Human–Wildlife Conflicts 1(2):224–234, Fall 2007

Efficacy of CPTH-treated egg baits for removing ravens

Peter S. Coates, Department of Biological Sciences, Idaho State University, Pocatello, ID 83209-8007, USA *coatpete@isu.edu*
Jack O. Spencer, Jr., USDA/APHIS/Wildlife Services, 4600 Kietzke Lane, Building O, Reno, NV, 89502, USA
David J. Delehanty, Department of Biological Sciences, Idaho State University, Pocatello, ID 83209-8007, USA

Abstract:
Human-altered landscapes have provided resource subsidies for common ravens (*Corvus corax*) resulting in a substantial increase in raven abundance and distribution throughout the United States and Canada in the past 25 years. Ravens are effective predators of eggs and young of ground-nesting birds. During 2002–2005, we tested whether chicken egg baits treated with CPTH (3-chloro-p-toluidine hydrochloride) could be used to manage raven numbers in an area where raven depredation was impacting sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) and greater sage-grouse (*Centrocercus urophasianus*) populations in Nevada. We performed multiple raven surveys at a treatment site and 3 control sites and used videography to identify predators and estimate egg bait consumption. We detected reductions in raven abundances over time at the treatment site during all years of this study and did not detect reductions in raven abundances at control sites. Videographic observations of egg consumption indicated that the standard 1:2 ratio (1 raven removed/2 eggs consumed) substantially overestimated raven take because nontarget species (rodents) consumed some egg baits. The technique described here likely will be effective at reducing raven densities where this is the intended management action.

Key Words: 3-chloro-p-toluidine hydrochloride, avicide, chicken egg baits, common raven, CPTH, *Corvus corax*, DRC-1339, human–wildlife conflicts, Nevada, wildlife damage management

Human-altered landscapes provide resource subsidies to common ravens (*Corvus corax*) that frequently lead to their increased reproduction and survival (Boarman 1993, Webb et al. 2004). Ravens often use electrical transmission towers, highway overpasses, and railroad trestles as nesting substrate (Boarman and Heinrich 1999), aiding reproduction in areas that lack natural nest sites. Ravens forage efficiently in agricultural fields (Engel and Young 1992*a*), landfills (Webb et al. 2004), lambing sites (Larsen and Dietrich 1970), rangelands (Knight 1984), and linear right-of-ways of electric power transmission lines (Knight and Kawashima 1993). Raven abundance has tripled in the past 40 years throughout North America (Sauer et al. 2004), and increased as high as 1,500% since the 1960s in portions of the western United States (Boarman 1993, Sauer et al. 2004).

In the Great Basin, ravens feed opportunistically on eggs and young of many birds and animals (Boarman and Heinrich 1999), including prairie grouse (*Centrocercus urophasianus*;Schroeder et al. 1999, Schroeder and Baydack 2001, P. S. Coates, unpublished data). Unnaturally high raven populations as a consequence of anthropogenic resource subsidies may cause "spillov-er predation" (Schneider 2001). Spillover predation occurs when raven abundance increases due to resource subsidies. As individual ravens move to and hunt for prey in adjacent landscapes, they cause unnaturally high predation rates (Kristen and Boarman 2003). Concern that subsidized increases in raven abundances are adversely affecting sensitive species is growing because ravens are effective predators of many threatened and endangered species (Boarman and Heinrich 1999).

Managers often rely on multiple methods to reduce raven predation including shooting, trapping, and poisoning, as well as habitat manipulation (Boarman and Heinrich 1999). Even where long-term management programs (e.g., natural habitat restoration) are carried out, managers often include short-term lethal programs to reduce raven numbers. Toxic compounds are often a method of choice for lethal control because of advantages of reduced

labor (Conover 2002) and applications designed to target specific species. The compound CPTH (3-chloro-p-toluidine hydrochloride), or DRC-1339, is the only legal toxicant currently registered by the U. S. Environmental Protection Agency (EPA) for raven population control (Larsen and Dietrich 1970, Spencer 2002). A lethal dose of CPTH causes irreversible kidney necrosis (DeCino et al. 1966) resulting in a period of listlessness followed by death within 24–72 hours of ingestion (Cunningham et al. 1979). Lethal dosages vary substantially among avian species, and corvids are highly sensitive to CPTH (LD_{50} = 5.6 mg/kg; Larsen and Dietrich 1970). Other avian species found in shrub-steppe communities that are also highly sensitive to CPTH include red-winged blackbirds (*Agelaius phoeniceus*; LD_{50} = 1.8 to 3.2 mg/kg) and mourning doves (*Zenaida macroura*; LD_{50} = 5.6 to 10.0 mg/kg) (DeCino et al. 1966).

To target ravens and other corvids, managers inject CPTH into chicken egg baits and place baits where they are likely to be encountered by ravens but not by nontarget species that also are sensitive to CPTH effects from ingesting the compound (Spencer 2002). No cases of secondary poisoning by CPTH of raptors or mammals have been observed (Cunningham et al. 1979), most likely because of rapid degradation of CPTH following ingestion coupled with relatively low CPTH sensitivity of species that would typically scavenge raven carcasses. CPTH has been used to reduce abundance of other birds that were judged to be pests, including red-winged blackbirds (Blackwell et al. 2003), American magpies (*Pica hudsonia*; Guarino and Schafer 1967), European starlings (*Sturnus vulgaris*; Besser et al. 1967; Royall et al. 1967), American crows (*Corvus brachyrhynchos*; Boyd and Hall 1987) and herring gulls (*Larus argentatus*; Seamans and Belant 1999).

Many managers have had limited success in using CPTH in the field to remove ravens, perhaps because published descriptions of application techniques and their efficacy are lacking or have not been previously developed. Managers typically estimate the number of ravens removed by interpolating from number of egg baits that disappear from bait stations, assuming that missing egg baits have been consumed by ravens (Spencer 2002). A common estimate is that 1 raven is removed from the population for every 2 missing egg baits at a station (Spencer 2002).

Our objectives were to develop, apply, and measure the efficacy of using systematically placed chicken eggs treated with CPTH to remove ravens. From 2002–2005, the raven removal program was necessary to reduce their predation during the breeding season of a small, reintroduced population of sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) and a natural population of greater sage-grouse (*Centrocercus urophasianus*) in northeastern Nevada. Here, we describe the CPTH application technique and its effects on a raven population. We also used video surveillance to identify consumers of egg baits and to estimate the number of ravens removed from the population by quantifying consumed CPTH egg baits.

Study areas

We conducted systematic raven removal and raven surveys on transects that overlap a treatment site of approximately 10,000 ha located on the east side of the Snake Mountains in northeastern Nevada, USA (N 0670859, E 4599749, zone 11, NAD 83), during the springs of 2002–2005. The study area was chosen by Nevada Department of Wildlife (NDOW) based on efforts to establish a reintroduced, nascent population of sharp-tailed grouse (Coates and Delehanty 2006). NDOW, in cooperation with the U.S. Department of Agriculture, Animal Health Inspection Service, and Wildlife Services (WS) chose to remove ravens because they were thought to be a primary predator of sharp-tailed grouse nests. Their assumption was based on interpreting nest and egg remains following depredation during 1999–2001 (P. S. Coates, unpublished data). Dominant plant communities were shrub-steppe at lower elevations and mountain shrub at higher elevations. Several other potential egg predators occupying the study area included coyotes (*Canus latrans*), striped skunks (*Mephitis mephitis*), American badgers (*Taxidea taxis*), ground squirrels (*Spermophilus* spp.), American magpies, and American crows.

Methods

Raven surveys

We conducted transect surveys (n = 64; Table 1) following the technique of Garton et al. (2005). Surveys were conducted every 3–7 days at the

treatment site between late March and late June during 2002–2005. This period coincided with the periods of egg-bait treatment and sage-grouse nesting. During 2004 and 2005, we con-ducted raven surveys (n = 60) every 3–7 days at 2 and 3 untreated (UNT) sites (no CPTH application), respectively, using the same standard protocol as the treatment site. The first (UNT-1), second (UNT-2), and third (UNT-3) untreated sites were located approximately 22, 37, and 53 km from the treatment site, respectively. We chose untreated sites located at distances >3 times the reported average foraging distance by ravens (6.9 km; Engel and Young 1992*b*). Our reason for spacing apart treated and untreated sites was to prevent transient ravens from traveling from untreated sites into the area of raven removal and thereby affecting numbers of ravens at untreated sites. This average raven travel distance was derived from the nearest studied population of ravens (southwestern Idaho), and was located in a similar shrub-steppe community.

All survey transects were a distance of 27 km during 2002–2003 and 20 km during 2004–2005. We established 25 and 33 survey points along each 20- and 27-km transect, respectively. Points along each transect were separated by 800 m. Using binoculars at each survey point, we searched for a 3-minute period and counted the number of ravens and other corvids, flying or perched. We avoided recounting individual ravens by keeping track of ravens previously counted as we moved from 1 survey point to the next. We indexed raven abundance by calculating the number of ravens counted per 10 km along transects. Our objective was to compare indices of raven abundance among and within sites through the sage-grouse nesting season and not to estimate raven population density. We did not correct for the probability of detecting ravens in relation to distance from transect. Using binoculars to scan the shrub-steppe, we were confident that ravens within the transect width (0–500 m) would be detected without difficulty, regardless of whether the ravens were perching or flying.

Because we used vehicles to move between points, we designated survey transects based on unpaved roads at the treatment and untreated areas. Vehicle-use along roads was approximately the same among sites. Also, we selected transects that intersected ≥1 sage-grouse leks (sage-grouse breeding grounds) at all sites. The treatment site transect also intersected a newly established sharp-tailed grouse lek.

During 2002 and 2003, WS personnel performed 10 surveys as standard operational protocol. We occasionally observed and recorded crows and magpies at the treatment area during raven surveys. However, observations of these species were rare, perhaps because of the remote location of the treatment site, and they were not included in data analyses.

CPTH application

Raven removal was carried out in conjunction with WS personnel. We followed standard operational procedures for preparation of eggs treated with CPTH (Spencer 2002). We hard-boiled 220 eggs/week by placing 100 raw eggs at a time in an egg basket and boiling them in water for 13–15 minutes. We then removed the eggs and allowed them to cool for several hours. Cooling eggs prior to applying CPTH prevents cracking and toxicant decomposition from heat exposure. Eggs were rubber-stamped with a warning skull-and-crossbones or marked with the word poison, as instructed on the CPTH label. After the eggs cooled, we used a 6.3 mm ratchet hex screwdriver to punch an injection hole at the end opposite the air cell. The injection hole must reach the center of the yolk with a diameter large enough to contain 1 ml of solution without spillage.

To prepare the CPTH solution, we complied with all precautionary statements and directions indicated on the CPTH label. We made a 2% CPTH solution by dissolving 2 g of CPTH concentrate in 100 ml of potable water warmed to 43°C. We injected 1 ml of 2% CPTH solution into each egg injection hole using a 5-ml syringe or a 1-ml pipette. Prior to placement of egg baits at the treatment site, we stored the eggs in an upright position without covering injection holes for 2–4 hours to allow absorption of the compound into the albumen and yolk of each egg and prevent spillage.

Every 7 days at the treatment site from late March to late June 2002–2005, we placed 2 egg baits on the ground/bait station every 250 m along a 27.5-km route. We placed a total of approximately 10,560 eggs (2,640/year) through the duration of the study. The egg bait route intersected the recently established population

TABLE 1. Linear regression analyses of common raven abundances throughout the nesting season of sharp-tailed grouse and sage-grouse at the treatment site, where we distributed egg baits treated with CPTH (3-chloro-p-toluidine hydrochloride), and 3 untreated sites (UNT-1, UNT-2, and UNT-3) in northeastern Nevada during 2002–2005.

Year	Treatment				UNT-1				UNT-2				UNT-3			
	n[a]	r^2[b]	P[c]	Trend	n[a]	r^2[b]	P[c]	Trend	n[a]	r^2[b]	P[c]	Trend	n[a]	r^2[b]	P[c]	Trend
2002	12	0.381	0.033	Decrease												
2003	15	0.428	0.008	Decrease												
2004	20	0.283	0.016	Decrease	9	0.502	0.033	Increase					10	0.192	0.206	Stable
2005	17	0.734	<0.001	Decrease	13	0.031	0.856	Stable	13	0.011	0.733	Stable	15	0.038	0.488	Stable

[a] Number of surveys conducted.
[b] Coefficient of determination.
[c] Probability values from regression analyses comparing raven abundance to the ordinal date.

of sharp-tailed grouse and sage-grouse leks. We positioned eggs upright to prevent spillage of any compound that may not have been completely absorbed into the egg. Also, we placed eggs directly on the ground between shrubs with no vegetation covering them. To facilitate consumption by ravens we did not use unnatural objects (e.g., platforms) because ravens can be highly neophobic (Heinrich 1988). Also, every year the treatment site was prebaited with nontoxic egg baits 2–3 times to habituate ravens to egg baits as a food source. Prebaiting took place for 1–2 weeks. Between 62–72 hours following placement of egg baits (both treated and nontoxic), we recorded the number of eggs depredated, missing, or undisturbed, and collected and disposed of all remaining eggs. No eggs were left in the environment for more than 2–3 days, and no eggs were reused at a later date.

To identify egg bait predators, we used 4 miniature cameras with video-recording systems to monitor a random sample of egg baits throughout the treatment period (n = 18, 2004; n = 28, 2005). Also, we used 4 cameras to video-monitor nontoxic egg baits (no CPTH treatment) at random locations throughout the untreated sites during the same dates used to video record eggs at the treatment sites. This allowed us to compare frequencies of egg bait predator consumption among sites. Video-monitored eggs at untreated sites also had injection holes and warning labels. These were the only eggs placed at the untreated sites to prevent supplementing raven diets with a large quantity of unnatural food and, thereby, influencing raven abundances by attracting ravens into untreated areas. Cameras (40 × 40 × 60 mm) were deployed approximately 1 m from egg baits in a nearby shrub and equipped with infrared night illumination (850–950 nm wavelength), which is not detectable by vertebrates (Pietz and Granfors 2000). A 20-m cable was buried and connected to a time-lapsed, continuous-recording VCR (Pietz and Granfors 2000). We allowed video systems to record continuously for 72 hours. To avoid bias in the encounter frequency of animals that rely on visual cues to locate nests, we used adhesive camouflage tape and vegetation for concealment of the camera (Herranz et al. 2002). To avoid olfactory-related biases (Harriman and Berger 1986, Whelan et al. 1994), we used rubber boots and gloves to mask human scent during camera installation.

Statistical analyses

We used PROC MIXED procedures (SAS Institute Inc., Cary, N.C.) to test if changes in raven abundance indices differed through time among the treatment site and control sites. Year was assigned as a random effect. Raven abundance indices recorded at the treatment site during prebaiting were not assigned as a treatment variable in the analyses because CPTH eggs were not yet placed at the site. Also, we performed simple linear regressions at each site using abundance indices as the response variable and ordinal date (number of days elapsed from January 1) as the explanatory variable. Where the slope of a best-fit regression line differed statistically from zero, we determined whether the relationship was positive or negative.

Results

Indices of raven abundance changed through time at the treatment site (Figure 1) differently than at the untreated sites (F = 3.77; df = 3,115; P = 0.12; Figure 2). Raven abundances declined substantially at the treatment site during each year of the study, whereas abundances remained stable or increased at the untreated sites (Table 1). In each of the 4 years, raven abundance indices declined to near zero by mid-June in the treatment area, regardless of inter-year variation in raven abundance indices during March. An increase in abundance through time was detected at UNT-1 during 2004 (t = 2.66; df = 8; P = 0.033; Figure 2).

Of the 2,640 eggs placed at the treatment site/year, we found 756 eggs missing in 2002; 1,432 in 2003; 721 in 2004; and 1,736 in 2005. We video-recorded a total of 42 eggs consumed during 2004–2005. At the treatment site, 2 of 22 (9%) consumptions were by ravens, while at untreated sites ravens were responsible for 18 of 20 (90%) consumptions. Other consumers were Wyoming ground squirrel (*Spermophilus elegans*) (n = 14, treatment site only), Piute ground squirrel (*S. mollis*) (n = 3, treatment site only), Great Basin pocket mouse (*Perognathus parvus*; n = 1, treatment site only), American magpie (n = 2, treatment site only), and domestic cattle (n = 2, untreated site only). All rodents completely consumed the egg baits. Using videography, we found 1:11 ratio of

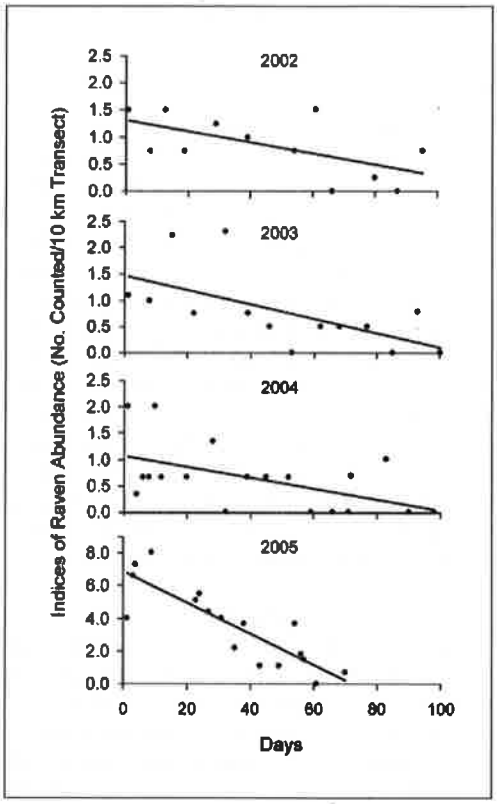

FIGURE 1. Indices of common raven abundance in relation to days of treatment using CPTH (3-chloro-p-toluidine hydrochloride), which was injected into chicken egg baits and placed in the environment for consumption by ravens every 7 days in northeastern Nevada during 2002–2005. Days of surveys were conducted from late March to mid-June, which encompassed the treatment period.

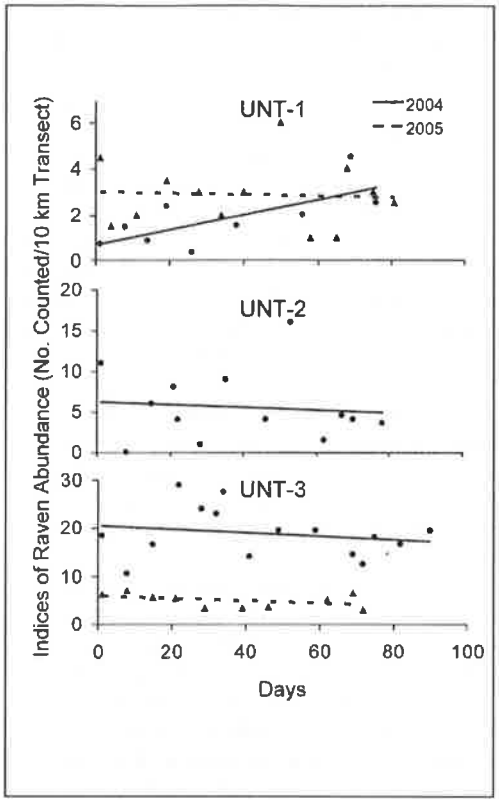

FIGURE 2. Indices of common raven abundance at 3 untreated sites in northeastern Nevada during 2004 (▲) and 2005 (●). UNT-1, UNT-2, and UNT-3 represent untreated sites (no CPTH application). Days of surveys were conducted from late March to mid-June.

raven consumption to missing eggs.

Discussion

We measured the effects of CPTH application using chicken egg baits on raven numbers in the wild and found substantial short-term reductions in raven population abundances associated with CPTH application. This is an important first test of the efficacy of CPTH at removing ravens using actual field conditions and untreated sites. It provides valuable information for making informed policy decisions. Removal of nest predators often increases nest success of ground nesting birds (Greenwood 1986, Garrettson and Rohwer 2001, Littlefield 2003), a necessary antecedent to recruitment and population renewal. Ravens have been documented to be important predators of sage-grouse nests at the treatment site (P. S. Coates, unpblished data) and elsewhere (Autenreith 1981, Schroeder et al. 1999, Schroeder and Baydack 2001), and removal of ravens may increase nest success of grouse (Batterson and Morse 1948).

Videography did not capture any nontarget species that are known to be at risk of fatality from CPTH effects consuming egg baits. However, ground squirrels, which are not known to be vulnerable to the dosage of CPTH we injected into eggs, were commonly observed consuming eggs. Ground squirrel LD_{50} values have not been described, but reported values of other rodents are relatively high. For example, mouse and white rat LD_{50} values were reported as 2,000 and 1,170-1,770 mg/kg, respectively (Clark 1986). The EPA

A raven is pictured in the act of taking an egg bait (left), then eating it (below).

approved CPTH for use primarily because of its rapid degradation and specificity to ravens and other corvids (raven's LD_{50} = 5.6 mg/kg; Larsen and Dietrich 1970). Therefore, chicken egg baits treated with CPTH to remove ravens from areas of raven damage appear to have low nontarget hazards, i.e., threat of affecting nonoffending animals (Conover 2002), something our finding supports. We did not observe dead animals or noticeable impairment of live animals of nontarget species due to the effects of CPTH. Furthermore, secondary poisoning hazards have not been observed in other studies and are thought to be unlikely to occur (Cunningham et al. 1979, Johnston et al. 1999). Although CPTH decomposes rapidly, it is important to remove all nonconsumed eggs from the field within 24–72 hours of placement to further reduce any unintended effects.

Recent evidence suggests that Richardson's ground squirrels (*Spermophilus richardsonii*), Wyoming ground squirrels, and Piute ground squirrels are not effective at depredating grouse eggs unless the eggs have been damaged (Coates and Delehanty 2004, Michener 2005). Our video observations indicate that ground squirrels used injection holes to open and consume our egg baits. Thus, while ground squirrels may not be important predators of grouse eggs (Michener 2005), they are an important predator of egg baits. We found that Wyoming and Piute ground squirrels were responsible for 71% of egg consumptions by species other than ravens.

Failure to consider ground squirrels as egg bait predators will lead to substantial error when using egg bait disappearance as a proxy for raven take. Egg bait consumption by ground squirrels will lead to overestimation of raven take, but the relationship has its own complexities. Ground squirrels were common at the untreated sites, but none were video-recorded consuming egg baits, as all squirrel consumptions took place at the treatment site. Ravens were primarily responsible for consumption (18 of 20 eggs) at untreated sites. Perhaps, in areas where ravens were abundant, they consumed egg baits prior to squirrels encountering and consuming them. Also, nocturnal rodents rarely consumed eggs. Egg baits were set out in morning hours providing ravens first access to bait relative to nocturnal mammals.

Alternatively, it is possible that ravens avoided treated eggs at the treatment site and not untreated eggs at the untreated sites. However, this seems unlikely because we found no videographic evidence of raven avoidance, and we measured a marked decline in raven abundance of the treatment site consistent with lethal consumption of egg baits.

Ravens and ground squirrels left similar signs following consumption of egg baits. For example, both species partially consumed eggs at the site and then moved eggs to another location, leaving fragmented egg shells at the bait site. Thus, ground squirrel and raven consumptions

of egg baits were indistinguishable using diagnostic egg remains. Relying on more precise ratios derived from unambiguous identification techniques may be the most practical method to estimate raven removal. These estimates should be accompanied with weekly raven surveys in the treatment and untreated areas.

Our results suggest that CPTH application may cause short-term reductions in raven numbers without long-lasting effects on raven populations because of reoccupation of any vacant territories. Within raven populations, many nonbreeding ravens without territories are transient (Boarman and Heinrich 1999) and have been reported to travel 40–65 km in a day (Engel and Young 1992*b*, Heinrich et al. 1994). Furthermore, raven numbers rebounded each spring to abundances seen prior to CPTH application. Therefore, reapplication of CPTH must be made annually.

Prebaiting the treatment area with nontoxic eggs for approximately 2 weeks appeared to facilitate the consumption of egg baits by ravens. Because chicken eggs differ noticeably from wild grouse eggs and territorial ravens are often neophobic (Heinrich 1988), territorial ravens may be less likely to eat egg baits. Therefore, prebaiting may help to target territorial and nonterritorial ravens.

Indices of raven abundance at UNT-3 were substantially greater than those of the other 2 sites (Figure 1). Perhaps, the high abundances at UNT-3 were associated with greater availability of anthropogenic subsidies. UNT-3 was located <5 km from a landfill and surrounded by agricultural activity, while the other sites were >30 km from a landfill with less agriculture. Also, we observed more human-made structures, standing water, linear right-of-ways (e.g., roads and transmission power-lines), and livestock at UNT-3. Our findings are consistent with other recent evidence that indicates increases in raven populations are due to anthropogenic alterations in water, food, and nest sites (Boarman 1993, Knight and Kawashima 1993, Boarman and Heinrich 1999).

When applying CPTH chicken egg baits directly on the ground to remove ravens, we recommend avoiding the 1:2 ratio (ravens to missing eggs) that is currently used by managers to estimate raven take throughout the treatment period because it may substantially overestimate raven take, especially if ground squirrels begin consuming egg baits after an initial period of raven removal. A 1:2 ratio may more accurately reflect raven take in areas of concentrated raven populations without egg-bait consumption by nontarget species (e.g., treatment at sanitary landfills).

In our study, the frequency of egg predators that consumed egg baits differed among sites, where ravens were most responsible for egg depredation at untreated sites, and ground squirrels were most responsible for egg depredation at the treatment site. The initial week of treatment following prebaiting may have resulted in high raven take, but prolonged treatment did not appear to continue to remove ravens at high rates, even though eggs disappeared at high rates throughout the treatment period. Unfortunately, we were unable to estimate raven take using videography during initial treatment. However, following the first week of application, our estimated raven take was 1:11 ratio, rather than the 1:2 ratio that is currently used. A 1:11 ratio would lead to an estimated 69, 130, 66, and 157 ravens removed from the treatment site during 2002, 2003, 2004, and 2005, respectively. Even using a 1:11 adjustment, these values still appear high. Perhaps, continued research using unambiguous identification techniques will improve or confirm our estimates.

Also, ratios likely will change over time at treatment sites, perhaps resulting in a continuum of ratios, especially if the rate of raven take is continually decreasing and ground squirrel numbers are unaffected. Our sample sizes did not permit calculating multiple ratios through time, but further research regarding changing ratios would greatly improve our understanding of estimating raven take based on egg-bait consumption. Also, videography may lead to minor overestimation in raven take because ravens are known to take eggs and cache them for later consumption (Boarman and Heinrich 1999), and eggs may be consumed when CPTH is no longer viable or eggs are taken but not consumed.

In conclusion, using the technique described here, CPTH egg-bait treatment is effective in reducing raven abundance for short periods and in the immediate area of treatment. Lethal removal of predators is often an effective short-term management action for increasing nest suc-

cess of ground nesting birds (Greenwood 1986, Garrettson and Rohwer 2001, Littlefield 2003). However, reducing anthropogenic resource subsidies of raven populations (Boarman 1993), and other long-term management actions, may be ultimately needed to reverse effects of spillover predation (Smith and Quinn 1996).

Acknowledgments

We thank T. Peterson, C. Simms, R. Troy, J. Warwick, and N. Sparks for significant field contributions, assistance in data collection, and providing logistic support. Valuable comments on earlier drafts of this manuscript were received from R. Mason. Jack H. Berryman Institute and Idaho National Engineering Laboratory/Bechtel funded this research with grants to David J. Delehanty through Idaho State University. Many thanks to the multiple generous sportsman and conservation organizationss that provided financial support, including Safari Club International (Idaho, Desert and Northern Nevada chapters), Carson Valley Chukar Club, Wildlife and Habitat Improvement of Nevada, Sportsmen for Fish and Wildlife, and Nevada Chukar Foundation. Also, we thank Nevada Department of Wildlife for funding the raven removal activities. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, carried out raven removal actions and were instrumental in our research.

Literature cited

Autenrieth, R. E. 1981. Sage grouse management in Idaho. Idaho Department of Fish and Game. Wildlife Bulletin 9. Boise, Idaho, USA.

Batterson, W. M., and W. B. Morse. 1948. Oregon sage grouse. Oregon Game Commission, Oregon Fauna Service 1, Portland, Oregon, USA.

Besser, J. F., W. C. Royall, and J. W. Degrazio. 1967. Baiting starlings with DRC-1339 at a cattle feedlot. Journal of Wildlife Management 31:48–51.

Blackwell, B. F., E. Huszar, G. M. Linz, and R. A. Dolbeer. 2003. Lethal control of red-winged blackbirds to manage damage to sunflower: an economic evaluation. Journal of Wildlife Management 67:818–828.

Boarman, W. I. 1993. When a native predator becomes a pest: a case study. Pages 191–206 *in* S. K. Majumdar, E. W. Miller, D. E. Miller, E. K. Brown, J. R. Pratt, and R. F. Schmalz, editors. Conservation and resource management. Pennsylvania Academy of Science, Philadelphia, Pennsylvania, USA.

Boarman, W. I. and B. Heinrich. 1999. Common raven (*Corvus corax*). *In* A. Poole and F. Gill, editors. The birds of North America 476. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington, D.C., USA.

Boyd, F. L., and D. I. Hall. 1987. Use of DRC-1339 to control crows in three roosts in Kentucky and Arkansas. Proceedings of the Eastern Wildlife Damage Control Conference 3:3–7.

Clark, J. P. 1986. Vertebrate pest control handbook. Division of Plant Industry, California Department of Food and Agriculture, Sacramento, California, USA.

Coates, P. S., and D. J. Delehanty. 2004. The effects of raven removal on sage grouse nest success. Proceedings of the Vertebrate Pest Conference 21:17–20.

Coates, P. S., and D. J. Delehanty. 2006. Effect of capture date on nest attempt rate of translocated sharp-tailed grouse *Tympanuchus phasianellus*. Wildlife Biology 12:277–283.

Conover, M. R. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. CRC, Boca Raton, Florida, USA.

Cunningham, D. J., E. W. Schafer, Jr., and L. K. McConnell. 1979. DRC-1339 and DRC-2698 residues in starlings: preliminary evaluation of their secondary hazard potential. Proceedings of the Bird Control Seminar 8:31–37.

DeCino, T. J., D. J. Cunningham, and E. W. Schafer. 1966. Toxicity of DRC-1339 to starlings. Journal of Wildlife Management 30:249–253.

Engel K. A., and L. S. Young. 1992*a*. Daily and seasonal activity patterns of common ravens in southwestern Idaho. Condor 91:372–378.

Engel K. A., and L. S. Young. 1992*b*. Movements and habitat use by common ravens from roost sites in southwestern Idaho. Journal of Wildlife Management 56:596–602.

Garrettson, P. R., and F. C. Rohwer. 2001. Effects of mammalian predator removal on production of upland-nesting ducks in North Dakota. Journal of Wildlife Management 65:398–405.

Garton, E. O., J. T. Ratti, and J. H. Giudice. 2005. Research and experimental design. *In* C. E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wild-

life Society, Bethesda, Maryland, USA.

Greenwood, R. J., 1986. Influence of striped skunk removal on upland duck nest success in North Dakota. Wildlife Society Bulletin 14:6–11.

Guarino, J. L., and E. W. Schafer. 1967. Magpie reduction in an urban roost. U.S. Department of Interior, Fish and Wildlife Service Special Scientific Report—Wildlife, No. 104. Washington, D.C., USA.

Harriman, A. E., and R. H. Berger. 1986. Olfactory acuity in the common raven (*Corvus corax*). Physiology and Behavior 36:257–262.

Heinrich, B. 1988. Why do ravens fear their food? Condor 90:950–952.

Heinrich, B., D. Kaye, T. Knight, and K. Schaumburg. 1994. Dispersal and association among common ravens. Condor 96:545–551.

Herranz, J., M. Yanes, and F. Suarez. 2002. Does photo-monitoring affect nest predation? Journal of Field Ornithology 73:97–101.

Johnston, J. J., D. B. Hurlbut, M. L. Avery, and J. C. Rhyan. 1999. Methods for the diagnosis of acute 3-chloro-p-toluidine hydrochloride poisoning in birds and the estimation of secondary hazards to wildlife. Environmental Toxicology and Chemistry 18:2533–2537.

Knight, R. L. 1984. Responses of nesting ravens to people in areas of different human densities. Condor 86:345–346.

Knight, L. R. and J. Y. Kawashima. 1993. Responses of raven and red-tailed hawk populations to linear right-of-ways. Journal of Wildlife Management 57:266–271.

Kristen, W. B., and W. I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84:2432–2443.

Larsen, K. H., and J. H. Dietrich. 1970. Reduction of a raven population on lambing grounds with DRC-1339. Journal of Wildlife Management 34:200–204.

Littlefield, C. D. 2003. Sandhill crane nesting success and productivity in relation to predator removal in southeastern Oregon. Wilson Bulletin 115:263–269.

Michener, G. R. 2005. Limitation on egg predation by Richardson's ground squirrels. Canadian Journal of Zoology 83:1030–1037.

Pietz, P. J., and D. A. Granfors. 2000. Identifying predators and fates of grassland passerine nests using miniature video cameras. Journal of Wildlife Management 64:71–87.

Royall, W. C. Jr., T. J. DeCino, and J. F. Besser. 1967. Reduction of a starling population at a turkey farm. Poultry Science 46:1494–1495.

Sauer, J. R., J. E. Hines, and J. Fallon. 2004. North American breeding bird survey, results and analysis 1966–2003. Version 2004.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Schneider, M. F. 2001. Habitat loss, fragmentation and predator impact: spatial implications for prey conservation. Journal of Applied Ecology 38:720–735.

Schroeder, M. A., and R. K. Baydack. 2001. Predation and the management of prairie grouse. Wildlife Society Bulletin 29:24–32

Schroeder, M. A., J. A. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). *In* A. Poole and F. Gill, editors. Birds of North America 425. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington, D.C., USA.

Seamans, T. W., and J. L. Belant. 1999. Comparison of DRC-1339 and alpha-chloralose to reduce herring gull populations. Wildlife Society Bulletin 27:729–733.

Smith, A. P., and D. G. Quinn. 1996. Patterns and causes of extinction and decline in conilurine rodents. Biological Conservation 77:243–267.

Spencer, J. O., Jr. 2002. DRC-1339 use and control of common ravens. Proceedings of the Vertebrate Pest Conference 20:110–113.

Webb, C. W., W. I. Boarman, and J. T. Rotenberry. 2004. Common raven juvenile survival in a human-augmented landscape. Condor 106:517–528.

Whelan, C. J., M. L. Dilger, D. Robson, N. Hallyn, and S. Dilger. 1994. Effects of olfactory cues on artificial-nest experiments. Auk 111:945–952.

Peter S. Coates is a Ph.D. candidate in biology at Idaho State University. He received a B.S. degree in conservation biology and an M.S.degree in biology at the University of Nevada–Reno. He is an associate wildlife biologist with The Wildlife Society and worked seasonally for USDA/Wildlife Services and Nevada Department of Wildlife. His research interests are restoration and management of native bird populations, particularly human influences on predator communities and habitat of birds. His current research focuses on nest success of sage-grouse in relation to predators, habitat, and grouse incubation behavior in northeastern Nevada.

Jack O. Spencer, Jr. graduated with a fish and wildlife degree from North Dakota State University and began his career with USDA/Wildlife Services in 1994 as a wildlife specialist in eastern Oregon. Currently he a supervisory wildlife biologist for USDA/APHIS/Wildlife Services in western Nevada. He and his family have worked for USDA/APHIS/Wildlife Services for several generations.

David J. Delehanty is an associate professor of biology at Idaho State University where he teaches ornithology, animal behavior, and conservation biology to graduate and undergraduate students. He maintains an active research laboratory, and his research focuses on the reproductive biology of birds especially as it applies to the conservation and restoration of native species and to advancing our understanding of linkages between environmental factors and reproductive readiness. He is also the curator of birds at the Idaho Museum of Natural History, home to a growing collection of birds of the Intermountain American West.

Journal of Field Ornithology

J. Field Ornithol. 79(4):421–428, 2008 DOI: 10.1111/j.1557-9263.2008.00189.x

Predators of Greater Sage-Grouse nests identified by video monitoring

Peter S. Coates,[1,3] John W. Connelly,[2] and David J. Delehanty[1]

[1] *Idaho State University, Department of Biological Sciences, Pocatello, Idaho 83209-8007, USA*
[2] *Idaho Department of Fish and Game, 1345 Barton Road, Pocatello, Idaho 83204, USA*

Received 23 February 2008; accepted 25 August 2008

ABSTRACT. Nest predation is the primary cause of nest failure for Greater Sage-Grouse (*Centrocercus urophasianus*), but the identity of their nest predators is often uncertain. Confirming the identity of these predators may be useful in enhancing management strategies designed to increase nest success. From 2002 to 2005, we monitored 87 Greater Sage-Grouse nests (camera, $N = 55$; no camera, $N = 32$) in northeastern Nevada and south-central Idaho and identified predators at 17 nests, with Common Ravens (*Corvus corax*) preying on eggs at 10 nests and American badgers (*Taxidea taxis*) at seven. Rodents were frequently observed at grouse nests, but did not prey on grouse eggs. Because sign left by ravens and badgers was often indistinguishable following nest predation, identifying nest predators based on egg removal, the presence of egg shells, or other sign was not possible. Most predation occurred when females were on nests. Active nest defense by grouse was rare and always unsuccessful. Continuous video monitoring of Sage-Grouse nests permitted unambiguous identification of nest predators. Additional monitoring studies could help improve our understanding of the causes of Sage-Grouse nest failure in the face of land-use changes in the Intermountain West.

SINOPSIS. **Depredadores de nidos del *Centrocercus urophasianus* identificados durante monitoreos con cámaras de video**

La depredación de nidos es la principal causa del fracaso de las nidadas del Greater Sage-Grouse (*Centrocercus urophasianus*), pero la identidad de los predadores de los nidos es usualmente incierta. Confirmar la identidad de estos depredadores puede ser útil para el desarrollo de estrategias de manejo diseñadas para incrementar el éxito de las nidadas. Entre el 2002 y el 2005, monitoreamos 87 nidos del Greater Sage-Grouse (cámaras, $N = 55$; sin cámara, $N = 32$) en el noreste de Nevada y en el centro-sur de Idaho e identificamos predadores en 17 nidos, en donde el Raven común (*Corvus corax*) depredo las nidadas de 10 nidos y el American badgers (*Taxidea taxis*) las de siete nidos. Se observaron frecuentemente roedores en los nidos de grouse, pero no depredaron los huevos de grouse. Debido a que los rastros dejados por los ravens y los badgers fueron indistinguibles después de un evento de depredación, identificar los depredadores de nidos basado en la remoción de huevos, en la presencia de cascaras de huevos, u otro tipo de clave no fue posible. La mayoría de eventos de depredación ocurrieron cuando las hembras estaban en el nido. La activa defensa del nido por los grouse fue rara y siempre fue poco exitosa. El monitoreo continuo de nidos del sage-grouse mediante cámaras de video permito la identificación previamente ambigua de los depredadores de los nidos y comportamientos en el nido. Adicionalmente los estudios de monitoreo pueden ayudar a mejorar nuestro conocimiento sobre las causas del fracaso de los nidos del sage-grouse durante los cambios del uso de la tierra entre las montañas del oeste.

Key words: American badger, camera, *Centrocercus urophasianus*, Common Raven, Greater Sage-Grouse, ground squirrel, nest predation, Nevada, video monitoring

Greater Sage-Grouse (*Centrocercus urophasianus*) populations are declining in most portions of their range (Connelly and Braun 1997, Connelly et al. 2004), and nest failure is thought to be an important factor in those declines (Schroeder and Baydack 2001). The primary source of Sage-Grouse nest failure is predation, accounting for an average of 94% of nest loss (Moynahan et al. 2007). Although nest predators of Sage-Grouse have been reported in the literature (Schroeder and Baydack 2001), identification has generally been based on interpreting ambiguous remains of predated nests rather than unequivocal identification (Holloran and Anderson 2003, Moynahan et al. 2006). However, using nest and egg remains to identify predators can lead to misidentification (Marini and Melo 1998, Larivière 1999).

Confirming the identity of nest predators would aid Sage-Grouse conservation efforts by

[3] Corresponding author. Current address: USGS, Western Ecological Research Center, Dixon Field Station, 6924 Tremont Road, Dixon, CA 95620. Email: pcoates@usgs.gov

©2008 No claim to original U.S. government works. Journal compilation
©2008 Association of Field Ornithologists

helping to guide management actions designed to increase or maintain nest success, such as direct predator control or indirectly decreasing the chances of specific predators from locating nests through habitat manipulation. Erroneous identification of nest predators based on conventional methods may lead to poor management decisions. Video monitoring has been shown to be a reliable and accurate method for identifying predators (Cutler and Swann 1999, King et al. 2001). Such monitoring has never been employed at Sage-Grouse nests, but could confirm the identity of nest predators. Thus, our objective was to identify Sage-Grouse nest predators by video monitoring nests and to determine the kinds of sign that predators leave at predated nests.

METHODS

We monitored nests of Sage-Grouse in northeastern Elko County, Nevada (Universal Transverse Mercator [UTM] Zone 11, Range = E 648194–706275, N 4564368–4673994, NAD 83) from March to July 2002–2005. We chose four sites to monitor nests based on known breeding areas (Fig. 1). We also monitored four nests in south-central Idaho (25–35 km from the northernmost study site in Nevada).

Lower elevations (1550–1900 m) were dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and basin big sagebrush (*A. t. tridentata*), with an understory of grasses. Higher elevations (1900–2350 m) were characterized by mountain big sagebrush (*A. t. vaseyana*), Saskatoon serviceberry (*Amelanchier alnifolia*), and native bunchgrasses. Topography consisted primarily of rolling hills and creek drainages that held surface water throughout the year.

Within the study area, we observed many species of potential egg predators (reported in Schroeder et al. 1999), including coyotes (*Canus latrans*), weasels (*Mustela* spp.), elk (*Cervus elaphus*), American badgers (*Taxidea taxis*), ground squirrels, Black-billed Magpies (*Pica hudsonia*), American Crows (*Corvus brachyrhynchos*), and Common Ravens (*Corvus corax*). Cattle (*Bos taurus*) grazed most of the study site seasonally every year.

We captured female Sage-Grouse by spotlighting (Wakkinen et al. 1992, Connelly et al. 2003) near lek sites from 15 March to 1 May 2002–2005. We equipped grouse with

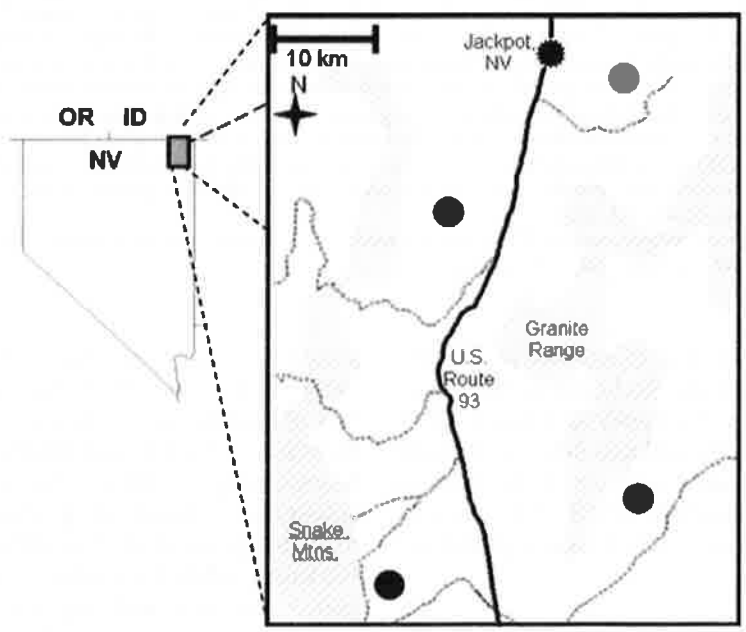

Fig. 1. Greater Sage-Grouse study sites in northeastern Nevada, 2002–2005. Study sites were based on lek routes and were separated by distances ≥20 km. We video monitored an additional four nests in south-central Idaho, 25–35 km from the northernmost study site in Nevada. A public landfill was located approximately 7 km from the northernmost Nevada site.

necklace-style, radio transmitters (Series A4000, Advanced Telemetry Systems, Isanti, Minnesota) that were <3% of grouse body mass (1–1.8 kg; Schroeder et al. 1999). Antennae were bent near their bases and rested along the backs of grouse to minimize interference with flight (Marks and Marks 1987). To locate nests, we located radio-marked grouse every 2–3 d using 3-element hand-held Yagi antennae and receivers (Models R4000 and R2000, Advanced Telemetry Systems, Isanti, Minnesota). Aircrafts were used to locate missing grouse, followed by ground surveys to verify grouse location. We recorded UTM coordinates for each grouse location using hand-held Global Positioning System units (eTrex, Legend, Garmin International, Olathe, Kansas).

When a grouse was located within 30 m of the previous position on three consecutive occasions, we visually confirmed the presence of a nest. We located all nests either during the laying period or the initial stages of incubation. We monitored nesting females every 3 d to record their status (present or absent) and determine nest fate. Clutch size was measured when females were away from nests during early stages of incubation or during camera installation if a female was inadvertently flushed.

We identified nest predators and recorded predator and grouse behavior using continuously recording video-monitoring systems (Pietz and Granfors 2000). We used miniature (40 × 40 × 60 mm), camouflaged cameras (Fuhrman Diversified, Seabrook, Texas; Supercircuits, Austin, Texas) equipped with 12 infrared-emitting diodes (850–950 nm wavelength) that allowed night video monitoring using light that was likely undetectable by vertebrates. We used time-lapse VCR systems operating at 2–3 frames/s.

Nests ($N = 55$) were chosen for video monitoring based on fewest estimated days of incubation, but not on distance and access to nests. However, to minimize the risk of abandonment (Renfrew and Ribic 2003), video systems were deployed at nests ≥7 d after the onset of incubation. We estimated day of incubation through telemetry monitoring. We placed cameras 0.5–1.0 m from nests and 10–20 cm above ground. We mounted cameras on the nearest shrub trunk or a camouflaged stake using rebar tie wire. Stakes were also covered with grasses and shrub branches. Cables that extended 15–20 m to a VCR system and power source were buried 3–5 cm in the ground to reduce the chances of damage and either attracting or deterring predators. We scattered litter over the buried cord and human tracks. Recorders were housed in camouflaged cases and placed under the canopy of a large shrub. We powered cameras and recorders with two deep-cycle, 12-volt marine batteries. Burlap and vegetation were used to cover the VCR cases and batteries. We replaced batteries and tapes every 3 d.

We camouflaged all cameras and other equipment with camouflage vinyl photography tape and paint that matched the colors of the shrub-steppe microhabitat. Grasses and small sagebrush branches and leaves were secured to camera casings with painted wire. We applied camouflage, adhesive cloth tape over the light emitting diodes (LEDs). We used rubber boots and gloves during video system deployment and maintenance to minimize human scent at nests (Whelan et al. 1994).

Most cameras were installed ($N = 45$, or 82%) while grouse were incubating, and they typically flushed from the nests. To minimize the risk of egg mortality, we did not install cameras during times of snow, rain, high winds, or extreme ambient temperatures. We continued video monitoring nests for 24 h after termination of nesting attempts to identify any subsequent animal encounters and record post-nest-fate behaviors of predators at hatched and predated nests. We then moved cameras to other nests.

We used nests without video systems as controls to measure camera effects and visited these nests every 3 d to document nesting status and control for potential bias caused by our visits to nests. To estimate the camera effect on nest fate, we used the nest survival module in program MARK (White and Burnham 1999) and employed an information-theoretic approach (Anderson and Burnham 2002) based on Kullback-Leibler information (Kullback and Leibler 1951) and maximum likelihood estimation (de Leeuw 1992) to simultaneously evaluate the support for two a priori models: an intercept-only (β_0) model and an intercept with camera covariate ($\beta_0 + \beta_1$CAM) model. We used Akaike's information criterion (Akaike 1973) corrected for small sample size (AIC_c; Anderson and Burnham 2002) to evaluate the relative support of candidate models using Akaike's differences (ΔAIC_c) and weights (ω_i) (Anderson and Burnham 2002) for each model. We also

performed a likelihood ratio test to determine if the more complex model fit the data significantly better ($\alpha = 0.05$). Values are reported as means $\pm$ SE.

Predated nests were classified as either partial (≥ 1 intact egg remained in the nest bowl) or complete (all eggs destroyed or missing from nest bowl). We considered nests successful if ≥ 1 egg hatched (Rearden 1951), as determined by observation of ≥ 1 whole eggshell, egg membrane, or chick in the nest bowl, and unsuccessful if completely predated, abandoned, or partially predated and subsequently abandoned. Descriptions of predated nest remains were recorded, including condition of nest bowl and surrounding vegetation (disturbed or destroyed), missing eggs, eggshell fragments, punctured eggs, and condition of eggshell membranes (missing, fragmented, or intact).

RESULTS

We monitored 87 Sage-Grouse nests ($N = 55$ with camera and $N = 32$ with no camera), with 37 (43%) partially or completely predated, six (7%) abandoned, and 44 (51%) successful. Nests were monitored with cameras for about 15,500 h, or an average of 12.0 $\pm$ 0.83 d of incubation per nest. We identified predators at 16 nests, and one predation event was observed in the field at a nest with no camera. At four nests with cameras, predation events were not recorded due to camera failure. Of the video-monitored nests, grouse abandoned all nests that were partially predated.

Model selection indicated no support for an effect of camera presence ($\Delta AIC_c = 1.02$) (Fig. 2). The best-approximating model (β_0, $\omega_i = 0.63$) was 1.7 times (ω_i/ω_j) more likely to

Fig. 2. Images of Sage-Grouse nests in northeastern Nevada: (A) incubating grouse, (B) Common Raven predation with no diagnostic egg remains, (C) badger removing eggs from nest bowl, (D) Wyoming ground squirrels biting intact egg, (E) fragmented (arrow) and crushed eggshells resulting from badger predation, and (F) holes (arrow) in eggshells due to badger predation.

describe the data than the $\beta_0 + \beta_1$CAM model ($\Delta AIC_c = 1.02$, $\omega_i = 0.37$), but β_0 model did not have substantially greater support from the data (Burnham and Anderson 1998). The more complex model ($\beta_0 + \beta_1$CAM) was not the best-fit model (likelihood ratio test, $\chi^2 = 0.98$, $P = 0.32$). The estimated camera effect was 0.330 ± 0.329 (95% CI –0.315 to 0.976). Estimated daily survival rate (DSR) for nests with and without cameras were 0.980 ± 0.004 and 0.973 ± 0.007, respectively. Estimated DSR was 0.978 ± 0.003. Calculated point estimate of nest success was 0.44 (95% CI 0.35–0.55), using 37-d nest survival (laying and incubation period). Point estimates for nests with and without cameras were 0.47 (95% CI 0.34–0.62) and 0.36 (0.20–0.55), respectively.

Raven encounters. We documented predation by ravens at 10 nests (Fig. 2), with three cases of partial predation and seven with complete predation. When a grouse was present ($N = 8$), one or more ravens flushed the female from the nest before predating eggs. We observed differences among ravens and predation events in nest and egg sign.

On three occasions, a female stood over the eggs between ravens that were taking eggs. One grouse actively, but unsuccessfully, defended her nest from two or more ravens. The grouse lunged across the nest, toward a raven, with wings extended on three occasions. However, as the grouse lunged at one raven, another would take an egg on the other side of the nest. All three attempts at nest defense by grouse were unsuccessful and the nests were predated.

During all 10 predation events involving ravens, one or more eggs were consumed or taken from the nest. At two nests, ravens left holes in the sides or tops of eggs and left the rest of the eggshell intact. At two other nests, ravens broke eggshells into fragments.

Badger encounters. We recorded seven predation events by badgers and all resulted in complete nest predation (Fig. 2). Grouse flushed just prior to badgers arriving at nests. Badgers did not attempt to capture fleeing grouse, and grouse did not attempt to deter badgers from eating eggs.

Postpredation badger sign varied within and among predation events (Fig. 2). At four nests, badgers left holes in the sides or tops of eggs and left the rest of the eggshell intact. At five nests, badgers broke eggshells into fragments while consuming egg contents with their tongues. During two events, badgers consumed the entire egg and shell, leaving no eggs or eggshells. During all events, most eggs were consumed by badgers outside the nest bowl. However, on three occasions, badgers ate eggs in the nest bowl and left fragments or largely intact eggshells with holes. Nest material was removed from bowls at five nests destroyed by badgers, whereas, at two nests, nesting material was not disturbed and we found no badger tracks or sign. One badger completely destroyed the nest and removed it from below the shrub.

Rodent encounters. Rodents frequently visited Sage-Grouse nests ($N = 167$), but none consumed eggs. However, rodents often consumed remnant eggshells and membranes following normal hatches or after predation by ravens or badgers ($N = 42$) often leaving the appearance that the nests had been predated by rodents. Rodents identified at nests included least chipmunks (*Tamias minimus*; $N = 73$), Wyoming ground squirrels (*Spermophilus elegans*; $N = 16$), Piute ground squirrels (*S. mollis*; $N = 7$), northern pocket gophers (*Thomomys talpoides*; $N = 3$), Great Basin pocket mice (*Perognathus parvus*; $N = 22$), North American deer mice (*Peromyscus maniculatus*; $N = 31$), and sagebrush voles (*Lemmiscus curtatus*; $N = 2$). Many small rodents visiting nests at night could not be identified by species ($N = 29$).

Least chipmunks regularly consumed or picked up eggshells, eggshell membranes, embryonic membranes, feathers, and nest material. Least chipmunks attempted to perforate eggs twice, but were unsuccessful. No ground squirrel encounters resulted in egg predation. Ground squirrel visits were generally brief (1–3 s) and took place during incubation recesses or at abandoned nests. Wyoming ground squirrels bit intact eggs during four visits, but were unsuccessful at opening them (Fig. 2).

Other encounters. On two occasions, Great Basin gopher snakes (*Pituophis catenifer deserticola*) visited nests during incubation recesses. Each snake appeared to be >1 m long and about 4 cm at maximum body width. Snakes lightly touch eggs with their mouths, but did not attempt to consume them.

One of six encounters by cows resulted in damage to one egg. At one nest, a cow flushed an incubating grouse, causing an egg to be displaced from the nest bowl; the cow subsequently was

recorded eating the egg, leaving shell fragments. The cow sniffed and moved, but did not eat, other eggs in the nest bowl, then moved the camera out of position. Following subsequent nest visitation, three other eggs were damaged in the nest and the grouse appeared to abandon the nest. In each of the five other cow encounters, grouse were flushed from their nests and cows sniffed eggs, but did not consume them. We suspected abandonment by a cow flushing the grouse at one other nest.

DISCUSSION

As also reported by previous investigators, we identified ravens (Connelly et al. 1991, Schroeder et al. 1999, Vander Haegan et al. 2002) and badgers (Petersen 1980, Ritchie et al. 1994) as Sage-Grouse nest predators. Sage-Grouse habitat has become highly fragmented (Knick et al. 2003) and fragmentation may increase nest vulnerability to corvids (Hartley and Hunter 1998, Vander Haegen et al. 2002). Current land-use practices in the Intermountain West favor high raven abundance (Boarman and Heinrich 1999) relative to historic numbers (Sauer et al. 2004).

Rodents were frequently observed at grouse nests in our study, but did not prey on grouse eggs. Other investigators have reported that ground squirrels are Sage-Grouse nest predators (Patterson 1952, Gill 1965, Petersen 1980, Niemuth and Boyce 1995). We found that ground squirrels and other rodents often left sign at predated nests after nest predation or hatch, and such scavenging may result in incorrectly attributing predation events to rodents when nest sign is used to identify predators. Wyoming ground squirrels in our study were limited by their gape-width and were unsuccessful at predating Sage-Grouse eggs, similar to reported observations of Richardson's ground squirrels (*Spermophilus richardsonii*) that encountered eggs of domestic fowl (*Gallus gallus*) and Ring-necked Pheasant (*Phasianus colchicus*; Michener 2005). Ground squirrels may not be capable of opening eggs because the average width of Sage-Grouse eggs (38–39 mm, Schroeder et al. 1999) is greater than their functional gape-width (Richardson's ground squirrel was $\leq$21 mm, Michener 2005). Using still photography, Holloran and Anderson (2003) also found that thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) and Richardson's ground squirrels were unsuccessful at predating Sage-Grouse eggs in Wyoming.

Our observations clearly demonstrate that signs left by ravens and badgers were often indistinguishable following nest predation, and support other observations of interspecific similarities in nest and egg remains (Larivière 1999). For example, one or more eggs or eggshells were missing from 12 nests, with 10 predated by ravens and two by badgers. Moreover, several eggs with holes were observed following raven predation, similar to eggs predated by badgers. In addition, both badgers and ravens sometimes scattered egg shells around the nest bowl. Thus, documenting the removal of eggs from nests does not permit accurate identification of predators even to higher taxonomic levels (i.e., class; Larivière 1999). Furthermore, interpretation of nest sign becomes even more difficult with the confirmation of intraspecific differences in sign (Larivière 1999). For example, some badgers disturbed nest bowls and left crushed egg shells and some did not, and nests predated by ravens were often missing all or most of the eggs whereas others contained eggshells with holes in the sides.

We found no evidence that video monitoring influenced predation rates. Waiting until $\geq$ 7 d after the initiation of incubation by female Sage-Grouse may have contributed to the tendency of daily survival rates to be higher at nests with video systems. As indicated by other investigators (Moynahan et al. 2006), Sage-Grouse nests that survived to the later stages of incubation were often successful, and we observed more predation at nests during the initial stages of incubation.

Our results confirm that Common Ravens and badgers are predators of Sage-Grouse nests, and suggest that previous investigators have incorrectly identified scavenging rodents as predators. We also found that female Sage-Grouse are not able to defend nests successfully when confronted with ravens or badgers, but are able to escape direct predation. Video monitoring is an effective tool, especially when certain predators are thought responsible for nest predation and identification of those predators must be confirmed. Additional video-monitoring studies would help further our understanding of the causes of Sage-Grouse nest failure in the face of land-use changes in the Intermountain West.

ACKNOWLEDGMENTS

Jack H. Berryman Institute and Idaho National Engineering Laboratory/Bechtel provided funding for this research with grants to D. J. Delehanty at Idaho State University. Many thanks to the generous sportsman and conservation organizations that provided financial support including Safari Club International (Idaho and Desert and Northern Nevada chapters), Carson Valley Chukar Club, Wildlife and Habitat Improvement of Nevada, Sportsmen for Fish and Wildlife, and Nevada Chukar Foundation. We thank T. Peterson for statistical consulting, and C. Simms, R. Troy, J. Warwick, and N. Sparks for significant field contributions. We are grateful to personnel of the Nevada Department of Wildlife, Idaho Department of Fish and Game, and U. S. Department of Interior, Bureau of Land Management for assistance with data collection and logistical support.

LITERATURE CITED

AKAIKE, H. 1973. Information theory as an extension of the maximum likelihood principle. In: Second international symposium on information theory (B. N. Petrov and F. Csaksi, eds.), pp. 267–281. Akademiai Kiado, Budapest, Hungary.

ANDERSON, D. R., AND K. P. BURNHAM. 2002. Avoiding pitfalls when using information-theoretic methods. Journal of Wildlife Management 66: 912–918.

BOARMAN, W. I., AND B. HEINRICH. 1999. Common Raven (*Covus corax*). In: The birds of North America online (A. Poole, ed.), Cornell Lab of Ornithology, Ithaca, NY. Available at: http://bna.birds.cornell.edu/bna/species/476.

BURNHAM, K. P., AND D. R. ANDERSON. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York.

CONNELLY, J. W., AND C. E. BRAUN. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3: 229–234.

CONNELLY, J. W., S. T. KNICK, M. A. SCHROEDER, AND S. J. STIVER. 2004. Conservation assessment of Greater Sage-Grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

CONNELLY, J. W., K. P. REESE, AND M. A. SCHROEDER. 2003. Monitoring of Greater Sage-Grouse habitats and populations. College of Natural Resources Experiment Station, Station Bulletin 80, Moscow, ID.

CONNELLY, J. W., W. L. WAKKINEN, A. D. APA, AND K. P. REESE. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal of Wildlife Management 55: 521–524.

CUTLER, T. L., AND D. E. SWANN. 1999. Using remote photography in wildlife ecology: a review. Wildlife Society Bulletin 27: 571–581.

DE LEEUW, J. 1992. Introduction to Akaike (1973) information theory and an extension of the maximum likelihood principle. In: Breakthroughs in statistics (S. Kotz and N. L. Johnson, eds.), pp. 599–609. Springer-Verlag, London.

GILL R. B. 1965. Distribution and abundance of a population of sage grouse in North Park, Colorado. M.S. thesis, Colorado State University, Fort Collins, CO.

HARTLEY, M. J., AND M. L. HUNTER, JR. 1998. A meta-analysis of forest cover, edge effects, and artificial nest predation rates. Conservation Biology 12: 465–469.

HOLLORAN, M. J., AND S. H. ANDERSON. 2003. Direct identification of Northern Sage-Grouse, *Centrocercus urophasianus*, nest predators using remote sensing cameras. Canadian Field-Naturalist 117: 308–310.

KING, D. I., R. M. DEGRAAF, P. J. CHAMPLIN, AND T. B. CHAMPLIN. 2001. A new method for wireless video monitoring of bird nests. Wildlife Society Bulletin 29: 349–353.

KNICK, S. T., D. S. DOBKIN, J. T. ROTENBERRY, M. A. SCHROEDER, W. M. VANDER HAEGEN, AND C. VAN RIPER. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. Condor 105: 611–634.

KULLBACK, S., AND R. A. LEIBLER. 1951. On information and sufficiency. Annals of Mathematical Statistics 22: 79–86.

LARIVIÈRE, S. 1999. Reasons why predators cannot be inferred from nest remains. Condor 101: 718–721.

MARINI, M. A., AND C. MELO. 1998. Predators of quail eggs, and the evidence of the remains: implications for nest predation studies. Condor 100: 395–399.

MARKS, J. S., AND V. S. MARKS. 1987. Influence of radio collars on survival of Sharp-tailed Grouse. Journal of Wildlife Management 51: 468–471.

MICHENER, G. R. 2005. Limitation on egg predation by Richardson's ground squirrels. Canadian Journal of Zoology 83: 1030–1037.

MOYNAHAN, B. J., M. S. LINDBURG, J. J. ROTELLA, AND J. W. THOMAS. 2007. Factors affecting nest survival of Greater Sage-Grouse in north-central Montana. Journal of Wildlife Management 71: 1773–1783.

MOYNAHAN, B. J., M. S. LINDBERG, AND J. W. THOMAS. 2006. Factors contributing to process variance in annual survival of female Greater Sage-Grouse in north-central Montana. Ecological Applications 16: 1529–1538.

NIEMUTH, N. D., AND M. S. BOYCE. 1995. Spatial and temporal patterns of predation of simulated sage grouse nests at high and low densities: an experimental study. Canadian Journal of Zoology 73: 819–825.

PATTERSON, R. L. 1952. The sage grouse of Wyoming. Sage Books, Denver, CO.

PETERSEN, B. E. 1980. Breeding and nesting ecology of female sage grouse in North Park, Colorado. M.S. thesis, Colorado State University, Fort Collins, CO.

PIETZ, P. J., AND D. A. GRANFORS. 2000. Identifying predators and fates of grassland passerine nests using miniature video cameras. Journal of Wildlife Management 64: 71–87.

REARDEN, J. D. 1951. Identification of waterfowl nest predators. Journal of Wildlife Management 36: 87–98.

RENFREW, R. B., AND C. A. RIBIC. 2003. Grassland passerine nest predators near pasture edges identified on videotape. Auk 120: 371–383.

RITCHIE, M. E., M. L. WOLFE, AND R. DANVIR. 1994. Predation of artificial sage grouse nests in treated and

untreated sagebrush. Great Basin Naturalist 54: 122–129.

SAUER, J. R., J. E. HINES, AND J. FALLON. 2004. The North American Breeding Bird Survey, results and analysis 1966 – 2003. Version 2004.1. United States Geological Survey. Patuxent Wildlife Research Center, Laurel, MD.

SCHROEDER, M. A., AND R. K. BAYDACK. 2001. Predation and the management of prairie grouse. Wildlife Society Bulletin 29: 24–32.

SCHROEDER, M. A., J. R. YOUNG, AND C. E. BRAUN. 1999. Sage Grouse (*Centrocercus urophasianus*). In: The birds of North America, online (A. Poole, ed.), Cornell Lab of Ornithology, Ithaca, NY. Available at: http://bna.birds.cornell.edu/bna/species/425.

VANDER HAEGEN, W. M., M. A. SCHROEDER, AND R. M. DEGRAAF. 2002. Predation on real and artificial nests in shrubsteppe landscapes fragmented by agriculture. Condor 104: 496–506.

WAKKINEN, W. L., K. P. REESE, J. W. CONNELLY, AND R. A. FISCHER. 1992. An improved spotlighting technique for capturing sage grouse. Wildlife Society Bulletin 20: 425–426.

WHELAN, C. J., M. L. DILGER, D. RONSON, N. HALLYN, AND S. DILGER. 1994. Effects of olfactory cues on artificial-nest experiments. Auk 111: 945–952.

WHITE, G. C., AND K. P. BURNHAM. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46: 120–138.