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DETECTABILITY AND OCCUPANCY OF THE COMMON RAVEN IN CLIFF HABITAT OF CENTRAL APPALACHIA AND SOUTHEASTERN KENTUCKY

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
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By

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ABSTRACT OF THESIS

DETECTABILITY AND OCCUPANCY OF THE COMMON RAVEN IN CLIFF HABITAT OF CENTRAL APPALACHIA AND SOUTHEASTERN KENTUCKY

Nearly extirpated from the Central Appalachians, USA by the mid-1900s as a result of human persecution, loss of forests, and absence of large mammal carrion, remnant populations of common ravens (*Corvus corax*) have recolonized portions of their historical range. One such area of recolonization is southeastern Kentucky where the species is listed as state threatened. Southeastern Kentucky appears to have extensive suitable breeding habitat, but raven records remain relatively rare with sightings and a few nests being confirmed during the past three decades. Because little is known about local ecology or population status of this reclusive corvid in Kentucky, I assessed distribution and occupancy of ravens in available cliff habitat to quantify factors that affect detectability of ravens, identify landscape attributes important to raven breeding locations at multiple scales, and develop a protocol for monitoring occupancy of potential raven breeding habitats in Kentucky. Based on surveys of 23 cliff sites during 2009–2010, I found that ravens are highly detectable ($p=0.90$ (95% CI = 0.81–0.95)) at known occupied cliff sites, suggesting a survey effort consisting of two visits, each lasting one hour, will enable occupancy to be determined with 95% confidence. Using this and the habitat information associated with occupancy (cliff area and horizontal strata orientation), a monitoring protocol was developed and initiated in 2011 that should be useful to wildlife managers and land stewards interested in long-term monitoring, management, and conservation of common ravens in Kentucky's cliff habitat.

KEYWORDS: Common Raven, *Corvus corax*, Detectability, Occupancy, Recolonization

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Chapter One: Introduction

Distribution and Taxonomy

The family Corvidae (corvids) in the avian order Passeriformes originated from Australasian ancestors and is comprised of 120 species of crows, jays, magpies and their relatives spread among 25 genera (Goodwin 1986, Madge and Burn 1994, Sibley and Ahlquist 1990, Ericson et al. 2002, Ericson et al. 2005). *Corvus* is the most prolific of the Corvidae genera with 44 species of crows, ravens, jackdaws, and rooks (dos Anjos et al. 2009). *Corvus* species are characterized by their predominately black plumage, stout bills and feet, rictal bristles covering their nostrils, large brains with corresponding intelligence, extensive vocal repertoire, and a bold and gregarious nature (Elphick et al. 2001, Marzluff and Angell 2005).

Colonization of North America by ravens and crows occurred via the Bering Land Bridge over two million years ago (Emslie 1998, Omland et al. 2000, Marzluff and Angel 2005). The common raven (*Corvus corax*) apparently made this colonization twice as Omland et al. (2000) determined that a genetic break occurred during the last ice age, thereby splitting the species into two clades: the original Holarctic Clade and the geographically isolated California Clade. The California Clade gave rise to a new species, the Chihuahuan raven (*Corvus cryptoleucus*), prior to the recolonization of the Holarctic Clade and the subsequent remerging of the two lineages (Omland et al. 2000, Marzluff and Angel 2005, Webb et al. 2011).

Currently, the common raven is among the most widespread naturally distributed birds in the world with populations ranging throughout much of North America, Europe, Asia, and northern Africa (Boarman and Heinrich 1999, Marzluff and Angell 2005). The species is divided into 10 subspecies occupying a variety of habitats including forests, mountains, shrublands, coastal areas, deserts, tundras, grasslands, agricultural areas, and urban areas (Ratcliffe 1997, Boarman and Heinrich 1999, Marzluff and Angell 2005). Four of these subspecies reside in North America including the lone member of the California Clade: *C. c. clarionensis* – found in extreme southwestern North America to northwestern Mexico (Rea 1986, Boarman and Heinrich 1999) and members of the Holarctic Clade: *C. c. kamtschaticus* – northeast Asia to Aleutian Islands and Alaska Peninsula, *C. c. principalis* – northern and eastern North America including the Appalachian Mountains, *C. c. sinautus* – western North America excluding California to south central North America to Mexico and Central America. *C. c. principalis* is the largest race found in the continental United States and is the focus of this study (Willett 1941).

The common raven is the largest of the all-black corvids in the world (Goodwin 1986), with weights reaching over 1.5 kg and wingspans over 1.4 m (Boarman and Heinrich 1999, Marzluff and Angell 2005). The common raven's size, wedge-shaped tail, throat hackles, and prominent bill help to differentiate it from North American relatives: the American crow (*Corvus brachyrhychos*) (Figure 1.1), Northwestern crow (*Corvus caurinus*), and fish crow (*Corvus ossifragus*) (Boarman and Heinrich 1999, Elphick et al. 2001, Marzluff and Angell 2005). The soaring ability and hoarser and more varied vocalizations of the common raven also sets it apart from its smaller cousins (Boarman and Heinrich 1999, Elphick et al. 2001, Marzluff and Angell 2005). The distinctive whitish base of the neck feathers and typically longer rictal bristles of the nearly identical

Chihuahuan raven are the most visually discerning features separating it from the common raven (Boarman and Heinrich 1999, Elphick et al. 2001).

Ecological Importance

Ecologically, the common raven is an omnivorous scavenger (Harlow 1922, Bent 1946, Murray 1949) and predator (Tyrrell 1945, Knight and Call 1980). Ravens provide breeding habitat to other species via construction of nesting platforms that birds such as raptors frequently use (Bowles and Decker 1930, Decker 1931, Jones 1935, Ratcliffe 1962, Ratcliffe 1997). Sergio et al. 2004 found that nesting common ravens prove important to the breeding-site selection of peregrine falcons (*Falco peregrinus*) in the Italian Alps as ravens may offer early alerts against potential predators and act as indicators of breeding habitat quality. Their presence and behavior is often used by other scavengers and predators to indicate food availability or threats (Knight and Call 1980, Heinrich 1999, Snyder and Snyder 2005). Ravens also help to control populations of certain rodents (Knight and Call 1980). Knight and Call (1980) effectively summarized this ecological importance.

Cultural Importance

Ravens have long been associated with humans of the northern hemisphere and are important to many cultures (Sprunt 1956, Ratcliffe 1997, Boarman and Heinrich 1999, Marzluff and Angell 2005). In Tibetan funeral rituals, ravens and other scavengers were considered carriers of the dead into the afterlife (Marzluff and Angell 2005). Nordic religion held the raven as its sacred bird because it was the shoulder companion and messenger to the god Odin (Ratcliffe 1997, Heinrich 1999, Marzluff and Angell 2005).

The raven is also notably entrenched in spiritual beliefs and culture of many indigenous tribes, particularly those of North America's Pacific Northwest, where it is considered a creator and trickster (Ratcliffe 1997, Boarman and Heinrich 1999, Marzluff and Angell 2005). Superstition throughout the ages has marked the raven as a conveyer of omens, both good and bad, depending on the situation and the people (Ratcliffe 1997). The presence of ravens on a hunting expedition was usually viewed as an omen of good luck and success, while battles and disease, which often attracted these corvids, made ravens a symbol of ominous death and "prophets of doom and gloom" (Sprunt 1956, Heinrich 1999, Marzluff and Angell 2005). Common ravens have served as inspiration for European and American literature and art in works by such authors as Edgar Allen Poe, Wilhelm Busch, and Aesop (Boarman and Heinrich 1999, Marzluff and Angell 2005). Ravens have even infiltrated our language with terms such as "ravenous" and "raving" as well as served as a derivation of many place names throughout their extensive range (Cox and Larkin 2004, Marzluff and Angell 2005). Despite being viewed as evil or economically destructive (Sprunt 1956), the raven continues to enthrall people to this day with its intelligence, splendor, and fascinating behavior (Knight and Call 1980).

Diet

Common ravens are opportunistic omnivorous generalists (Tyrell 1945, Ratcliffe 1962, Harlow et al. 1975, Boarman and Heinrich 1999) that consume a diversity of food items including insects, arthropods, mollusks, fish, amphibians, reptiles, birds, mammals, carrion, seeds, grains, buds, fruit, other vegetative matter, and refuse (Ratcliffe 1962, Harlow et al. 1975, Heinrich 1999, Boarman and Heinrich 1999). Refuse disposal sites, garbage dumps, and roadways represent further anthropogenic food sources often frequented by ravens near developed areas (Bent 1946, Dorn 1972, Harlow et al. 1975, Conner and Adkisson 1976, Kristan et al. 2004). Ravens forage most frequently on the ground and in trees, but ravens will occasionally prey on birds and flying insects while in flight (Boarman and Heinrich 1999). In southwestern Virginia, Harlow et al. (1975) found mammalian items to be the most prolific dietary component during all seasons, with avian prey, including eggs and young, becoming more prevalent in spring and summer. Similarly, in southeastern Oregon, mammals comprised the majority of raven diets while birds and their offspring came in a close second (Stiehl and Trautwein 1991). In other areas, like southwestern Idaho, agricultural grains appear to be the most prolific component of the diet (Engel and Young 1989). Carrion plays a major role in their diet (Ratcliffe 1962, Dorn 1972), especially during the winter months (Bent 1946); however, ravens are dependent on large predators and other scavengers to open carcasses as they are unable to do so themselves (Boarman and Heinrich 1999). This reliance has been clearly shown by ravens' preferential association with wolves (Harrington 1978, Stahler et al. 2002). Heinrich (1999) stated that human hunters have taken on the role of the primary predator in many areas supplying ravens with large animal carrion. In Wyoming, hunters' gunshots attract ravens looking for food, thus signifying a similar relationship to ravens' attraction to wolf howling (White 2005).

Nest Site Selection and Breeding

Common ravens nest in and on a variety of substrates including cliffs, both natural (Harlow 1922, Jones 1935, Tyrell 1945, Murray 1949, Ratcliffe 1962, White and Cade 1971, Hooper et al. 1975, Hooper 1977) and man-made (Ratcliffe 1997, Trently 1999, Larkin et al. 1999, Cox et al. 2003), trees (Harlow 1922, Hooper et al. 1975, Hooper 1977, Dunk et al. 1994), windmills (Stiehl 1985), abandoned and occupied buildings (Bowles and Decker 1930, Stiehl 1985, Heinrich 1999, Johnson and Rodenhouse 2013, P. Dickinson pers. comm.), overpasses and billboards (White and Tanner-White 1988, B. Lamadue pers. comm.), train trestles (Bowles and Decker 1930, Shedd and Shedd 2004), bridges (White and Tanner-White 1988), utility poles and electrical transmission line towers (Bowles and Decker 1930, Knight and Kawashima 1993, Steenhof et al. 1993, Howe et al. 2014), and even sports stadiums (Heinrich 1999). The majority of observed nests in the Appalachian region are situated on cliffs (Harlow 1922, Hooper et al. 1975, Hooper 1977), with Hooper (1977) documenting a 17:1 cliff to tree nest ratio in Virginia, a finding similar to the 8:1 cliff:tree nest ratio in Pennsylvania (Harlow 1922). Harlow (1922) stated that breeding pairs use the same substrate year after year irrespective of its level of availability compared to other substrates.

Hooper (1977) concluded that two factors, cliff profile and proximity to other active raven nests, were linked with cliffs chosen as nest sites. The most important cliff profile characteristics are a suitable ledge with an associated overhang and a precipitous rock face below (Harlow 1922, Jones 1935, Murray 1949, Ratcliffe 1962, White and Cade 1971, Conner et al. 1976, Hooper 1977). Overhangs are beneficial to the birds due to their early nesting, providing protection from winter weather conditions (Harlow 1922, Ratcliffe 1962, Knight and Call 1980). Steep rock faces serve as deterrence to potential land predators (Hooper 1977).

Tree nests in the eastern United States are usually situated in a crotch of the tree near the top protected by good canopy cover (Harlow 1922, Boarman and Heinrich 1999). Harlow (1922) stated that trees used for nesting were often among the tallest in the area. Coniferous trees seem to be preferred to deciduous in the east (Tyrell 1945). Hooper (1977) noted three tree nests in Virginia, one in a Virginia pine (*Pinus virginanus*) and two in shortleaf pines (*Pinus echinata*). Ravens in Pennsylvania tended to choose remote mountain swamps which still held some large white pines and hemlocks (Harlow 1922). Ravens in the northeast also often use pine trees as nest sites (Heinrich 1999).

Proximity of active nests has varied across studies. In England, Ratcliffe (1962) reported the average minimum distance between nests to be 2.7 km. Spacing between active nests tends to be less in areas with abundant nesting substrate and greater in areas with limited nesting structures (Dorn 1972, Steenhof et al. 1993, Boarman and Heinrich 1999). In nearby Wales, Dare (1986) gave a slightly lower distance of 2 km in mixed agricultural and deciduous woodland habitat. Dunk et al. (1994) observed a mean nearest distance between occupied tree nests of 1.6 km in Wyoming and Hooper et al. (1975) reported a mean distance of 4.8 km in Virginia, less than half the distance of 9.7 km found by Harlow (1922) in Pennsylvania.

Occupied cliff breeding sites show considerable variation in height, proximity to human habitation, and predominant aspect. In England, Ratcliffe (1962) characterized suitable inland nesting cliffs as between 245 m and 610 m above sea level, ≥30 m tall in rugged country and >10 m tall in moorland, and situated at least 0.8 km from the nearest human development unless the cliff in question is on the taller, steeper end of the spectrum. In Virginia, Hooper (1977) reported nesting elevations of 305-1035 m and occupied cliff heights of 4.5-35 m with an average height of 18 m. Murray (1949) noted active nest cliffs from 22.9-30.5 m tall. Nests at lower elevations and closer to human habitation were associated with increased productivity (Hooper 1977, Kristan et al.

2004). The predominant aspect of cliff nests in England ranged between north and east (Ratcliffe 1962) while those in Virginia faced northeast to southwest (Hooper 1977). Boarman and Heinrich (1999) stated that ravens tend to avoid easterly aspects.

Ravens show high site fidelity and nest cliffs are regularly used for many years (Harlow 1922, Murray 1949, Conner 1986). In Utah, some nesting sites were thought to have been occupied for over 40 years (White and Cade 1971, Dorn 1972). In Virginia, breeding sites have been documented as being active every year for up to 14 years (Jones 1935, Murray 1949); however, ravens often employ alternate nesting cliffs (Ratcliffe 1962, Hooper et al. 1975, Hooper 1977, Boarman and Heinrich 1999). Ratcliffe (1962) found that two or three alternate nesting cliffs were typically used by individual breeding pairs, and up to six were observed, although one site was usually preferred over the others. The distance between the alternate nesting sites was rarely more than 4.8 km (Ratcliffe 1962). Hooper et al. (1975) reported that some pairs nest 3.2 km apart in successive years, but most birds choose alternate nests within 0.5 km. At times, breeding pairs will switch back and forth between the sites each year (Boarman and Heinrich 1999). The same nest may be reused for several years (Harlow 1922, Ratcliffe 1962, Stiehl 1978), or a new nest may be constructed on the same cliff as the year before (Harlow 1922, Fowler et al. 1985, Cox et al. 2003).

In the mid-Atlantic region of the United States, nest building or repair is usually initiated in early February (Hooper et al. 1975), but start dates may vary (Conner 1986). Timing varies with latitude (Harlow 1922, Knight and Call 1980) and intensity of the winter season (Dunk et al. 1997, Boarman and Heinrich 1999), with delayed nest building farther to the north and during harsh winters. Early stages consist of sticks followed by a layer of soil, then as the nest approaches completion, lining materials such as dry grasses, shredded bark, mammal fur, and man-made products such as lint, stuffing material, and insulation may be added (Harlow 1922, Dorn 1972, Stiehl 1978, Boarman and Heinrich 1999). The nest is constructed primarily by the female (Harlow 1922, Bowles and Decker 1930, Boarman and Heinrich 1999); however, the male may assist by carrying materials to the nest site (Harlow 1922, Jones 1935, Stiehl 1985); nest building usually takes between 10 and 20 days until completion (Harlow 1922, Dorn 1972, Conner 1986).

Ravens typically begin egg-laying within a week of the conclusion of nest construction (Harlow 1922, Dorn 1972). Increased attendance and copulation by the breeding pair occurs just prior to the first egg being laid (Boarman and Heinrich 1999). Eggs are usually laid daily (Harlow 1922, Bowles and Decker 1930, Stiehl 1985, Ratcliffe 1997), with clutches in the central Appalachians reaching completion in early March (Tyrell 1945, Hooper 1977, Williams 1980, Palmer-Ball 1996, Trently 1999). Clutch sizes usually range from 3-7 eggs (Goodwin 1986, Dunk et al. 1997, Boarman and Heinrich 1999), with 4-5 typically occurring (Harlow 1922, Dunk et al. 1997). The female primarily incubates the egg (Harlow 1922, Bowles and Decker 1930, Stiehl 1985, Ratcliffe 1997, Heinrich 1999), but exceptions have been noted (Tyrell 1945, Conner et al. 1976). During the incubation stage, the male spends most of his time provisioning food to his mate, acting as a sentinel, and engaging in nest defense when encroachment is made by other individual ravens, raptors, and other nest predators (Harlow 1922, Stiehl 1985, Ratcliffe 1997, Boarman and Heinrich 1999). The female assists in nest defense and during incubation bouts takes short flight breaks usually under 10 minutes a few times a day (Stiehl 1985, Ratcliffe 1997, Boarman and Heinrich 1999) resulting in asynchronous hatching (Dorn 1972, Hooper et al. 1975, Conner et al. 1976, Ratcliffe 1997). Incubation, which lasts around 21 days (Harlow 1922, Tyrell 1945, Dorn 1972, Conner et al. 1976, Stiehl 1978, Stiehl 1985, Heinrich 1999), begins before the clutch is complete.

Twenty-four hours or less typically separates the hatching of each egg in the order that they were laid (Dorn 1972). Stiehl (1978, 1985) found that one egg regularly tends to be infertile, thus creating smaller brood sizes than clutch sizes. Brooding of young is done constantly by the female after hatching and tapers off as the chicks get older (Dorn 1972, Kochert et al. 1977, Williams 1980, Heinrich 1999). The male takes on most of the feeding duties during the first couple of weeks with the female increasingly sharing that responsibility once brooding becomes less of a necessity (Ratcliffe 1997, Heinrich 1999). Dorn (1972) found that diurnal brooding came to a halt by the time the chicks were 25-28 days old, while Ratcliffe (1997) reported that brooding stops at around 18 days. Boarman and Heinrich (1999) state that adults eat the feces of week-old nestlings and carry away the fecal sacs of chicks that are about 2-3 weeks old, with older chicks capable of defecating more fluid feces over the edge of the nest. Young are fully feathered by week five and become increasingly more active, often flapping wings at the edge of the nest or on the nest ledge, resulting in the breakdown of the nest itself (Dorn 1972, Ratcliffe 1997, Boarman and Heinrich 1999). Reported age at fledging varies from four (Harlow 1922) to seven weeks (Conner et al. 1976), but most broods leave the nest at about six weeks old (Dorn 1972, Stiehl 1985, Heinrich 1999). Ratcliffe (1997) notes that due to asynchronous hatching and the consequent dissimilarities in development, a period of a few days may elapse between the first and last sibling's nest departure. Hooper et al. (1975) found that most fledging in southwest Virginia occurs in late April and early May. The family group remains near the nest site for one or more weeks before gradually leaving the area as the fledglings become more capable of flight (Harlow 1922, Dorn 1972, Conner et al. 1976, Kochert et al. 1977, Ratcliffe 1997). Fledglings may stay with their parents for over a month or more as they become more adept at caring for themselves (Dorn 1972, Ratcliffe 1997, Heinrich 1999). Upon leaving their parents, fledglings that survive become part of the "floater" population (Heinrich 1999) and often make use of communal roosts and feeding crowds consisting of fellow juveniles and non-breeders (Dorn 1972, Ratcliffe 1997). The adults return to their nesting territory (Ratcliffe 1997).

The Common Raven in Kentucky and the Central Appalachians

The raven appears to have been widespread throughout Kentucky during early European settlement with verifiable observations in Fulton, Carroll, and Bell Counties (Mengel 1965). However, the raven was probably most common in the eastern portions of the state characterized by the rugged Pine, Cumberland, and Black Mountains, and the Cliff Section of the Cumberland Plateau (Mengel 1965, Palmer-Ball 1996, Cox and Larkin 2004). Mengel (1949) reported that local residents described what appeared to be breeding pairs and nesting activity of ravens in cliff areas of Laurel, Pulaski, Powell, McCreary, and Wayne counties during the early 1900's. However, Mengel (1949) found it peculiar that Howell (1910) and Stone (1921) failed to note even a single raven during their respective forays in Kentucky's highest elevation areas on Black and Pine Mountains.

The common raven population declined and was nearly extirpated in the eastern U.S. by the mid-1900's (Mengel 1965, Hooper et al. 1975), as a result of human persecution (Harlow 1922, Sprunt 1956), forest loss (Harlow 1922, Jones 1935), and the likely absence of large mammal carrion and large predators to open carcasses (Cox et al. 2003). Mengel (1949) listed 1935 as a tentative date for extirpation of ravens in Kentucky with a small population possibly persisting up until that time in Powell County. Population declines occurred in neighboring states as well, with assumed extirpation in Ohio (Peterjohn 2001) and Alabama (Imhof 1962) around 1905 and 1915, respectively (Ganier and Clebsch 1944, Sprunt and Chamberlain 1949, Burleigh 1958). The raven, like many other species in the eastern U.S., including the black bear (*Ursus americanus*), was greatly reduced in number and range, becoming largely restricted to high elevation strongholds in the most remote rugged reaches of the Appalachians at the species lowest distribution (Cox and Larkin 2004).

The raven has recently recolonized portions of its historic range including southeastern Kentucky where sightings and a handful of nests have been observed during the past three and a half decades. The first documented raven observation since 1935 was of three individuals in the mountainous regions of southeastern Kentucky in the summer of 1969 (Croft 1970). More sightings followed, becoming more plentiful at the turn of the century with observations in Bell (Smith and Davis 1979, Davis et al. 1980, Stamm 1989), Harlan (Smith and Davis 1979, Stamm 1981, Hall 1982, Stamm 1989), Letcher (Fowler et al. 1985, KDFWR 2004), Pike (Heilbrun 1983), Floyd (Palmer-Ball and McNeely 2004), Johnson (KDFWR 2004), Knott (Palmer-Ball 1996, Larkin et al. 1999, KDFWR 2004), Breathitt (Lacki and Baker 1998), Morgan (Palmer-Ball and McNeely 2004), and Powell counties (Stamm 1989, Palmer-Ball 1996).

Twelve years after the observation made by Croft (1970), an active nest was recorded on a large sandstone cliff at Bad Branch State Nature Preserve in Letcher County (Fowler et al. 1985). This site has been active ever since. In March 1998, Larkin et al. (1999) observed a pair of ravens carrying nesting material towards a strip mine highwall at Cypress Amax Wildlife Management Area in Knott County. The nesting attempt was deemed unsuccessful as the highwall was subsequently demolished by ongoing mining and reclamation. The following year, Larkin et al. (1999) witnessed a pair of adults feeding two fledglings on another highwall at Cypress Amax WMA, but it was destroyed by reclamation early the next year (Cox et al. 2003). Cox et al. (2003) reported what they thought to be the same breeding pair of ravens nesting in approximately the same location in 2001 and 2002 on a highwall 4 km northwest of the Cypress Amax nest in Breathitt County. Another raven nest site was discovered on the ledge of a cliff along the water at Paintsville Lake WMA in Morgan County in 2004 (Palmer-Ball and McNeely 2004), which has remained occupied since that time (R. Hamilton pers. comm., S. Friedhof pers. comm.). An assumed breeding pair was observed at a nest site at Rebel Rock in Harlan County in early March 2006 (Palmer-Ball and McNeely 2006). Observations of territorial ravens have persisted in the general locality for the past several years (B. Begley pers. comm.). These breeding locations stand as the only documented nests at the beginning of my study in 2009.

The recolonization of ravens throughout Kentucky and other parts of the eastern U. S. has been attributed to the regions' shift away from an agrarian society and the resultant reclamation and maturation of forests, raven behavioral adaptations to anthropogenic environments, and a resurgence of large herbivore populations that have supplied more carrion through vehicle collisions and hunting (Buckelew and Hall 1994, Boarman and Heinrich 1999, Cox et al. 2003). The Commonwealth appears to have extensive suitable breeding habitat but Kentucky's ravens have remained relatively rare and unstudied, thus little is known about the local ecology or population status of this often reclusive corvid (Palmer-Ball 1996, Cox and Larkin 2004). Currently, the common raven is of conservation interest in Kentucky and is listed as state threatened and as a Species of Greatest Conservation Need in Kentucky's State Wildlife Action Plan (Kentucky's Comprehensive Wildlife Conservation Strategy 2013).

Detection Probability

Sampling and long-term monitoring of rare and elusive species is a continuing challenge for wildlife managers tasked with maintaining species viability. Presence-absence information has usually assumed perfect detection of a species when it is present in an area, resulting in a negative bias in the estimation of a species' presence (Vojta 2005). MacKenzie (2005) emphasized that "the imperfect detection of a species seriously impedes our ability to make reliable, informed management decisions." For example, a species may be falsely declared absent from an area as a result of a survey effort failing to detect the species when in fact, the species is actually present (MacKenzie 2005).

Vojta (2005) reviewed the history of presence –absence studies and the incorporation of detection probabilities to estimate occupancy of a species. Detection probabilities can be estimated from repeated surveys of the same sites and can reduce bias in estimates of a species' presence (Geissler and Fuller 1987). Azuma et al. (1990)

used repeated site visits to estimate the number of visits needed to obtain the first detection of their target species, the northern spotted owl. They described repeated site visits as a series of independent Bernoulli trials where presence (1) and absence (0) were noted. The outcome of these trials could be used to estimate the proportion of sites occupied by a species while adjusting for imperfect detection.

Numerous investigations have been conducted using detection probabilities since the inception of the idea. Examples include recent occupancy surveys of forest owls and arboreal marsupials in south-eastern Australia (Wintle et al. 2005), golden-cheeked warblers (*Setophaga chrysoparia*) in central Texas (Watson et al. 2008), golden-winged warblers (*Vermivora chrysoptera*) in West Virginia (Aldinger and Wood 2015), Palm Springs ground squirrels (*Spermophilus tereticaudus chlorus*) in southern California (Ball et al. 2005), European tree frogs (*Hyla arborea*) and natterjack toads (*Epidalea calamita*) in western Switzerland (Schmidt and Pellet 2005), swift foxes (*Vulpes velox*) in eastern Colorado (Finley et al. 2005), aquatic snakes in Georgia (Durso et al. 2011), and three snake species in Europe (Kèry 2002). Kèry (2002) states that detection probability information can be used to evaluate a monitoring program’s efficacy, cost effectiveness, and value in development of more effective protocols. Using detection probability to account for imperfect detection, wildlife managers have become more capable and confident of making better informed management decisions using species occupancy data.

Study Objectives

The objectives of this project are fourfold. First, I quantified factors affecting the detectability of the common raven in cliff habitat by determining the intensity and duration of survey visits at occupied raven nests required to detect these species with a high level of confidence. Second, I quantified landscape attributes of raven breeding locations at multiple spatial scales by collecting habitat data at both occupied and unoccupied sites. Third, I developed and initiated protocols for monitoring the occupancy of key potential breeding habitats in Kentucky by using the information we gathered from the first two objectives. This protocol should prove useful to wildlife managers and land stewards interested in long-term monitoring, management, and conservation of the species in cliff habitat. Finally, I located previously undocumented raven breeding pairs and nests within the Commonwealth through our protocol initiation and communication with birders, naturalists, and local residents.

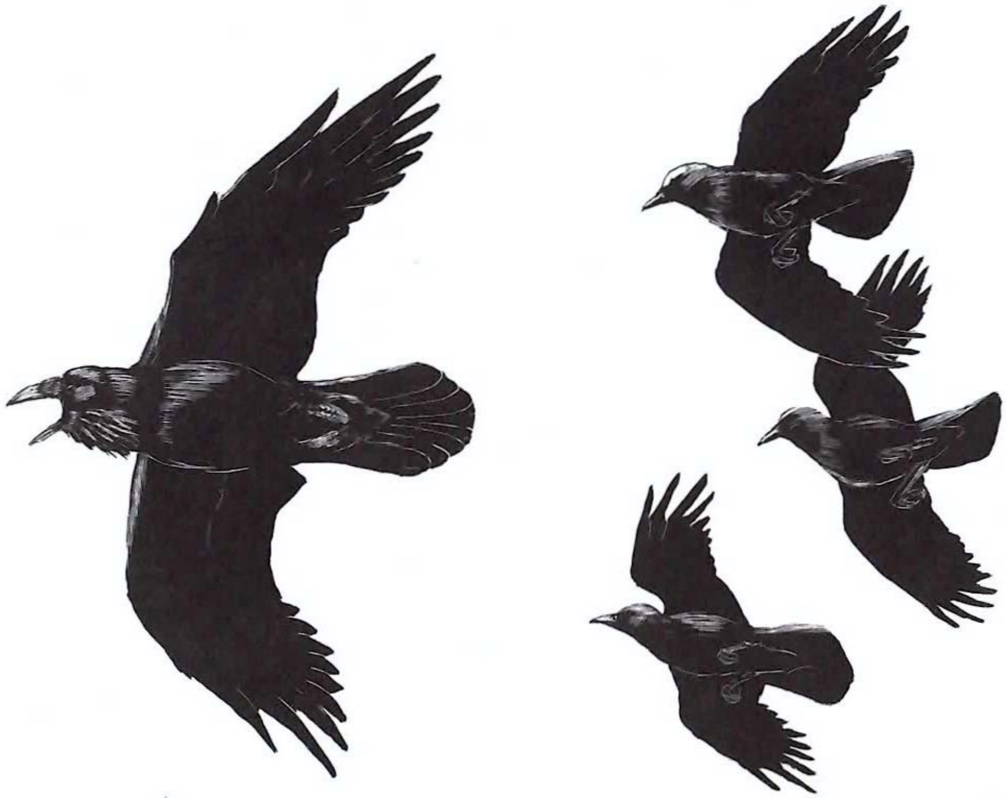

Figure 1.1. Common raven (left) and American crows (Marzluff and Angell 2005, illustration by Tony Angell).

Chapter Two: Detectability and Occupancy of the Common Raven (*Corvus corax*) in Cliff Habitat of Central Appalachia and Southeastern Kentucky

Abstract

Nearly extirpated from the Central Appalachians, USA, by the mid-1900s as a result of human persecution, loss of forests, and absence of large mammal carrion, remnant populations of common ravens (*Corvus corax*) recolonized portions of their historical range. One such area of recolonization is southeastern Kentucky where the species is listed as state threatened. Southeastern Kentucky appears to have extensive suitable breeding habitat, but raven records remain relatively rare with sightings and a few nests being confirmed during the past three decades. Because little is known about local ecology or population status of this reclusive corvid in Kentucky, I assessed distribution and occupancy of ravens in available cliff habitat to quantify factors that affect detectability of ravens, identify landscape attributes important to raven breeding locations at multiple scales, and develop a protocol for monitoring occupancy of potential raven breeding habitats in Kentucky. Based on surveys of 23 cliff sites during 2009–2010, I found that ravens are highly detectable ($p=0.90$ (95% CI = 0.81–0.95)) at known occupied cliff sites, suggesting a survey effort consisting of two visits, each lasting one hour, will enable occupancy to be determined with 95% confidence. Using this and the habitat information associated with occupancy (cliff area and horizontal strata orientation), a monitoring protocol was developed and initiated in 2011 that should be useful to wildlife managers and land stewards interested in long-term monitoring, management, and conservation of common ravens in Kentucky's cliff habitat.

Introduction

Cliff-nesting common ravens (*Corvus corax*) were widespread throughout the Central Appalachian region during early European settlement, including Kentucky, USA, with verifiable observations in Fulton, Carroll, and Bell Counties (Mengel 1965). However, the raven was probably most common in the eastern portions of the state characterized by the rugged Pine, Cumberland, and Black Mountains, as well as the Cliff Section of the Cumberland Plateau (Mengel 1965, Palmer-Ball 1996, Cox and Larkin 2004). As settlement increased throughout the eastern U.S., the common raven population declined and the species was nearly extirpated in this region by the mid 1900's (Mengel 1965, Hooper et al. 1975, Palmer-Ball 1996). Mengel (1949) listed 1935 as a tentative date for extirpation of ravens in Kentucky with a small population possibly persisting up until that time in Powell County. Population declines occurred in neighboring states as well, with assumed extirpation in Ohio (Peterjohn 2001) and Alabama (Imhof 1962) around 1905 and 1915, respectively (Ganier and Clebsch 1944, Sprunt and Chamberlain 1949, Burleigh 1958). Persecution by humans (Harlow 1922, Sprunt 1956), loss of forest habitat due to timber harvest and agricultural needs (Harlow 1922, Jones 1935, Palmer-Ball 1996), and likely absence of large mammal carrion have been attributed as the main factors leading to extirpation (Cox et al. 2003). Remnant raven populations appear to have been largely restricted to high elevation strongholds in the most remote rugged reaches of the Central Appalachian region (Cox and Larkin 2004).

Beginning in the mid-1900s, ravens began to increase in number and recolonize portions of their former range in Central Appalachia, including southeastern Kentucky, where sightings and a handful of nests have been observed during the past three decades (Croft 1970, Smith and Davis 1979, Davis et al. 1980, Stamm 1981, Heilbrun et al. 1983, Fowler et al. 1985, Lacki and Baker 1998, Larkin et al. 1999, Cox et al. 2003, Palmer-Ball and McNeely 2004, Palmer-Ball and McNeely 2006). Raven recovery has been credited to the regions' reduction in agriculture and logging, subsequent increase in forest cover and forest stand age, raven behavioral adaptations to anthropogenic environments, and a resurgence of large herbivore populations that have supplied more carrion through vehicle collisions and hunting (Buckelew and Hall 1994, Boarman and Heinrich 1999, Cox et al. 2003). Common ravens are currently listed as threatened in Kentucky and a Species of Greatest Conservation Need (Kentucky's Comprehensive Wildlife Conservation Strategy 2013).

The Commonwealth appears to have extensive suitable breeding habitat, but Kentucky's ravens have remained relatively rare and unstudied, thus little is known about the local ecology or population status of this often reclusive corvid (Palmer-Ball 1996, Cox and Larkin 2004). First, information on factors that affect our ability to detect ravens at cliff breeding sites does not exist, so reliably inferring presence/absence in an area is difficult. Second, further knowledge on raven nest site habitat attributes in the Central Appalachians is needed for future presence/absence surveys in Kentucky. Third, very little information is available on current locations and numbers of raven breeding pairs in Kentucky. Finally, a long-term monitoring program targeting historic habitats and breeding sites does not currently exist making the status of ravens within the state uncertain. Development of such a monitoring protocol should be useful to wildlife managers and land stewards interested in long-term monitoring, management, and conservation of common ravens in Kentucky's cliff habitat.

The objectives of my study were to: (1) quantify factors that affect detectability of ravens in Kentucky cliff habitat; (2) identify landscape attributes important to raven breeding locations at multiple spatial scales; and (3) develop a protocol for monitoring occupancy of potential raven breeding habitats in Kentucky.

Field-Site Description

The Central Appalachian region where the study was implemented is comprised of three main ecoregions: Central Appalachians, Central Appalachian Ridges and Valleys, and Blue Ridge Mountains (Omernik 1987). Collectively, the three ecoregions are comprised of mainly linear, hydrologically-dissected plateaus, and ridges with low valleys that are oriented in a northeast to southwest trajectory (Woods et al. 1996). The Central Appalachians ecoregion is the largest of the three at 59,800 km^2 and covers a wide swath of primarily forested land from south central Pennsylvania to northern Tennessee with Kentucky and Virginia on the western and eastern ends (Sayler 2016). The Ridge and Valley ecoregion is situated between the more western Central Appalachians and the more eastern Blue Ridge Mountains and contains a greater proportion of wider valleys and agricultural lands between its parallel ridges (Friesen and Stier 2016). Public lands comprise a greater extent of the Blue Ridge Mountain ecoregion (approximately one third) than the other two ecoregions creating intact sections of forest with an intermittent mosaic of agriculture and development (Taylor and Kurtz 2016). The Central Appalachians' rugged topography and geological composition tend to limit agricultural cropland use, but large scale surface mining operations for coal and to a lesser extent limestone, combined with ongoing logging in the region, continue to fragment the historically dense forested landscape (Woods et al. 1996, Saylor 2016).

The majority of the study was conducted in four states within the Central Appalachians (Kentucky, West Virginia, and Virginia) and Central Appalachians Ridges and Valleys (North Carolina and Virginia) ecoregions, but a few detectability surveys were performed within the Blue Ridge Mountains of Virginia. Raven monitoring surveys were conducted in southeastern Kentucky in and near Cumberland Gap National Historical Park, Shillalah Creek Wildlife Management Area, Martin's Fork State Natural Area, Cranks Creek Wildlife Management Area, Stone Mountain State Natural Area, Kentennia State Forest, Pine Mountain Trail State Park and Nature Preserve, Hi Lewis Pine Barrens State Nature Preserve, Kingdom Come State Park and Nature Preserve, Hensley-Pine Mountain Wildlife Management Area, Bad Branch State Nature Preserve, and Jefferson National Forest.

Methods and Materials

Detectability

I identified known raven breeding locations on natural cliffs in Kentucky and the neighboring Central Appalachian states of North Carolina, Virginia, and West Virginia through coordination with biologists, naturalists, birders, and others throughout the region. A subset of known nest sites were visited based on accessibility to a suitable observation point, travel time, and whether or not the site was occupied during the present year. At each of the chosen occupied sites (n=23; 1 in NC, 2 in KY, 4 in WV, 16 in VA), an observation point was selected in a location that enabled visual survey of as large of a portion of the cliff as possible (Figure 2.1). For some surveys, the observation point was located on top of the cliff being surveyed because of available view and accessibility. Auditory and visual surveys with binoculars and spotting scope were conducted three times within the same year at each site during the 2009-2010 breeding seasons (late January-early May) until first detection, or until occupied detection or two hours had elapsed. First detection was defined as first sight or sound of a raven in the survey area, and occupied detection was defined as detection of a pair or of a single individual exhibiting territorial or breeding behavior (*e.g.,* territorial calls, territorial chases, pair flights, carrying nesting material, three or more visits to the same cliff site, *etc*.; Boarman and Henrich 1999). Environmental, temporal, and climatic factors thought to affect detectability of raven occupancy were recorded (e.g., time-of-day, sky conditions, predominant aspect, wind speed (Beaufort scale), percent cloud cover (rough estimate), precipitation, temperature, percent forest cover (GIS), and distance of observation point from site) and defined as a small set of models likely explaining detection probability (Bernatas and Nelson 2004). Times and distance at first detection were recorded for each detection category. To minimize variation in detection probability due to time of day, surveys were only conducted between 0600 and solar noon during the breeding season and were not conducted during times of inclement weather (i.e. high winds, fog, snow other than light flurries, and rain greater than a very light drizzle). Detection probabilities for half hour time intervals up to a maximum of two hours were estimated using logistic regression in SAS 9.4 (SAS Institute Incorporated 2013).

Breeding Habitat

For each known occupied cliff site, an equal number of unoccupied cliff sites (n=26; 20 in KY and 6 in VA) were chosen from the sites that were visited during 2009–

2010 to provide the basis for a site-attribute model to characterize breeding habitat in eastern Kentucky (Flesch 2003, Dzialak et al. 2007). Data for habitat characteristics associated with local cliff physiography (e.g., cliff length, cliff height, degree of occlusion, cliff area, orientation of strata, degree of access, predominant aspect) were collected in the field following the methods used by Watts (2006), and additional landscape data (e.g., proximity to roads, proximity to human habitation, elevation) were obtained using ArcGIS 10.1 (ESRI 2012).

Binomial logistic regression via maximum likelihood was implemented in the statistical software R (R Core Team 2017) to compare habitat variables between occupied and unoccupied cliff sites. Given the small sample size for occupied cliff sites, overfitting the data was a concern; therefore, I first conducted simple logistic regression in which a model was constructed for each predictor variable. Akaike's Information Criterion corrected for small sample size (AIC_c) was used to compare variable-specific models (Burnham et al. 2011), and only variables in which their respective model had an AIC_c value lower than that of the null model were retained. I then performed multiple logistic regression in which models were constructed that included all possible additive combinations of those variables to identify the habitat and landscape characteristics most important to raven breeding site selection. The multiple logistic regression model with the lowest AIC_c value was considered the most influential, and coefficient estimates (β) from that model were considered significant if $P < 0.05$. A Hosmer-Lemeshow test was performed via the R statistical program (R Core Team 2012) package ResourceSelection (Lele et al. 2017) to evaluate goodness-of-fit of the top model (Hosmer et al. 1997).

Monitoring

The detection probabilities for each half hour time interval were computed using a probability model proposed by McArdle (1990) and used by Kèry (2002):

$$N\ min = \log(\alpha) / \log(1 - p)$$

where ($N\ min$) is the minimum number of visits and (p) is the estimated probability of detection at any one visit. This was done to ascertain the necessary allocation of survey effort needed to determine the minimum number of visits and length of time required to infer absence of ravens with 95% confidence.

A preliminary list of areas where ravens were most likely to breed in Kentucky was created based on historical observations, recent sightings, expertise of biologists and local birders, and areas containing suitable nesting substrate. These areas included cliffs associated with Pine, Black, and Cumberland Mountains, Paintsville Lake area, and natural cliffs and high walls associated with coal surface mining. Due to limited resources, I was only able to conduct monitoring surveys on Pine and Cumberland Mountains during the 2010 and 2011 breeding seasons. All cliffs on Pine and Cumberland Mountains were identified visually using GIS and during a flight over the study area. A subset of these cliffs were randomly chosen from the identified cliffs to be monitored for occupancy during the 2010 breeding season by a field technician. Selected cliffs were separated by at least 1200 meters to increase spatial coverage. This distance was chosen because it was < 1600 km, which corresponds to the lowest mean distance between raven nests previously reported (Dunk et al. 1994), and was within a reasonable range of an observer's ability to detect ravens when present. During the 2011 breeding season, a subset of cliffs on Pine and Cumberland Mountains were randomly selected to be monitored within and near the same management areas as 2010 (Figure 2.2). The selected cliffs were spaced closer together (~800 m) than during 2010 to limit the possibility of not detecting ravens if present and to increase the possibility of locating a nest if a territorial pair was detected. Monitoring consisted of auditory and visual surveying with binoculars and a spotting scope, as well as use of a wildlife caller to elicit vocal or territorial responses from ravens that may be occupying or passing through the area if no raven was detected within an hour of survey time.

Results

Detectability

The average time until first detection was 14 min and 23.6 min until occupied detection was determined. The estimated probability for first detection ranged from 0.80 (95% CI = 0.68–0.89) to 0.99 (95% CI = 0.91–0.99) for a 30 min and 2 hr survey, respectively (Table 2.1). The estimated probability for occupied detection was the same as first detection at the 1.5 hr and 2 hr surveys, but differed at the 30 min and 1 hr survey with probabilities of 0.65 (95% CI = 0.53–0.75) and 0.90 (95% CI = 0.80–0.95), respectively (Table 2.1). I was unable to identify any statistically significant factors influencing detectability.

During the Fall of 2009, preliminary detection probability estimates were used to determine the appropriate allocation of effort for monitoring occupancy of ravens in eastern Kentucky. Analysis showed that surveying a cliff site twice for 1.5 hrs ($p=0.99$ (95% CI = 0.91–0.99)) was required to determine raven occupancy with a 99% confidence level. More precise detection probabilities, using data collected during the 2010 and the 2009 breeding seasons, reduced the necessary survey effort to two site visits, each lasting 1 hr (p=0.90 (95% CI = 0.81–0.95)), thus enabling the occupancy of a given cliff site to be determined with a 95% confidence level.

Breeding Habitat

Based on the simple logistic regression analysis, cliff length, cliff height, degree of occlusion, cliff area, and orientation of strata had AIC_c values less than that of the null model (Table 2.2) and were, therefore, retained for multiple logistic regression analysis. Among 32 considered multiple logistic regression models, the top model had an AIC_c value that was 2.29 units lower than the next competing model (i.e., ΔAIC_c) and included cliff area and horizontal strata orientation as significant predictors (Table 2.3, 2.4); Hosmer-Lemeshow test demonstrated adequate fit of this model (χ^2_8 = 7.88, P = 0.44). The probability of a given cliff site being occupied increased by a factor of 3.13 (95% CI = 1.34–5.73) as the area of a cliff increased, but the probability of occupation decreased by a factor of –2.89 (95% CI = -6.04–-0.67) if the strata was horizontal (Table 2.4).

Monitoring

I detected ravens at 5 sites during occupancy surveys conducted at 24 cliffs on Pine and Cumberland Mountains during the 2010 breeding season; four in Harlan County (south side of Pine Mountain southwest of Kingdom Come State Park, Stone Mountain WMA, Cranks Creek WMA, and Martins Fork WMA) and one in Bell County (Shillalah Creek WMA). Three of these sites appeared to have territorial breeding adults at them (Stone Mountain WMA, Cranks Creek WMA, and just outside of Shillalah Creek WMA near Hensley Settlement at Cumberland Gap National Historical Park) but no nest was located. The cliff sites where ravens were not detected were used as unoccupied sites listed above in Objective 2. I also located two other sites that held territorial pairs on Pine

Mountain: Rebel Rock vicinity through past observations (Palmer-Ball and McNeely 2006b, B. Begley, Pine Mountain Settlement School, pers. comm.) and Jenkins, KY; an active nest was located at the latter.

I monitored 52 cliff sites during the 2011 breeding season on Pine and Cumberland Mountains and detected ravens in five areas: Hensley Pine Mountain WMA, Pine Mountain State Park, Cranks Creek WMA, Martins Fork WMA, and just outside of Shillalah Creek WMA and Hensley Settlement at Cumberland Gap National Historical Park. Four of the locations contained definite territorial breeding pairs (Hensley Pine Mountain WMA, Pine Mountain State Park, Martins Fork WMA, and just outside of Shillalah Creek WMA and Hensley Settlement at Cumberland Gap National Historical Park); only one nest was located during these surveys. Conversations with others led to the confirmation of additional active or older nests outside the occupancy survey area, including: one active nest on a highwall in the Pineville Quarry operated by Bluegrass Materials Company near Pine Mountain State Park, an active nest and a pair of old nests at two other limestone quarries (Harlan County and Letcher County) based on my own suspicion and subsequent visitation, an active nest in Elkhorn City (Pike County) (D. Raines, Buchanan County Bird Club, pers. comm.), an active nest on an old highwall near Starfire Mine (Knott County) (K. Heyden and B. Palmer-Ball, Kentucky Department of Fisheries and Wildlife Resources, pers. comm.), and perhaps the same active nesting pair in the Rebel Rock vicinity (Harlan County) that I detected in 2010 (Figure 2.3).

Discussion

I used sites (cliffs) with a history of target species occupancy to increase the likelihood of detecting ravens, thereby maximizing sample size to estimate detection probability, and an approach more robust than those derived from theoretical survey methods (Aldinger and Wood 2015). Ravens are large, black birds that stand out against a lighter colored habitat when flying and perched, and their loud and often frequent vocalizations, as well as territorial behavior towards other ravens and potential predators near breeding sites, renders them highly detectable in most locations (Boarman and Heinrich 1999). In fact, my findings indicate that common ravens in the Central Appalachians are highly detectable at known occupied cliff sites, with detection rates comparable to other studies of ravens and similar avian species. Aerial surveys from fixed-wing aircraft in the Ingakslugwat Hills of the Yukon Delta National Wildlife Refuge in western Alaska yielded a high detection probability (0.85) for breeding cliff-nesting common ravens; although, detection probability via helicopter surveys in the Kilbuck Mountains was lower (0.45) (Booms et al. 2010). Farnsworth et al. (2002) reported a high detection probability (>0.80) for the closely related American crow (*Corvus brachyrhychos*) in their 10 minute point count surveys in the Great Smoky Mountains National Park. Vocalization-based detection and occupancy studies have proven to be an effective technique for determining the status of known northern goshawk (*Accipiter gentilis atricapillus*) nest sites with high accuracy rates of 100% (Penteriani 1999) and 90% (Dewey et al. 2003) using dawn vocalization surveys.

Innate territorial behavior towards conspecifics and strong nest defense with associated interspecific aggression towards raptors and crows in the immediate nest vicinity (Boarman and Heinrich 1999) increases breeding ravens' detectability. Broadcast of conspecific calls during surveys can maximize probability of detection of territorial woodland raptors such as northern goshawks (Kennedy and Stahlecker 1993), Cooper's hawks, (*Accipiter cooperii*) (Rosenfield et al. 1988, Mosher et al. 1990), broad-winged hawks (*Buteo playpterous*) (Mosher et al. 1990), red-shouldered hawks (*Buteo lineatus*) (Mosher et al. 1990, McLeod and Anderson 1998), and barred owls (*Strix varia*) (Mosher et al.1990). Barnes et al. (2012) found that call-broadcast surveys using conspecific vocalizations proved to be an effective technique to determine peregrine falcon (*Falco peregrinus*) territory occupancy during the breeding season, especially during the courtship stage. Furthermore, their 10-min call-broadcast survey protocol yielded a mean 78% detection rate across the breeding season, only one percent lower than the detection rate of 79% (Barnes et al. 2012) derived from use of the traditional four-hour passive survey protocol (U.S. Fish and Wildlife Service 2003). The effect of conspecific broadcasts in my study was less substantial, as the wildlife caller was not used during the detectability surveys until 1 hr had passed so as to limit the chance of habituation to the caller; however, the strong territorial behavior response of territorial and interspecific chases by breeding ravens resulted in nest area occupancy determination in 10 separate surveys. The average time of first detection and occupied detection was under 25 min, which further supports my decision to delay the caller broadcasts.

Background noise is known to substantially affect detection probability (Simons et al. 2007, Pacifici et al. 2008) as is the presence of foliage on trees (Pacifici et al. 2008). My study was likely affected by background noise derived from vehicular traffic, heavy machinery associated with strip-mining activities, rivers and streams, and wind. While I tried to mitigate background noise as much as possible, such as canceling surveys during times of high winds (>4 on the Beaufort scale), there were instances where other background noise variables were unavoidable due to the cliff's proximity to said sources.

Leaf-on conditions were less likely to have an impact, except later in the breeding season when leaves had fully emerged. Leaf-on conditions coincided with the mid to late nestling stage of the regions' breeding ravens, and any detrimental effect to detection probability should be considered minor because of the increased nest attentiveness by both adults to feed their growing chicks.

Evaluation of suitable habitat for ravens produced similar findings to those of Hooper (1977) with ravens preferring cliffs with at least one suitable ledge for a nest with an associated overhang above and a precipitous rock face below to deter land predators. Overhangs are beneficial due to ravens' early nesting, providing protection from winter weather conditions (Harlow 1922, Ratcliffe 1962, Knight and Call 1980). Cliff area proved to be the top predictor of nest site selection corresponding with Ratcliffe's (1962) assessment that the largest cliffs are the most attractive to both ravens and peregrine falcons due directly to their size/noticeability, but also because suitable nest sites and their respective protection tend to increase with cliff area. In locations of high conspecific nesting density, smaller cliffs are used more often due to competition and territoriality (Ratcliffe 1962, Hooper 1977). Cliffs with horizontal or tilted strata tend to have significantly better access than cliffs with vertical or no strata (Watts 2006). My finding that horizontal strata decreased the probability of occupation in these larger cliffs is likely confounded by the fact that 22 of unoccupied cliff sites surveyed had horizontal strata versus 14 occupied cliff sites with horizontal strata; however, the ratio was reversed for tilted strata with two unoccupied cliffs with tilted strata surveyed versus seven occupied cliffs with tilted strata, thereby bringing the number of unoccupied cliffs versus occupied cliffs surveyed with horizontal or tilted strata to 24 and 21, respectively. Furthermore, most of the surveyed unoccupied cliffs were located in Kentucky where the raven density is known to be lower than West Virginia, Virginia, and North Carolina. Boarman and Henrich (1999) also noted that ravens tend to use east- facing cliffs less than cliffs facing the other cardinal directions. However, Ratcliffe (1962) claims that aspect is not an important factor in nest site selection as ravens do not show any preference in areas where suitable cliffs face in all directions, which agrees with my findings of aspect having the lowest likelihood of determining selection of a particular nest cliff.

Prior to this study, there were only five confirmed nests within Kentucky: Bad Branch State Nature Preserve, two nests on surface mine highwalls in Knott and Breathitt Counties, Paintsville Lake, and Rebel Rock (Fowler et al. 1985, Larkin et al. 1999, Cox et al. 2003, Palmer-Ball and McNeely 2004, Palmer-Ball and McNeely 2006). The newly discovered breeding areas found during my study have tripled the number of breeding areas. In talking with quarry staff, it appears that ravens have nested in eastern Kentucky quarries for at least the last few years, and perhaps as early as the mid-1980's as suggested by one manager (M. Roark, Bluegrass Materials Company – Cumberland Rock Quarry, pers. comm.). It is very possible that ravens may have nested in eastern Kentucky prior to being first seen again in 1969 (Croft 1970).

Although the majority of observed raven nests in the Central Appalachians are on cliffs (Harlow 1922, Hooper et al 1975, Hooper 1977), I observed one nest located in a tree in late January 2009 at Shenandoah National Park, Virginia. Other tree nests have been found throughout the region (Harlow 1922, Hooper et al. 1975, Hooper 1977). These tree nests, nests on highwalls and in quarries, and particularly those observed in human constructs (e.g., radio towers, buildings, billboards, train tressels) in Appalachia, suggest that the notoriously reclusive ravens in this region appear to have become increasingly tolerant of humans and their artifacts (Boarman and Henrich 1999, Larkin et al. 1999, Cox et al. 2003, Shedd and Shedd 2004).

My findings on raven detection and occupancy have provided an empirical basis for future investigation of the species, including location data that could serve as the foundation for initiation of resource use and demographic studies to further inform research and management in Kentucky and beyond. Despite the apparent successful recolonization of eastern Kentucky by ravens over the past 40 years, my survey findings of the more rugged cliff areas of the southeastern portion of the state indicate that breeding areas remain few and far between. As observed in states adjacent to Kentucky (Hall 1977, Buckelew and Hall 1994, Robbins 1996, Nicholson 1997, Potter et al. 2006), the increased number and geographic range of observations suggests the raven population is growing and expanding; however, despite its loud vocalizations and associated ease of detectability, accurately estimating the population of this elusive corvid in the remote, mountainous areas of Appalachia will likely prove challenging. I recommend that the raven remain listed as state threatened and a Species of Greatest Conservation Need until further monitoring and research indicates sufficient improvement in numbers and distribution to warrant delisting.

Management Recommendations

In supporting continued listing of the raven in Kentucky, I recommend the following measures to protect the species and facilitate its recolonization. Although ravens can adapt, live, and nest in close proximity to humans (Knight 1984, White and Tanner-White 1988, Boarman and Heinrich 1999), I suggest that wildlife managers and land stewards limit human encroachment in areas where ravens are known to nest for the immediate future by adopting the Hooper (1977) guidelines concerning human activity near active raven nest sites. I further propose that lengthening the rock climbing ban to the end of May should account for variation in the timing of raven nests in the region, although in some cases, these nest protection guidelines may not be feasible given recreational and industrial demands. Case in point, two active nests were located on highwalls at active limestone quarries on Pine Mountain and one active nest was observed within 25 m of a road in Knott County. In situations like these, and ones where ravens are using strip-mine highwalls for breeding, the guidelines could be relaxed where heavy machinery and blasting appear to be of little deterrence to nesting activities. Ravens choosing more remote breeding sites may be much less tolerant of such disturbance. Of greatest importance where ravens nest in mined areas is the preservation of the highwall in which the nesting pair resides. This may be plausible in cases where the highwall in question is an older one that is not being actively mined, but may be otherwise economically difficult for mine operators. Where legally and economically feasible, leaving some old highwalls that are suitable nesting sites may benefit ravens and other cliff-nesting species such as golden eagles (*Aquila chrysaetos*) (Fala et al. 1985), peregrine falcons (Ratcliffe 1993), and great horned owls (*Bubo virginianus*) (Schwarzkoph 1980). Larkin et al (1999) stated that unreclaimed highwalls may serve as significant landscape features promoting range expansion of ravens to other parts of the state and suggested that further surveys investigating ravens use of these manmade cliff-lines should be conducted.

Ravens are easily confused with their morphologically similar, but smaller relative, the American crow. Even trained wildlife biologists have difficulty distinguishing between the two species (J. Cox, University of Kentucky, pers. comm.). I therefore suggest that at minimum, educational outreach should be an important management strategy for recovery of this species. This could be done in a myriad of ways with a few being raven information booths at local festivals (e.g., annual Kentucky Black Bear festival in Cumberland, KY) in areas where ravens are known to inhabit, at park kiosks (e.g., Cumberland Gap National Historic Park), and links leading to further information about ravens in Kentucky on the Kentucky Department of Fish and Wildlife Resource's website. Training wildlife agency personnel to identify ravens would also likely be helpful. I found very few citizens who knew anything about ravens, or knew to whom they should report sightings and nests; therefore, this information should be made available through public outreach that could inform hunters, quarry staff, and surface coal mine employees. Furthermore, research examining survival and cause-specific mortality of ravens, particularly estimation of accidental take during crow hunting season, could inform managers as to whether prohibiting crow hunting in areas where ravens occur is warranted.

The reintroduction of elk to eastern Kentucky (Maehr et al. 1999) and the consequent rise in big-game hunting in the region has enabled ravens to take advantage of yet another food source. Ravens have a very diverse diet but often feed on carrion including elk and white-tailed deer (Boarman and Heinrich 1999). Observations of ravens feeding on elk and deer carcasses and associated gut piles in Kentucky and neighboring states are plentiful (Mengel 1965, B. Palmer-Ball, Kentucky State Nature Preserves

Commission, pers. comm., J. Cooper, Virginia Depatment of Game and Inland Fisheries, pers. comm., J. Hast and J. Cox University of Kentucky, pers. comm.); however, exploitation of such food sources may be harmful if the animal was shot with lead ammunition. Craighead and Bedrosian (2008) found elevated lead levels in blood of ravens during the elk-hunting season with a point source of lead ammunition. Offal piles and unrecovered carcasses left by hunters using lead shot have also been shown to pose a threat to other carrion feeding species such as California Condors (Hunt et al 2005). Banning lead ammunition within the Common Raven's range would minimize the risk of lead poisoning to it and other scavengers such as eagles and black bears that still occur in low numbers statewide, but also to the more common hawk and vulture species.

Table 2.1. Detection probabilities (with lower and upper bounds; ± 1 SE) for first detection (FD) and occupied detection (OD) of common ravens (*Corvus corax*) at 23 known cliff breeding sites in Appalachia at half hour increments with a 95% confidence interval.

Detection Type	Survey Time (hours)	Probability of detection (p)	Lower bound of estimate	Upper bound of estimate
FD	0.5	0.81	0.70	0.88
	1.0	0.96	0.88	0.99
	1.5	0.99	0.91	1.00
	2.0	0.99	0.91	1.00
OD	0.5	0.66	0.54	0.76
	1.0	0.90	0.81	0.95
	1.5	0.99	0.91	1.00
	2.0	0.99	0.91	1.00

Table 2.2. Simple logistic regression model selection investigating the habitat and landscape characteristics important to common raven (*Corvus corax*) occupation of cliffs in Appalachia (2009–2010). Akaike's Information Criterion corrected for bias (AIC_c) and calculated AIC difference (ΔAIC_c) and Akaike weight (wi) for each tested habitat variable.

Habitat Variable	AIC_c	ΔAIC_c	w_i
Area	63.97	0.00	0.887
Length	70.03	6.06	0.043
Height	70.77	6.80	0.030
Strata	71.98	8.00	0.016
Occlusion	72.66	8.68	0.012
Null	74.17	10.19	0.005
Proximity to Human Habitation	75.91	11.94	0.002
Proximity to Road	76.16	12.18	0.002
Elevation	76.33	12.35	0.002
Access	77.38	13.41	0.001
Aspect	79.13	15.16	0.000

Table 2.3. Multiple logistic regression model selection investigating the habitat and landscape characteristics important to common raven (*Corvus corax*) occupation of cliffs in Appalachia (2009–2010). Cliff occupation was used as the binary response variable, and cliff length (Lt), cliff height (Ht), degree of occlusion (DO), cliff area (Area), and orientation of strata (Strata) were used as predictor variables. One level of each variable was used as a reference; for brevity, only models ≤ 5 ΔAICc are presented.

Model	AIC_c	ΔAIC_c	w_i	logLik
~ Area + Strata	57.41	0.00	0.39	–23.03
~ Area + Strata + Height	59.70	2.29	0.12	–22.89
~ Area + Strata + Length	59.81	2.40	0.12	–22.95
~ Area + Strata + Occlusion	59.94	2.54	0.11	–23.02
~ Strata + Height + Length	62.13	4.75	0.04	–24.12
~ Area + Strata + Height + Length	62.32	4.91	0.03	–22.87
~ Area + Strata + Height + Occlusion	62.38	4.96	0.03	–22.89

[a] Akaike's Information Criterion corrected for small sample size.
[b] Difference between AIC_c of model and model with the lowest AIC_c.
[c] Model weight.
[d] log Likelihood.

Table 2.4. Coefficient estimates (β) from the top logistic regression model predicting occupation of a given cliff site by common ravens (*Corvus corax*) in Appalachia. Standard errors (SE), 95% confidence intervals, z-values, and the probabilities that β differed from 0 are also presented.

Variable	β	SE	95% CI	Z	Pr(>|Z|)
Intercept	1.05	1.14	-0.95–4.05	0.91	0.361
Area	3.13	1.08	1.34–5.73	2.89	0.004[a]
Strata Orientation					
Horizontal	–2.89	1.26	-6.04–-0.67	–2.29	0.022[a]
Tilted	–0.29	1.41	-3.58–2.43	–0.20	0.838
Vertical	–17.86	23.54	-63.99–28.28	–0.01	0.994

[a] $\alpha < 0.05$.

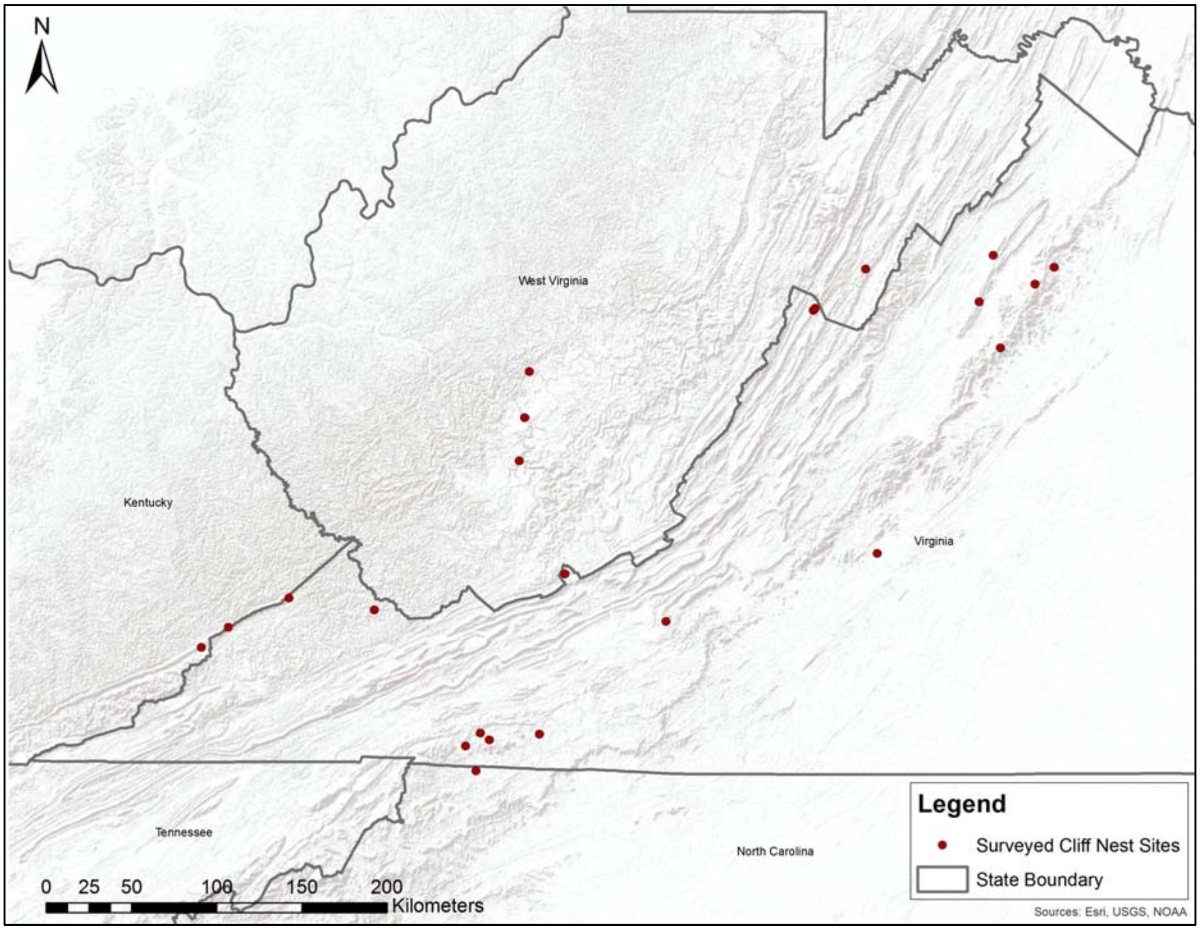

Figure 2.1: Known raven cliff nest sites surveyed for detectability in spring breeding season of 2009 and 2010 in Central Appalachia. Each site was surveyed three times.

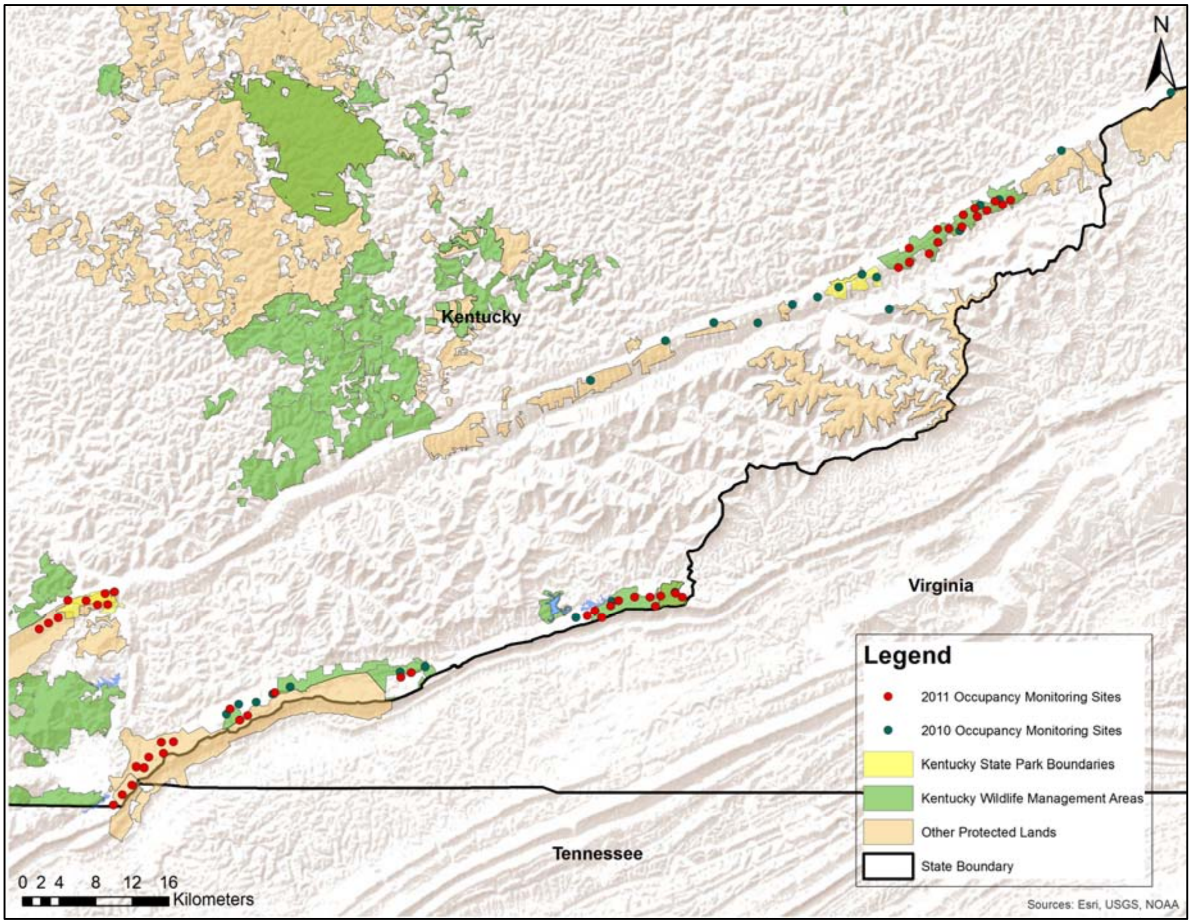

Figure 2.2: Cliff sites monitored for raven occupancy during the 2010 and 2011 breeding season in Kentucky.

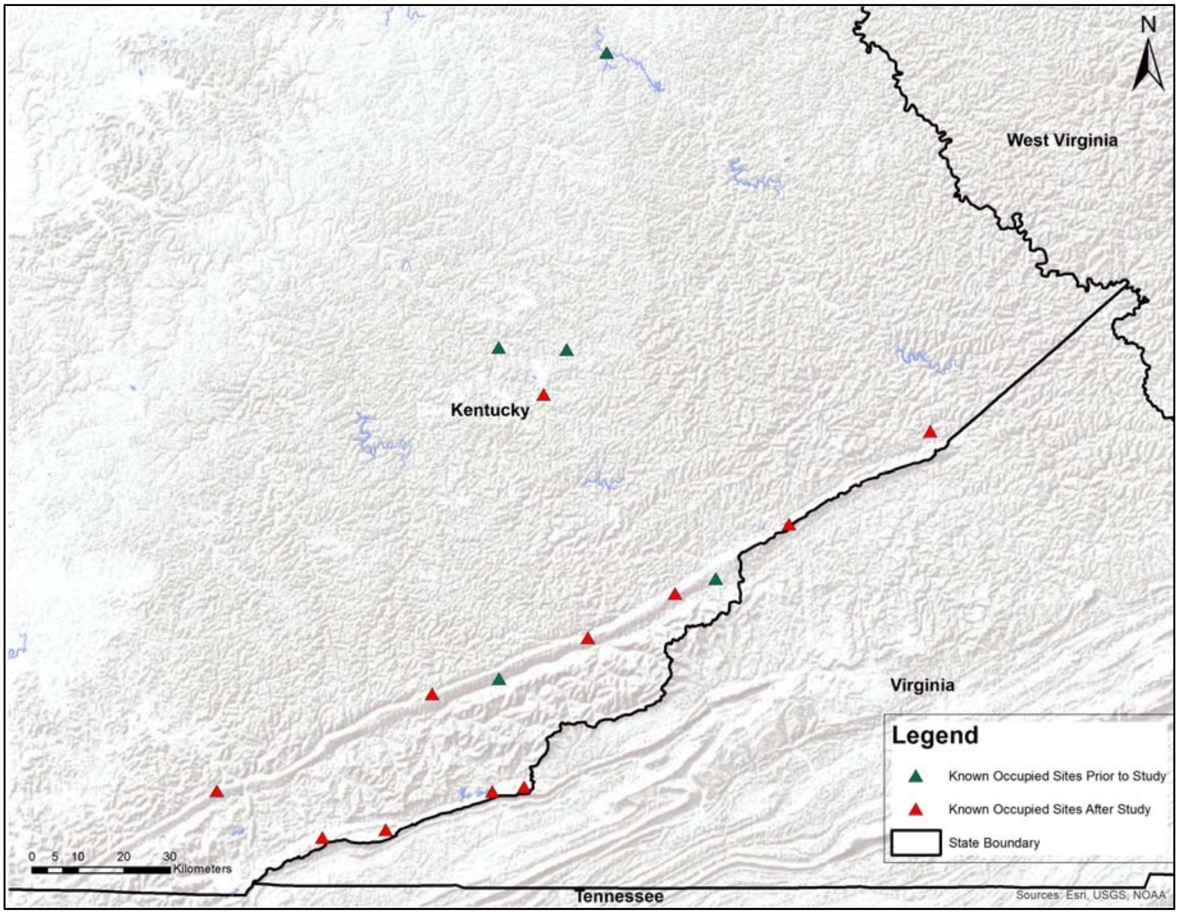

Figure 2.3: Known occupied raven breeding sites in Kentucky prior to and after this study.

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- The Wildlife Society Student Travel Grant, 2010, $300
- Xi Sigma Pi National Forestry Honor Society
- Phi Sigma Theta National Honor Society

PUBLICATIONS

- Olsen, B.J., R. Greenberg, I.A. Liu, **J.M. Felch**, and J.R. Walters. 2010. Interactions between sexual and natural selection on the evolution of a plumage badge. Evolutionary Ecology 24(4):731-748.
- Olsen, B.J., **J.M. Felch**, R. Greenberg, and J.R. Walters. 2008. Causes of reduced clutch size in a tidal marsh endemic. Oecologia 15(3): 421-435.

PRESENTATIONS (* indicates presenter)

- Kenyon, M.*, J. Brandt, C. Battistone, and **J. Felch**. 2013. Potential implications of pumas (Puma concolor) specializing on California condors (Gymnogyps californianus). California Department of Fish and Wildlife Science Symposium. Sacramento, California. Poster presentation.
- **Felch, J.M.***, J.J. Cox, and M.R. Dzialak. 2011. The Common Raven in cliff habitat: detectability and occupancy. 2011 Annual Meeting of the Southeast Partners in Flight. Lexington, Kentucky. Poster presentation.
- **Felch, J.M.***, J.J. Cox, and M.R. Dzialak. 2011. The Common Raven in cliff habitat: detectability and occupancy. 2011 Annual Meeting of the Kentucky Chapter of The Wildlife Society. Lake Cumberland State Park, Kentucky. Oral presentation.
- **Felch, J.M.***, J.J. Cox, and M.R. Dzialak. 2010. The Common Raven in cliff habitat: detectability and occupancy. The 17th Annual Conference of The Wildlife Society. Snowbird, Utah. Poster presentation.
- January 2010 University of Kentucky Department of Forestry Proposal Seminar. The Common Raven in cliff habitat: detectability and occupancy. Lexington, Kentucky. Oral Presentation.
- Olsen, B.J.*, R. Greenberg, I.A. Liu**, J.M. Felch**, and J.R. Walters. August 2007. Interactions between sexual and natural selection in the plumage divergence of the Coastal Plain Swamp Sparrow. 125th stated meeting of the American Ornithologists' Union, Laramie, Wyoming. Oral presentation.
- Olsen, B.*****, **J.M. Felch**, R. Greenberg, and J.R. Walters. October 2006. Life history divergence in two sub-species of the Swamp Sparrow: Incomplete bet-hedging? IV North American Ornithological Conference, Veracruz, Mexico. Oral presentation.