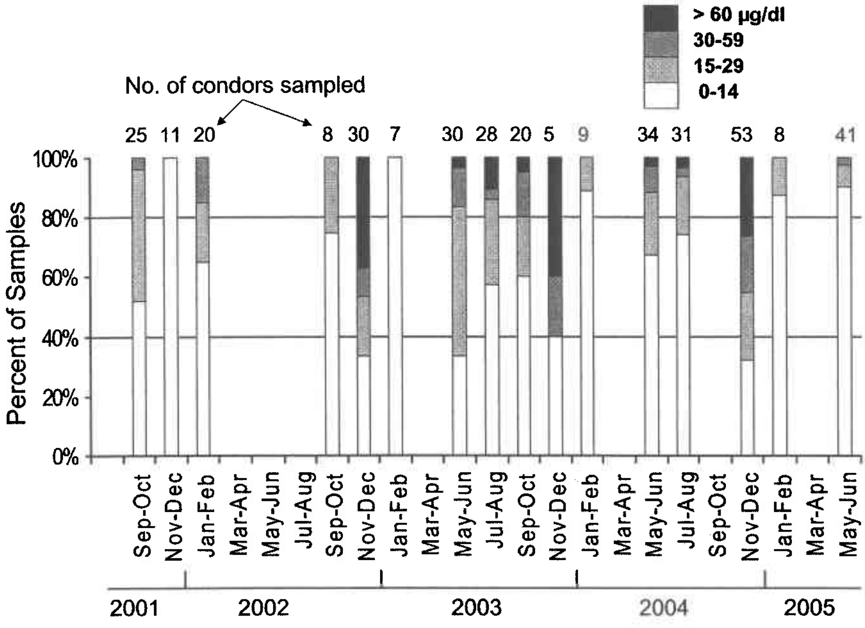

Fig. 5. Condor blood lead levels recorded from September 2001 through June 2005, Arizona.

evidence, and in consideration of the 7- to 20-day half-life of blood lead levels as reviewed by Fry and Maurer (2003), we ordered the data on movements to reflect condor roost zones during the 28 days prior to each blood lead sampling performed at the release site during July 2001–June 2005 (Parish et al. this volume). We calculated the percentage of roosting in each of the four zones, excluding the four Grand Canyon breeders and one wild-produced juvenile because of their association with active nests. We did not consider the West Zone in the analysis because condors visited it so rarely; only once was a condor detected in the West Zone during the 28-day period prior to testing.

Of 37 blood lead samplings of condors that roosted continually at the release site during the 28 days prior to sampling, none showed lead levels higher than 12 µg dL^{-1} (mean = 5.4, SD ± 3.3, see Parish et al. this volume). Among 11 additional lead samplings for which no data were available to indicate movement outside the release site, three condors showed exposures ranging from 20–26 µg dL^{-1}, and one indicated a high lead level of 81 µg dL^{-1}. However, its whereabouts outside the release site and those of the three with moderate exposure were unknown during most of the previous 28 days.

Two condors that died of ingesting shotgun pellets on 12 and 23 January 2005 were assumed to have obtained them from the same location

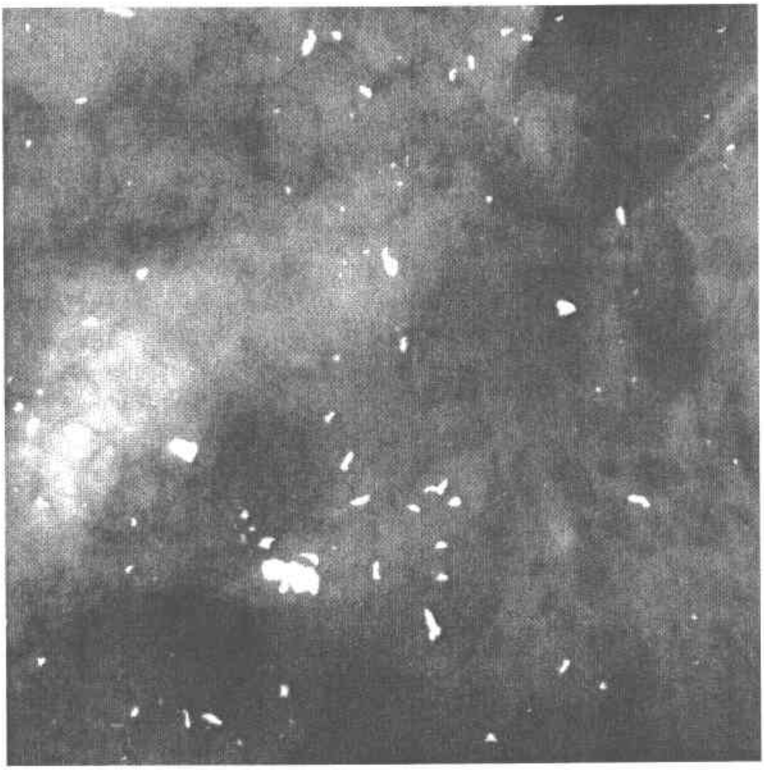

Fig. 6. Bullet fragments in the gut pile of a deer shot with a standard, lead-based, soft point hunting bullet as revealed by radiography.

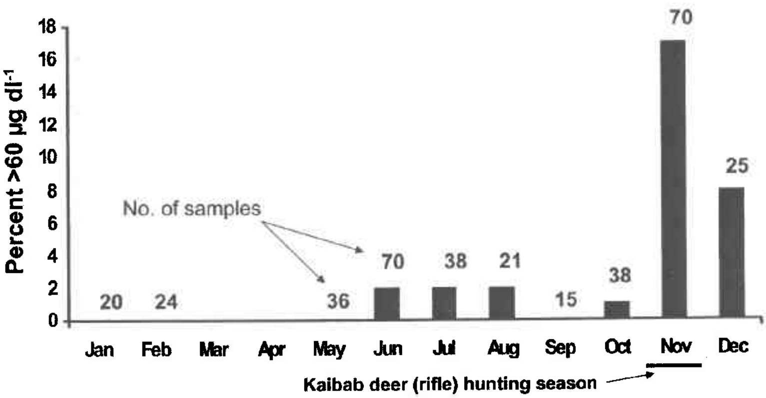

Fig. 7. Monthly differences in the percent of condor blood samples showing lead levels greater than 60 µg dL^{-1}. Monthly data are pooled from July 2001 to June 2005.

in the River Corridor Zone where they were observed together until 21 and 38 days prior to death. They both returned to the release site where they remained for 19 and 26 days before dying. The delay between exposure and death may have resulted from the retention of shotgun pellets in the stomach, evident in radiographs obtained at necropsy, a tendency also noted in an earlier episode involving ingestion of shotgun pellets by multiple condors in the summer of 2000 (Woods et al. this volume). The infrequent documentation of bullet fragments relative to the large number of putative exposures to rifle-killed animals in the region may result from the very small mass of most bullet fragments, allowing their complete absorption prior to radiography (Hunt et al. 2006). Additionally, their irregular shapes may adhere to food passing from the stomach into the intestine, whereas spherical shotgun pellets may be less likely to adhere, resulting in a protracted period of absorption.

The Kaibab Plateau showed a clear positive relationship between condor visitation and lead exposure ($\chi^2 = 24.4$, df = 3, $P < 0.001$, $n = 283$ samples), and the relationship remained pronounced when the analysis was shortened to 14 days prior to sampling ($\chi^2 = 22.0$, df = 3, $P < 0.001$) and even to seven days ($\chi^2 = 13.8$, df = 3, $P < 0.005$) (Table 1). This result is consistent with the hypothesis of hunter-killed deer on the Kaibab Plateau as a principal source of lead to condors tested in November and December. As a notable example, a 3.5-year-old condor tested on 26 November 2004 showed blood lead levels approaching 700 µg dL^{-1} and numerous metal fragments in radiographs of the stomach (Parish et al. this volume). Tracking data indicated that this condor had spent at least 21 of the previous 28 days on the Kaibab Plateau where the deer (centerfire rifle) season occurred within the period of 22 October to 28 November. In November 2004, 12 condors showing <30 µg dL^{-1} had an average of 3.7 recorded roosts in the Kaibab Zone during the previous 28 days, whereas 11 individuals showing >30 µg dL^{-1} averaged 8.1 roosts in that zone ($t = 1.9$, $P = 0.04$).

Table 1. Percentage of blood samples (n = 283) in which tested condors were detected in each zone at least once during the 28-day period prior to testing (see Parish et al. this volume for discussion of blood-lead levels); the period of study extended from September 2001 through June 2005.

Blood-lead level (µg dL^{-1})	No. of blood samples	Kaibab Zone (%)	Grand Canyon Zone (%)	River Corridor Zone (%)	Utah Zone (%)
0–14	141	76 (54)	110 (78)	40 (28)	19 (13)
15–29	63	33 (52)	49 (78)	8 (13)	8 (13)
30–59	40	30 (75)	30 (75)	8 (20)	3 (8)
>60	39	36 (92)	23 (59)	4 (10)	5 (13)

The other three zones showed no increasing trend of lead levels with condor visitation (Table 1). The River Corridor Zone had relatively few deer, and that portion of the Grand Canyon Zone most frequented by condors was national park land, an area where hunting was prohibited. The Utah Zone showed no relationship even though it had fall deer and elk hunting seasons and one condor died there of lead ingestion in August 2002. However, condors only recently began frequenting the region in numbers, and the sample of blood-assays of condors visiting that zone was relatively small (n = 35, compared with 175, 212, and 60 for the Kaibab, Grand Canyon, and River Corridor zones, respectively).

Condors were also exposed to lead in summer, albeit in lower proportion than fall (Fig. 7). Unlike the predictable annual production of rifle-killed deer carrion, however, we have no clear hypothesis regarding the sources of summer lead exposure. There were no summer firearms seasons for ungulates anywhere within the condor range in Arizona or Utah. The episode of multiple condor poisonings by shotgun pellets in June 2000 was therefore unexpected, like the similar poisonings in January 2005 (Woods et al. this volume). However, the chance discovery of a condor feeding upon a rifle-killed coyote in summer 2003 in a roadside meadow on the Kaibab Plateau suggested the possibility that predator shooting might be a significant factor in condor lead exposure (Parish et al. this volume). Radiographs of the partial remains of that coyote showed rifle bullet fragments, and radiographs of two condors associated with it showed bullet fragments in their stomachs. Subsequent inquiries suggested that coyote shooters travel to the Kaibab Plateau soon after snowmelt in mid-May when the roads open for travel. Predator shooting occurs throughout the condor range, but our data on movements indicated no principal area of summer exposure to lead.

Condor Use of Deer Remains

Monitoring of condor movements from January 2002 through September 2005 led to the discovery of 196 dead animals within the study area. We found condors in association with the remains of 78 (40%) deer, 42 (21%) elk, 10 (5%) coyotes, 51 (26%) domestic livestock (cattle, horses, mules, and sheep), and 16 (8%) miscellaneous animals (Table 2). Carcasses in the Grand Canyon Zone, mainly elk, were primarily victims of road-vehicle collisions and falls from cliffs within the Grand Canyon National Park. In the Kaibab Zone, at least 15 of the 55 deer had been killed by hunters (six were gut piles); the remaining fatalities included 9 from road vehicle collisions and 32 from unknown causes. Twenty-five (78%) of the latter were found during fall deer hunting periods (50%) or in the weeks between them (28%). At least two of the nine coyotes on the

Table 2. Animal remains recorded in association with condors from 2002 through September 2005 in three zones in Arizona. We also found condors at two additional carcasses in other zones (a coyote and a horse).

	Deer	Elk	Coyote	Livestock	Miscellaneous	Total
Kaibab Zone	55	0	9	37	4	107
Grand Canyon Zone	21	41	0	6	9	77
Utah Zone	2	1	0	7	3	13

Kaibab Plateau had been shot (both contained bullet fragments), two were killed by road vehicles, and the remainder died of unknown causes.

Discussion

The several lines of evidence presented in this report support the hypothesis that deer killed with lead-based rifle bullets on the Kaibab Plateau during the November hunting season were the primary source of elevated blood lead levels measured in condors in northern Arizona during 2002–2004. First, there is the known history of exposure. Although our data on blood lead levels were relatively sparse in the early years, the incidence and predictability of exposure increased dramatically in fall 2002 when condors began frequenting the Kaibab Zone in numbers (e.g., Plate 9, see also Parish et al. this volume). Second, the sharp annual peaks of exposure in November and December 2002–2004 were synchronous with the November deer hunting season in the Kaibab Zone (Fig. 7). Third, the exposure peak was also synchronous with the peak of condor occurrence there (Plate 9). Fourth, blood lead levels of condors visiting the Kabaib Zone within 7–28 days of testing were significantly higher than those of condors undetected in the zone during those periods; the other zones showed no trend of increase of lead exposure with visitation. These results were expected because the Kaibab Zone, an area of close proximity to the release site and of frequent use by condors, is one where many deer are annually killed by rifles. Hunters necessarily leave the offal of each harvested deer in the field, and most rifle-killed deer gut piles and whole deer lost to wounding are now known to contain numerous lead bullet fragments (Hunt et al. 2006).

As a result of these findings, the schedule of lead testing in Arizona is now geared in part to the regularity of the fall deer seasons so that the majority of condors can be screened. Lead exposures outside the time frame of the deer hunting seasons are more difficult to detect because of the evident scattering of exposures in time and space. Of the two other known avenues of lead exposure—shotgun pellets in the carcasses of unknown species and lead bullet fragments in coyote carcasses—neither can yet be anticipated or connected with specific condor-use areas. Data on movements suggest that the pellet episode exposing 12 or more condors in June

2000 derived from the western portion of the Grand Canyon Zone, and the two pellet ingestion fatalities in January 2005 appear to have been come from the River Corridor Zone. However, neither supposition can be corroborated with available evidence.

We believe that rifle-killed coyotes may be a frequent source of lead exposure in summer because there is widespread interest in coyote hunting in the region, and rifle-killed coyotes are likely to contain lead. Polymer-tipped bullets made specifically for coyote hunting are designed to explode into tiny fragments upon impact and remain entirely within the animal (Fig. 8). There is, however, little direct evidence to suggest that condors encounter rifle-killed coyotes in numbers sufficient to account for the rate of lead exposure recorded in summer (Fig. 7). Much, therefore, remains unknown about the geography of lead exposure among condors in Arizona and Utah and its implications for the welfare of the population. Although the evidence for lead-based projectiles as the main pathway of lead ingestion by condors released in Arizona is now unequivocal, we will continue to explore the possibility of other sources as the population expands.

Of particular interest is the demographic question of what proportion of condors showing high blood lead levels or lead bodies in radiographs

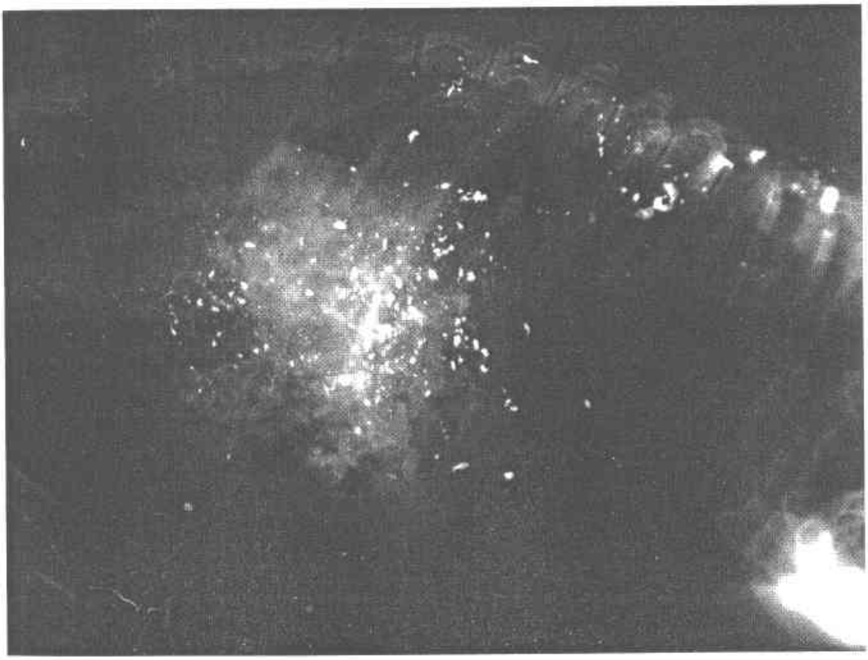

Fig. 8. A profusion of metal fragments is visible in this radiograph of a coyote shot with a standard, lead-based, polymer-tipped "varmint bullet." (Photo by Erin Gott.)

would die without the mitigating effects of monitoring and treatment. Computations by Woods et al. (this volume) suggest that an increase in the adult mortality rate arising from lack of such intervention would likely tip the demographic balance toward decline. Our data and those of Parish et al. (this volume) suggest that virtually all free-ranging condors in Arizona have been exposed to lead, and there is likely a proportion of the population that has survived high, undetected exposures. Whereas all exposed condors have ingested lead, removal of lead bodies by purging or surgery has occurred in only nine cases (Parish et al. this volume), implying that the majority of lead bodies are either passed into the intestine, expelled in castings, or completely absorbed. It is thus worth considering the possible long-term sub-lethal effects of repeated exposure, chelation, and radiography on condor health and fecundity. There is good evidence for other species of birds that lead exposure during development may permanently impair brain function (see Burger and Gochfeld 2005), an important issue considering the long developmental period in nestling condors and the likelihood of exposure during this period. In light of all these considerations, our findings suggest that a reduction in the use of lead-based ammunition within the condor range could well enable the existence of a self-sustaining condor population. Nontoxic bullets of proven high efficacy in deer hunting are readily available to hunters (McMurchy 2003, Towsley 2005, Sullivan et al. this volume), and shooters could easily remove coyotes, hares, and other species killed with lead-based bullets from the field.

Acknowledgments

Funding was provided by The Peregrine Fund, the U.S. Fish and Wildlife Service, and the Arizona Game and Fish Department. We thank Bill Burnham, Tom Cade, Bill Heinrich, Pat Hughes, Lloyd Kiff, Brian Mutch, Angel Montoya, Kurt Burnham, Pete Weidner, Chad Olson, Erin Gott, Kathy Orr, Sophie Osborn, Andi Rogers, Travis Rosenberry, Maggie Sacher, Duane Shroufe, Kathy Sullivan, Bruce Talbert, Paul Juergens, and Randy Townsend. Telemetry trackers included Jill Adams, Brandon Breen, Jessi Brown, Ann Burke, Daniel Burnetti, Gant Charping, James Christian, Joseph Crapanzano, Chris Crowe, Janelle Cuddeford, Marta Curti, Ann Marie DiLorenzo, Stephen Agius, Tyrone Donnelly, Gretchen Druliner, Sam Elizondo, Beau Fairchild, Kevin Fairhurst, Edward Feltes, Chadd Fitzpatrick, Paul Flournoy, Lisa Fosco, Vincent Frary, Jody Bartz, Melissa Gray, Sean Grimland, Courtney Harris, Adam Hutchins, Helen Johnson, Jeffrey Kingscott, Karen Leavelle, Kristine Lightner, Roger Benefield, Amy Lindsley, David Loomis, Megan Lout, Tanya Maddock, Michael Maglione, Frank Nebenburgh, Blake Massey, Khris McConnell, David McGraw, Phil McKenna, Grant Merrill, Tim Bischof, Christopher

Michaud, Betty Moore, Dennis Mott, Paul Mueller, Nichole Munkwitz, Curt Mykut, Frank Nebengurgh, Amy Nicholas, Jason Blackburn, Hannah Ogden, Kathryn Parmentier, Michael Maglione, Mary Schwartz, Molly Severson, Kirk Stodola, Elise Snyder, Melanie Spies, Molly Thomas, Mark Vekasy, Kristy Bly, Jonna Weidmaier, Eric Weis, Anne Welch, and Jim Wilmarth. Tom Cade, Allan Mee, and Linnea Hall provided critical reviews of the manuscript.

Literature Cited

Burger, J., and M. Gochfeld. 2005. Effects of lead on learning in Herring Gulls: an avian wildlife model for neurobehavioral deficits. Neurotoxicology 26:615–624.

Cade, T. J., S. A. H. Osborn, W. G. Hunt, and C. P. Woods. 2004. Commentary on released California Condors *Gymnogyps californianus* in Arizona. Pages 11–25 *in* Raptors Worldwide: Proceedings of VI World Conference on Birds of Prey and Owls (R. D. Chancellor and B.-U. Meyburg, Eds.). World Working Group on Birds of Prey and Owls/MME-Birdlife, Hungary.

Eisler, R. 1988. Lead hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.14). Patuxent Wildlife Research Center, Laurel, Maryland.

Fry, D. M., and J. R. Maurer. 2003. Assessment of lead contamination sources exposing California Condors. Final report to the California Department of Fish and Game, Sacramento.

Hoffmeister, D. M. 1986. The Mammals of Arizona. University of Arizona Press, Tucson.

Hunt, W. G., W. Burnham, C. N. Parish, K. Burnham, B. Mutch, and J. L. Oaks. 2006. Bullet fragments in deer remains: implications for lead exposure in scavengers. Wildlife Society Bulletin 34:168–171.

Janssen, D. L., J. E. Oosterhuis, J. L. Allen, M. P. Anderson, D. G. Kelts, and S. N. Wiemeyer. 1986. Lead poisoning in free-ranging California Condors. Journal of the American Veterinary Medical Association 189:1115–1117.

Koford, C. B. 1953. The California Condor. National Audubon Research Report 4: 1–154.

Kramer, J. L., and P. T. Redig. 1997. Sixteen years of lead poisoning in eagles, 1980–95: an epizootiologic view. Journal of Raptor Research 31:327–332.

McMurchy, I. 2003. Barnes XLC bullets. American Hunter 31 (January):70–71.

Mee, A., J. A. Hamber, and J. Sinclair. 2007. Low nest success in a reintroduced population of California Condors. Pages 163–184 *in* California Condors in the 21st Century (A. Mee and L. S. Hall, Eds.). Series in Ornithology, no. 2.

Meretsky, V. J., and N. F. R. Snyder. 1992. Range use and movements of California Condors. Condor 94:313–335.

Meretsky, V. J., N. F. R. Snyder, S. R. Beissinger, D. A. Clendenen, and J. W. Wiley. 2000. Demography of the California Condor: implications for reestablishment. Conservation Biology 14:957–967.

Parish, C. N., W. R. Heinrich, and W. G. Hunt. 2007. Lead exposure, diagnosis, and treatment in California Condors released in Arizona. Pages 97–108 *in*

California Condors in the 21st Century (A. Mee and L. S. Hall, Eds.). Series in Ornithology, no. 2.

Sullivan, K., R. Sieg, and C. Parish. 2007. Arizona's efforts to reduce lead exposure in California Condors. Pages 109–122 *in* California Condors in the 21st Century (A. Mee and L. S. Hall, Eds.). Series in Ornithology, no. 2.

Towsley, B. M. 2005. The hunting bullet redefined. American Rifleman 153 (December):34–43.

Wallace, M. P., M. Fuller, and J. Wiley. 1994. Patagial transmitters for large vultures and condors. Pages 381–387 *in* Raptor Conservation Today: Proceedings of the IV World Conference on Birds of Prey and Owls (B.-U. Meyburg and R. D. Chancellor, Eds.). World Working Group for Birds of Prey. Pica Press, Shipman, VA.

Wallace, M. P., and S. A. Temple. 1987. Competitive interactions with and between species in a guild of avian scavengers. Auk 104:290–295.

White, C. 2005. Hunters ring dinner bell for ravens: experimental evidence of a unique foraging strategy. Ecology 86:1057–1060.

Wiemeyer, S. N., J. M. Scott, M. P. Anderson, P. H. Bloom, and C. J. Stafford. 1988. Environmental contaminants in California Condors. Journal of Wildlife Management 52:238–247.

Woods, C. P., W. R. Heinrich, S. C. Farry, C. N. Parish, S. A. H. Osborne, and T. J. Cade. 2007. Survival and reproduction of California Condors released in Arizona. Pages 57–78 *in* California Condors in the 21st Century (A. Mee and L. S. Hall, Eds.). Series in Ornithology, no. 2.

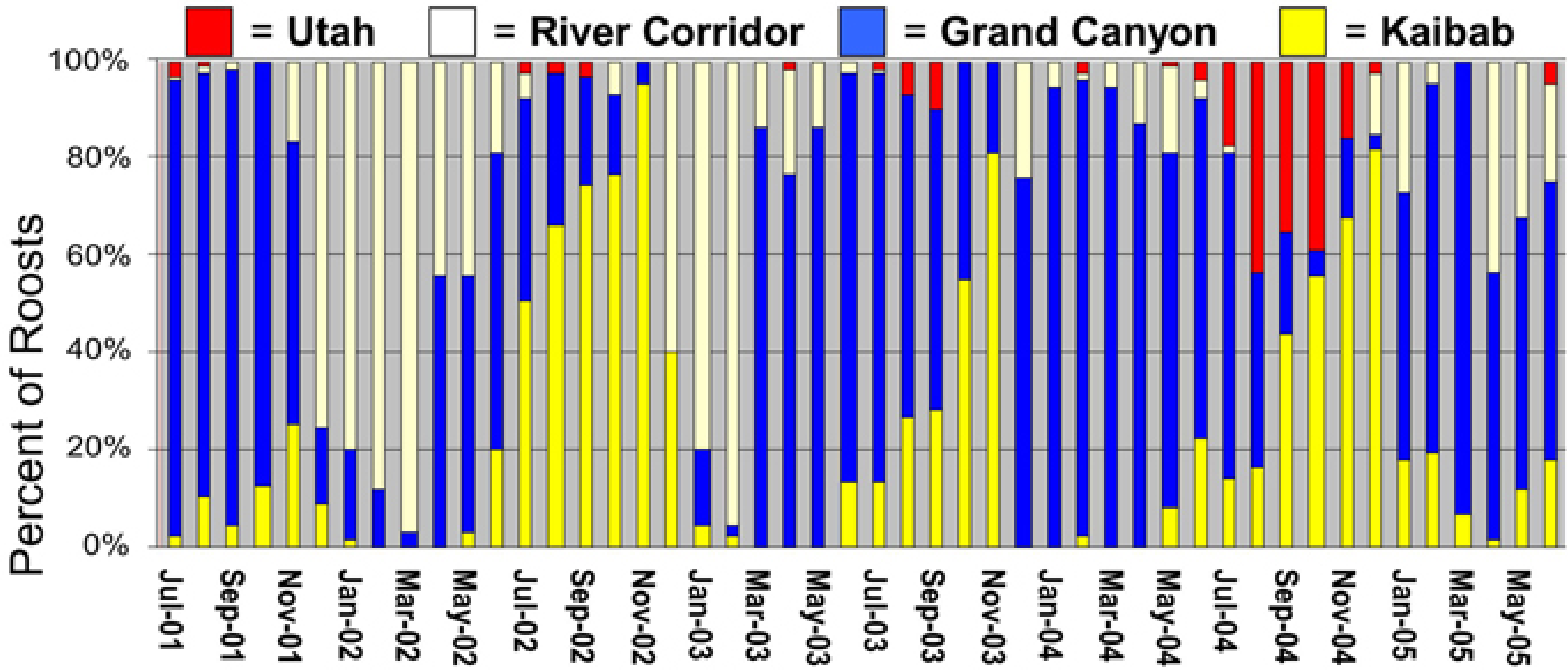

Plate 9. Monthly roost allocation by free-ranging condors (excluding breeders and wild-produced young) among four zones outside the Paria (release site) Zone from July 2001 through June 2005 (n = 34,018 relocations). The number of free-ranging condors represented in the graph increased each year, as follows: 23 individuals in 2001, 29 in 2002, 37 in 2003, 37 in 2004, and 42 in 2005.