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Effects of common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success

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ABSTRACT

Predator removal has been simultaneously proposed and criticized as a mitigation measure for low reproductive rates of prey species, including greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse"). Depredation of sage-grouse nests can limit their productivity. In Wyoming, lethal removal of common ravens (*Corvus corax*: hereafter "ravens") and coyotes (*Canis latrans*) has been conducted by USDA/APHIS/Wildlife Services (WS) for the protection of livestock. During 2008–2011, we evaluated sage-grouse nest success in study sites (1) where WS initiated a raven removal program, (2) WS removed coyotes, and (3) WS did not manipulate ravens and/or coyotes. Precipitation and temperature were analyzed individually and as interactive effects with coyote removal numbers as sources of annual variation in nest success. Over the course of our study, raven densities decreased at study sites with WS raven removal, while sage-grouse nest success in those study sites was higher during years with reduced raven density. Temperature effects on nest success were dependent on timing with successful nests having cooler temperatures prior to the nesting season (conditions promoting water retention and grass growth) and warmer temperatures the week before nest fate (conducive to degradation of sage-grouse odorants used by mammalian predators). Lower nest success was associated with more lethally removed coyotes interacting with greater precipitation suggesting mesopredator release. Raven removal may have a place in sage-grouse management as an interim mitigation measure when sage-grouse populations are subjected to high densities of ravens. However, long-term solutions are necessary, such as reducing supplemental food sources and perch structures used by ravens.

1. Introduction

Predator removal has been employed worldwide as a mechanism to increase reproductive rates of upland game species. Unlike other population limiting factors (e.g., habitat, weather, and drought), predation may be reduced by wildlife management agencies (Cote and Sutherland 1997). For example, removal of red fox (*Vulpes vulpes*), carrion crow (*Corvus corone*), and mustelids led to increases in breeding populations of lapwing (*Vanellus vanellus*), golden plover (*Pluvialis apricaria*), and red grouse in northern England (*Lagopus lagopus scotica*; Fletcher et al., 2010). However, predator removal has been connected with increased reproductive success without increase in bird population size for black grouse (*Lyrurus tetrix*) and willow ptarmigan (*Lagopus lagopus*; Parker, 1984) and sandhill cranes (*Grus canadensis*) and Eurasian curlews (*Numenius arquata*; Madden et al., 2015).

Greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") abundance in western North America has declined over the last century (Connelly et al., 2011, Garton et al., 2011, Nielson et al., 2015). Many factors have been attributed to this decline including habitat loss, habitat fragmentation, habitat degradation, and predation (Connelly et al., 2011, USFWS, 2015). However, there are no predators that specialize on sage-grouse during any life history stage (egg, chick, or adult), and Hagen (2011) suggested that in general predation is not limiting sage-grouse population growth. Concurrently, common raven (*Corvus corax*; hereafter "ravens") abundance has increased throughout the historic range of sage-grouse following human development (Andrén, 1992, Boarman et al., 1995, Engel and Young, 1992, Larsen and Dietrich, 1970, Sauer et al., 2011). Raven depredation of sage-grouse nests has been implicated as a potential factor limiting sage-grouse productivity especially in fragmented habitats (Batterson and Morse, 1948, Bui et al., 2010, Coates and Delehanty, 2010, Gregg et al., 1994, Lockyer et al., 2013, Schroeder and Baydack, 2001, Willis et al., 1993). Thus, raven removal may serve to provide a release of nest

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depredation rates in fragmented habitats and areas with human-subsidized raven populations.

Similar to ravens, coyote abundance has been suggested as a limiting factor to sage-grouse productivity (Batterson and Morse, 1948, Willis et al., 1993). Lower sage-grouse productivity after the early-1970s has been anecdotally connected to increased abundance of coyotes throughout the western United States after the 1972 banning of wide spread application of the poison 1080 on federal lands (Executive Order 11,643 and EPA PR Notice 72-2; Heath et al., 1997, Willis et al., 1993). Coyote depredation of sage-grouse nests has been documented with videography and genetic analyses (Lockyer et al., 2013, Orning, 2013). However, coyote abundance has not been associated with unusual depredation rates of sage-grouse nests (Orning, 2013, Slater, 2003).

Lethal removal of coyotes has been associated with changes in predator community abundances and behavior with smaller mammalian predators increasing in abundance and distribution (mesopredator release; Crooks and Soulé, 1999; Prugh et al., 2009). Mesopredator release has been associated with increased negative effects of secondary mammalian predators (e.g., red fox, raccoon [*Procyon lotor*], and striped skunk [*Mephitis mephitis*]) on waterfowl nest success (Greenwood et al., 1995, Mezquida et al., 2006, Prugh et al., 2009, Sovada et al., 1995). Mezquida et al. (2006) suggested that lethal removal of coyotes may induce indirect negative effects on sage-grouse populations, such as mesopredator release, with potential increased depredation of sage-grouse nests by badgers (*Taxidea taxus*), red foxes, and ravens.

In response to raven depredation of livestock, lethal removal of ravens (hereafter "raven removal") was initiated by WS in Carbon, Lincoln, Sweetwater, and Uinta counties in Wyoming, 2007–2011. This provided a unique opportunity to study the potential effects of raven removal on sage-grouse nest success. Thus, we evaluated the change in density of ravens and sage-grouse nest success in areas associated with WS raven removal efforts and areas farther away during 2008–2011. While the focus of our study was to assess the effect of WS removal of ravens on sage-grouse nest success, WS also manipulates coyote populations annually via lethal removal for the benefit of livestock and in some cases wildlife. Thus, we evaluated nest success of sage-grouse in study sites (1) where WS initiated a raven removal program, (2) WS lowered the abundance of coyotes, and (3) WS did not manipulate ravens and/or coyotes.

The foraging ability of olfactory predators should be enhanced by cool wet conditions and reduced by hot dry conditions (Conover, 2007, Gutzwiller, 1990, Ruzicka and Conover, 2012). However, precipitation also increases grass and herbaceous cover, which provide concealment and higher success to sage-grouse nests (Doherty et al., 2014, Holloran et al., 2005). As such, precipitation and temperature effects on nest success of sage-grouse may be contradictory depending on the timing of weather events. As secondary objectives, we conducted post-hoc analyses to evaluate annual variation in nest success of sage-grouse attributed to precipitation and temperature prior to the nesting season, 1-year lags, and the week before nest fate. We also considered interactive effects between precipitation and temperature and coyote removal numbers. We hypothesized that weather conditions promoting grass growth prior to the nesting season would be associated with higher sage-grouse nest success; whereas, interactive effects between weather variables and coyote removal numbers would align lower sage-grouse nest success with weather conditions conductive to predators using olfaction to locate prey.

2. Materials and methods

2.1. Study area

Our study was conducted in southwest and south-central Wyoming to evaluate the response of sage-grouse nest success to raven removal. Eight 16-km diameter study sites were located in southwest Wyoming and approximately centered around leks where hens were captured (Fig. 1); the size of these study sites was based on results found by Holloran and Anderson (2005). In addition, four 24-km diameter study sites were located in south-central Wyoming, because sage-grouse were captured at several nearby leks over a larger area. Five out of 12 study sites were within 15 km of WS raven removal activities (Fig. 1). Study sites within 15 km of WS raven removal were considered 'removal study sites' and those at a distance >15 km were considered 'non-removal study sites'. We adapted the criteria of 15 km (15-km radius equivalent to 706.5 km^2) to define study sites potentially impacted by WS raven removal from reported average home-range sizes of breeding and non-breeding ravens (California 0.3–45.8 km^2 [Linz et al., 1992], Minnesota 27.3–195 km^2 [Bruggers, 1988]) and average daily movements (Mojave Desert 4.5 km [Boarman et al., 1995], Idaho 6.9 km [>95% of movements within 12.5 km; Engel and Young, 1992]). Lethal removal of coyotes was conducted by WS in all of the raven removal study sites and 5 of the 7 non-raven-removal study sites. Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southern Wyoming with a variety of land uses, topographic features, and raven management.

Removal and non-removal study sites had similar topographic features, weather, and vegetation. Elevation ranged from 1950 m to 2600 m among removal study sites and 1925 m to 2550 m among non-removal study sites. Most of the land within all of the study sites was federally owned and administered by the Bureau of Land Management (BLM) with a small percentage of private lands. Domestic sheep and cattle grazing were the dominant land uses in the study sites. Overall annual coyote population reductions were similar between removal (annual range of number coyotes removed = 0.01–0.18 coyotes/km^2) and non-removal (annual range of number coyotes removed = 0.0–0.15 coyotes/km^2) study sites. All study sites had anthropogenic habitat modifications, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, coalbed methane natural gas, and/or conventional oil extraction was present in two of the removal study sites and four of the non-removal study sites.

The dominate vegetation at all study sites was Wyoming big sagebrush (*A. tridentata wyomingensis*), mountain big sagebrush (*A. t. vaseyana*), black sagebrush (*A. nova*), and little sagebrush (*A. arbuscula*). Other common shrub species included alderleaf mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*), common snowberry (*Symphoricarpos albus*), greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* spp.), Saskatoon serviceberry (*Amelanchier alnifolia*), and spiny hopsage (*Grayia spinosa*). Juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were present at the higher elevations in isolated stands.

2.2. Sage-grouse capture and monitoring

During 2008–2011, we monitored sage-grouse hens during the nesting season (late-April to mid-July). Hens were captured, radio-collared, and released in April of each year. We captured hens at night using ATVs, spotlights, and hoop-nets (Connelly et al., 2003, Giesen et al., 1982, Wakkinen et al., 1992). Sage-grouse hens were fitted with 17.5-g or 22-g (<1.5% body mass) necklace radio collars (Holohil Systems Ltd, RI-2D, Ontario, Canada or Advanced Telemetry Systems Inc, A4060, Isanti, MN, USA). We aged sage-grouse hens as yearlings or adults by examining outer primary feathers (Patterson, 1952), which we classified into a binary variable (AGE) designating 0 for adults and 1 for yearlings.

Late April through July 15, we located hens weekly with VHF receivers (Communications Specialists, R-1000, Orange, CA, USA) and 3-way Yagi antennas (Communications Specialists, Orange, CA, USA). The start date of nest monitoring was similar in date and timing after peak sage-grouse lek attendance among study sites and years to generate a relative assessment of nest success. Potential nests were identified with binoculars from >15 m by circling a radio-marked hen until she