DRAFT FINAL REPORT
Submitted to
Colorado Parks and Wildlife
and
Gunnison County

Common Raven Use of Human Subsidized Resources

An investigation of the spatial and temporal abundance and distribution patterns of common ravens (*Corvus corax*) in relation to anthropogenic subsidies in an altered landscape in the Gunnison Basin, Colorado

23 December 2014

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Spatial and temporal abundance and distribution patterns of common ravens (*Corvus corax*) in relation to anthropogenic subsidies in an altered sagebrush ecosystem in the Gunnison Basin, Colorado

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Abstract:
Common raven (Corvus corax) numbers have increased dramatically in the Gunnison Basin and throughout western North America in the last 50 years. The rise of ravens corresponds to the dramatic alteration of western landscapes including the sagebrush biome. Anthropogenic subsidies such as landfills, transmission lines, encroaching trees and other invasive vegetation, and pronounced fragmentation of the landscape have all benefitted ravens. Recently, ravens were implicated as primary nest predators of greater sage-grouse (Centrocercus urophasianus) in the Great Basin and elsewhere in the western U.S. Little is known regarding the effects of raven depredation on Gunnison sage-grouse (Centrocercus minimus) nests and chicks. I studied raven abundance and frequency of occurrence in the Gunnison Basin, Colorado in relation to anthropogenic resources. Twelve sites of varying anthropogenic impact were surveyed for one year from August 2013 to July 2014. I conducted point counts at each site 3 times per sampling day and twice each month. I determined patterns of raven use in relationship to time of day and season and according to the degree of human alteration of the site. Ravens, ubiquitous in the study area, were present at all sites, at all times of day, in all seasons, and ravens were present on nearly half of all point counts. Over 81% of all ravens were detected at the landfill and used the landfill in a bimodal diurnal pattern throughout most of the year. The pattern changed to continuous use throughout the day in winter, particularly on days with inclement weather. Ravens were highly active in morning and mid-day periods from fall through early spring especially flying and presumably foraging along the east-west river corridor. In late November, ravens started feeding on carcasses and from December through March road kill highway carcasses were an important part of their diet. Ravens used town sites such as the grocery store parking lot and the residential area less than other anthropogenic sites. The Gunnison County Airport was among the sites that had the least use by ravens. Ravens were observed flying low and circling over sagebrush during the Gunnison sage-grouse nesting season. Numerous opportunities to reduce raven populations or to modify raven behavior in the Gunnison Basin are available primarily through reduction of anthropogenic resources. These management efforts should focus on burial of waste at the landfill and removal of road kill carcasses. Future research should determine the efficacy of management actions to reduce anthropogenic subsidies on subsequent raven abundance. Importantly, which ravens are targeted for management (territorial, dominant adults vs. juveniles) plays a major role in how management activities impact potential effects of ravens on sage-grouse.

INTRODUCTION

Common raven (*Corvus corax*) populations have increased dramatically in the last 50-60 years across the western United States (Sauer et al. 2014). Of the four sub-species of common ravens, *Corvus corax sinuatus* occurs in Colorado and across much of the western U.S. from British Columbia and Montana south through Mexico (USFWS 2008). In Colorado they have increased at a rate of 3.29% annually from 1968-2012 (Sauer et al. 2014). According to these data, in Colorado their population has doubled twice in the last 45 years. In the Gunnison Basin, historic raven population data are available through Christmas Bird Counts which date back to 1954. In that year, 1 common raven was observed. By 1967, 21 ravens were observed and this increased to 126 ravens in 1972. By 1987, 202 ravens were sighted. In 1993 the count was 503 ravens and 591 ravens were reported in 2006. In 2014, the count was 540. Although Christmas Bird counts are not robust and fluctuate annually, they provide evidence for a substantial local increase in ravens in the last 60 years that corresponds with raven population explosions throughout the western U.S. (Boarman and Heinrich 1999, Sauer et al. 2014).

The rapid increase in common ravens, especially in the western U.S., has been attributed to changing landscapes and that ravens are ecological generalists benefitting from human subsidies. The breadth of their diet is impressive; they are alternatingly granivores, frugivores, insectivores, piscivores, carnivores, egg eaters, scavengers and garbage collectors (Boarman and Heinrich 1999). They often feed on the ground but scan for food from high perches or on the wing. Anthropogenic food subsidies include road kill carrion, landfill bonanzas, dumpster trash, varied trash where human activity is high, agricultural fruits and grains, rodents in freshly hayed meadows, offal left by big game hunters, afterbirth of livestock and sickly lambs and calves may be devoured or have had their eyeballs poked out and consumed by ravens (Boarman and Heinrich 1999). Bridges, transmission poles and towers, oil derricks, railroad trusses and billboards serve as nesting, roosting, and perching substrates (Boarman and Heinrich 1999). Raven population explosions have led to conflicts with humans and impacts to wildlife populations in several ecosystems (Boarman 2003, Austin and Mitchell 2010).

The once vast sea of sage encompassed 307 million ha of western North America, but now occupies only 166 million ha (Schroeder et al. 2004). Approximately 13% (402,000 km^2) of the western U.S. is dominated by human altered landscapes (agriculture, urbanization, transmission lines, roads) (Leu et al. 2008). As the sagebrush biome has been converted to other land uses, fragmented into smaller pieces, and degraded, ecosystem processes have failed and wildlife populations have declined (Knick et al. 2003, Boyle and Reeder 2005, Welch 2005). Currently greater sage-grouse (*Centrocercus urophasianus*) occupy 56% of their historic range, and Gunnison sage-grouse (*Centrocurcus minimus*) occur on just 10% of their historic sagebrush landscape (Schroeder et al. 2004). Using videography, researchers have linked ravens directly to depredation of greater sage-grouse eggs and chicks (Coates et al. 2008, Coates and Delehanty 2008, Coates and Delehanty 2010, Lockyer et al. 2013). The rise of ravens has led to a changed sagebrush predator community, with ravens as the most numerous representative. At the

Idaho National Laboratory, raven nesting densities are 4-9X higher than three species of sympatric buteo hawks and of the four avian predatory species, almost 50% of nests belong to ravens (Coates et al. 2014). That 73% of their nests are located on anthropogenic structures compared to 2-3% for the buteos, suggests a mechanism for raven dominance (Coates et al. 2014). The degradation of the sagebrush ecosystem has led to long-term population declines in sagebrush obligate species including sage-grouse (Connelley et al. 2004, Schroeder et al. 2004, Connelley et al. 2011). In contrast, habitat fragmentation and the creation of habitat edges, human infrastructure, and expansion of non-native vegetation have benefitted ravens (Coates et al. 2014, Howe et al. 2014) (Table 1). Recent studies of raven impacts on greater sage-grouse (Coates et al. 2008, Coates and Delehanty 2008, Coates and Delehanty 2010, Lockyer et al. 2013, Howe et al. 2014, Coates et al. 2014) have provided substantial evidence that artificially boosted raven populations may impact grouse nesting success and chick survival, however, less is known about impacts of ravens on Gunnison sage-grouse.

Table 1. Anthropogenic features of sagebrush landscapes and common raven response.

Anthropogenic Feature	**Raven Response**	**Literature Reference**
Electrical transmission lines	Perch sites Nest sites	Coates et al. 2014, Lammers and Collopy 2007, Prather and Messmer 2010, Slater and Smith 2010, Howe et al. 2014
Roads and highways	Road kill food source Edge habitat preferred	Coates et al. 2014
Invasive plant community	Edge habitat preferred	Howe et al. 2014, Coates et al. 2014
Conversion to agricultural	Consume waste grain Edge habitat preferred	Coates et al. 2014, Evans 2004
Habitat fragmentation	Edge habitat preferred	Dinkins 2013, Coates et al. 2014, Howe et al. 2014
Increased frequency of wildlife and conversion to annual grass	Edge habitat preferred	Howe et al. 2014
Suppression of wildfire and piñon-juniper afforestation	Nest sites Edge habitat preferred	Howe et al. 2014
Decreased sagebrush canopy cover	Increased grouse predation	Coates and Delehanty 2010, Coates et al. 2014
Landfill	Food bonanza	Heinrich 1989, Boarman and Heinrich 1999
Urbanization	Food, nest sites, roosts	Leu et al. 2008

The purpose of this study was to quantify raven distribution and abundance at various sites in the Gunnison Basin, where 85% of the global population of the Gunnison sage-grouse occur (Gunnison Sage-grouse Rangewide Conservation Plan 2005). The chief goal was to determine spatial (site) and temporal (seasonal and time of day) patterns of use by ravens in the study area. Sites were chosen to provide a gradient of anthropogenic impact with relatively low impact sagebrush reference sites representing more historical landscapes before raven abundance increased dramatically. While the study did not directly assess impacts of ravens on Gunnison sage-grouse, it was conceived as a first step in better understanding local raven ecology and provided initial insight into raven use of sagebrush habitats. Because ravens are a synanthropic species, I hypothesized that they would use sites in proportion to the extent of human modification and resource subsidies available.

METHODS

Study Area

The study was conducted in the Gunnison Basin located in south-central Colorado in the Southern Rocky Mountain/Colorado Plateau Bird Conservation Region (BCR 16). An 18 km west to east expanse roughly paralleling U.S. Highway 50 from Mile Mark (MM) 153 to 164 served as the study area and the location of 12 sampling sites. In the center of the west-east band was the town of Gunnison with a population of 5,854 people (15,507 in the county and a population density of 4.7 people per square mile). At 2,348 m msl (7,703 feet msl), Gunnison is within a high elevation intermountain basin receiving approximately 26.5 cm (10.4 inches) of annual precipitation and 128.3 cm (50.5 inches) of yearly snowfall. The mean maximum temperature is 13.1^{o}C (55.5^{o}F) and the mean minimum temperature is -6.8^{o}C (19.7^{o}F) (Western Regional Climate Center 1900-2005, www.wrcc.dri.edu). During the study period (August 2013 – July 2014) the annual precipitation was 15.9 cm (6.3 inches) which was 60% of the long-term average (dry year). September had the highest monthly precipitation with 2.8 cm (1.1 inches); February had the highest snowfall with 39.6 cm (15.6 inches). December was the only month (-13.7^{o}C or 7.4^{o}F) with noticeable departure in temperature from the long-term mean (-10.6^{o}C or 13.0^{o}F). Overall the mean temperature during the study period was 2.9^{o}C (37.3^{o}F), slightly above the long-term mean temperature for Gunnison (2.7^{o}C or 36.9^{o}F) (USClimatedata.com).

The Gunnison Basin below elevation 2,500 m msl (approximately 8,000 feet msl) is dominated by sagebrush. Tomichi Creek parallels U.S. Highway 50 east of Gunnison, whereas the Gunnison River is the main stream corridor west of town. Tomichi Creek winds its way through hay meadows and skirts the town to the south and generally has willow (*Salix* spp.) dominating the riparian plant community. Riparian vegetation along the Gunnison River is dominated by a narrowleaf cottonwood (*Populus angustifolia*) gallery forest. The Gunnison River flows through portions of Gunnison and is a prominent feature of the Dos Rios Golf Course and Gunnison Wastewater Treatment Facility, before entering agricultural land to the west.

Twelve sampling sites were chosen within the west to east river corridor and sagebrush ecosystem. Three sites were sagebrush reference sites. Two were located on the east end of the corridor and one was on the west end of the corridor. The basic premise was that fewer ravens would be present in the less anthropogenically influenced sagebrush reference sites. These sites were generally located 5 km from a paved highway, although in some winter months I was unable to access these sites that were beyond plowed roads, so moved them closer to a paved highway. Despite being relatively undisturbed, the reference sites had plenty of human activities on the landscape (roads, power lines, disturbed vegetation, mining exploration dig sites).

The remaining nine sites were influenced by anthropogenic factors and included an irrigated hay meadow at the Old Miner horse ranch, the Gunnison wastewater treatment plant, the Gunnison County landfill, a one mile section of U.S. Highway 50 (between mMM 161-162), the Gunnison County airport, the Dos Rios Golf Course, the Western State Colorado University campus, a one mile loop along the streets in a residential area of Gunnison, and the parking lot of the local City Market grocery store (Table 2, Appendices A and B).

Study Design and Data Collection

I counted common ravens and American crows (*Corvus branchyrhynchos*) by sight and sound using 6-minute point counts at ten of the sites twice per month for one year (August 2013 to July 2014). I conducted a 6-minute drive survey for the two 1-mile road segments. I divided the 12 months into four seasons including summer (June, July, August), fall (September, October, November), winter (December, January, February), and spring (March, April, May). I visited each of the twelve sites three times per sampling day divided into morning (sunrise to 1000 h), mid-day (1000 to 1400 h) and evening (1400 h to sunset) periods. I sampled with maximum efficiency to be able to visit each site three times per day, which was challenging on short winter days. This included running the route from east to west during one time period and then reversing the route in the subsequent time period. I adjusted the location of the three sagebrush sites seasonally depending on road access. Most winter locations were at least 1.6 km off the highway, but beginning in February, the Cabin Creek site was completely inaccessible and counts were made from the highway. Due to time constraints, I was unable to walk from the highway to count points away from the highway.

Table 2. Study sites for common raven and American crow point counts conducted in the Gunnison Basin, Colorado from August 2013 to July 2014. Sites are generally ordered from lowest anthropogenic influence to highest.

Site Name	**Anthropogenic Feature**	**Highway Mile Marker**	**Description**
McCabe's reference site	Sagebrush	153	West end of study area, 5 km from highway in sagebrush with diverse topography and rock outcrops, Douglas fir and aspen stands nearby at higher elevations, numerous dirt roads, willow dominated riparian area present adjacent to road, lies below airport flight path
Long Gulch reference site	Sagebrush	163	East end of study area 5 km southeast of highway and adjacent to landfill, numerous roads, a distant power line, sagebrush mechanical treatments and fencing, diverse topographically, rock outcrops, riparian area heavily incised – with little riparian vegetation
Cabin Creek reference site	Sagebrush	164	East end of study area 5 km north of highway in a topographically diverse landscape dominated by sagebrush with a willow dominated riparian area parallel to road, a patch of mature cottonwood, rock outcrops, aspen and Douglas fir nearby
Lost Miner Ranch	Agriculture	162	Irrigated hay meadow, horse barns and pastures, adjacent to landfill, power lines and fences
Gunnison wastewater treatment plant	Wastewater treatment plant	153	Treatment plant (continuous noise), cottonwood gallery forest, rocky ridge with updrafts, nearby wetlands and open fields, power lines
Gunnison County Landfill	Landfill	163	Landfill in sagebrush landscape, diverse topographically, fences, heavy machinery active during week days (hours 0900-1600 h)

Site Name	Anthropogenic Feature	Highway Mile Marker	Description
US Highway 50	Highway	161	One mile segment of primary 2 lane highway through the Gunnison Basin, heavy traffic including trucks during day, fences, power lines parallel highway, source of road kill animals
Gunnison County Airport	Airport	157	Small airport on south edge of Gunnison, surrounded by ag fields, wetlands and sagebrush, high chain-link fences, large areas of pavement, dumpster present, adjacent to recycling facility
Dos Rios Golf Course	Golf course	155	Golf course on the Gunnison River bottomland with mature cottonwood trees and large areas of lawn (putting greens and fairways), includes club house, parking lot and dumpsters
Western State Colorado University	University campus	158	Campus with large open lawn, tall blue spruce and cottonwood trees, numerous tall buildings, sidewalks, power lines, parking lots, dumpsters, walking and bicycle traffic, construction projects
Gunnison residential area	Residential area	157	One mile segment of residential streets in town of Gunnison, houses with lawns and numerous blue spruce and cottonwood trees, power lines, street lights, fences, irrigation ditches, included larger government buildings and lawns
Parking lot of City Market grocery store	Parking lot	157	Parking lot adjacent to grocery store and restaurant, included many street lights, a few medium sized cottonwoods, large paved surface with heavy use in mid-day and evening, adjacent to Main Street and numerous businesses, open dumpsters present

RESULTS

Sampling Effort

A total of 857 point counts were conducted from August 2013 to July 2014. Seven point counts were not conducted for the following reasons: 3 point counts were missed during survey 7 at the landfill due to the landfill gate lock malfunction and therefore no access was possible, both Long Gulch and Cabin Creek (both sagebrush reference sites) were not surveyed during survey 12 because the time period ran out, Long Gulch was not surveyed during survey 8 because the road was too muddy, and Cabin Creek was not surveyed during survey 1 because the site was added as a third reference site after the morning sampling period. The 857 point counts equated to 85.7 hours of sampling.

Abundance and Frequency of Occurrence by Site

I counted ravens on 48% of the counts (412 out of 857), whereas crows were present on 20% (175 out of 857) of the counts (Table 3). I counted 10,384 ravens and 556 crows over the entire study. The vast majority of ravens were recorded at the landfill (81.6%) followed by the Cabin Creek sagebrush site (5.6%) and the ranch (4.2%). Ravens occurred at all 12 sites (Fig. 1). Crow prevalence was highest at the residential area (36.7%) followed by the grocery store parking lot (20.2%) and the golf course (19.6%).

Ravens were present 94% of the time at the landfill and 81% of the time at the ranch site. They occurred 60% of the time at the Long Gulch reference site and 58% of the time at the wastewater treatment plant (Table 1). In contrast, they were present only 15% of the time at the grocery store parking lot, 22% of the time at the airport and 25% of the time in the city residential area. Raven use of the airport was minimal and nearly every observation of ravens at the airport count point was of ravens nearby the airport in a prominent cottonwood tree, rather than in association with airport infrastructure. Ravens were present on average 50% (38-60% range) of the time at sagebrush reference sites (Table3).

Abundance and Frequency of Occurrence by Site and Time of Day

Abundance and frequency of occurrence of ravens differed among the 12 sites and among the three time periods (Table 4). A distinct bimodal pattern of use was evident on three sites (landfill and two of the sagebrush sites on the east side of the valley – adjacent to landfill) in which ravens had relatively high abundance in the morning and evening and had lower abundance at mid-day. At five sites ravens had relatively high abundance during mid-day with lower abundance in the morning and evening (ranch, highway, university, residential, and wastewater facility). At five sites ravens showed a pattern of lowest use in the evening (golf course, grocery store, university, highway and ranch).

Abundance and frequency of occurrence of crows was different among sites and times of day (Table 5). Crows did not visit the three sagebrush sites throughout the year-long study and they rarely used the highway and airport. They were associated most with the urban sites (residential, grocery store, golf course, and university) and on all of these sites they tended to have relatively high abundance and frequency of occurrence during the morning and mid-day and use declined in the evening (Table 5).

Abundance and Frequency of Occurrence by Season and Time of Day

Raven abundance and frequency of occurrence differed among seasons and times of day. In fall, ravens had a bimodal pattern with higher abundance in morning and evening, this shifted to a winter pattern where raven abundance was high in morning and mid-day, but lower in the evening and by spring and summer a strong bimodal activity pattern returned (Table 6). In fall and winter, frequency of occurrence was relatively high in morning and at mid-day but this pattern disappeared in spring and summer. For all three time periods, ravens showed a pattern of increased abundance and occurrence from fall into winter and spring and with declining use in summer. These observations support the idea that ravens are active during winter and early spring in the morning and mid-day periods and are highly visible at many sites.

Crow abundance and frequency of occurrence differed by season and time of day (Table 6). A consistent pattern of highest use in morning, intermediate use at mid-day and lowest use in evening occurred for crow abundance in all seasons. This pattern was also evident for crow frequency of occurrence, except in summer. Crows were generally more active and abundant during the early part of the day especially in fall and winter and these metrics decreased into spring and summer.

Road Kills and Carcass Use

The first road kill was observed along U.S. Highway 50 in late November 2013. Road kill increased in January and peaked by mid-March 2014. Mule deer was the main road kill species with 29 fresh carcasses counted, followed by raccoon and red fox (3 carcasses each). Other road kill species included striped skunk, Gunnison's prairie dog, Wyoming ground squirrel, coyote, mink, and an unidentified bird carcass. Raven use was primarily associated with mule deer. Road kill numbers remained high into May, although many of the road kills in later spring were old kills that were not being used by ravens (Fig. 2).

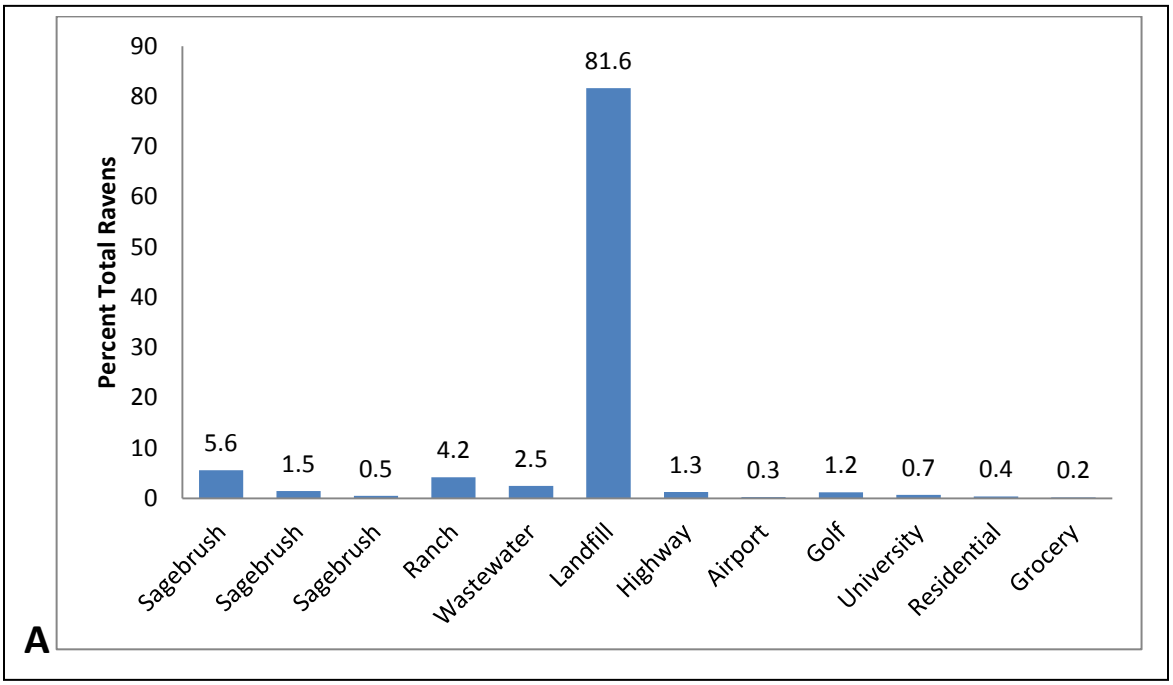
First carcass use by ravens was observed on 25 November at the McCabe's sagebrush site. A mountain cottontail had been killed by a rough-legged hawk and ravens and black-billed magpies were scavenging the carcass. Further, a coyote carcass was found along a BLM road (likely shot by a human) and 3 ravens and a golden eagle foraged on the carcass. Later in the day, 5 ravens and several magpies used the same carcass. On 11 December, 19 ravens vigorously foraged throughout the day on two coyote carcasses at one location adjacent to a BLM road. Also on 25 November, the first use of highway road kill by ravens was observed – 5 ravens fed on a fresh mule deer carcass. Few carcasses were produced along the highway in December, but the two that I observed were attended by ravens. On 16 January, 6 fresh carcasses were observed with 4 of them attended by ravens, including 33 ravens on a single carcass! Highway 50 travelers produced 12 fresh road kills on 27 February including 9 mule deer, 1 elk, 1 red fox, and 1 coyote. Of these 7 were attended by ravens. On 12 March, 4 fresh mule deer road kills were produced and ravens were present at three of them. By late March raven use of road kills had declined dramatically, although many old and a few fresh carcasses remained available.

Table 3. Common raven and American crow abundance and frequency of occurrence in relationship to site and time of day in the Gunnison Basin, Colorado from August 2013 to July 2014.

Site	Common Raven			Sample Size	American Crow		
	Time	Count	Frequency		Time	Count	Frequency
Cabin Creek Reference Sagebrush	Morning	261	0.39	23	Morning	0	0
	Day	41	0.48	23	Day	0	0
	Evening	275	0.71	24	Evening	0	0
	Total	577	0.51	70	Total	0	0
	% Ravens	5.6%			% Crows	0	
Long Gulch Reference Sagebrush	Morning	58	0.71	24	Morning	0	0
	Day	24	0.61	23	Day	0	0
	Evening	74	0.52	23	Evening	0	0
	Total	156	0.60	70	Total	0	0
	% Ravens	1.5%			% Crows	0	
McCabe's Lane Reference sagebrush	Morning	14	0.42	24	Morning	0	0
	Day	17	0.38	24	Day	0	0
	Evening	16	0.33	24	Evening	0	0
	Total	47	0.38	72	Total	0	0
	% Ravens	0.5%			% Crows	0	
Lost Miner Ranch Hay Meadow	Morning	135	0.96	24	Morning	0	0
	Day	188	0.67	24	Day	0	0
	Evening	113	0.79	24	Evening	16	0.04
	Total	436	0.81	72	Total	16	0.01
	% Ravens	4.2%			% Crows	2.8	
Gunnison Wastewater Treatment Plant	Morning	37	0.54	24	Morning	13	0.17
	Day	189	0.75	24	Day	37	0.17
	Evening	39	0.46	24	Evening	3	0.08
	Total	265	0.58	72	Total	53	0.14
	% Ravens	2.5%			% Crows	9.2%	
Gunnison County Landfill	Morning	3483	1.0	23	Morning	6	0.13
	Day	1720	0.91	23	Day	7	0.13
	Evening	3274	0.91	23	Evening	2	0.04
	Total	8477	0.94	69	Total	15	0.01
	% Ravens	81.6%			% Crows	2.6%	
U.S. Highway 50	Morning	51	0.38	24	Morning	0	0
	Day	62	0.54	24	Day	3	0.04
	Evening	26	0.29	24	Evening	0	0
	Total	139	0.40	72	Total	3	0.01
	% Ravens	1.3%			% Crows	0.5%	
Gunnison County Airport	Morning	25	0.33	24	Morning	3	0.08
	Day	4	0.13	24	Day	4	0.08
	Evening	6	0.21	24	Evening	3	0.13
	Total	35	0.22	72	Total	10	0.10
	% Ravens	0.3%			% Crows	1.7%	

Table 3. Continued

Site	Common Raven			Sample Size	American Crow		
	Time	Count	Frequency		Time	Count	Frequency
Dos Rios Golf Course	Morning	61	0.67	24	Morning	46	0.67
	Day	42	0.50	24	Day	41	0.58
	Evening	18	0.42	24	Evening	25	0.38
	Total	121	0.53	72	Total	112	0.54
	% Ravens	1.2%			% Crows	19.6%	
Western State Colorado University	Morning	28	0.38	24	Morning	22	0.38
	Day	31	0.50	24	Day	11	0.25
	Evening	10	0.29	24	Evening	4	0.13
	Total	69	0.39	72	Total	37	0.25
	% Ravens	0.7%			% Crows	6.5%	
Gunnison Residential	Morning	10	0.33	24	Morning	114	0.88
	Day	24	0.29	24	Day	64	0.79
	Evening	9	0.13	24	Evening	32	0.63
	Total	43	0.25	72	Total	210	0.77
	% Ravens	0.4%			% Crows	36.7%	
City Market Parking Lot	Morning	10	0.25	24	Morning	57	0.79
	Day	6	0.13	24	Day	44	0.50
	Evening	3	0.08	24	Evening	15	0.25
	Total	19	0.15	72	Total	116	0.51
	% Ravens	0.2%			% Crows	20.2%	
Grand Total	**Ravens**	**10,384**	**0.48**	**857**	**Crows**	**556**	**0.20**
	Morning	4173	0.53	286	Morning	261	0.26
	Day	2348	0.49	285	Day	211	0.21
	Evening	3863	0.43	286	Evening	90	0.14



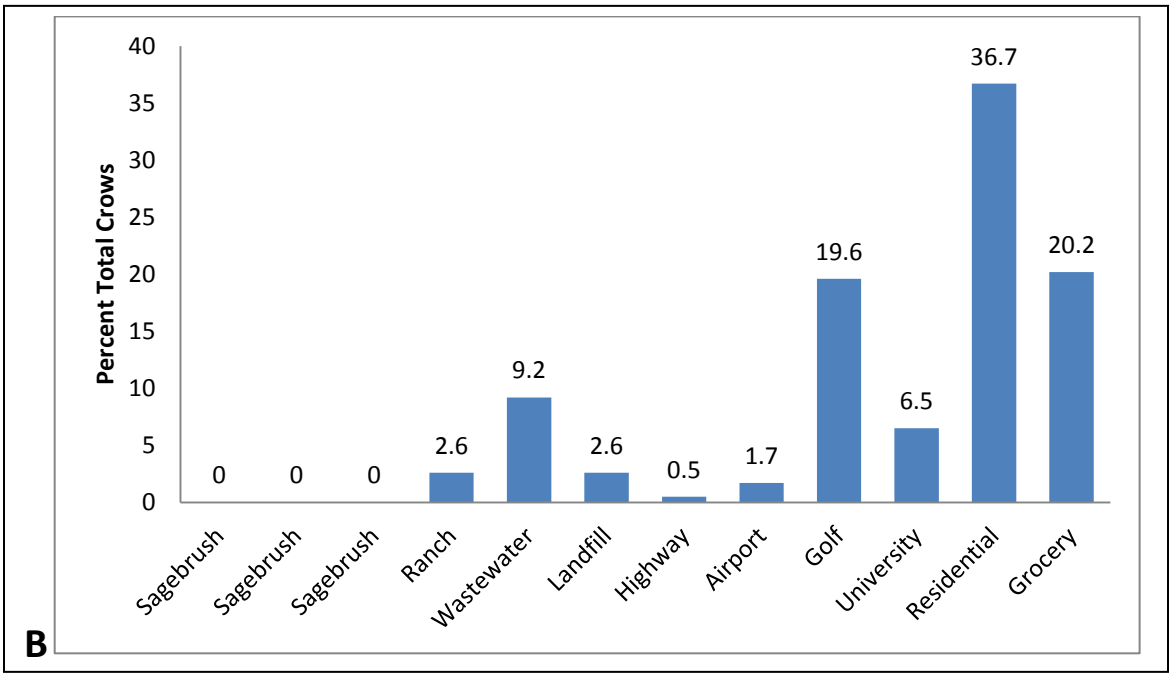


FIG. 1. Percent of total common ravens (A) and American crows (B) counted throughout the study by site. The sites are more or less arranged from rural with less anthropogenic influence on the left (sagebrush reference sites) to urban with highest anthropogenic influence on the right. The sagebrush sites from left to right are Cabin Creek, Long Gulch, and McCabe's. Data collected from August 2013 to July 2014 in the Gunnison Basin, Colorado.

Table 4. Mean number and mean frequency of occurrence of ravens in relationship to site and time of day. Data were collected from August 2013 to July 2014 in the Gunnison Basin, Colorado.

Common Raven					
Site	**Variable**	**Morning**	**Day**	**Evening**	**Pattern**
Cabin Creek Sagebrush	Abundance	10.9	1.7	11.5	Bimodal
	Frequency	0.38	0.46	0.71	Evening high
Long Gulch Sagebrush	Abundance	2.4	1.0	3.1	Bimodal
	Frequency	0.71	0.58	0.50	--
McCabe's Sagebrush	Abundance	0.6	0.7	0.7	Equal use
	Frequency	0.42	0.38	0.33	Equal use
Lost Miner Ranch	Abundance	5.6	7.8	4.7	Day use high
	Frequency	0.95	0.67	0.79	--
Wastewater Treatment	Abundance	1.5	7.9	1.6	Day use high
	Frequency	0.54	0.75	0.46	Day use high
Gunnison County Landfill	Abundance	145.1	71.7	136.4	Bimodal
	Frequency	0.96	0.88	0.88	Ubiquitous
U.S. Highway 50	Abundance	2.1	2.6	1.1	Day use high
	Frequency	0.38	0.54	0.29	Day use high
Gunnison County Airport	Abundance	1.0	0.2	0.3	--
	Frequency	0.33	0.13	0.21	--
Dos Rios Golf Course	Abundance	2.5	1.8	0.8	Evening low
	Frequency	0.67	0.50	0.42	Evening low
Western State CO University	Abundance	1.2	1.3	0.4	Evening low
	Frequency	0.38	0.50	0.29	Day use high
Gunnison Residential	Abundance	0.4	1.0	0.4	--
	Frequency	0.33	0.24	0.13	Evening low
City Market Parking Lot	Abundance	0.4	0.3	0.1	Evening low
	Frequency	0.25	0.13	0.08	Evening low

Table 5. Mean number and mean frequency of occurrence of American crows in relationship to site and time of day. Data were collected from August 2013 to July 2014 in the Gunnison Basin, Colorado.

American Crow					
Site	**Variable**	**Morning**	**Day**	**Evening**	**Comment**
Cabin Creek Sagebrush	Abundance	0	0	0	No use
	Frequency	0	0	0	No use
Long Gulch Sagebrush	Abundance	0	0	0	No use
	Frequency	0	0	0	No use
McCabe's Sagebrush	Abundance	0	0	0	No use
	Frequency	0	0	0	No use
Lost Miner Ranch	Abundance	0	0	0.63	Low use
	Frequency	0	0	0.04	Low use
Wastewater Treatment	Abundance	0.54	1.54	0.13	Day use high
	Frequency	0.17	0.17	0.08	Evening low
Gunnison County Landfill	Abundance	0.25	0.29	0.08	Evening low
	Frequency	0.13	0.13	0.04	Generally low
U.S. Highway 50	Abundance	0	0.13	0	Low use
	Frequency	0	0.04	0	Low use
Gunnison County Airport	Abundance	0.13	0.17	0.13	Low use
	Frequency	0.08	0.08	0.13	Low use
Dos Rios Golf Course	Abundance	1.92	1.71	1.04	Evening low
	Frequency	0.67	0.58	0.38	Evening low
Western State CO University	Abundance	0.92	0.46	0.17	Evening low
	Frequency	0.38	0.25	0.13	Evening low
Gunnison Residential	Abundance	4.75	2.67	1.33	Evening low
	Frequency	0.88	0.79	0.63	Evening low
City Market Parking Lot	Abundance	2.38	1.83	0.62	Evening low
	Frequency	0.79	0.50	0.25	Evening low

Table 6. Mean number and mean frequency of occurrence of ravens in relationship to season and time of day. Data were collected from August 2013 to July 2014 in the Gunnison Basin, Colorado.

Common Raven					
Season	**Variable**	**Morning**	**Day**	**Evening**	**Pattern**
Fall	Abundance	11.8	5.9	6.2	Weak bimodal
	Frequency	0.40	0.44	0.29	Evening low
Winter	Abundance	16.2	16.6	6.6	Evening low
	Frequency	0.69	0.62	0.47	Evening low
Spring	Abundance	15.9	5.3	22.2	Bimodal
	Frequency	0.61	0.58	0.51	Steady
Summer	Abundance	14.1	4.8	18.6	Bimodal
	Frequency	0.38	0.27	0.41	Weak bimodal
American Crow					
Fall	Abundance	1.15	0.67	0.31	Evening low
	Frequency	0.29	0.22	0.08	Evening low
Winter	Abundance	1.15	1.26	0.08	Evening low
	Frequency	0.29	0.29	0.07	Evening low
Spring	Abundance	0.72	0.65	0.44	Evening low
	Frequency	0.25	0.19	0.19	Morning high
Summer	Abundance	0.60	0.35	0.33	Morning high
	Frequency	0.19	0.14	0.19	Weak bimodal

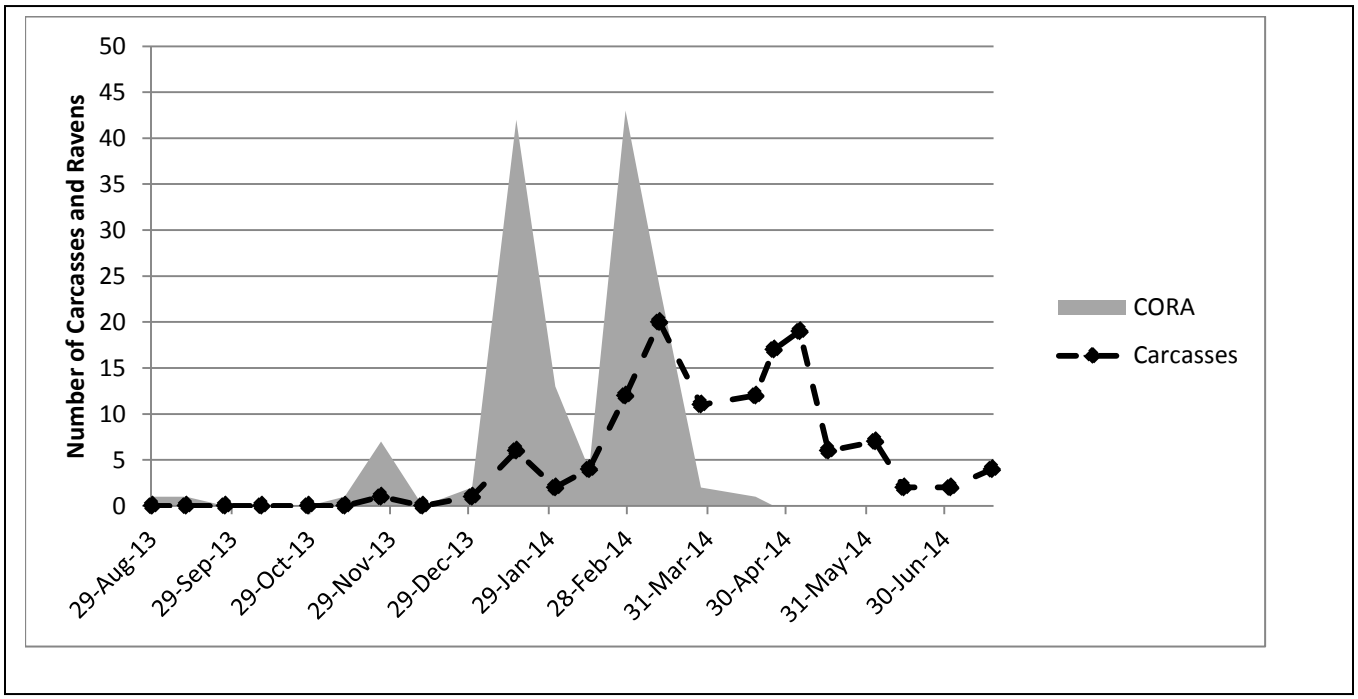


FIG. 2. Number of carcasses (dotted black line) and number of ravens using road kills (gray shading) counted along an 18 km (11 mile) segment of U.S. Highway 50 in Gunnison, Colorado (MM 153-164) from August 2013 to July 2014. The peaks in use in January and February correlated with snowstorms.

DISCUSSION

Common ravens are nearly ubiquitous in the study area; they were observed at every site, they were observed during all 48 sampling dates, they were observed at every time of day, and they were observed on approximately 50% of the 857 point counts. In contrast American crows occurred 20% of the time and did not use any of the sagebrush sites and had very low use of three additional sites. They had high use of the four most intensely urban sites (grocery store, residential, golf course and university). Crow distribution and abundance matched my hypothesis that the birds would be associated with the most urbanized sites and less likely to associate with the least urban sites in the sagebrush. Ravens, on the other hand, did not strictly follow the hypothesized pattern and tended to be associated with the more rural sites that simultaneously provided anthropogenic resources (landfill, ranch, and wastewater treatment plant). Further they were relatively abundant (second highest abundance accounting for 5.6% of all ravens counted) at the Cabin Creek sagebrush site. However, this site was between the landfill and their nocturnal roost site and many of the observed ravens at this site were flying at high altitude en route to or from the roost rather than using the sagebrush habitat directly. A second sagebrush site (Long Gulch), located just east of the landfill had higher use compared to the third sagebrush site (McCabe's) on the far west end of the study area about 10 km from the landfill. Raven use of the McCabe's site consisted of low flights over sagebrush and feeding on human generated carcasses. A nest was also discovered in the vicinity of this sampling point.

Common ravens are nearly ubiquitous in the study area; they were observed at every site, they were observed during all 48 sampling dates, they were observed at every time of day, and they were observed on approximately 50% of the 857 point counts.

The ranch was also directly adjacent to the landfill, and its relatively high use (ranked third among all sites – 4.2% of ravens observed at ranch site) was not independent of ravens use of the landfill. The ranch represented an agricultural landscape and ravens were observed on the ground and perched in cottonwood trees or on fences in the hay fields throughout the year. They were present on the ground in the fields on the day of hay cutting in July 2013 and they made relatively heavy use of the fields in the spring – walking, foraging and perching on the ground and perching in cottonwoods or on fences. They were also observed in the fields on snow during winter. This horse ranch did not have cattle, but at other ranches in the basin, where cattle were present and winter feeding operations occurred, ravens and crows were regularly seen in pastures foraging on the ground adjacent to cattle, but not directly within the herd. On one occasion I counted 92 crows in one field.

The landfill was by far the most used site by ravens in the study area. I counted a total of 8,477 ravens at the landfill throughout the year which accounted for 81.6% of all raven observations. The mean number of ravens counted at the landfill over all dates and time periods was 118 per count. The total number of ravens counted was considerably lower than the number of ravens that occurred at the landfill. I counted ravens from a point below the landfill trash pile and did not have a complete view of

the landscape. Therefore on every count my estimates were likely biased low. For example, on 31 January 2014, my official mid-day count was 475 individuals, however, as I waited beyond the 6 minute point count period and watched ravens occasionally fly up from the trash pile, I estimated that there were at least 600 ravens present.

While ravens were present at all 12 sites, a few sites had low use including the grocery store parking lot, the residential area, and the airport. In fact, use of the airport was biased high in the study because most of the ravens counted at this site were observed adjacent to the airport in cottonwood trees and were not using airport infrastructure. The grocery store parking lot, the residential area, and the airport were sites with the highest human impact. While ravens clearly benefit from human activities, they appear to prefer sites with a combination of human and natural features, whereas crows were associated more with human dominated landscapes (parking lots, streets, lawns).

Ravens showed distinct daily patterns of use which varied among sites. They had a bimodal pattern at the landfill throughout the year in which they had high use in the morning and the evening, but largely departed the landfill during the mid-day period. Other researchers have also documented bi-modal foraging peaks in morning and late afternoon (Engel and Young 1992a, Sherman 1993). While ravens frequently occurred at the landfill at mid-day (91% of the time) their numbers (mean mid-day count 72 ravens) were much lower than during morning (mean count 145 ravens) and evening (mean count 136 ravens). Mid-day counts were highest during winter and when weather was inclement. The bi-modal pattern changed seasonally such that in winter raven numbers were high in the morning and at mid-day, but relatively low in the evening. This is likely due to a strategy of foraging all day at the landfill (especially during snow storms) and returning to the roost early in the day during winter.

The bimodal pattern of use at the landfill was the driver for distribution and resource use for ravens throughout the study. Other sites that showed the bimodal pattern included the sagebrush site (Long Gulch) adjacent to the landfill and a second sagebrush site (Cabin Creek) that was located between the landfill and a nocturnal roost site. Therefore, the bimodal use pattern at these sites was directly related to the movement of ravens to and from the landfill in the morning and evening. After ravens departed the landfill in the morning, use picked up at several sites in the study area (especially the ranch and wastewater plant, but also the highway, university, and residential area). However, raven abundance at the other sites did not nearly account for the number of ravens that used the landfill in the morning and evening. This pattern is supported by other research where landfills provide the main human subsidy but raven use of the surrounding environment is important yet dispersed (Boarman et al. 2006).

Another diel pattern of use observed was the relatively low use of sites by ravens in the evening period. From 28 October to 13 February the landfill evening raven counts ranged from 0 to 77 birds. The explanation for these lower counts is partly related to sampling and the narrow window of time ravens were present compared to the count period (1400 h to sunset). On some days I counted the landfill at the beginning of the evening period (1400 – 1530 h) and ravens had not yet arrived at landfill; other times I counted the landfill at the end of the evening period and ravens had already departed for the roost. In part, the low raven counts for the landfill may be explained by early roosting behavior in winter. Low raven counts in the late afternoon at all twelve sites beginning in late November support this contention that raven behavior changes in winter toward early movement to the landfill and their roost site. Noticeable reduction in activity occurred beginning around 1530 h, still leaving 2 hours of daylight on the shortest winter days.

The bimodal use of the landfill was especially pronounced in summer and it is unclear where ravens went following their morning foraging bout at the landfill. While some sites showed a moderate increase in raven use during the day during summer, the more notable conclusion was that ravens largely disappeared in summer during the day. Likely many ravens roosted during the day in dispersed day roost sites including mature cottonwood trees, and during summer when the trees were fully leaved-out, they concealed the ravens well. During fall and into winter, day use was much more pronounced, especially along the Gunnison River corridor that included the river, the cottonwood gallery forest, and the highway all running parallel to one another. Ravens apparently were foraging throughout the day, representing a dramatic shift from their summer day roost behavior.

Raven use generally declined in spring perhaps as a combined result of dispersal for breeding, migration, and over winter mortality (Boarman et al. 2006). General activity at all sites was relatively low beginning in late March and persisting through mid-summer.

My observations provide evidence for a large, permanent, nocturnal, raven roost northeast of the landfill somewhere in the Lost Canyon area. Often raven roosts move in relation to location of food bonanzas, but when the food bonanza is permanent (landfill) roosts may be permanent (Heinrich 1989). Ravens fly daily from the northeast over the Cabin Creek sagebrush site and on toward the landfill. These flights are at high altitude and ravens are purposeful in their movement toward the landfill. Ravens call in flight during morning flights. On 6 August 2013, I arrived at the landfill at 0515 h and the first raven arrived at 0557 h. By 0628 I had counted 463 ravens in the morning flight. From the time I could see the ravens, it took them 2 minutes and 45 seconds to gain the landfill. They flew directly to the trash pile, landed and generally began foraging. Similarly, on 26 September, I arrived at the landfill at 0639 h and four ravens were already present, by 0712 h, about 30 minutes later, 202 ravens had arrived. On 29 October the first raven arrived at 0710 h and 36 minutes later 183 ravens were observed. Beginning on 25 November ravens begin flying in to landfill from the southwest as well as the northeast. Eventually the southwest flight from roost dominated in winter. For example, on 15 January 2014, the first raven arrived at the landfill at 0708 h and 46 minutes later at 0754 h 535 ravens had arrived, 193 from the northeast, 314 from the southwest, and 28 from other directions (similarly, on 17 January 2014, during the evening roost flight, 315 ravens flew southwest from the landfill, 89 flew northeast and 9 flew other directions). By June, the northeast roost flight dominated and fewer birds used the southwest roost.

In the evening, ravens depart the landfill and fly toward a northeast destination. On 29 August 2013, 243 ravens were counted at the landfill at 1832 h, at 1928 h I observed 40 ravens flying past the Cabin Creek sagebrush site, I observed 31 ravens flying overhead at 1939, 8 ravens flew by at 1941, and 4 more flew past the observation point at 1946. I counted a total of 83 ravens flying from the direction of the landfill to the unknown nocturnal roost site. Raven flight was uniquely different from the direct morning flight behavior. In the evening ravens circled and often changed flight path before resuming their general movement toward the roost. The more leisurely flight behavior toward the roost was coupled with many varied calls.

"The raven succeeds on the spoils of our success" – Henry Brean

MANAGEMENT IMPLICATIONS

Response to growing raven populations in the western U.S. has taken three forms: 1) lethal removal of ravens, 2) aversive conditioning, and 3) reduction of anthropogenic subsidies (Bui et al. 2010). All raven management efforts require an understanding of key life history characteristics of ravens.

Key Characteristics of Common Raven Life History Useful for Targeting Management Actions

Habitat

Common ravens are habitat generalists, preferring vertical structures such as trees, cliffs or anthropocentric features. Ravens occur in just about every habitat in Colorado including alpine, sub-alpine forests, grasslands and shrublands, desert river canyons, agricultural landscapes and urban areas. As human commensals, ravens use ranches, highways, transmission lines, campgrounds, and other human infrastructure.

Reproduction

Ravens reach sexual maturity at 2-4 years old and form long-term monogamous pair bonds. Year-round, pairs defend non-overlapping breeding territories within their home ranges. They nest on vertical structures such as cliffs, trees, light poles, transmission poles, bridges/overpasses, and buildings and have site fidelity to nests. After nest building, ravens lay 3-7 eggs usually in March-April, and have a 20-25 day incubation period and a 5-7 week nestling period, before fledging. Fledglings remain near the nest and adults for another 4-8 weeks. Adults may roost near their nest year-round.

Non-breeding Ravens and Roosts

Ravens feed at concentrated food sources (food bonanzas) and form loose aggregations called crowds. Crowds, consisting primarily of non-breeding juveniles, roost together at night nearby the food source in trees, on transmission lines, or on communication towers. Evidence suggests these aggregations serve as information centers.

Foraging Ecology

Omnivorous ravens prey on live animals, collect garbage, feed on carrion, depredate eggs, and consume grains and fruit, among other foods. The diet reflects patterns of food availability. Adult territorial ravens feed relatively close to their nests (within 400 m), whereas juvenile ravens forage over larger distances. They typically have a bi-modal foraging pattern, using visual cues in the morning and late afternoon. Ravens cough up pellets, typically at roost sites and they cache food via burial.

References: Boarman and Heinrich 1998, Engel and Young 1992, Engel et al. 1992, Heinrich 1988, Kristan et al. 2004, USFWS 2008

Raven Management Justification

Videography suggests that common ravens are the primary nest predator of greater sage-grouse (Coates and Delehanty 2008, Coates et al. 2008, Lockyer et al. 2013). Direct evidence is lacking for Gunnison sage-grouse, but it is likely that ravens depredate eggs and possibly prey on Gunnison sage-grouse chicks. In a Nevada study, ravens depredated half the greater sage-grouse nests contributing to a 22.5% nest success of the grouse (Dan Gibson, unpublished data). Due to their site fidelity, sage-grouse may have dysfunctional habitat selection by using habitats that reduce their fitness, therefore sagebrush nesting sites may be ecological traps (Dan Gibson, unpublished data). In contrast, researchers in Wyoming observed that greater sage-grouse select nesting and brood rearing sites that obscure visual predators (birds, ravens) but not olfactory predators (mammals) (Conover et al. 2010, Dinkins et al. 2012). Avian predators are likely a larger threat and grouse habitat selection that reduces visual detection results in avian and mammalian predators taking equal numbers of nests. Research justifies developing an **integrated raven management** (IRM) program to reduce raven depredations on sage-grouse through a strategic planning process and with a diverse menu of management options (Table 7).

Raven Lethal Control

In addition to ravens, carnivores such as coyotes, red fox and badgers have been the targets of predator removal efforts. Success of such efforts has been mixed. For example, red fox removal in Strawberry Valley, UT resulted in increased greater sage-grouse adult survival and productivity, including an increase in nest success form 43.6% prior to red fox control (1998-99) to 67.8% after control (2000-2005) (Baxter et al. 2007). Importantly, the experiment lacked spatial controls limiting the inference that predator control was the factor causing grouse nest success to increase. Coyote control in Wyoming had no effect on greater sage-grouse nest success or chick survival (Slater 2006). Some evidence suggests that coyote control can lead to unexpected outcomes including meso-predator release of red fox (Mezquida et al. 2006).

In an effort to control raven numbers in Nevada, USDA Wildlife Services removed approximately 684 ravens in 2002 and 2003, effectively reducing raven density from 5/km^2 in March 2003 to 0.31/km^2 in July 2003 (Coates and Delehanty 2004). Greater sage-grouse nest success increased from 42% pre-control to 74% after control was initiated (Coates and Delehanty 2004). Despite some successes, raven control studies generally conclude that lethal removal of ravens is ineffective at providing recovery of sage-grouse (Hagan 2011). For example, where Wildlife Services reduced raven population density by 61% from 2008-2011 in Wyoming, greater sage-grouse nest success did not measurably improve (Dinkins 2013). Often, predator control programs effectively reduce predator populations in the short-term, but predators bounce back rapidly once the control program ceases. For example, red fox control in California to enhance clapper rail productivity, successfully removed 50% of adult red fox and 25% of juveniles; after 3 months fox populations reached pre-control densities (Cote and Sutherland 1997). In a Nevada study, 6,743 common ravens and 107 other grouse nest predators were killed using egg avicides at a cost of $147,500, and raven populations recovered each spring (Coates et al. 2007).

Lethal removal of ravens requires a take permit from the U.S. Fish and Wildlife Service, as ravens are protected under the Migratory Bird Treaty Act of 1918. Typically, USDA Wildlife Services is employed to conduct such lethal control projects and they regularly use DRC-1339 tainted egg baits to lure ravens to the lethal poison. This poison is also called 3-chloro-p-toluidine hydrochloride (CPTH). Hard boiled chicken eggs are treated with the highly toxic avicide that targets corvids and a few other bird species (doves, starlings, owls and grouse). In other raven control programs, DRC-1339 is injected into meat baits. Ingestion of the toxin leads to a non-violent death by kidney failure or depression of the central nervous system in 1-2 days (BLM 1990).

Table 7. Potential methods for inclusion in an integrated raven management program. The most effective strategies include use of multiple tactics. Not all tactics are effective or reasonable but are listed to demonstrate breadth of thinking needed to creatively solve problem.

An Integrated Raven Management Program -- Potential Control Methods	
Lower Number of Ravens	***Comments***
1. Lethal poisoning with DRC-1339	1. Widely used by Wildlife Services, egg or meat baits, target breeding adults with territories
2. Shooting by wildlife consultants	2. Ravens learn to avoid shooters, inefficient
3. Public hunting season	3. Ravens protected by MBTA, classified as non-game species
4. Hunt ravens with falconer	4. Ravens protected by MBTA, classified as non-game species
5. Chemical sterilization	5. Currently no approved raven contraceptive, sterile ravens continue to depredate grouse eggs for 10+ years
6. Trap and relocate	6. Transporting problem to new location, move ravens a minimum distance of 125 miles from original location
7. Adopt-a-raven	7. Not legal under MBTA
8. Introduce raven predator	8. Executive Order 13112 prohibits introduction of invasive species, adult ravens with few predators
Modify Behavior of Ravens	
1. Hazing	1. Ravens generally acclimate to hazing, recommended to use multiple methods and change location of hazing
Motion-sensor squirt guns	
Electric zappers	Landing surface produces electric shock
Irritating scents	
Ultrasonic bird repellants	Broadband Pro, Bird-X
Gas operated exploders	
Battery operated alarms	
Screamers (fire crackers)	
Bangers (shells going off)	
Pyrotrechnics	
Shiny tape or streamers	
Optical fire gel (birds see in UV)	
Rotating blades	
Decoys – birds of prey	
Inflatable balloons	
Terror eyes, prowler owl	
Chemical frightening	Treat bait with Avitrol (4-aminopyridine) at low level, kills birds that ingest it, may deter other birds from baits
2. Patrol	Use patrol to ward off ravens at lambing grounds or other sites that attract ravens
Falconer or sheep dog	
Model airplane	
3. Anti-perch devices	Install devices that render perches and nest sites unusable
Spikes, wires, nets	

4. Reduce food subsidies	Use of non-lethal methods to reduce human subsidized food
Food burial	Bury trash at least daily at landfill
Treat food waste with chemical	Methylanthranilate (MA) sprayed on garbage is inedible
Hang grid over food source	Hang wire or monofilament line in a grid to prevent access to garbage
Netting system	
Bury deceased livestock, afterbirth	
Collect roadkill carcasses	
Prevent roadkill	Highway underpasses, overpasses, driver warning systems
Reduce hunter produced offal	
Use raven proof garbage containers	
Keep dumpsters closed	
Food trash sorting system	Reduce food trash going to landfill, sort food/organic trash from inorganic trash
5. Remove raven nests	Along transmission lines and on other human structures remove raven nests
6. Eliminate standing water	Ravens require free water, reduce availability of water permanently or after rains or snowmelt

A complexity to raven lethal control relates to the efficacy of killing the right ravens. The most significant threat to sage-grouse is from breeding adult ravens within their territories and from spillover predation by juvenile crowds at human subsidized food sources (Kristan and Boarman 2003). Targeting control on specific individual ravens is likely more productive than non-targeted removal. Ravens have delayed maturation and a prolonged juvenile life stage, requiring 4 years to reach sexual maturity (Webb et al. 2009). Large crowds of ravens are probably dominated by juveniles that congregate at food bonanzas in order to overwhelm dominant adult birds (Boarman and Heinrich 1999). Ravens feeding in the sagebrush are likely paired adult birds with territories. Reducing raven numbers at the landfill where juvenile crowds form, may not have a noticeable effect of raven activity in the sagebrush as the targeted birds at the landfill are not the same social class as the birds that potentially feed on eggs of ground nesting sagebrush species. Juvenile crowds are spatially restricted to human subsidized food bonanzas and use other non-breeding ravens as cues to location of food supplies (Kristan and Boarman 2003). My observations support this hypothesis as I only saw single or paired ravens foraging low over sagebrush. Single birds likely are a member of a pair foraging while its partner may have been incubating eggs or attending to the territory. Targeting adult territorial birds would likely remove "problem" ravens that have learned to feed on grouse eggs (Kristan and Boarman 2003), and non-egg eating ravens would likely move into unoccupied territories. However, some evidence suggests that removing an original pair of ravens from their territory may result in two new pairs moving in and splitting the original territory (Brean, unpublished report).

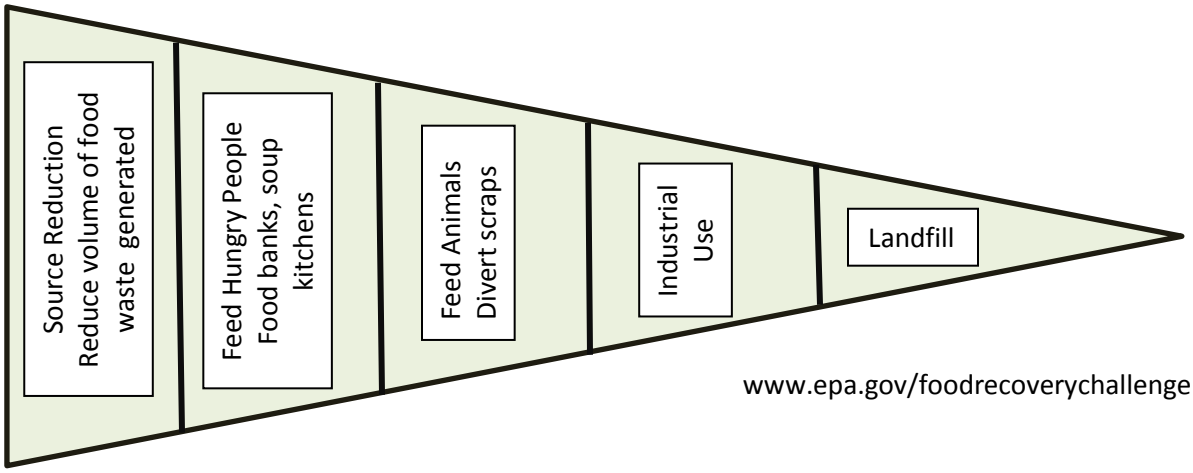
Spillover predation by juvenile ravens at human subsidized food bonanzas is an issue (Kristan and Boarman 2003). Reduction in raven use at these large, permanent food sources is justified but due to the ineffectiveness and high cost of lethal removal, reduction in availability of food sources would provide a longer-term solution.

Aversive Conditioning
Aversive conditioning or behavioral modification involves training ravens to not eat sage-grouse eggs, making perch and nest sites on anthropogenic structures unusable, and hazing. Training ravens to avoid eating sage-grouse eggs involves treating chicken eggs with unpalatable chemicals (e.g., carbachol) that make the raven sick, and thus encourage ravens to avoid eggs as a food source (Boarman and Heinrich 1999, Bui et al. 2010). This method has had mixed results and shows some potential, although the length of time ravens adjust their egg foraging behavior is unknown. Apparently ravens learn quickly to avoid tainted eggs. The method may be useful if management is targeting a few problem birds, but at a population scale, taste aversion seems impractical. The plethora of existing human structures that ravens potentially use for perch and nest sites could be manipulated with anti-perch devices. These devices include spikes and wires or nets that restrict the perching surface. A variety of hazing options is available as well to modify raven behaviors (Table 7).

Removal of Human Subsidies
Removal of human subsidies is likely the most effective way to reduce unnaturally inflated raven populations in a sustained way. I discuss several opportunities in the Gunnison Basin for such anthropogenic subsidy reduction at a variety of sites studied.

Landfill. At the Gunnison County landfill I observed a pronounced bimodal daily use pattern by ravens associated with their movement from the nocturnal roost to the landfill food bonanza in the morning. Following a foraging bout ravens largely dispersed from the landfill throughout the day and returned in the afternoon or evening before heading back to their roost for night. These observations are consistent with raven behavior described in other studies suggesting that communal nocturnal roosting is common and the roosts likely serve as communication centers (Boarman and Heinrich 1999). One hypothesis for the diurnal dispersal is that landfill staff arrives and ravens don't tolerate disturbance during working hours; at 4 pm workers end their day and ravens return for several hours before roosting. But in winter this pattern changes, especially when weather is inclement and ravens remain in high numbers throughout the day (during days of inclement weather, landfill staff and visitors are usually less active as well). Trash is highly visible and uncovered 24 hours a day, seven days a week. I didn't study whether daily use patterns change on weekdays vs. weekends and holidays when human activity patterns changed.

The most important efforts to reduce potential impacts of ravens on Gunnison sage-grouse revolve around reducing ravens at the landfill, where 82% of all ravens were detected during the study. The optimal long-term solution is to reduce the availability of organic food trash. Trash burial would eliminate the food bonanza and eliminate morning and evening raven congregations around the food source. Trash burial is expensive and complicated, but should be seriously considered as the fundamental method for removing human subsidized food used by ravens. Another method that has been used at landfills (e.g., the Crow Wing County Landfill in Brainerd, MN) involves spraying landfill trash with a chemical deterrent called methylanthranilate (MA). This substance renders the food inedible. Also, efforts to sort trash and reduce food trash from entering the landfill would involve commercial and domestic initiatives and various waste stream reduction programs are currently active in many municipalities around the world. To reduce food waste, which comprises about 21% of the volume of landfill solid waste, it would need to be collected in separate containers and large scale composting operations would need to be developed (www.epa.gov/foodrecoverychallenge). The EPA has created a program to encourage reduction in food wastes at landfills and emphasizes that the landfill is the last resort for food wastes after exhausting numerous other options.



Roost sites. Direct documentation that ravens in the Gunnison Basin use communal, nocturnal roosts was not accomplished in this study. Although roost sites were not located, raven behavior and movement to and from the landfill suggested the location of at least two large roosts. One roost lying northeast of the landfill was used year round. The second roost was southwest of the landfill and was the dominant roost seasonally (winter/spring). Ravens also arrived to the landfill in small numbers from other directions. Exact location of roost sites would allow potential management of these sites to reduce raven use. I hypothesize that the roosts are located in forested areas, either Douglas fir patches or spruce/fir forests. Aversive conditioning such as loud noises or human activity at roost sites could be used to drive ravens out of those areas. Likely there is no shortage of roosting locations (forested habitat) so the long-term efficacy of this approach is questionable.

Transmission lines. Raven nesting in sagebrush ecosystems in southeastern Idaho declines by 31% for every 1 km further away from a transmission line (Howe et al. 2014). And these nesting ravens used transmission poles or towers for 58% of their nests in sagebrush habitat and used other anthropogenic features for nesting substrates 14% of the time, thus 72% of raven nests were on human made structures (Howe et al. 2014). Electrical transmission highways are not just routes for electricity to be transferred from source to customer, but they also serve as "roadways" for ravens to move into more isolated sagebrush landscapes that historically have lacked adequate nesting and perching substrates (Coates et al. 2014). Ravens using sagebrush habitats are mostly paired territorial adults using natural nesting sites (cliffs or trees) or human subsidized nest sites in the form of transmission lines (Howe 2012). Transmission lines also provide perches for ravens to scan visually for prey. I regularly observed ravens perched on transmission lines, light poles, and telephone poles. The magnitude of raven use of transmission lines for nesting is undocumented in the Gunnison Basin. Research should be completed to determine the prevalence of raven nests on transmission lines locally and if justified a potential management action involves removing raven nests and/or reducing the use of perch and nest substrates associated with transmission poles and towers by introducing anti-perch structures. Companies such as Zena Design provide various perch preventers and pole caps to reduce perching and nesting by ravens and birds of prey on transmission infrastructure (www.zenadesign.com).

Carcasses: Highway road kill, ranching, and hunting. I documented fairly heavy scavenging use of road kill carcasses by ravens along U.S. Highway 50 from December to mid-March. The use varied depending on weather and availability of carcasses. In February, following a recent snowstorm, a maximum of 12 fresh carcasses was counted on one survey and raven use peaked with 33 ravens on a single carcass. Not all carcasses were used by ravens. Ravens may have trouble accessing carcasses due to the thick impenetrable skin of mule deer or because carcasses freeze (Heinrich 1989). Ravens are known to associate with mammalian scavengers and carnivores that are well armed for ripping open carcasses (Heinrich 1989), however, road kills along highways often are opened up by the trauma of the collision. It is not clear why some carcasses are heavily used by ravens and others are not used. I may have missed observing use of certain carcasses due to the frequency of my surveys.

Adult ravens are dominant within the population and if they use a carcass they are likely to defend it aggressively and not advertise its presence. However, juvenile ravens may "yell" when they find a carcass to recruit other ravens to the meat bonanza (Heinrich 1989, Boarman and Heinrich 1999). The recruitment allows juveniles to overwhelm adults and compete for the available meat. Road kill carcasses and other human produced carcasses and gut piles during hunting season likely attract adult territorial ravens as well as juveniles. Carcasses appear to be an important human subsidy for ravens in the Gunnison Basin.

Carcass removal along U.S. Highway 50, followed by burial, would directly remove a major anthropogenic resource that ravens use extensively in winter. In addition to carcass removal, which is an on-going maintenance effort requiring human labor and annual expense, attempts to reduce automobile/wildlife collisions is worth pursuing. Innovative technologies are available to warn drivers of the presence of large mammals on the highway. Detector pads or other devices recognize the presence of an animal and trigger a flashing sign ("Deer on Highway"). This innovation is more effective as it avoids the problem of driver acclimation to reduced speed limit zones, passive signing or constantly flashing signs. A key to these installations is locating highway crossing focal points. In the highway stretch that I observed, the majority of carcasses were produced within a 3.2 km (2 mile) segment between MM 161-163.

U.S. Highway 50 generated roadkill carcass of a mule deer photographed on 31 January 2014. The carcass was largely devoured by ravens.

Besides roadway carcasses, many carcasses and gut piles (or offal) are generated by hunters and others killing coyotes, prairie dogs, and the like. Experimental evidence suggests ravens have developed a strategy of following gunshot to hunters and use the offal that is left after field dressing a harvested animal (White 2005a, White 2005b). Burial of offal piles by hunters and carcasses produced by ranchers and others shooting "vermin" (coyotes, prairie dogs) would reduce this human subsidy for ravens. Furthermore, livestock afterbirth could also be removed and buried.

Interestingly, where ravens gathered at carcasses along the highway, I made several observations of ravens in agricultural fields adjacent to road kill sites. These ravens were on the ground either perched or walking on the snow. I did not determine their exact behaviors, but hypothesized that ravens buried fat or meat from the carcasses as a scatter hoarder cache strategy (Heinrich 1988, Heinrich 1989).

Agriculture. Raven use of the Lost Miner horse ranch was relatively high and some of this use probably reflected the landscape position of the ranch relative to the landfill. Ravens flew from the north over the ranch en route to the landfill and used the sagebrush hill that separated the ranch from the landfill. Ravens used the irrigated hay meadow at the horse ranch throughout the year, but as snow accumulation deepened they tended to use the ground less. Ravens routinely forage on the ground and were observed not only at the Lost Miner Ranch, but at other ranches within the study area. Crows, more so than ravens, were observed foraging on the ground in pastures occupied by cattle. The crows seemed to be foraging on waste grain or other resources associated with plowed hay fields where cattle feeding operations occurred. I observed crows associated with cattle dung, but no direct evidence suggested they consumed the dung or insects associated with it. In addition to ground foraging, ravens at the Lost Miner Ranch also used trees and fences as perch sites. Tomichi Creek flowed through the ranch and the willow and cottonwood riparian area received fairly regular use by ravens for diurnal perching/roosting. As with other human inhabitations, ranches represent disturbed natural landscapes that attract ravens. Ranchers have the opportunity to reduce raven subsidies associated with available afterbirth during calving, available carcasses of deceased livestock, and available waste grain. Raven hazing methods (Table 7) could be used following haying or in winter when ravens aggregate in fields where snow has been plowed for cattle feeding.

Wastewater Treatment Plant. The Gunnison wastewater treatment plant is located adjacent to the Gunnison River and within the historic Gunnison River floodplain. Ravens used the cottonwoods surrounding the plant throughout the year as diurnal perches. Further, ravens seemed to use the east-west river corridor as a major flight path for diurnal foraging from mid-fall through winter, especially in late morning and throughout the mid-day periods. I made no direct observations of ravens using the infrastructure of the treatment facility, although fecal whitewash was observed on several of the light poles. A rocky ridge formed the eastern border of the treatment plant property and this ridge produced warm air updrafts that were used by soaring ravens. In spring, I observed groups of ravens soaring in rising circles above the wastewater treatment plant, gaining altitude until they reached a certain point and then returned to lower elevations and started over. Usually, a juvenile golden eagle was associated with the raven flock. Ravens also were observed in acrobatic flight, producing numerous vocalizations and likely were courting or playing on the wing. Ravens do not appear to be a problem at the wastewater treatment plant and natural landscape and vegetation features, as well as human conversion of the habitat, attracts ravens to this site.

Golf Course. Like the wastewater treatment plant, the golf course provided a unique combination of anthropogenic resources and natural features, although most of the landscape is artificially created – lawns, mature cottonwoods, dumpsters and other trash. Both ravens and crows used the golf course in fairly equal proportion. Crows clearly preferred lawn foraging, although they often perched in cottonwoods and were observed raiding the always open dumpster. Ravens usually flew over the golf course or used cottonwoods as perch sites. Golf course personnel could easily reduce human food subsidies by managing their dumpster more effectively. Other local businesses could also purchase raven proof dumpsters and more importantly keep dumpster lids closed and reduce trash on the ground. I witnessed ravens and crows using dumpsters at several restaurants, apartment buildings, and at individual homes.

Gunnison Residential Area and Grocery Store Parking Lot. The town was dominated by crows, whereas ravens were relatively rare in the residential area and the grocery store parking lot. Crows were present throughout the year at all time periods (but with lowered abundance and frequency of occurrence in the late afternoon and evening). Crows used blue spruce and cottonwood trees, as well as roof tops, fences, light poles and power/communication wires for perching. They ground foraged heavily on lawns, in gardens, and at bird feeders, and drank from irrigation ditches and gutters. Crows were highly associated with parking lots and scanned the area from light pole perches and foraged on trash on the ground. Further, at the restaurant adjacent to the grocery store parking lot, an open dumpster was readily used by crows. Dumpster management and anti-perch structures in commercial locations could reduce crow use in these locations, but generally the basic mix of trees, energy infrastructure, buildings and food subsidies makes management to reduce corvids in residential areas multifaceted and challenging. Ravens used these sites much less than crows, so with respect to impacts on Gunnison sage-grouse, residential habitat is less of a source problem.

Airport. The airport was one of the least used sites by ravens and crows. The only observations of ravens or crows at the airport were associated with perching behavior in nearby cottonwoods and on light poles. I observed crows drinking from airport parking lot puddles, and observed a raven perching an a snow bank (produced by plowing the parking lot) on the north side of an airport building that provided shade. The perched raven was scavenging a fish carcass of unknown origin. The airport dumpster was always closed and did not provide accessible food subsidies. I did not observe corvids on the runway or associated with other airport infrastructure.

Sagebrush. During the nesting season from 18 April to 2 July I documented 17 ravens flying low and circling over sagebrush, possibly foraging. I observed 6 instances of low flying, circling ravens at the Long Gulch site, 1 at Cabin Creek and 10 at McCabe's, the site furthest from the landfill. Eight of the ravens represented 4 pairs, 6 ravens were singles, and one 3-bird group was observed. The three ravens may have been a pair with a juvenile, as they were observed in the vicinity of a raven nest. Greater sage-grouse hens evolved a four point adaptive suite to reduce potential avian nest predation, including near constant incubation of eggs for 96% of the total incubation period, two short recesses daily for foraging during morning and evening, hens leave and return to nests in low light conditions, and females choose dense vegetation structure for nest placement (Coates and Delehanty 2008). Ravens have adapted to the grouse's lines of defense by visually searching for sage-grouse hens during incubation recesses and most depredations occur from 0630-0930 h or 1800-1900 h after recesses, with the hen on the nest when discovered (Coates and Delehanty 2008). Of the 17 ravens I observed flying low over sagebrush, 10 made these flights at mid-day, 6 in the morning and 1 in the evening. If Gunnison sage-grouse incubation patterns are similar to those documented for greater sage-grouse, and if low flying

ravens are searching for hens to follow to nests, ravens do not appear to be timing their foraging flights to the activity of the grouse. However, much more data are needed to make any legitimate conclusions.

If ravens are finding Gunnison sage-grouse hens and following them to nests, habitat enhancement is the optimal tool to reduce predation. High quality nesting habitat allows hens to remain on their nests longer and reduce recess periods (thermal habitat, water from dew and frost, some food on nest) and makes hens less detectable where horizontal cover adequately conceals nest sites. Aversive conditioning to train ravens not to prefer egg diets may hold promise as territorial, year-round resident ravens would remain in sagebrush habitats and focus on a diet other than eggs of ground nesting birds. Whether this method is effective is unknown and needs to be tested. Lethal removal of paired adult territorial ravens is also an option, but success in other studies is limited and removing territorial ravens may encourage multiple new pairs to take over vacant territories, thus exacerbating the problem.

Integrated Raven Management Strategy

I recommend that an Integrated Raven Management Strategy (IRM Strategy) be developed by a local collaboration of scientists, biologists, land managers, county and city staff (landfill, wastewater treatment plant, airport), business owners (City Market, restaurants), chamber of commerce, USDA Wildlife Services consultants, and other relevant participants. The purpose of the strategy would be to reduce raven abundance as a component of a larger Gunnison sage-grouse conservation effort. Further, lowering local raven numbers could meet multiple objectives, such as airport concerns. The committee would develop a detailed IRM Strategy that includes a multifaceted approach to reducing anthropogenic subsidies to ravens and potentially would include strategic lethal removal of ravens (Table 7). Lethal removal is generally expensive and ineffective as a long-term solution to raven depredation problems, so should be used only as a second tier strategy after non-lethal reduction of human subsidies is fully implemented. If lethal removal is used USFWS permits are required and take should focus on adult breeding pairs of ravens nesting in sagebrush. These are likely the most problematic individuals in the population that would be depredating sage-grouse nests. Some spillover predation from the landfill by juvenile ravens is likely, so after targeted lethal removal of territorial, adult ravens is attempted and monitored, lethal removal of raven crowds could be implemented. However, if non-lethal methods are fully developed, landfill subsidies should be greatly reduced, thus eliminating the need for killing ravens at the landfill. The committee should develop an implementation strategy with a budget and timeline. Further, the IRM Strategy should include a capacity development plant to identify partners and resources required to implement the IRM Strategy. The IRM Strategy should include monitoring efforts to provide an adaptive management process that emphasizes gaining understanding of the effectiveness of various management approaches. Further, monitoring is required to determine whether lethal killing is advised after implementation of non-lethal approaches. The USFWS, CPW and Gunnison County should share lead roles in developing the IRM Strategy.

Integrated Raven Management Strategy Priorities:

1. Non-lethal methods focus on reducing human subsidies, monitor to assess effectiveness
2. Limited lethal removal of adult, territorial pairs, monitor to assess effectiveness
3. Lethal removal of juvenile raven crowds at landfill to reduce spillover predation, only if non-lethal methods fail to reduce raven population at landfill

FUTURE RESEARCH

To quantify impacts of ravens on Gunnison sage-grouse, several research approaches are available and some have already documented that ravens are prime nest predators of greater sage-grouse in Idaho and Nevada (Coates and Delehanty 2008, Coates et al. 2008, Coates and Delehanty 2010, Lockyer et al. 2013). These studies employed videography of active sage-grouse nests to identify nest predators. To initiate such a study, Gunnison sage-grouse nests would have to be located, most likely through applying radio transmitters to female grouse. It is likely that ravens are a nest predator of Gunnison sage-grouse, as has been documented for greater sage-grouse, but the magnitude of raven depredations is not known for Gunnison sage-grouse. While ravens have been implicated as the primary nest predator for greater sage-grouse in some areas, the magnitude of these depredations do not necessarily limit sage-grouse populations (Hagan 2011). A greater understanding of raven impacts on Gunnison sage-grouse nest success and chick survival would help inform biologists regarding limiting factors on grouse population growth.

A low cost and indirect approach to determine whether ravens consume sage-grouse or sage-grouse eggs would involve location of raven communal nocturnal roost sites where regurgitated pellets could be examined to determine food items ingested.

While this study provided a qualitative survey of raven spatial and temporal use patterns, a more detailed resource selection function approach would allow analysis of use patterns at multiple spatial and temporal scales and analysis of relationships between raven occupancy and abundance with anthropogenic features. In this study, evidence of sagebrush use by ravens was observed, but all three sagebrush sites were relatively close to an urban center (Gunnison) and raven use of two of the sites was influenced by use of the landfill. Raven use of more remote sagebrush sites has not been studied in the Gunnison Basin. In studies of greater sage-grouse, presence of transmission lines in remote sagebrush habitats increases raven nesting and perching, and suggests a mechanism for reduced sage-grouse nest success and chick survival (Coates et al. 2014, Howe et al. 2014). To determine the magnitude of raven impact on Gunnison sage-grouse a study of raven movements and resource selection would require trapping and marking ravens with GPS collars.

Reduction of human subsidies for ravens should be thoughtfully implemented in the Gunnison Basin. For example, changing practices at the landfill could substantially reduce human food subsidies and potentially limit raven abundance in the region as the landfill represents the largest and most predictably available food bonanza in the basin. Studies should be designed in concert with management activities to measure raven response to mitigation of human resources that have supported the expansion of ravens locally in the basin.

CONCLUSIONS

This study provides an initial framework to understand raven ecology in the Gunnison Basin with emphasis on the daily and season patterns of use in a variety of human altered habitats. Ravens in the Gunnison Basin in and around Gunnison are ubiquitous, they are highly associated with human features of the landscape, and they use a diversity of resources to meet their needs. The epicenter of raven activity and abundance in the Gunnison Basin is the county landfill and patterns of use seem to revolve around the use of the landfill by ravens. It is a key gathering spot in mornings at all times of year and presumably occurs after nocturnal communal roosting. Unexpectedly, highest raven use was not associated with sites most altered by human activities (instead crows used these sites), but highest raven use was associated with sites that had a mix of natural and anthropogenic features. Lowest raven use was associated with sites that had been most dramatically altered from pre-development condition (grocery store parking lot, residential area). Ravens are associated with sagebrush habitats although numbers were lower in these habitats relative to sites with moderate to high human impact. Preliminary evidence suggests they fly over sagebrush during the sage-grouse nesting season in low, circling flights. The majority of these flights were observed during mid-day when sage-grouse are likely incubating and well concealed if habitat structure is adequate. Research to document impacts of ravens on sage-grouse would provide more clear evidence of the magnitude of the problem for Gunnison sage-grouse, however, management strategies to reduce raven impacts would be similar whether the problem was quantified or not. The main effort immediately required to provide protection for the Gunnison sage-grouse should focus on reducing human subsidies to ravens at the landfill, along U.S. Highway 50, and potentially in sagebrush habitat where transmission lines are present in nesting, brood rearing and lek habitat.

ACKNOWLEDGEMENTS

The study was conducted during 2013-14 when I was on sabbatical from Western State Colorado University; University support is gratefully acknowledged. The study was funded by the Gunnison Sage-grouse Conservation Trust Fund and Colorado Parks and Wildlife. Nathan Seward and Scott Wait both from CPW supported the study financially and conceptually. Further, Gunnison County's Gunnison Sage-grouse Strategic Committee and their Predation Sub-committee supported the project concept and facilitated opportunities for funding. Jim Cochran facilitated county funding opportunities and encouraged the project. Marlene Crosby and Allen Moores of Gunnison County facilitated access to the landfill and project funding. Anne Hausler provided access to the Lost Miner Ranch. Justus Williams and Rory Magee assisted with raven counts.

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APPENDIX A
Common Raven Sampling Locations

Site Number	Site Name	Easting UTM	Northing UTM	Elevation	Natural Habitat	Anthropogenic Resources
1	Cabin Creek*	0343009	4270393	8,325	Sagebrush Cottonwood/ aspen riparian valley bottom	Reference site, gravel road
2	Long Gulch*	0342183	4261865	Data missing	Sagebrush Topographically complex	Reference site, gravel road, distant transmission line
3	Landfill	0339368	4264917	8,206	Sagebrush Hilltop	Trash pile, buildings, tire pile, bare ground, fences, gravel roads
4	Lost Miner Ranch	0339946	4266318	7,798	Tomichi Creek valley bottom, cottonwoods	Irrigated hayfield, barn and corral, horses and goats, homes, lawn, pond, garden, road
5	US Highway 50 MM 161-162	0337755	4267892	7,804	Tomichi Creek bottomland, sagebrush upland, rock outcrops	1 mile transect along 2-lane highway, heavy traffic volume, parallel transmission lines, homes, industrial park, hayfields
6	Western State Colorado University	0332761	4268379	7,730	Sagebrush	Taylor Quad, lawn, dorms, library, Taylor Hall, cottonwoods and spruce, light poles, construction projects
7	City Market Parking Lot	0332160	4268994	7,791	Sagebrush	City Market building, gas station, large parking lot, numerous vehicles, light poles
8	Gunnison Residential	0331980	4268703	7,704	Historic river channel, sagebrush	Paved residential streets, homes, lawns, large parking area, light poles, transmission lines, traffic
9	Gunnison County Airport	0331244	4267123	7,720	Tomichi Creek valley bottom	Concrete parking lot, runway, airport buildings, fences, recycle center, dumpster
10	Dos Rios Golf Club	0328929	4265920	7,669	River bottomland, cottonwoods	Golf course, club house, parking lot, numerous vehicles, transmission lines, dumpster

Site Number	Site Name	Easting UTM	Northing UTM	Elevation	Natural Habitat	Anthropogenic Resources
11	Wastewater Treatment Plant	0326686	4265034	7,620	Gunnison River valley bottom, cottonwoods, rocky ridge to the east	Wastewater plant, buildings, roads, loud industrial noise, compost pile, transmission lines
12	McCabe's*	0323255	4259606	8,123	Sagebrush, willow riparian, rock outcrops, aspen/Douglas fir stands	Reference site, gravel Road

UTMs in NAD83 (13 S)
*Surveyed these locations from multiple points in winter (see below). Site Access determined by road conditions. Snow depth and mud affected access to survey points.

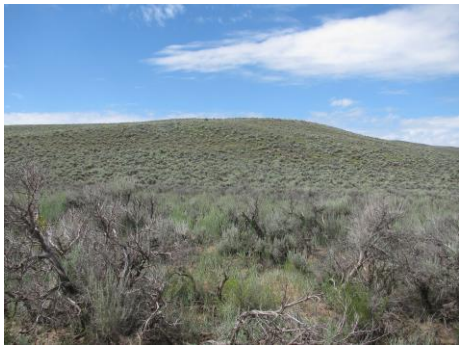
Winter Locations of Sagebrush Survey Points

Site Number	Site Name	Easting UTM	Northing UTM	Dates	Description
1	Cabin Creek*	0342446	4267449	11-25-13 mid-day, evening 12-11-13 12-30-13 1-16-14	1.8 km north U.S. Highway 50 on Cabin Creek Road
		0342388	4267020	1-31-14	1.0 km north of U.S. Highway 50 on Cabin Creek Road
		0341915	4265735	2-13-14 2-27-14 3-12-14 3-28-14	At Junction of U.S. Highway 50 and Cabin Creek Road
2	Long Gulch*	0482833	4255294	12-11-13 1-31-14 2-27-14 3-28-14	Junction of Six Mile Lane and Long Gulch Road
		0339762	4262801	12-30-13 1-16-14 2-13-14	0.8 km south of Junction on Six Mile Lane
				2-27-14 mid-day, evening	At Hollenbeck Ranch Muddy Road
				3-12-14 3-28-14 mid-day	At BLM Gate Closure
12	McCabe's*	0324667	4260555	2-13-14 2-27-14 3-12-14 evening	2.0 km south on McCabe's Lane from ranch gate
		0324644	4260943	2-27-14 mid-day 3-28-14	McCabe's cattle guard

APPENDIX B

Common Raven Survey Location Photographs

Site 1: Cabin Creek Reference



Site 2: Long Gulch Reference

Site 3: Landfill

Site 4: Lost Miner Ranch

Site 5: US Highway 50 (MM161-162)

Site 6: Western State Colorado University

Site 7: City Market parking lot

Site 8: Gunnison Residential

Site 9: Gunnison Airport

Site 10: Dos Rios Gold Course

Site 11: Wastewater Treatment Plant

Site 12: McCabe's Lane Reference Site