FY2021 Predator Management Status Report Appendix

Annual Predator Management Project Reporting From

Please fill out this form to the best of your ability. If you have questions please contact Predator Management Staff Specialist Pat Jackson at Pjackson@ndow.org or 775-688-1676. If necessary please use additional pages in your responses.

1. Fiscal Year Reporting: 7/1/2020-6/30/2021
2. Date Report Submitted: 7/31/2021
3. Name of Contractor (include name of submitter if different): Brian Jansen
4. Address of Contractor: 3656 E Mocking Bird Ln, Camp Verde, AZ 86322
5. Phone Number of Contractor: 928-925-8189
6. Email of Contractor: bighorns101@yahoo.com
7. Contract Number: 72DOW-S1271
8. Dates of Contract: 12/2021 - 11/2025
9. Dates Worked: 135 days total

Jackson Mts: 7/23-25, 27-31; 8/1-2; 12/19/2020; 1/15-18; 2/6-11; 3/11-16; 4/4, 8-9; 5/24-25/2021
Calico Mts: 7/26; 11/6-9; 12/9-14/2020, 3/30-31; 4/1-8/2021
Snowstorm Mts: 7/6-11, 13-21/2020; 2/4-5/2021
Massacre Rim: 12/15-18/2020; 2/18-22/2021
Delamar/Clover Mts: 9/10-28, 30-31; 10/1, 3-5, 7-8, 10-11, 13, 15-20, 23, 26, 29; 11/17-24, 26, 28; 12/20-21/2020
Pah Rah Area Recaptures = 5/19-23/2021

10. Assessment of Habitat Conditions of Project Area (if applicable):

11. Briefly describe work conducted: Lethal removal of mountain lions within distribution of select bighorn sheep populations. GPS/Satellite collar deployment on mountain lions in conjunction with a predation study of horses by mountain lions in Delamar and Clover Mts. Collar Recaptures for trapped animal survival study. Collar tracking and kill-site visitation for data collection for predation study.

12. List number and species of predators removed.

<u>Mountain lion = 17 total (9 Lethal, 8 Collar)</u>

- Snowstorm Mts. = 4 (2F, 2M) Lethally Removed
- Jackson Mts = 2 (2F) Lethally Removed
- Calico Mts = 1 (1M) Lethally Removed
- Massacre Rim = 2 (2M) Lethally Removed

– Delamar / Clover Mts. = 6 (4F, 2M) GPS Collars Deployed
– Pah Rah Area = 2 (2F) GPS Collars Removed

13. Provide an overall assessment of project. In your opinion should the project continue?

Ungulates reproduce slowly, especially bighorn sheep. It takes multiple years of sustained predation control to create observable changes in bighorn populations. Most of the ranges worked are small in physical size and bighorn population size; small numbers of mountain lions can negatively impact these populations and continued removal of only a few animals annually will result in observable changes to population sizes. The predation on feral horse population study in Delamar and Clover is a very important aspect of feral horse ecology with native ungulates that needs to be continued to understand the larger scale impacts of removing feral horses and necessary wildlife management activities that likely need to occur in conjunction with removals, if sudden impacts to native ungulates are to be mitigated. The study is also yielding powerful insights into the dispersal of mountain lions from a natal range into other ranges and how reproduction in 1 range impacts populations in sometimes disparate ranges. I encourage all of the project work sites to continue until at such time population objectives for bighorn sheep have been reached.

Annual Predator Management Project Reporting From

Please fill out this form to the best of your ability. If you have questions please contact Predator Management Staff Specialist Pat Jackson at Pjackson@ndow.org or 775-688-1676. If necessary please use additional pages in your responses.

1. Fiscal Year Reporting: 2020-2021
2. Date Report Submitted: September 27, 2021
3. Name of Contractor (include name of submitter if different): Joshua J. Millspaugh and Robert A. Montgomery
4. Address of Contractor: University of Montana, Wildlife Biology Program, W.A. Franke College of Forestry and Conservation, 32 Campus Drive, Stone Hall 113, Missoula, MT 59812
5. Phone Number of Contractor: 406-243-4989
6. Email of Contractor: joshua.millspaugh@mso.umt.edu
7. Contract Number: F17AF00482
8. Dates of Contract: January 2018 – June 2021
9. Dates Worked: January 2018 – Present
10. Assessment of Habitat Conditions of Project Area (if applicable): N/A
11. Briefly describe work conducted: We are evaluating several research objectives regarding the spatial distribution and abundance of black bears in Nevada via the application of two non-invasive research techniques; spatial-capture recapture (SCR) methods from black bear hair snaring and both density estimation and probability of occurrence mapping using camera trapping procedures.
12. List number and species of predators removed (if applicable): N/A
13. Provide an overall assessment of project. In your opinion should the project continue?

The project has progressed smoothly and efficiently since its inception in January of 2018. The only perturbation has been the onset of the COVID-19 pandemic, which shifted the timing of the field season in the summer of 2020 from an intended start date of May to a start date of July. That being said, we adjusted the end date of the field season accordingly and continued to make progress. We have collected image data from a grid of approximately 100 camera traps distributed across ~5000 km^2 of black bear habitat since June of 2018, resulting in approximately 3.7 million images. These images have been analyzed and the animals identified to the species level. We have also collected hundreds of hair samples over the first two summer field seasons, which have been analyzed at the Institute for Quantitative Health Sciences and Engineering at Michigan State University. We also had a paper (see below) accepted for publication in peer-review with another that it is in preparation.

Moll, R.J.[3], P.J. Jackson, B.F. Wakeling, C.W. Lackey, J.P. Beckmann, J.J. Millspaugh, and R.A. Montgomery. 2021. An apex carnivore's life history mediates a predator cascade. Oecologia 196: 223–234.

STUDY PROGRESS UPDATE (DRAFT FY 2021)
October 25, 2021
From: U. S. Geological Survey, Western Ecological Research Center
To: Nevada Department of Wildlife

Project Update of Research Projects to Inform Management of Common Ravens in Nevada

This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government may be held liable for any damages resulting from the authorized or unauthorized use of the information.

Project # 1 (*Completed*)
MODELING COMMON RAVEN OCCURRENCE ACROSS SAGEBRUSH ECOSYSTEMS IN THE GREAT BASIN, USA

Background

- Raven populations across the Great Basin have been increasing during the last several decades. However, methodology and resolution of data are inadequate for estimating abundance, density, and true occurrence of ravens.
- Spatially explicit information on raven density and occurrence is also needed at regional and local levels in order to guide management, especially where high raven prevalence overlaps sage-grouse breeding habitats.

Methods

- We used hierarchical occupancy models to estimate and predict probability of raven occurrence across the Great Basin, using data from >15,000 point-count surveys.
- We related raven occurrence to a large suite of natural and landscape predictors, which were then used to predict spatial variation in raven occurrence across regions where surveys did not occur.
- We generated model predictions of areas where raven occupancy was likely driven by anthropogenic as opposed to natural factors; these products were overlapped with sage-grouse concentration areas to identify areas where spatial prioritization can either target habitat improvements or reduction of subsidies on the landscape.

Results

- Results indicated high raven occurrence (>0.8) across much of the study area
- Many of the drivers of raven occurrence were anthropogenic (road density, landfills, transmission lines, agriculture).

Synthesis

- Findings will be used to help inform science-driven solutions for management of ravens and sensitive prey species across the semi-arid ecosystems of the Great Basin.
- Specifically, spatial products from this project can be used in targeted management plans that include identifying regions where ravens likely have strong top-down impacts on breeding sage-grouse. They are also useful for providing guidance on specific categories of management actions that may likely be most effective for a given areas.

Products

1a. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Moser AM, Foster LJ, Delehanty DJ (2018). Broad-scale occurrence of a subsidized avian predator: reducing impacts of ravens on sage-grouse and other sensitive prey. *Journal of Applied Ecology*: https://doi.org/10.1111/1365-2664.13249

1b. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Moser AM, Foster LJ, Delehanty DJ (2018). Data from: Broad-scale occurrence of a subsidized avian predator: reducing impacts of ravens on sage-grouse and other sensitive prey. U.S. Geological Survey data release: https://doi.org/10.5066/p93oniqt

1c. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2018; *presentation*) Broad-scale occurrence of a subsidized avian predator: implications for reducing impacts of ravens on sage-grouse. Western Association of Fish and Wildlife Agencies Sage and Columbian Sharp-Tailed Grouse Workshop, June 18–21, 2018, Billings, MT, USA.

1d. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2020; *presentation*) Factors influencing common raven occurrence and density across cold-desert sagebrush ecosystems of the southwestern U.S. Bird Damage Management Conference, February 10–13, 2020, Salt Lake City, UT, USA.

1e. O’Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2018; presentation). Spatially explicit modeling of common raven density and occurrence in sagebrush ecosystems. The Wildlife Society-Western Section Annual Meeting, February 5–9, 2018, Santa Rosa, CA, USA.

Project # 2

SCIENCE DRIVEN MANAGEMENT AND A RAPID SURVEY FOR SITE LEVEL ESTIMATES OF RAVEN DENSITIES

Background

- Raven populations across their range increased drastically in recent decades. Site-level surveys to inform management plans using breeding bird data are inadequate for estimating abundance, density, and true occurrence of ravens.
- A method for assessment of raven densities at the local level is needed to guide and evaluate the effectiveness of raven management strategies within action plans

Methods

- We used distance sampling to estimate site-level densities of ravens across 41 field sites in the Great Basin region, 2007 – 2018.
- We explored the validity of using an index for rapid evaluation of raven density (# of ravens / # of surveys) to quickly inform raven densities and, thus, provide a metric for prescribing management actions by land and wildlife managers.
- We developed a user-friendly model that converts ravens / number of surveys to density with 95% confidence intervals.

Results (PRELIMINARY)

- Comparisons of model-based raven density estimates to the index of raven density indicated a strong relationship between estimated raven density and number of ravens/survey ($R^2 = 0.86$).

Synthesis

- In the absence of large sample sizes (number of surveys at a site), we have developed a user-friendly method to input number of ravens/survey to predict raven density with confidence intervals, based on established relationships with distance sampling models.
- This quick survey method could be rapidly applied with reasonable accuracy to evaluate the effects of management actions at reducing raven densities and might be carried out within targeted management frameworks.
- Findings could help inform broader survey protocols for raven targeted management plans that rely on science-driven solutions for management of ravens and sensitive prey species across raven range.

Products

2a. Brussee BE, Coates PS, O'Neil ST, Dettenmaier SJ, Jackson PJ, Howe KB, Delehanty DJ (*In press*). A rapid assessment function to estimate common raven population densities: implications for targeted management. *Human-Wildlife Interactions*.

2b. O'Neil ST, Coates PS, Brussee BE, Delehanty DJ, Jackson PJ, Howe KB, Foster LJ, Moser AM (2018; *presentation*) Spatially explicit modeling of common raven density and occurrence in sagebrush ecosystems. The 65th Annual Meeting of The Western Section of The Wildlife Society, February 5–9, 2018, Santa Rosa, CA, USA.

2c. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2019; *presentation*) Factors influencing common raven occurrence and density across cold-desert sagebrush ecosystems of the southwestern U.S. The 18th Wildlife Damage Management Conference, March 25–27, 2019, Starkville, MS, USA.

2d. Coates PS, O'Neil ST, Atkinson JL, Brussee BE, Jackson PJ, Delehanty DJ (2019; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. The 18th Wildlife Damage Management Conference, March 25–27, 2019, Starkville, MS, USA.

2e. Coates PS, Webb WC, Dettenmaier SJ, O'Neil ST, Brussee BE, Harju SM, Dinkins JB (*In review*) Occurrence, resource use, and demography of the Common Raven (*Corvus corax*) in western North America: a synthesis of existing knowledge and assessment of impacts on sensitive species. U.S. Geological Survey, Restricted-File Federal Interagency Report (*Submitted internally with USGS, 2020*).

2f. Dettenmaier SJ, Coates PS, O'Neil ST, Brussee BE, Jackson PJ (2020; *presentation*) A tiered management approach to reduce raven impacts on sensitive species. Bird Damage Management Conference, February 10–13, 2020, Salt Lake City, UT, USA.

2g. Dettenmaier SJ, Coates PS, O'Neil ST, Brussee BE, Jackson PJ (2020; *presentation*) Science-driven management: Example of a 3-tiered hierarchical framework. The Wildlife Society 27th Annual Conference, Sept. 28–Oct. 2, 2020, TWS Virtual Online.

2h. O'Neil ST, Coates PS, Dettenmaier SJ, Brussee BE, Jackson PJ, Atkinson JL, Dinkins JB, Delehanty DJ (2020; *presentation*) Decision support tools to support management of raven populations for the benefit of greater sage-grouse and other prey populations. Nevada Dept of Wildlife (NDOW) Commissioners Meeting, Nov. 6, 2020, Virtual.

2i. O'Neil ST, Coates PS, Brussee BE, Dettenmaier SJ (2020; *presentation*) Decision support tools for managing expanding raven populations and assessing risks to sensitive species. BLM Information Transfer Workshop. Dec. 17, 2020, Virtual.

2j. Dettenmaier SJ, Coates PS, O'Neil ST, Brussee BE, Jackson PJ (2021; *presentation*) Science-driven management: Example of a 3-tiered hierarchical framework. The 68th Annual Meeting of the Western Section of The Wildlife Society, February 3, 2021, Virtual.

2k. Dettenmaier SJ, Coates PS, Roth CL, Webster SC, O'Neil ST, Brussee BE, Jackson PJ (2021; *presentation*) Decision support tools for management of raven populations to benefit greater sage-grouse. Nevada Dept of Wildlife (NDOW) Commissioners Meeting, Aug. 6, 2021, Virtual.

2l. Coates PS, Roth CL, Dettenmaier SJ, O'Neil ST, Jackson PJ (2021; *presentation*) A science-driven actionable adaptive management framework with decision support tools for common ravens. NDOW Raven Management Workshop and Forum, August 31,2021, Elko, NV, USA.

2m. Dettenmaier SJ, Coates PS, Roth CL, Webster SC, O'Neil ST, Tull JC, Jackson PJ (*In review*). A science-driven actionable adaptive management framework for common ravens. *Human-Wildlife Interactions*.

2n. Rivera-Milan FF, Coates PS, Cupples JB, Green M, Devers PK (*In review*). A modeling framework to evaluate potential take levels of common ravens for greater sage-grouse conservation: an example in Oregon's Baker County Priority Area for Conservation and Great Basin Region. *Human-Wildlife Interactions*.

Project # 3

ESTIMATING COMMON RAVEN DENSITIES IN A SEMI-ARID ECOSYSTEM: IMPLICATIONS FOR CONSERVATION OF SAGE-GROUSE AND OTHER SENSITIVE PREY SPECIES

Background

- Raven populations across the Great Basin have been increasing during the last several decades. Methodology and resolution of existing data (e.g. breeding bird surveys) are inadequate for estimating abundance, density, and true occurrence of ravens.
- Landscape patterns and factors influencing raven density across the broader Great Basin study area have not been identified, and current density and abundance estimates are lacking.
- In addition, effects of ravens on sage-grouse reproductive success are largely unknown at broad spatial scales. Identifying a target raven density for minimizing impacts to sage-grouse is needed for implementation and evaluation of raven management actions.

Methods

- We used distance sampling to estimate site-level densities of ravens across 41 field sites in the Great Basin region, 2007 – 2016.
- We explored the effects of 15 landscape-level environmental covariates influencing raven densities at the field site level, and used these effects to generate predictions of raven density across the Great Basin
- We related raven density estimates to sage-grouse nest survival at the site level to evaluate possible effects of elevated raven density on sage-grouse reproduction. We also evaluated projected raven density overlap with sage-grouse breeding areas to indicate where elevated raven densities (above threshold value) may be leading to depressed nest success in sage-grouse.

Results Average sage-grouse nest success was ~ 0.26, and coincided with raven density of ~ 0.4 ravens km^{-2}.

- Raven densities commonly exceeded ~ 0.4 ravens km^{-2} across the Great Basin, and sage-grouse nest success at the site level declined significantly with increasing raven density. Raven densities > 0.4 ravens km^{-2} generally led to sage-grouse nest success of < 0.26. Several sites had raven densities > 0.6 ravens km^{-2}, and raven density appeared to be increasing at some sites.
- Across the Great Basin, average raven density was estimated at 0.54 ravens km^{-2}, corresponding to an abundance estimate of ~ 403,000 ravens (95% CI = 310,783–522,803). Density estimates were similar when restricting estimation to sagebrush environments (~ 0.53 ravens km^{-2}). Higher raven densities were associated with lower elevations in closer proximity to agricultural fields, development, and transmission lines.
- Raven densities were predicted to exceed 0.4 ravens km^{-2} (e.g. ecological threshold) within ~ 64% of current sage-grouse breeding concentration areas, suggesting potential for widespread impact on sage-grouse productivity.

Synthesis

- Findings will be used to help provide information for targeted management plan that rely on science-driven solutions for management of ravens and sensitive prey species across the semi-arid ecosystems of the Great Basin.
- Negative effects of raven density on sage-grouse nest survival are likely at raven densities > 0.4 and are associated with anthropogenic infrastructure and activity.
- Raven densities exceed the threshold value across much of the Great Basin region, including within areas that are important for sage-grouse breeding productivity.

Products

3a. Coates PS, O'Neil ST, Brussee BE, Ricca MA, Jackson PJ, Dinkins JB, Howe KB, Moser AM, Foster LJ, Delehanty DJ (2020) Broad-scale impacts of an invasive native predator on a sensitive native prey species within the shifting avian community of the North American Great Basin. *Biological Conservation* 243 (2020) 108409: https://doi.org/10.1016/j.biocon.2020.108409.

3b. Coates PS, O'Neil ST, Brussee BE, Ricca MA, Jackson PJ, Dinkins JB, Howe KB, Moser AM, Foster LJ, Delehanty DJ (2020) Data maps of predicted raven density and areas of potential impact to nesting sage-grouse within sagebrush ecosystems of the North American Great Basin. U.S. Geological Survey data release (2020), https://doi.org/10.5066/P9T5JT8N.

3c. O'Neil ST, Coates PS, Brussee BE, Delehanty DJ, Jackson PJ, Howe KB, Foster LJ, Moser AM (2018; *presentation*) Spatially explicit modeling of common raven density and occurrence in sagebrush ecosystems. The Wildlife Society-Western Section Annual Meeting, February 5–9, 2018, Santa Rosa, CA, USA.

3d. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2019; *presentation*) Factors influencing common raven occurrence and density across cold-desert sagebrush ecosystems of the southwestern U.S. The 18th Wildlife Damage Management Conference, March 25–27, 2019, Starkville, MS, USA.

3e. Coates PS, O'Neil ST, Atkinson JL, Brussee BE, Jackson PJ, Delehanty DJ (2019; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. The 18th Wildlife Damage Management Conference, March 25–27, 2019, Starkville, MS, USA.

3f. Coates PS, O'Neil ST, Atkinson JL, Brussee BE, Jackson PJ, Delehanty DJ (2020; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. Bird Damage Management Conference, February 10–13, 2020, Salt Lake City, UT, USA.

3g. Coates et al. (2020; *presentation*) Increasing population growth rates of common ravens across temperate North America and the anthropogenic factors driving their success. The Wildlife Society 27th Annual Conference, Sept. 28–Oct. 2, 2020, TWS Virtual Online.

3h

. Webster SC, O'Neil ST, Brussee BE, Coates PS, Jackson PJ, Tull JC, Delehanty DJ (*In review*). Spatial modeling of common raven density and occurrence helps guide landscape management within Great Basin sagebrush ecosystems. *Human-Wildlife Interact*ions.

Project # 4

RELATING RAVEN DENSITY TO SAGE-GROUSE NEST SUCCESS AT THE NEST LEVEL IN CALIFORNIA AND NEVADA

Background

- Effects of ravens on sage-grouse reproductive success are largely unknown at broad spatial scales
- Raven density likely varies within sites depending on local environmental drivers
- Raven effects on sage-grouse nests success are likely to be more precise when accounting for local variation

Methods

- We applied distance sampling procedures (Project # 2) combined with spatial kriging models to estimate local raven density at distances < 3.5 km of individual sage-grouse nests (n = 984) during years 2009–2017
- Using a Bayesian frailty model for sage-grouse nest survival, we included the local estimator for raven density as a covariate while also including relevant landscape predictors (% sagebrush, elevation, etc.)
- *Results* While greater elevations and sagebrush cover had positive influences on sage-grouse nest survival, local raven density had a strong negative effect (effect on hazard: β = 0.151, $p(\beta > 0) = 0.999$)

Synthesis

- Negative effects of raven density on sage-grouse nest survival are likely at raven densities > 0.5; probability of nest success is greatest at low raven density
- Local variation in raven density is likely driven by site-specific environmental drivers, with consequences for sage-grouse nesting in the same areas

Products

4a. O'Neil ST, Coates PS, Brussee BE, Jackson PJ, Howe KB, Moser AM, Foster LJ, Delehanty DJ (2018; *presentation*) Reduced nest success in greater sage-grouse associated with common raven density in Nevada & California, USA. International Grouse Symposium, Sep. 24–28, Logan, UT, USA.

4b. O'Neil ST, Coates PS, Dettenmaier SJ, Brussee BE, Jackson PJ, Atkinson JL, Dinkins JB, Delehanty DJ (2020; *presentation*) Impacts of subsidized ravens on greater sage-grouse populations within sagebrush ecosystems of western North America. The Wildlife Society 27th Annual Conference, Sept. 28–Oct. 2, 2020, TWS Virtual Online.

4c. O'Neil et al. (*Manuscript, In prep*) Linking hierarchical distance sampling models of predator abundance to vital rates of sensitive prey: spatially-explicit predator impact models for greater sage-grouse.

Project # 5

SPATIALLY-EXPLICIT PREDATOR IMPACT MODELS: LINKING COMMON RAVEN DENSITY TO SAGE-GROUSE NEST SUCCESS USING HIERARCHICAL MODELING

Background

- Ravens have been shown to impact the breeding productivity of sensitive prey species, such as greater sage-grouse
- Managers need spatially-explicit information to guide management actions, regarding where and when actions are needed
- Fine-scale information on spatial and temporal variation in raven density and associated predictors can be combined with information from sage-grouse nest survival models to identify areas where raven impacts occur, as well as the relative severity of expected impacts

Methods

- We developed hierarchical models of 1) raven density and abundance, and 2) sage-grouse nest success, using a finer spatial resolution than has been done previously to model spatiotemporal variation in raven density and impact co-occurring with sage-grouse nest and lek locations (within-site level analysis).
- Field data were collected beginning in 2009 and continuing through FY 2020. Information used in these analyses included fates of >800 sage-grouse nests and raven density information from >24,000 raven point count surveys in Nevada and California.

- We also incorporated temporally-varying predictors into these analyses to capture variation in raven abundance over time.
- We related sage-grouse nest success to fine-scale raven density that varied over time and also as a function of anthropogenic and natural landscape predictors.
- We developed a tool to predict impact based on first, the projected nest success from current raven predictions, and second, a new projection based on simulated removal or reduction of ravens to a target value.

Results (PRELIMINARY)

- Factors influencing raven abundance and density varied by field site and year, but were consistently related to anthropogenic factors such as distance to agricultural field, livestock presence, and transmission lines, while also being associated with valleys of lower elevation relative to the broader study area, and proximity to various water sources. Temporal variation in fine-scale raven density was partially explained by precipitation indices, with most explanatory time lags (6 months – 2 years) varying by field site.
- Raven density influences on sage-grouse nest success were prevalent and also varied by region/field site. Importantly, these influences were statistically evident while also capturing other important spatial predictors of nest success on the landscape.
- Linked hierarchical models and spatially-explicit impact surfaces delineated areas within sites where the removal or reduction of ravens could increase predicted nest success by as much as 0.2–0.25.

Synthesis

- <u>Results corroborate a growing body of evidence that raven abundance influences sage-grouse population dynamics at multiple spatial scales. Here, the localized, fine-scale influences are used to determine where ravens have the greatest impacts on sage-grouse and how these relationships shift over time.</u>
- Spatially-explicit impact surface models of raven density effects on sage-grouse can be used to delineate areas of greatest impact on sage-grouse nesting and breeding, as opposed to areas with minimal impact, thereby guiding management actions to specific locations and regions where implementation is likely to be most effective.

<u>Products</u>

5a. O'Neil ST, Coates PS, Brussee BE, Ricca MA, Jackson PJ, Espinosa SP, Delehanty DJ (2019; *presentation*) Spatially-explicit predator impact models: linking common raven density to sage-grouse nest success using hierarchical modeling. American Fisheries Society and The Wildlife Society, 2019 Joint Annual Conference, Sept 29–Oct 3, Reno, NV, USA.

5b. O'Neil ST, Coates PS, Dettenmaier SJ, Brussee BE, Jackson PJ, Atkinson JL, Dinkins JB, Delehanty DJ (2020; presentation) Impacts of subsidized ravens on greater sage-grouse populations within sagebrush ecosystems of western North America. The Wildlife Society 27th Annual Conference, Sept. 28–Oct. 2, 2020, TWS Virtual Online.

5c. O'Neil et al. (*Manuscript, In prep*) Linking hierarchical distance sampling models of predator abundance to vital rates of sensitive prey: spatially-explicit predator impact models for greater sage-grouse.

Project # 6

RAVEN INFLUENCES ON SAGE-GROUSE POPULATION GROWTH

Background

- Overabundant ravens have been shown to impact the breeding productivity of sensitive prey species, such as greater sage-grouse, through nest predation.
- While impacts of ravens on nest success of greater sage-grouse has become evident, it is still unclear the extent to which these effects might propagate to declines in population growth rate.

Methods

- We estimated raven density at ~ 200 sage-grouse leks in Nevada and California using distance sampling procedures and raven point count surveys.
- In addition, we developed spatially-explicit, temporally dynamic mapping products to make generalized predictions of raven abundance at additional leks across the Great Basins study region
- We related sage-grouse population growth rates to raven density and other important environmental covariates using Bayesian state-space models, with the estimated growth rate modeled as a function of covariates.

Results (PRELIMINARY)

- We demonstrate statistical evidence that reductions in sage-grouse lek counts and changes in population growth rate are negatively associated with spatial and temporal variation in local-scale raven abundance

Products

6a. O'Neil et al. (*Manuscript in prep)* Influences of common ravens on variation in greater sage-grouse population growth rates.

6b. O'Neil ST, Coates PS, Dettenmaier SJ, Brussee BE, Jackson PJ, Atkinson JL, Dinkins JB, Delehanty DJ (2020; presentation) Impacts of subsidized ravens on greater sage-grouse populations within sagebrush ecosystems of western North America. The Wildlife Society 27th Annual Conference, Sept. 28–Oct. 2, 2020, TWS Virtual Online.

6c. Webster et al. (2021; *presentation* Assessing impacts of common raven density on greater sage-grouse to develop science-driven adaptive management strategies. Western Association of Fish and Wildlife Agencies, June 23, 2021, Virtual.

6d. Coates, P.S., S.T. O'Neil, J.L. Atkinson, B.E. Brussee, P.J. Jackson, and D.J. Delehanty (2021; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. NDOW Raven Management Workshop and Forum, August 31,2021, Elko, NV, USA.

Project # 7

RAVEN AND SAGE-GROUSE INTERACTIONS AND BEHAVIORAL ECOLOGY

Background

- Behavioral ecology is important in understanding the impacts that breeding and territorial ravens might have on sage-grouse, as well as how human impacts of anthropogenic subsidies and predator control techniques such as egg oiling might affect ravens.

Methods

- Raven eggs were oiled on Alcatraz Island, CA and the nest was video-monitored
- A raven nest was also video-monitored without egg oiling at Virginia Mountains (VM), NV.
- Raven and sage-grouse behaviors were observed, and harassment behavior was documented at ~ 800 lek counts in NV and CA. Other predators and relevant sage-grouse reactions were also noted.
- Processed data for raven subsidy use analysis. Used hurdle model to show raven occupancy and numbers in the presence of various anthropogenic subsidies. This analysis will help determine whether transient or resident ravens are associated with a given subsidy.

Results (PRELIMINARY)

- Ravens exhibited cannibalism in three circumstances. It was suspected that raven parents consumed their own eggs after egg oiling occurred. Secondly, ravens attacked and killed conspecific chicks in Virginia Mountains.
- Observations of sage-grouse flushing and ceasing to display were documented when ravens were present.
- A Bayesian analysis indicated that sage-grouse were more likely to flush and less likely to display when ravens were present as opposed to when ravens were absent. Results for "sage-grouse presence, but without display" were inconclusive.

Synthesis

- Egg oiling may alter raven behavior in unanticipated ways.
- It is suspected that competing or transient ravens were responsible for killing the chicks of resident ravens at VM.
- Sage-grouse reproductive activity may be impacted by avian predators indirectly (e.g. altering behavior at leks) as well as directly (e.g. nest depredation).

<u>Products</u>

7a. Atkinson, J.L., P.S. Coates, B.E. Brussee, and D.J. Delehanty. (2020). First recorded observations of conspecific egg and nestling consumption in common ravens (*Corvus corax*). *Western North American Naturalist*, 80:236-242. https://doi.org/10.3398/064.080.0211

7b. Atkinson, J.L., P.S. Coates, M.A. Ricca, I.A. Dwight and B.E. Brussee (*In review*) Common ravens and other predators disrupt greater sage-grouse lekking activities. *Human-Wildlife Interactions* (2020).

7c. Atkinson, J.L., P.S. Coates, M.A. Ricca, I.A. Dwight and B.E. Brussee (2020, *poster presentation*) Common ravens and other predators disrupt greater sage-grouse lekking activities. The 67th Annual Meeting of the Western Section of The Wildlife Society, February 2–7, 2020, Redding, CA, USA.

7d. Brussee, B.E., P.S. Coates, C. Sanchez, M. Vaughn, T. Shields, K. Holcomb, and D.J. Delehanty (2020, *presentation*) Reproductive success of common ravens influences their prey: Implications for egg-oiling techniques. Bird Damage Management Conference, February 10–13, 2020, Salt Lake City, UT, USA.

7e. Atkinson, J.L., P.S. Coates, M.A. Ricca, I.A. Dwight and B.E. Brussee (2021; *presentation*) Common ravens and other predators disrupt greater sage-grouse lekking activities. The 68th Annual Meeting of the Western Section of The Wildlife Society, February 3, 2021, Virtual.

Project # 8

RAVEN MONITORING AT VIRGINIA MOUNTAINS

Methods

- Raven point count surveys were performed at Virginia Mountains in association with sage-grouse locations, nests, broods, and random locations.

Results

- Ravens have been monitored in Virginia mountains for 10 years with 4 years before raven removal activity and 7 years after.
- A total of 3,127 surveys have been conducted between 2009–2019.
- We have observed 1,090 ravens across all surveys.
- Using distance-based modeling of density, average density estimate were ~0.37 ravens km^{-2}.
- Average number of ravens per survey was 0.38.
- During 2019, 176 surveys were conducted overall, and 86 of these were independent random (IR) surveys (49%) while 51 were sage-grouse nest surveys (29%).
- Average raven density before removal in 2014 was 0.79 and 0.27 post removal efforts in 2019.

Synthesis

- Raven density appeared to remain relatively low at this site, compared to some previous years (0.5–0.96 ravens/survey; 2009–2011). Numbers are more similar compared to recent years, though raven density may have increased slightly (0.15–0.20 ravens/survey; 2013–2016).
- Raven numbers in 2019 appeared to be higher at random locations (0.22) than nest locations (0.11).

Products

8a. Tyrrell, E.A., P.S. Coates, and D.J. Delehanty (2017), Annual Data Summary 2009–2017: Monitoring and Research on Greater Sage-Grouse in the Virginia Mountains of Northwestern Nevada. U. S. Geological Survey, 55 p.

8b. Coates. P.S., B.G. Prochazka, E.A. Tyrrell, S.R. Mathews, M.A. Ricca, R.L. Kelble, E. Ammon, J. Boone, and D.J. Delehanty (2019). Annual Data Summary for Virginia Mountains, Nevada, 2012–18. U.S. Geological Survey, U.S. Department of the Interior.

8c. Coates. P.S., B.G. Prochazka, E.A. Tyrrell, S.R. Mathews, R.L. Kelble, M.A. Ricca, E. Ammon, J. Boone, and D.J. Delehanty (2018). Greater Sage-Grouse (*Centrocercus urophasianus*) Monitoring at Virginia Mountains, Nevada, 2008–18: U.S. Geological Survey, Data Series 2018–####.

8d. Coates et al. 2020. Greater Sage-Grouse (*Centrocercus urophasianus*) demographic and behavioral response to wildfire and within the Virginia Mountains Population. 2012–19. U.S. Geological Survey, U.S. Department of the Interior.

8e. Dudko JE, Coates PS, Delehanty DJ. 2019. Movements of female sage grouse *Centrocercus urophasianus* during incubation recess. *Ibis* 161:222–229. https://doi.org/10.1111/ibi.12670

8f. Tyrrell EA, Coates PS, O'Neil ST, Roth CL, Prochazka BG, Ricca MA, Mathews SR, Espinosa SP (2019, *presentation*) Wildfire impacts on demographics of greater sage-grouse. The Wildlife Society and American Fisheries Society Joint National Conference, Reno, NV, USA, September 29 – October 3, 2019.

8g. Tyrrell EA, Coates PS, O'Neil ST, Roth CL, Prochazka BG, Ricca MA, Mathews SR, Espinosa SP (2020, *presentation*): Wildfire impacts on demographics rates of greater sage-grouse. The Wildlife Society Western Section Annual Conference, Redding, CA, USA, February 4–7, 2020.

8h. Tyrrell EA, Coates PS, O'Neil ST, Roth CL, Prochazka BG, Ricca MA, Mathews SR, Espinosa SP (2021). Greater sage-grouse (*Centrocercus urophasianus*) demographic and behavioral response to disturbances within the Virginia-Pah-Rah Population Management Unit. U.S. Geological Survey, U.S. Department of the Interior.

Project # 9

RAVEN MONITORING ACROSS NEVADA

Methods

- Raven point count surveys were performed at 14 additional sites in Nevada and along the California border during FY2019
- Surveys were performed in association with sage-grouse locations, nests, broods, and random locations. The proportion of random locations was increased from previous years to also represent raven densities occurring away from sagebrush-dominant habitats and near development and anthropogenic subsidies

Results (PRELIMINARY)

- 4,095 surveys were conducted overall. 1,271 of these were independent random (IR) surveys (31%) and 1,417 were nest surveys (35%).
- 4,181 ravens were observed overall (includes all distances and ravens heard but not seen)
- 2,599 ravens were visually observed at distances < 1125 m
- Raven index for density across all sites = # ravens/survey = 0.635
    - Raven index with all sites equally weighted = 0.581 (95% CI = 0.32 – 0.96)
    - Range of raven densities across sites = 0.22 – 1.64
    - Probability of detecting ≥ 1 raven at a survey (visual or audible, all distances) = 0.25
    - Probability of visually observing ≥ 1 raven at a survey (distance < 1125 m) = 0.21
    - Average raven group size = 1.79

Synthesis

- Indices of raven density appeared to increase markedly from the previous year (from 0.39 to 0.58; all sites equally weighted). Probability of observing ravens also increased (0.14 to 0.21; probability of visually observing ravens at distance ≤ 1125 m). Part of this could be due to differences in sites monitored, although 13 of the 2018 sites were also monitored in 2017 (16 sites were monitored in 2017). In addition, 2017 was a remarkably wet year. Lagged or sustained boosts in raven breeding productivity resulting from above average precipitation may have contributed to increases in raven numbers observed in 2018.

Products

9a. Coates PS, Prochazka BG, Mathews SR, Ricca MA, Everett NS, Kelble RL, Ammon E, Dettenmaier SJ, Boone J, Delehanty DJ (2019). Annual Data Series Reports. Example: Greater sage-grouse (*Centrocercus urophasianus*) monitoring at the McGinness study area, California, 2012–18. Data Series. U.S. Geological Survey, U.S. Department of the Interior.

Project # 10

RAVEN DISEASE EXPOSURE IN THE GREAT BASIN

Background

- A seroprevalence study of select pathogens was completed in 2016 for Greater Sage-grouse populations within the Great Basin in which serum antibodies against Avian leukosis virus, Avian influenza virus and *Pasteurella multocida* were detected.
- Another important emerging disease in North America is mosquito-borne West Nile Virus (WNV). Previous studies in geographic regions outside the Great Basin have been conducted to establish environmental factors, prevalence, resistance, and mortality associated with West Nile virus in sage-grouse communities.
- Ravens, and other corvids, may play an important role in spreading infectious diseases, such as WNV, to wild and domestic animals within the U.S. Ravens are capable of long

distant movements and often use remote water sources where WNV exposure is increased. Furthermore, ravens often interact with each other and sensitive prey species, like sage-grouse, during feeding and social behaviors and have a potential to infect other species. To better understand potential avian diseases in ravens, we are collecting serological data from captured and deceased wild ravens across Nevada.

Methods

- Capture live ravens using spotlighting techniques at multiple sites in Nevada Ravens and collect serological data.
- Captured ravens are marked with Global Positioning System (GPS) satellite transmitters.
- Acquire deceased ravens from multiple sites in Nevada.
- Serum samples will be analyzed by an enzyme-linked immunosorbent assay (ELISA; IDEXX Laboratories, Inc., Westbrook, Maine, USA) for antibodies to Avian influenza virus, West Nile virus, Avian pox virus, Reticuloendothelial virus, Avian leukosis virus (subtypes A, B, J), Infectious Bronchitis virus, Infectious Bursal Disease virus, P. *multocida*, S. *enteritidis*, S. *typhimurium*, M. *gallisepticum*, and M. *synoviae*. Samples with positive Avian Influenza virus titers will be confirmed by Agar Gel Immunodiffusion.

Results (PRELIMINARY)

- We have captured and collected blood from 6 ravens in the Great Basin.
- Two were in the Virginia Mountains and four were captured in the Reese River Valley south of Battle Mountain.
- Samples are currently being stored at the Dixon Field office.

Products

- We anticipate publishing 1-2 peer reviewed papers, multiple reports, and presentations at scientific conferences from these data.

Project # 11

EFFECTIVENESS OF EGG-OILING RAVEN NESTS USING DRONE TECHNOLOGY AND SAGE-GROUSE NESTING RESPONSES

Background

- Ravens are a subsidized predator linked to population declines of several species of conservation concern, including sage-grouse.
- Multiple management options are needed to inform a targeted management plan aimed at reducing impacts of breeding ravens on their prey species.
- Oiling raven eggs during late incubation could be an effective approach to reduce nest predation activity by ravens for sage-grouse and other sensitive prey species.
- Recent advances in drone technology has reduced logistical challenges to oiling eggs in tall structures.
- Scientific study is needed to measure the efficacy of egg oiling as a management action.

Methods

- We are leveraging existing demographic data collected previously from four sage-grouse populations to estimate the impacts of egg-oiling in a Before After Control Impact (BACI) study design.
- We have established three control sites and two treatment (egg-oiling) sites with before and after data to measure differences in raven nest propensity, raven egg success, sage-grouse nest propensity, and sage-grouse nest success between before and after treatment in relation to the control.
- We are currently using drones equipped with sophisticated oiling equipment and guiding cameras to effectively oil eggs in tall structures that cannot be accessed with conventional methods.

Results (PRELIMINARY)

  - We have carried out field work for one season and preliminary findings suggest effectiveness at discouraging raven reproduction.
  - Preliminary results suggest an approximately 50% increase in nest survival rates between before and after relative to the control sites.

Synthesis

- These results will be used to help inform targeted management plans that minimize disease exposure to ravens.
- Results will also provide valuable information regarding the role of predation between transient (non-breeding) ravens versus resident (breeding) ravens.
- Ultimate results can be incorporated into conservation planning tools that target specific nest survival probabilities of sage-grouse that lead to sustainable populations.

Products

11a. Brussee BE, Coates PS (2018). Reproductive success of Common Ravens influences nest predation rates of their prey: implications for egg-oiling techniques. Avian Conservation and Ecology 13(1):17. https://doi.org/10.5751/ACE-01207-130117

11b. Sanchez CA, Coates PS, Shields T, Vaughn M, Delehanty DJ. (2021; *presentation*). Oiling common raven eggs to aid greater sage-grouse reproduction. Idaho Chapter of The Wildlife Society, Annual Conference, February 25, 2021, Virtual.

11c. Sanchez CA, Brussee BE, Coates PS, Holcomb KL, Harju S, Shields T, Vaughn M, Prochazka BG, Mathews SR, Cornell S, Olsen CV, Delehanty DJ (2021; *presentation*). Efficacy of common raven reproduction manipulations at conserving sensitive prey species: three case studies. Turtle Survival Alliance, Annual Conference, Virtual.

11d. Sanchez CA, Brussee BE, Coates PS, Holcomb KL, Harju S, Shields T, Vaughn M, Prochazka BG, Mathews SR, Cornell S, Olsen CV, Delehanty DJ (2021; *presentation*). Efficacy of common raven reproduction manipulations at conserving sensitive prey species: three case studies. The Wildlife Society, Virtual.

11e. Sanchez CA, Coates PS, Shields T, Vaughn M, Dudley IC, Delehanty DJ (2020; *poster presentation*). Oiling Common Raven Eggs to Aid Greater Sage-Grouse Reproduction. The 67th Annual Meeting of the Western Section of The Wildlife Society, February 2–7, 2020, Redding, CA, USA.

11f. Sanchez CA, Coates PS, Shields T, Vaughn M, Mathews SR, Delehanty DJ (2020; *poster presentation*). Oiling common raven eggs to aid greater sage-grouse reproduction. Poster presented at Bird Damage Management Conference, February 12, 2020, Salt Lake City, UT, USA.

11g. Sanchez CA, Coates PS, Shields T, Vaughn M, Mathews SR, Delehanty DJ (2020; *poster presentation*). Reducing the impact of common ravens on greater sage-grouse through egg-oiling. Idaho Chapter of The Wildlife Society, March 11, 2020, Moscow, ID, USA.

11h. Sanchez CA, Brussee BE, Coates PS, Holcomb KL, Harju SM, Shields TA, Vaughn M, Prochazka, BG, Mathews SR, Cornell S, Olson CV, Delehanty DJ (*In review*). Efficacy of common raven reproduction manipulations at conserving sensitive prey species: three case studies. *Human–Wildlife Interactions*.

Projects # 12

COMPREHENSIVE LITERATURE REVIEW OF RAVEN SPACE USE, DEMOGRAPHY, AND IMPACTS TO SENSITIVE PREY SPECIES

Background

- Ravens are generalist predators and have been documented depredating the eggs and young of other avian species.
- While demographic studies of ravens span decades, our understanding of the effects depredation by ravens on listed species remains in its infancy.
- To address the needs of wildlife biologists for the best available science in the development of species management plans, we set out to accomplish two main objectives.
- In Objective 1, we identified and summarized literature regarding the occurrence, resource use, and demography of ravens.
- In Objective 2, we conducted a literature review to assess the impacts that nest depredations by ravens have on listed avian species.

Methods

Objective 1.

- We reviewed the maturing scientific literature on the ecology of ravens in western North America and Greenland, regions characterized by concerns of the impacts of growing raven populations.
- We categorized studies as describing three ecological processes describing the ecology of ravens: raven occurrence, raven resource use and raven demography.
- We identified 49 studies, primarily original research papers.
- Most of these studies were conducted in western North America, primarily in the Mojave and Colombia Plateau ecoregions.
- Most studies reported on a single ecological process but nine reported on multiple ecological processes.

Objective 2

- We reviewed the scientific literature for impacts of nest predation by ravens on listed avian species in the U.S. and Canada.

Results (PRELIMINARY)

- Results related to raven occurrence appeared 28 times, demographic results appeared 21 times and resource use was reported 12 times.
- We also identified 13 explanatory covariates used to explain variation in raven ecological processes.
- Greater attention was given to covariates including vegetative landcover, human settlement and recreation and linear right-of-ways that were used to explain ecological processes.
- Most demographic studies considered reproduction only while few studied raven survival.
- We conclude by summarizing key findings as it relates to covariates used to explain variation in ecological processes.
- We found evidence that nest predation by ravens impacts nine listed avian species: greater sandhill cranes (*Antigone canadensis tabida*), piping plovers (*Charadrius melodus*), snowy plovers (*Charadrius nivosus nivosus*), least terns (*Sterna antillarum*), marbled murrelets (*Brachyramphus marmoratus*), California condor (*Gymnogyps californianus*), greater sage-grouse (*Centrocercus urophasianus*), Gunnison sage-grouse (*Centrocercus minimus*) and San Clemente loggerhead shrike (*Lanius ludovicianus mearnsi*).

Synthesis

- Our results reflect the known biological impacts of nest predation by ravens but are unavoidably biased by unequal information available between species.
- We intend for these results to serve as a reference for management and to help guide future research.

Products

12a. Coates PS, Webb WC, Dettenmaier SJ, O'Neil ST, Brussee BE, Harju SM, Dinkins JB (*In review*) Occurrence, resource use, and demography of the common raven (*Corvus corax*) in western North America: a synthesis of existing knowledge and assessment of impacts on sensitive species. U.S. Geological Survey, Restricted-File Federal Interagency Report (*Submitted internally with USGS, 2021*).

12b. Coates PS, O'Neil ST, Atkinson JL, Brussee BE, Jackson PJ, Delehanty DJ (2019; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. The 18th Wildlife Damage Management Conference, March 25–27, 2019, Starkville, MS, USA.

12c. Coates PS, O'Neil ST, Atkinson JL, Brussee BE, Jackson PJ, Delehanty DJ (2020; *presentation*) Effects of common ravens on greater sage-grouse in the Great Basin region, USA. Bird Damage Management Conference, February 10–13, 2020, Salt Lake City, UT, USA

12d. Webb WC, Coates PS, Dettenmaier SJ, & Delehanty DJ (*In review*). Occurrence, resource use, and demography of the common raven in North America: a research synthesis. *Human-Wildlife Interactions*

12e. Coates PS, Webb WC, Dettenmaier SJ, Harju SM, Delehanty DJ (*In review*). Synthesis of nest predation impacts of common ravens on sensitive avian species. *Human-Wildlife Interactions*

Other #13

OTHER RAVEN PRODUCTS

13a. Dwight IA, Coates PS, O'Neil ST, Brussee BE, Webster SC, Jackson PJ, Howe KB, Foster LJ, Moser AM, Delehanty DJ (2021; *presentation*) Environmental and anthropogenic factors that influence raven populations: implications for transmission lines and other tall structures. *NDOW Raven Management Workshop and Forum,* August 31,2021, Elko, NV, USA.

13b. Jackson PJ, Coates PS, O'Neil ST, Brockman JC, Spencer JO, Williams PJ (2021; *presentation*) Effects of corvicide DRC-1339 on raven density in Nevada. *NDOW Raven Management Workshop and Forum*, August 31,2021, Elko, NV, USA.

13c. O'Neil ST, Coates PS, Brockman JC, Jackson PJ, Spencer JO, Williams PJ (*In review*). Inter- and intra-annual effects of lethal removal on common raven abundance in Nevada and California, USA. *Human–Wildlife Interactions*.

13d. Harju SM, Coates PS, Dettenmaier SJ, Dinkins JB, Jackson PJ, Chenaille MP (*In press*). Estimating trends of common raven populations in North America 1966—2018. *Human-Wildlife Interactions*.

13e. Holcomb KL, Coates PS, Prochazka BG, Shields T, Boarman WI (*In review*). A desert tortoise-common raven viable conflict threshold. *Human-Wildlife Interactions*.