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Space Use and Nesting Ecology of Common Ravens (Corvus Corax) in Central Washington State

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SPACE USE AND NESTING ECOLOGY OF COMMON RAVENS (*CORVUS CORAX*) IN CENTRAL WASHINGTON STATE

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A Thesis

Presented to

The Graduate Faculty

Central Washington University

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In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

Biology

_____

By

Brandon Anthony Rossi

June 2019

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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ABSTRACT

SPACE USE AND NESTING ECOLOGY OF COMMON RAVENS IN SHRUB-

STEPPE HABITAT OF CENTRAL WASHINGTON STATE

By

Brandon Anthony Rossi

June 2019

The ecology and space use of Common ravens (*Corvus corax*; hereafter ravens) is not well understood in the shrub-steppe of central Washington State. Raven populations have increased by more than 254% since 1990 in Washington State (North American Breeding Bird Survey; www.mbr-pwrc.usgs.gov/bbs/). Ravens in central Washington are implicated as top predators of a small endemic population of greater sage-grouse (*Centrocercus urophasianus*). Researchers have related increased raven populations to anthropogenic subsidies such as landfills, agriculture, and livestock operations. Analyzing movement can help researchers understand the characteristics of habitat that are important and potentially drive population fluctuations. We found that daily and monthly movement distances for ravens were 19 kilometers (range = 3–238.5 km) and 505 kilometers (range = 102–1,575.4 km), respectively. Calculating Brownian Bridge home ranges shows that the average non-breeding raven home range size was 1,746 km^2 (range= 104–6,675 km^2), which is like home ranges from other studies. Annual reproductive output of ravens on YTC has been documented through nest monitoring since 2011. To better understand the factors that may be influencing raven reproduction, nest success was modeled against parameters thought to be important for ravens. YTC has a relatively high density of nesting ravens compared to other regions, and averages

51.5% annual nest success. We found that no habitat variables used for this analysis influenced raven nest success.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: LITERATURE REVIEW

INTRODUCTION

Common ravens (*Corvus corax*, hereafter ravens) are the largest member of the order Passeriformes. Their average size is 1.2 kilograms and 25 inches in length (Cornell). Ravens are a generalist omnivore species whose diet consists of a wide selection of food items, including carrion, seeds and grains, garbage, insects, eggs, and live prey. Raven abundance in Washington State has increased by 254% since 1990 (North American Breeding Bird Survey; www.mbr-pwrc.usgs.gov/bbs/). Ravens have demonstrated the ability to live in harsh environments (Restani et al. 2001), and it is believed this is due to human occupation of those landscapes (Webb et al. 2009). Anthropogenic subsidies provide a stable food and water source which allows the continued expansion and persistence of raven populations (Boarman 2003, Kristan and Boarman 2003). These subsidies potentially enable population increases that may exceed the natural carrying capacity of a given environment. This is especially of interest to people tasked with managing sensitive species, as these subsidies can lead to "spillover" predation (Holt 1984, Schneider 2001). Spillover predation is the result of ravens moving away from human subsidies and putting additional predation pressure on species at risk in the surrounding environment.

There have been several studies in relation to spillover predation and its effect on sensitive species. Studies on the Desert tortoise (*Gopherus agassizii*) have determined that the raven is a common predator, and have implicated ravens as one cause for the decline of this species (USFWS 1994, Boarman 2003, Boarman et al. 2006, Webb et al. 2009). Another species that is impacted by ravens is the Marbled murrelet

(*Brachyramphus marmoratus*), which is listed as threatened by the United States Fish and Wildlife Service (USFWS). Two studies show that ravens will use human augmented landscapes at a high rate, which leads to an increase in predation on the nests of Marbled murrelets (Marzluff and Neatherlin 2006, Scarpignato and George 2013). This predation pressure has caused continued declines in portions of the murrelets' range (DellaSala et al. 2015). Nest predation by ravens on ground nesting bird species has been documented in a Least tern (*Sterna antillarum*) colony (Marschalek 2010), and has been documented in Greater sage-grouse (*Centrocercus urophasianus*) populations as well (Coates and Delehanty 2004, Dinkins 2013, Lockyer et al. 2013).

Researchers have noted that raven populations should be studied regionally to better understand their local life histories (Bedrosian 2005). Home-range size of ravens differs greatly depending on the ecosystem in which they are found. Linz et al. (1992) found that the median home range for ravens in coastal California was 1.2 km^2, whereas in Prudhoe Bay, Alaska, home-range size was estimated to be 6.5 km^2 (Powell and Backensto 2009). These differing home range sizes show the importance of studying raven populations within a given region. Raven ecology has only been studied on two occasions in central Washington (Paulus and Malkin 1995 and Clayton 2005). Raptors and ravens have been monitored with varied intensity at the Yakima Training Center (YTC) in central Washington since 1981, with nest success, density, and number of young fledged monitored on a yearly basis since 2011 (Lannoye 2014). These studies provide baseline data for raven population dynamics and distribution, but do not address space use or movement.

Research Need

 Sage-grouse are a species of concern, especially in Washington State where they are listed as state threatened. Currently there are two small and geographically isolated endemic populations in Washington: the Moses Coulee population in Douglas County and the Yakima Training Center (YTC) population in Yakima and Kittitas Counties (Schroeder et al. 2014). Intensive sage-grouse population monitoring has occurred at YTC since 1989. Sage-grouse numbers have experienced an annual average decline (-4%) at YTC since 1999 (White 2017a) even though Sage-grouse hen survival at YTC is relatively high compared to range-wide averages (White *pers. com.*). Recent research has shown that nest success at YTC is comparable to the range-wide averages. However, these results also show that nest success is well below average (White et al. 2015), furthermore, brood survival at YTC appears to be low. These two factors are potentially contributing to the decline that the sage-grouse population is experiencing at YTC.

 The increasing raven abundance in Washington may be a contributing factor to these low rates of success, as researchers have discovered a correlation between raven abundance and sage-grouse nest success (Bui et al. 2010, Dinkins 2013). In 2014, a more intensive effort was placed on finding all raven and/or raptor nests within the core use area of sage-grouse at YTC, and an artificial nest study was designed and implemented to determine the guild of predators depredating sage-grouse nests. In this study, ravens accounted for 47% of all nest depredations (Lannoye and White 2014). The results of Lannoye and White (2014), coupled with other research that reported a positive correlation with raven abundance and reduced sage-grouse nest success (Bui et al. 2010, Coates and Delehanty 2010, Dinkins 2013), have implicated ravens as a top predator of

sage-grouse at YTC. The number of raven nests at YTC has continued to increase each year that intensive nest monitoring is implemented. The 2017 breeding season yielded the highest number of occupied raven nests at YTC to date (n=113; White 2017). With the increase in the number of nests comes an increase in reproductive output; 2017 yielded a 68% increase in young produced compared to the previous year, and the highest estimate of young fledged at YTC (White 2017). The anthropogenic features that surround YTC may be contributing to the increased number of raven nests found at YTC, as researchers have found that ravens can maintain populations above the carrying capacity of a given environment when anthropogenic resources are available (Boarman 2003, Kristan and Boarman 2003).

Movement

Animals move across the landscape in search of resources and these movements are influenced by a variety of interactions (Reynolds and Laundre 1990). These movements can be prohibitive to ravens in regards to time, risk, energy reserves, and reduced reproduction (Bonte et al. 2012). These movements also have an impact on population dynamics and species distribution (Allen and Singh 2016). Non-breeding ravens are often found in groups, which improves foraging ability and reduces conflicts with any breeding ravens that may be exploiting the same food source (Wright et al. 2003). Often the most common areas for large groups of non-breeding ravens to congregate are landfills and farms (Roth et al. 2004, Boarman et al. 2006, Web et al. 2011), but some ephemeral resources do exist on the landscape in the form of offal, including roadkill (Webb et al 2012). Breeding ravens are generally intolerant of conspecifics within their home territory, but non-breeding ravens will tolerate others,

4

especially when they are congregated near subsidies (Marzluff and Neatherlin 2006, Webb et al. 2012, Scarpignato and George 2013). Anthropogenic subsidies are shown to be a major contributing factor to population increases across the west (Boarman 2003, Kristan and Boarman 2003). Ravens that rely on anthropogenic subsidies to survive winter conditions are concentrated at these resources (Restani et al. 2001, Webb et al. 2009), but there is limited understanding of their dispersal from these areas in spring and summer months when natural resources are more abundant (Peebles and Conover 2017). Analyzing how ravens move across the landscape can provide insight into important resources, roosting areas, and the extent that ravens influence their surrounding environment. For managers to have the greatest impact on management of a sensitive species (i.e., sage-grouse) they must understand the landscape scale that management must take place.

Home range

Home range is a term used by researchers to define the area occupied by a species that fulfills their requirements to survive and reproduce (Burt 1943). Researchers have developed numerous ways to quantify home ranges; an early method was the minimum convex polygon (Mohr 1947). In this method, lines are used to connect all of the outer points around the area of use. This method leads to inaccuracies, as animals do not always have equal use of all areas contained within their home range (Anderson 1982). Advances in home range analysis have thus been developed to account for an animal's uneven use of its home range. Kernel density estimation was first used for analyzing home range in the case of small sample sizes (Worton 1989), but is currently accepted as the most reliable home range estimator in ecology (Hemson et al. 2005). Kernel densities

are used to make utilization distributions (UD), which are a bivariate frequency function (Van Winkle 1975). This method calculates the amount of time (Samuel and Garton 1987) or the likelihood of occurrence (Worton 1989) for an individual at any given location within their home range. One weakness of this method is it often over-smooths the home range when using large data sets (Hemson et al. 2005). This can be troublesome, as recent technological advances in Global Position System (GPS) tracking technology has outpaced our ability to accurately analyze the data. Brownian Bridge home ranges are a relatively new approach to analyzing home range for large GPS data sets (Horne et al. 2007). By adding a temporal structure and modelling the movement path of a species, the brownian bridge home range method has improved upon previous home range estimation analysis. Understanding basic ecology (i.e. home range) of a species can help managers make well-informed decisions regarding methods to manage the species.

Nest Success

Raven nest success in central Washington has been documented in the past (Stuart and Malkin 1995, Lannoye 2016, White 2017). However, no published research has modeled how ravens interact with habitat, and how this habitat influences nest success. Understanding the role of habitat in influencing nest success of ravens is important to wildlife professionals trying to manage sensitive wildlife species that ravens have been shown to depredate (e.g. greater sage-grouse). Howe et al. (2014) recently performed resource selection function analysis to determine what parameters were important for raven nest site selection in southwest Idaho. They found that ravens preferred sites in proximity to transmission lines, land cover edges, and habitat edges. Post hoc analysis of

the edge types showed that the edge between dense sagebrush and grass (both native and exotic) had the highest probability of selection by ravens (Howe et al. 2014). No equivalent studies have been conducted in central Washington, particularly where raven numbers are artificially inflated due to human activity on the landscape. With a greater understanding of how habitat influences raven nest success in central Washington, management practices can be applied or modified to naturally reduce raven populations, therefore reducing the burden on sensitive species.

Research Focus

GPS data from ravens captured as part of a larger research project and extensive nest monitoring data collected at YTC from 2014-2017 were utilized in this study. My objectives are to develop a better understanding of how ravens use the landscape in central Washington and determine what landscape variables present in shrub-steppe habitat at the Yakima Training Center influence nest success. The following goals are used to guide my research: 1) analyzing daily and monthly movement of ravens in central Washington, 2) estimating non-breeding raven home-range size, and 3) modeling habitat associations that influence nesting success of ravens at YTC. These will all provide a better understanding of how ravens use the landscape in central Washington. The biggest driver for this research is understanding how ravens influence a small struggling endemic population of greater sage-grouse found at YTC. Ravens have been implicated as a major predator of grouse at YTC, and at other places within their range (Bui et al. 2010, Coates and Delehanty 2010, Dinkins 2013, and Peebles et al. 2017). Increases in raven populations present a challenge, particularly when the increase is driven by human presence. Continued research with ravens in this region is necessary to better understand

their impact on all species and to identify possible ways to alter their use of

anthropogenic sites for the benefit of conservation.

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CHAPTER 2: HOME RANGE AND MOVEMENT OF COMMON RAVENS

(CORVUS CORAX) IN CENTRAL WASHINGTON STATE

INTRODUCTION

Common raven (*Corvus corax*, hereafter raven) abundance in Washington State has increased by an average annual rate of 8% since 1968 (Pardieck et al. 2018). Ravens have demonstrated the ability to live in harsh environments (Restani et al. 2001) such as the dry climate of the Mojave desert (Webb et al. 2009) and the shrub-steppe of eastern Washington State, mostly due to additional resources associated with human occupation of those landscapes (Webb et al. 2009). Ravens are a generalist predator and their impacts on sensitive species are well documented within their range, including the Desert tortoise (*Gopherus agassizii*) (USFWS 1994, Boarman 2003, Boarman et al. 2006, Webb et al. 2009), Marbled murrelet (*Brachyramphus marmoratus*) (Marzluff and Neatherlin 2006, Scarpignato and George 2013, DellaSala et al. 2015), and the California least tern (*Sterna antillarum*) (Marschalek 2010). Ravens have also been documented as a top predator of Greater sage-grouse (*Centrocercus urophasianus*) (Coates and Delehanty 2004, Dinkins 2013, Lockyer et al. 2013), which is particularly problematic in areas such as central Washington, where the remaining sage-grouse population is small, geographically isolated, and declining.

For managers to have the greatest impact on management of a sensitive species (e.g. sage-grouse) they must have an understanding of the landscape scale on which management must take place. Loretto et al. (2016) found that non-breeding ravens have much larger home ranges than previously reported, but comparisons between studies should be done with caution as different habitats and analysis methods may contribute to

differences in findings. Non-breeding ravens are often found in groups, which improves

foraging ability and reduces conflicts with breeding ravens that may be exploiting the

same food source (Wright et al. 2003). These non-breeding ravens have been shown to

cover large geographic areas while foraging (Loretto et al. 2016, Harju et al. 2018), and

these movements can be influenced by a variety of interactions other than foraging

(Reynolds and Laundre 1990). Large movements made by ravens can be problematic in

regard to time, risk, and energy reserves (Bonte et al. 2012). Differing movement

strategies are also likely to have an impact on population dynamics and distribution

(Allen and Singh 2016). Often the most common area for large groups of non-breeding

ravens to congregate are landfills and agriculture areas (Roth et al. 2004, Boarman et al.

2006, Web et al. 2011), but some ephemeral resources do exist on the landscape in the

form of carcasses and roadkill (Webb et al 2012). Breeding ravens are generally

intolerant of conspecifics within their home territory, but non-breeding ravens will

tolerate others, especially when they are congregated near subsidies (Marzluff and

Neatherlin 2006, Webb et al. 2012, Scarpignato and George 2013).

Analyzing how ravens use the landscape can provide insight into important

resources, roosting areas, and the extent to which ravens influence their surrounding

environment. Anthropogenic subsidies are shown to be a major contributing factor to

population increases across the west (Boarman 2003, Kristan and Boarman 2003).

Ravens that rely on anthropogenic subsidies to survive winter are concentrated at these

resources (Restani et al. 2001, Webb et al. 2009), but there is limited understanding of

their dispersal from these areas in spring and summer months when natural resources are

more abundant (Peebles and Conover 2017*a*).

Home ranges are often calculated by researchers to define the area occupied by a species. These analyses can be important in providing researchers insight into habitat features that fulfill the necessary components for survival and reproduction (Burt 1943), and many methods for estimating home ranges exist. One of the first estimation techniques to be developed was the minimum convex polygon (Mohr 1947). Although simple and straightforward, this method leads to inaccuracies, as animals do not generally show equal use of all areas contained within their home range (Anderson 1982). More recent advances in home range analysis have been developed to account for an animal's uneven use of its home range. Kernel density estimation was first used for analyzing home ranges for datasets containing a small sample size (Worton 1989), and was accepted as the most reliable home range estimator in ecology (Hemson et al. 2005). One weakness of this method is that over-smoothing of the home range often happens when using large data sets (Hemson et al. 2005). This can be troublesome as recent technological advances in Global Position System (GPS) tracking technology has outpaced the ability to accurately analyze the resultant data. Brownian bridge is a relatively new approach to analyzing home range for large GPS data sets (Horne et al. 2007). Brownian bridge home ranges are an improvement on previous methods for analyzing large GPS data sets for several reasons: they tend to be less sensitive to over smoothing (Hemson et al. 2005), and the assumptions of autocorrelation within the data do not need to be met (Silverman 1986), as time between successive points are used to calculate a random walk variable (Horne et al. 2007). Therefore, analysis of large datasets containing autocorrelated data from modern GPS transmitters are more accurately analyzed with brownian bridge home ranges (Horne et al. 2007).

The objectives of this study are to calculate the daily and monthly movement and home-range size for common ravens using shrub-steppe habitat in central Washington. Understanding how ravens use the landscape, and their interaction with anthropogenic resources, will allow better management practices to be implemented. This is of particular importance to prevent extirpation of a local sage-grouse population.

METHODS

Study Site

This study focused on ravens in Yakima and Kittitas Counties of central Washington State. This region has a diverse range of habitats, ranging from typical shrub-steppe to alpine meadows, agriculture, and several small towns and cities. Kittitas and Yakima Counties have a mix of federal, state, and private landownership, with most of the private land being used for agricultural production. The climate is characterized by cool, dry winters and hot, dry summers, with annual summer precipitation of 17–38 cm, and annual snowfall of 25–78 cm. Average winter temperatures range from -9– -4° C, and average summer temperatures range from 10–35° C, with occasional high temperatures over 37° C (Western Regional Climate Center 2001).

Capture

A net launcher (Trapping Innovations, LLC) deployed over a bait station was used in this study (Roth et al. 2004, Webb et al. 2011, Scarpignato and George 2013). Trapping took place at the Terrace Heights landfill in Yakima, Washington during May 2017. The Terrace Heights landfill has large concentration of ravens, likely due to frequent deposits of large amounts of refuse. This site is predominantly bare ground,

making for an ideal trapping area. Captured ravens were removed from the net quickly and placed in pet carriers with Astroturf lined floors. This allowed the ravens to have secure footing to reduce the possibility of injury. After capture, each raven was fitted with a size 7A metal United States Geological Survey (USGS) steel butt band placed on the left leg. Lastly, a 24-28 gram solar-powered GSM (Global System for Mobile Communication) backpack transmitter (Cellular Tracking Technology) was fitted prior to release (following Buehler et al. 1995). All capture and handling methods were approved through Central Washington University Institutional Animal Care and Use Committee (#A101501).

Monitoring

Five locations per day were collected by transmitters and stored onboard until in range of a 3G (3rd Generation) cellular network. At that time the transmitter automatically downloaded to the CTT (www.celltracktech.com) data portal, which allowed end users to view the data with Google Mapping software or download it to a desired database. Data were viewed for potential mortalities and downloaded on a weekly basis. Although the transmitters did not have mortality mode, point clusters were investigated on the ground for mortality or failed attachment whenever possible. All data was downloaded until transmitters lost too much battery power to collect data, when the transmitter failed, or September 30th, 2017, when data analysis began.

Movement

Movement was analyzed by summing the Euclidean distance moved between points on a daily and monthly timeframe. All movement data were analyzed in the package "move" (Kranstauber and Smolla 2016) in the R software environment (R Development Core

18

Team 2015). Distances were summed by day, month, and cumulatively for the data collection period to get a better understanding of how ravens use the landscape at each of those time scales. These movement parameters were then compared to home-range size to test for significant correlation. Maximum distance moved from capture site was calculated and used to analyze the regional use by non-breeding ravens in Central Washington. Comparing movement between breeding and non-breeding classes was performed with two-sample t-tests to determine if differences in movement patterns were significant.

Home range

Individual Brownian bridge home ranges were estimated for each individual raven using the "adeHabitatHR" package (Calenge 2006) in the R software environment (R Development Core Team 2015). Calculations were performed on all ravens that had more than 3 months of data. The adeHabitatHR package requires the geographical locations to be in meters, so the latitude longitude coordinates were converted to Universal Transverse Mercator (UTM) using ArcGIS 10.4 (Environmental Systems Research Institute, Redding, CA). Each raven had 50% (core use) and 95% (home range) contours calculated. Breeding ravens maintain territories year-round; therefore, a comparison of the home range size of breeding and non-breeding ravens was performed using t-tests.

RESULTS

Capture

Twenty ravens were captured, five of which were under the minimum weight to receive a transmitter, 23 April–17 May 2017. The underweight birds were banded and measured prior to release, and the remaining fifteen ravens were banded, measured, and

affixed with a transmitter. The average weight of all ravens captured (n = 20) was 1,066 grams (range 924-1237 g.). The age structure of captured ravens was 2 after hatch year (AHY), 5 second year (SY), and 13 after second year (ASY). Ten transmitters remained functional to collect data for the specified time of interest; the remaining transmitters could not be recovered to make a final determination of whether failure was caused by detachment or a mortality event.

Monitoring

After download and data organization, ravens averaged 537 locations (range = 351–703) during the data collection period of 22 May–30 September 2017. After examination of point clusters during the breeding season, it was found that three ravens were paired and had nested. One raven nested in the southwest corner of the Yakima Training Center, a Department of Defense Army training facility. The remaining two ravens nested within the Wenas Wildlife Area, which consists of shrub-steppe habitat and is owned by Washington Department of Fish and Wildlife. Six transmitters stopped functioning prior to the data cutoff point, and point clusters were located on private property that was inaccessible, therefore, no determination of mortality or attachment failure could be determined.

Movement

Ravens moved an average of 19.5 kilometers (range = 0–238.4 km; Table 1) per day, which is consistent with Loretto et al. (2016). The mean distance traveled per month was 504.5 kilometers (range = 102.8-1,575.5 km; Table 1). Breeding ravens showed limited use of the landfill capture site, except for one individual which nested within 3 km. Non-breeding ravens displayed 2 different movement strategies: some wandered

widely and others remained near the site of capture (Table 1). Using aerial photos to examine point clusters, we found the wandering exhibited by some ravens was the result of movement between anthropogenic subsidies in the region. The non-breeding ravens that wandered appeared to move disproportionately more than breeding and non-breeding stationary ravens, which remained at localized subsidies. The mean distance moved on a daily and monthly basis was not significantly different between breeding classes (daily, $p = 0.46$ and monthly, $p = 0.35$); however, the mean distances moved between wandering and stationary non-breeding ravens were significantly different for daily movement but not monthly movement (daily, $p = 0.004$ and monthly, $p = 0.27$; Figure 1).

Home Range

The average 95% home range size was 2,046.3 km^2 (range= 220.1–6,675 km^2) and the average 50% core use area was 263.8 km^2 (range= 9-978 km^2; Table 2.). Both 50% and 95% home ranges showed no correlation with the number of data points collected (Spearman rank correlation, 50%: $R^2 = -0.003$, $P = 0.89$, n = 10; 95%: $R^2 = -0.045$, $P = 0.55$, n = 10). The 95% home ranges did not exhibit correlation with the mean or maximum distance moved per day (Spearman rank correlation, mean distance: $R^2 = 0.36$, $P = 0.07$, n = 10; maximum distance: $R^2 = 0.33$, $P = 0.09$, n = 10), which differs from findings for non-breeding ravens (Loretto et al. 2016). However, on two occasions ravens split their time between the landfill and a previously unknown communal roost; these individuals represent the two smallest home ranges and least distance traveled. Using a simple t-test to compare home range size between breeding statuses showed no significant difference in space use (t = 2.26, $p = 0.20$).

DISCUSSION

The goal of this study was to determine the extent of space use by ravens in central Washington. Understanding space use is important because it directly relates to resource use, which has an influence on reproduction, survival, and potential to increase predation on sensitive species (Webb et al. 2012). In other studies, non-breeding ravens have exhibited the ability to make large movements across the landscape and use anthropogenic subsidies at higher rates than that of breeders (Loretto et al. 2016, Harju et al. 2018). Here, we found no difference in space use between the breeding classes even though movement between anthropogenic sources appeared to increase distance of movement for non-breeding ravens. However, our small sample size of breeding ravens results in low statistical power to test for differences in movement between these two breeding classes. Ravens used anthropogenic subsidies at much greater rates than natural areas, indicating that subsidies are an important factor that very likely contributes to population increases. While attempting to determine what was driving the ravens' movement, we discovered that when ravens moved, they generally ended up at other anthropogenic sites, one of which was 90 km from the capture site. The density of anthropogenic subsidies had similar effects on the amount of movement seen in other populations of ravens (Webb et al. 2012, Loretto et al. 2016, and Harju et al. 2018). We could not determine if this was a learned behavior and/or resource sharing, as described by Heinrich (1989). There were also areas that ravens moved into and remained in briefly that had no known anthropogenic resources available and we are still unclear as to what was driving use of these areas.

We found that home-range size is comparable with those in other environments and home-range sizes were not influenced by movement between anthropogenic resources. Home-range size of the three breeding ravens was smaller than those of the non-breeders, but this difference was not statistically significant. The small sample size limits our power to detect differences in home range sizes among the 2 classes, however. Webb et al. (2012) found that non-breeding home ranges were statistically larger than that of breeders. There is potential that, with increased sample size of breeding ravens in central Washington, the trend we found may become statistically significant. Visual assessment of home range overlap appeared to be consistent with that of non-breeding ravens from other studies (Webb et al. 2012). Targeting ravens found at the Yakima Training Center due to its high density and potential overlap with sage-grouse range will be important to understanding the ecological interaction between the species.

Most ravens captured during this study exhibited very little use of the Yakima Training Center (YTC), which coincidentally has a high density of breeding ravens (unpublished data). This could be contributing to the lack of use by non-breeding ravens seen during this time, as breeding ravens are intolerant of others within their territory. The high number of non-breeding ravens in this region is likely contributing to this high density of breeding ravens seen at YTC. It is possible that once a breeding territory becomes available it could be easily occupied by non-breeding ravens, and this could occur any time of year as this raven population does not exhibit any migratory tendencies.

There is a large, non-breeding population of ravens in central Washington, and the easily accessible anthropogenic resources in this area are likely contributing to an inflated

population size. In particular, the Terrace Heights landfill site is likely contributing to an

increase in the raven population, which is further supported by landfill census counts

performed in 2015, prior to initiation of raven captures at this location. These surveys

resulted in an average weekly count of 106 ravens from Feb 9th through September 8th

(unpublished data; Harris Environmental). Further research into land use patterns of

ravens in central Washington is necessary to understand the movement of ravens and

their impact on struggling populations of sensitive species such as the greater sage-grouse

found at the nearby Yakima Training Center.

<div align="center">MANAGEMENT IMPLICATIONS</div>

The ability of ravens to easily move between anthropogenic resources shows that

management of this species will need to be undertaken at a regional scale for any

measurable change to their impacts on sensitive species. This is necessary as ravens

readily traveled up to 90 km from the capture site, leading to occupation of a much larger

area than anticipated. The number of anthropogenic subsidies available and the spatial

distribution of these resources likely influence raven population size and the geographic

area they occupy in central Washington. Working in conjunction with municipalities on

spatial organization and better management practices of anthropogenic sites could benefit

species of concern through natural reduction of raven populations. Lethal removal of

ravens has been used in other parts of sage-grouse range (Dinkins et al. 2016, Peebles and

Conover 2017*b*), with varying success. However, lethal control of ravens has been met

with great opposition in recent years, and opposition may be more intense in areas where

ravens are culturally significant to indigenous peoples, such as in the Pacific Northwest

United States. Beyond cultural importance, socio-political influence also hampers the

ability of managers to use this tool to manage declining populations of sensitive species. Even if it is possible, lethal removal should be considered as a temporary solution to reduce the overall population of ravens until beneficial management of anthropogenic sites can be implemented. This would also provide an opportunity to test the effectiveness of this particular method to prevent negative impacts by ravens on sensitive species.

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Table 1. Daily and monthly movement of common ravens found in shrub-steppe habitat in central Washington State. Breeding ravens (*) are differentiated from non-breeding ravens, and stationary (+) non-breeding ravens are differentiated from wandering non-breeding ravens. Landfill use is the percent of data points obtained at either of 2 landfills in this region. Landfill use is a percentage of total data points where the individual was at a landfill site.

Raven ID	Age	Daily Movement (m)			Monthly Movement (m)			Landfill Use (%)
		Average	Min	Max	Average	Min	Max	
1767	SY	29.6	0.1	143.5	740.2	293.3	1004.9	17.0
7421	ASY	31.2	0.0	238.4	849.8	406.9	1551.8	16.8
9134	SY	10.8	0.1	227.1	305.3	187.4	542.5	0.0
9209	ASY	30.5	0.3	171.5	775.4	625.9	933.4	13.9
5573+	ASY	25.7	3.8	198.2	661.5	250.8	1575.5	45.7
7454+	ASY	16.9	0.0	84.8	396.9	354.7	461.6	35.4
9167+	ASY	12.0	0.3	33.1	277.1	102.8	440.8	47.8
2088*	ASY	6.6	0.0	53.7	172.8	138.7	212.3	3.6
8692*	ASY	18.2	0.0	187.9	503.5	227.4	1057.8	11.1
8714*	ASY	13.1	0.0	44.2	362.8	148.1	592.1	29.7
Mean		19.5	0.5	138.2	504.5	273.6	837.3	

Table 2. Home range size for breeding and non-breeding common ravens in central Washington State, calculated using Brownian Bridge home range method (km^2). Breeding ravens (*) are differentiated from non-breeding ravens. Average nesting dates from this region was used to calculate breeding season home range for all ravens regardless of breeding status.

Raven ID	50% Core area	95% Home range	Breeding season 95% Home Range
1767	367.7	2181.9	2819.3

TABLE 2 CONT....

5573	243.8	3115.2	5715.7
7421	738.8	4855.1	6332.7
7454	< 1.0	477.9	249.5
9134	87.4	1311.1	1311.1
9167	17.9	104.5	104.5
9209	978.3	6675.6	9975.6
2088*	9.7	328.4	328.4
8692*	166.5	1193.1	1193.1
8714*	28.1	220.1	28.1
Mean	263.8	2046.3	2805.8

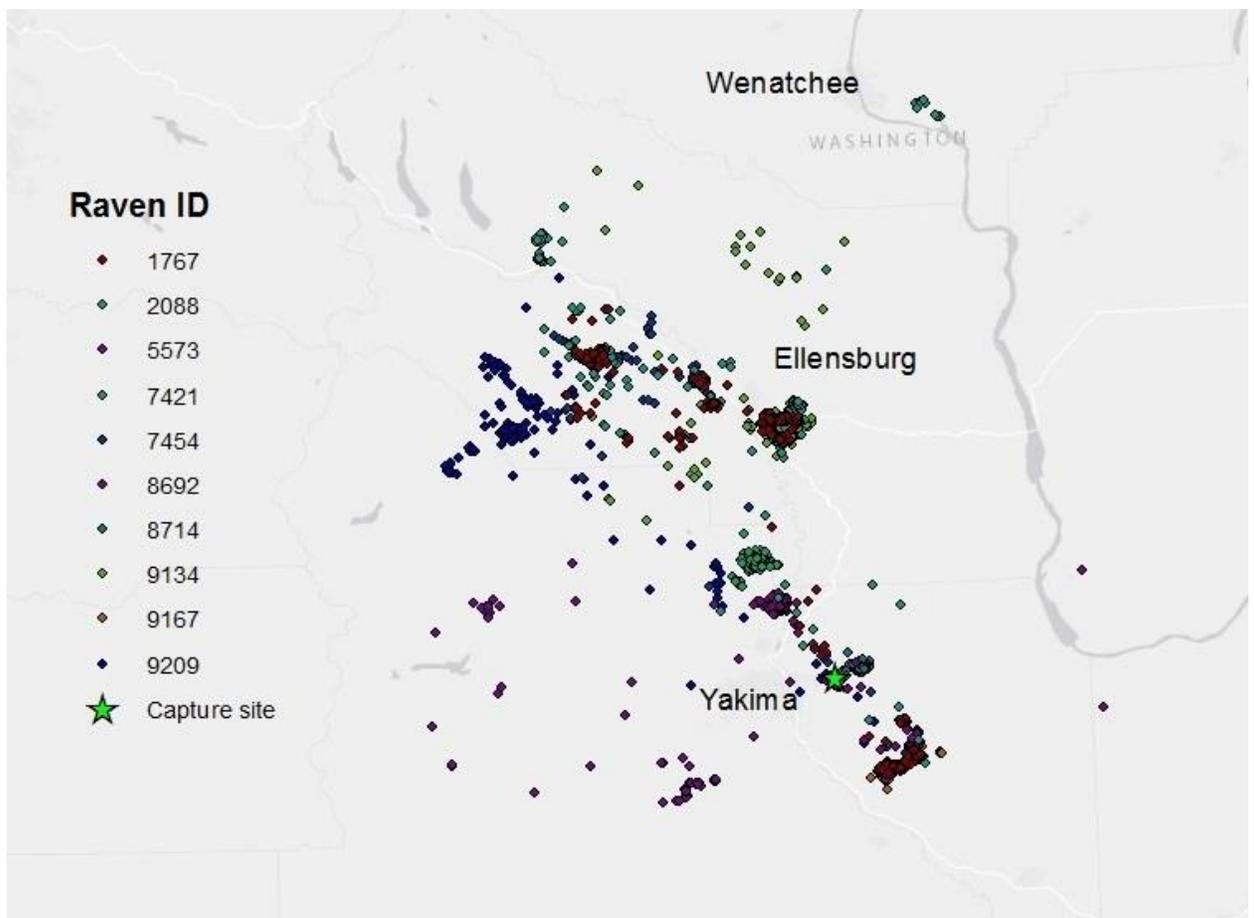Figure 1. Location of ravens used for movement analysis in central Washington State.

Note the extensive movements of some ravens from the capture sight. Raven ID is a

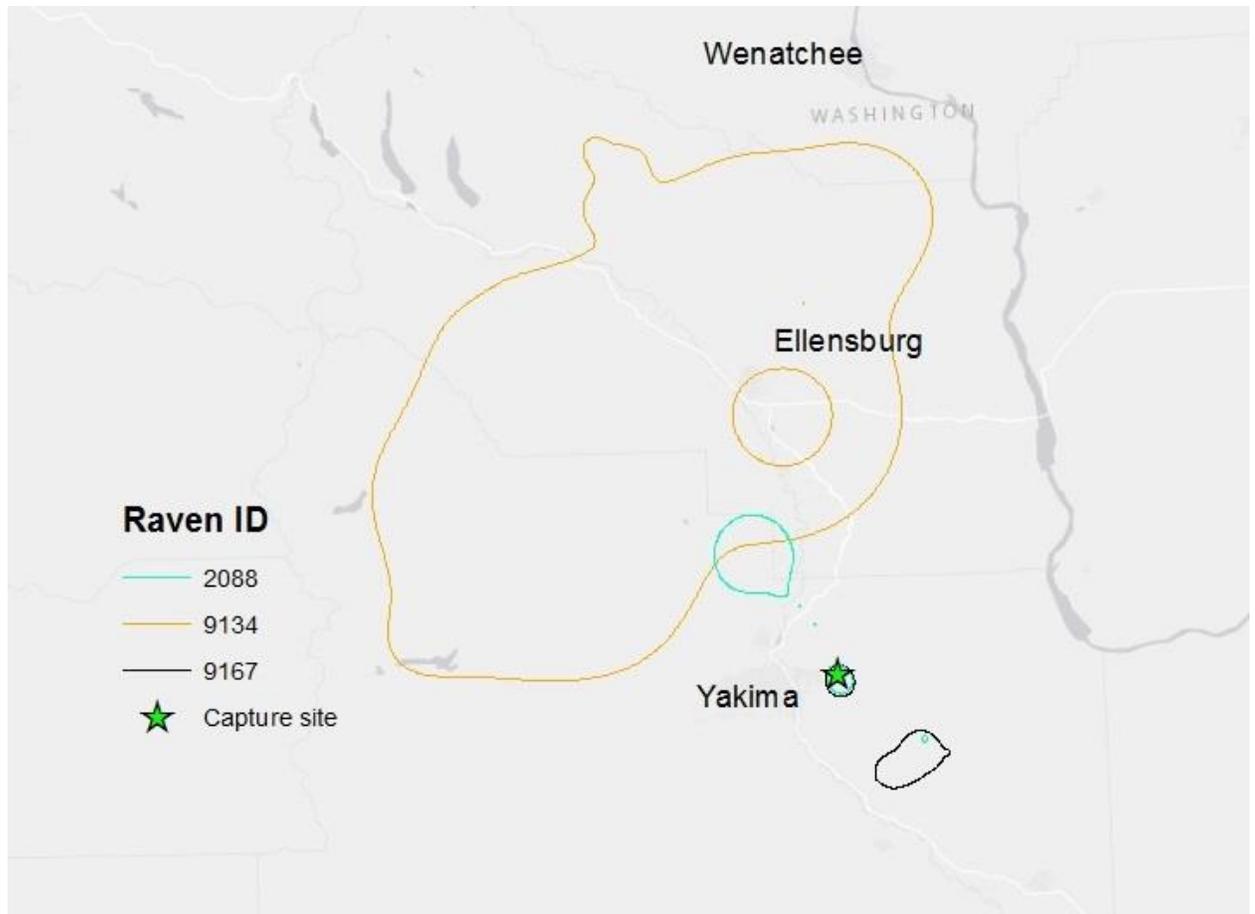unique number for each individual raven with a transmitter attached.

Figure 2. Example of breeding (2088), non-breeding stationary (9167), and non-breeding
wandering (9134) home range sizes for ravens in central Washington State, including
capture site location.

CHAPTER 3

INTRODUCTION

Common raven (*Corvus corax*, hereafter ravens) numbers continue to increase
across the west (Pardieck et al. 2018). Human settlement, and the resulting anthropogenic
subsidies which occur, allow for occupation in these environments, driving continued
expansion (Boarman 2003, Kristan and Boarman 2003, Webb et al. 2009). Ravens are a
generalist omnivore, and they greatly benefit from a multitude of human-related subsidies
such as road-killed animals (Heinrich 1989), offal from hunters (White 2006), agriculture
(Engel and Young 1989), livestock operations (Fuller and Gough 1999), and landfill sites
(Kristan et al. 2004). Absent of anthropogenic subsidies the local habitat would limit the
carrying capacity; however, when subsidies are present, they enable a population to be
artificially inflated.

As a well-documented predator of sensitive species, the increase in raven
populations poses a challenge to wildlife managers. The Yakima Training Center
(hereafter; YTC) in central Washington State has a raven density of 1.2 individuals/km^2
(Lannoye and White 2014). This high density of ravens can be problematic as raven
proximity to greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse)
nests has been shown to reduce nest success (Bui et al. 2010, Dinkins 2013). Vander
Haegan et al. (2002) found that increased predation rates by corvids were present in
fragmented shrub-steppe landscapes. With current land use and increasing fire return
rates at YTC, understanding how those patterns influence habitat suitability for ravens is
critical for sage-grouse persistence at YTC.

Studying raven populations regionally is beneficial to understanding their local life histories (Bedrosian 2005), and a lack of scientific knowledge about the ravens at YTC makes them a difficult species to manage. For example, little is known about what drives nest success of ravens at YTC and how it influences the local raven population. Raptors and ravens have been monitored with varying intensity at YTC in central Washington since 1981, with apparent nest success, density, and number of young fledged monitored on a yearly basis since 2011 (White and Bader 2017). However, no detailed study of potential factors that influence nest success of ravens has been undertaken.

While much of the current research focuses on how ravens influence the population size and distributions of sensitive species, little is known about how they interact with species with which they compete for space and resources (i.e. shrub-steppe raptor species). Ravens are kleptoparisitic on other raptor species in nearby breeding territories (Hunter et al. 1993, Bertran and Marglida 2004, and Sergio et al. 2004), and it is currently unknown if this method of food procurement can further influence raven nest success. If ravens occupy an area that is proximal to both high raptor densities and ample anthropogenic resources, there is potential for populations to be inflated well beyond the natural carrying capacity of the area.

This research is intended to provide information that can guide decisions related to managing raven populations for the benefit of sage-grouse. Raven management is important to implement for isolated sage-grouse populations. This is especially important at YTC, as ravens have been implicated as the dominant predator of sage-grouse nests there (Lannoye and White 2014), as well as in other areas of sage-grouse occupancy

(Coates and Delehanty 2010). The sage-grouse population at YTC has experienced an average annual decline of 4% since 1999 (White 2017), and ongoing habitat restoration and temporal protections during the breeding season have done little to slow this decline.

To this point there has been no detailed study on how the combination of endemic raptors and anthropogenic resources influence the nesting success of ravens. The focus of this research is to analyze extrinsic factors that influence productivity in nesting ravens at YTC. This is done by modeling the effect of proximity to inter- and intraspecific avifauna, distance to anthropogenic features, and existence of different habitat types using generalized linear models.

METHODS

Study Site

The Yakima Training Center (YTC) is a 1,323 km^2 training facility for the United States Army (Fig 1). YTC is bordered on the north and west sides by major Interstate highways (I-90 and I-82 respectively), on the east by the Columbia River, and on the south by private land. YTC is dominated by Wyoming big sagebrush (*Artemesia tridentatta*) and Bluebunch wheatgrass (*Pseudoroegneria spicata)* typical of shrub-steppe habitat types and is one of the largest intact shrub-steppe areas left in Washington (Schroeder and Vander Haegen 2011). The climate around YTC typically consists of cool, dry winters and warm, dry summers. Annual temperatures range from -9–-4° C in winter to 10–35° C in summer, with occasional high temperatures over 37° C (Western Regional Climate Center 2001). Annual precipitation ranges 17–38 cm in summer and 25–78 cm in winter, with most winter precipitation as snow.

Nest Monitoring

From 2014–2017 raptor and raven nests were monitored for occupancy and reproductive output at YTC. Beginning in March of each year, known and historic nesting sites were searched for nesting avifauna. Additionally, each year areas with suitable habitat, identified using satellite imagery (Google Earth Version 7.1, www.google.com/earth), were searched for raptors or ravens. Raven nests were monitored through four breeding phases: occupied, incubating, hatchlings, and fledglings. Nests were considered occupied when pair bonding or copulations were observed, the pair was perched at the nest site, or repairs to the nest were being performed. Once occupied, nests were visited a minimum of every other week until each of the remaining breeding phases was confirmed. Nests were classified as abandoned, successful, or unknown based on recorded field observations after all species had completed their annual breeding cycle (Lannoye 2014). All nests that were found outside of the breeding season and were assumed to have been occupied were classified as unknown and monitored the following season. Nests were classified as successful if young reached at least 80% of fledgling age (Steenhof and Kochert 1982) as many species are unlikely to fail after this time frame. Nest occupancy and success were compared between years to determine if there was yearly variation in the number of occupied or successful nests.

Nesting Variables

Nesting features, habitat, and anthropogenic landscape variables thought to be important to ravens were modeled as predictors of nest success to determine what drives reproductive success. Nests were classified into three substrate types: trees, shrubs, and cliffs. Cliffs included all rock structures that supported nests. Active management to

reduce use of anthropogenic structures by ravens is performed at YTC; therefore, anthropogenic structures were not included in the analysis. Euclidean straight-line distances to inter- and intraspecific species nests, nearest edge, nearest road, and nearest landfill site were mapped using ArcMap 10.4 (ESRI, Redlands, CA). Nest sites that were occupied by ravens in multiple years were randomly selected with the sample function in Program R (R Core Team 2015). Selecting unique sites in this manner removed the issue of pseudoreplication. Each unique site occupied by ravens during this time span was included in the final model selection. Nest sites were buffered by 570 m, which equates to a 102.1-hectare territory size (Howe et al. 2014). Howe et al. (2014) found this territory size to yield significant assciations with for nest-site selection among ravens in sagebrush ecosystems. Habitat variables were calculated within each buffer with ArcGIS 10.4, using a habitat map developed to map canopy cover of the two dominant shrub types (*Artemisia tridentata* and *Artemisia tripartite*) across YTC (White and Lannoye 2014). Some variables from the original map were combined to produce the following habitat variables for analysis: bare ground, grassland, <15% shrub cover, and >15% shrub cover. An additional habitat variable, road density, was developed by buffering roads by 20 m, which is an average width of roads found at YTC, and summing the total hectares of roads per territory.

Model selection

Raven nest success was modeled with all covariates using generalized linear models (GLMs; Nelder and Wedderburn 1972) using the "GLM" function in Program R (R Core Team 2015). All covariates were z-standardized to be on a similar scale for comparison. Covariates were then analyzed for collinearity and non-linear trends. Each

covariate was modeled separately with a univariate model that was compared to a null model. All models were ranked according to their AIC_c score and validated by interpreting beta estimates and 85% confidence intervals (Arnold 2010). Covariates were considered to be supported when AIC_c scores exceeded those of the null model and confidence intervals of the beta estimate did not overlap zero.

RESULTS

Nest monitoring

Nest monitoring was performed each year beginning in March and ravens occupied an average of 96 nests per year (n= 85, 2014; n= 88, 2015; n= 97, 2016; n= 113, 2017; Table 3). The increasing number of nests that were found each year are likely a result of more efficient searches and better aerial photo interpretation of suitable nesting substrate. The average number of successful nests for ravens over the same period was 50 per year (n= 37, 2014; n= 48, 2015; n= 45, 2016; n= 70, 2017; Table 3). Apparent nest success averaged 51.5% per year (n= 43.5%, 2014; n= 54.5%, 2015; n= 46.3%, 2016; n= 61.9%, 2017; Table 3). However, caution should be used while interpreting these results, as apparent nest success has a positive bias due to the difficulty inherent in detecting unsuccessful nests (Mayfield 1975).

Model selection

There were 144 unique sites occupied by ravens between 2014–2017. Of those, 124 nest sites were included for analysis (n= 35, 2014; n= 26, 2015; n= 30, 2016; n= 33, 2017). A total of four nests were removed from analysis as they were classified as unknown success, and 15 nest sites were removed as they fell outside the boundaries of YTC, where there was no habitat data available for analysis. Nest sites were more

39

abundant on trees (n= 77, 61%) than cliffs (n= 34, 27%) or shrubs (n= 16, 12%). There were no variables that outperformed the null model according to AIC_c scores (Table 4) and therefore calculating 85% confidence intervals was not necessary.

DISCUSSION

Raven nest density at YTC (1.28 nests/10 km^2, White and Bader 2017) is like densities found in other studies (1.88 nests/10 km^2, Bedrosian 2005; and 2.13 nests/10 km^2, Linz et al. 1992). It is plausible that differing strategies for locating raven nests can account for the relatively small difference seen between these studies. It is unknown if the non-breeding raven populations in central Washington (Chapter 2) are also like other areas, but these locally inflated populations are likely leading to artificially high nesting densities. This is problematic, as fragmentation and alteration of this landscape is likely to continue, thus increasing or maintaining current raven nest densities.

The area used for analysis around each nest is likely a minimum home range size for ravens during the breeding season at YTC. Although, it has been documented that ravens will travel smaller distances for foraging during the nesting season (Boarman and Heinrich 1999, Roth et al. 2004), knowledge of actual territory size would likely increase the accuracy of modeled interactions. Further research is needed to determine the actual home range size for nesting ravens at YTC, which could result in the development of more useful management strategies. Development of a habitat map that is not constrained to the boundaries of YTC will enable a larger sample size, increasing the power of this analysis to identify habitat variables that impact nest success. Finally, development of a habitat model that incorporates additional vegetation characteristics would be beneficial

and may be able to inform management practices that can indirectly influence raven nest success.

Alternatively, because ravens are a generalist that can thrive in many harsh environments, there may not be any variables that will alter nest success. "Winners", a recently coined term for generalist species, rings true in this case. The ability of ravens to adapt to changing environments and their apparent plasticity in diet could mean that lowered nest success may not be achievable by habitat alteration alone. In this instance it may require human intervention to reverse the upward trend in population size due to anthropogenic alteration of the landscape.

As human augmentation of the landscape continues raven numbers are also likely to continue growing. Imminent population increases will present management challenges that must be met with a growing knowledge of raven ecology. Continuing to monitor raven nests at YTC will be a benefit as it will provide information on long-term nesting trends for this region and provide critical information to researchers trying to find effective methods of population management. Future management should focus on how to reduce the continued fragmentation and alteration of our natural areas. In addition, continued research habitat and its influence on raven nest success will be important for the persistence of sensitive species such as the sage-grouse at YTC.

MANAGEMENT IMPLICATIONS

YTC sage-grouse are possibly already experiencing a hyperpredation scenario (Howe et al. 2014) given the raven densities that are currently present. Developing a better understanding of how nest success drives population growth is vital in

understanding the current and future impacts ravens may have on sage-grouse at YTC. Without clear results on how habitat can be altered to reduce raven success, the sage-grouse in central Washington will likely experience extirpation. Although habitat manipulation is generally a preferred practice to increase struggling populations of sensitive species, lethal control of an important predator (i.e. ravens) is sometimes necessary. Lethal removal of ravens is a tool that has been used in other parts of sage-grouse range (Dinkins et al. 2016, Peebles and Conover 2017), with varying success. This tool is something that needs to be explored at a regional level, as a single anthropogenic site can inflate raven populations regionally rather than just locally (Chapter 2). While ongoing raven research is important to better understand their interactions with the ecosystem at YTC, lethal control to ensure sage-grouse persistence at YTC is likely the best short-term solution. This has potential to increase the sage-grouse population at YTC and provide researchers with more time to unravel the complex interaction between ravens, sage-grouse, and their habitats prior to sage-grouse extirpation.

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Table 3. Number of occupied and successful nests, including apparent nest success for common raven nests monitored at the Yakima Training Center, Yakima, WA.

Year monitored	Number of Occupied Nests	Number of Successful Nests	Apparent Nest Success (%)
2014	85	37	43.5
2015	88	48	54.5
2016	97	45	46.3
2017	113	70	61.9

Table 4. Results from model selection using generalized linear models to compare common raven nest success to landscape variables at the Yakima Training Center, Yakima, WA, USA, 2014–2017. Delta AICc is the difference in AICc from the top model, Wi is the model weight, and K is the number of model parameters.

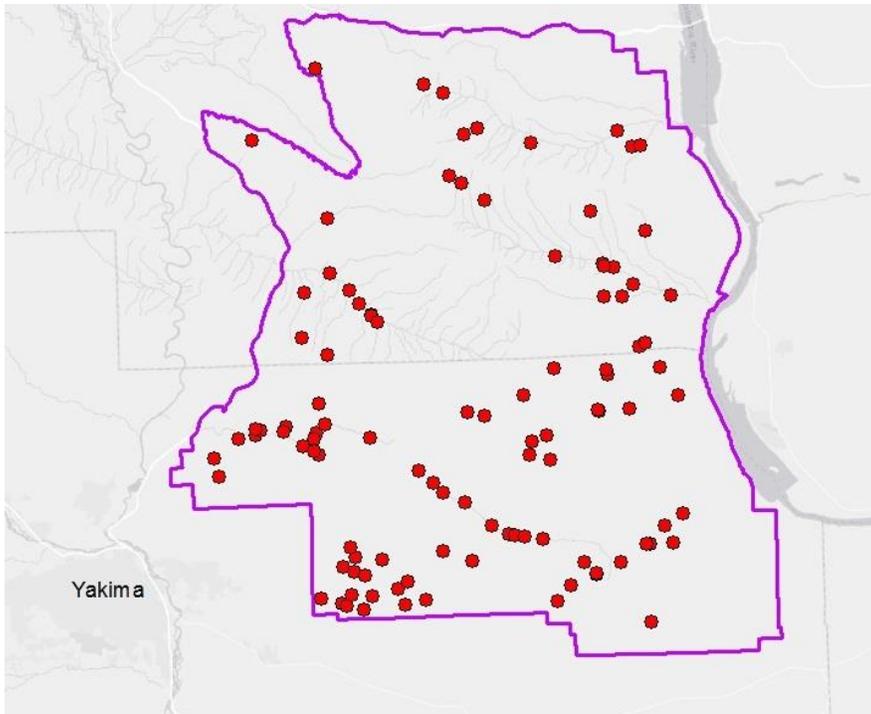| Variable	ΔAICc [a]	*Wi*	K
NULL	0.00	0.19	2
Distance to Allospecific	1.19	0.10	3
Less Than 15% Shrub	1.40	0.09	3
Greater Than 15% Shrub	1.64	0.08	3
Distance to Road	1.77	0.08	3
Distance to Landfill	1.96	0.07	3
Distance to Conspecific	1.98	0.07	3
Grass	2.02	0.07	3
rddensity	2.05	0.07	3
Distance to edge	2.08	0.07	3
Bare ground	2.10	0.07	3
Substrate	3.36	0.03	4
Year	5.20	0.01	5

[a] Lowest AICc = 184.1

Figure 3. The Yakima Training Center (YTC) in central Washington State, USA, study site. This site was used for modeling nest success of common ravens from 2014–2017. Red dots indicate all unique nest site locations used to model the influence of shrub-steppe habitat on common raven nest success.