GROUSE NEWS

Newsletter of the Grouse Group *of the*
IUCN-SSC Galliformes Specialist Group

Galliformes Specialist Group

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Chair Grouse Group within the IUCN-SSC Galliformes Specialist Group

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Editorial Board

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From the Editors

Back in 1978 when the first International Grouse Symposium was arranged there was already considerable knowledge of grouse ecology. And the amount of scientific publications has increased since that time. This has resulted in a better management of these birds. Despite this many grouse populations are still declining in many areas.

Grouse News has been in existence for more than 30 years. It started after the 5th International Grouse Symposium at Elverum, Norway, where Professor David Jenkins suggested the need for a publication to connect grouse people. The first years much of the contributions where from Europe, but in the recent years more and more has come from outside this area. The aim is to have a more even distribution of contributions throughout the grouse area, and also species of grouse.

In this issue you may read about drivers of black grouse *Tetrao tetrix* trends in the French Alps, the prevailing contribution of climate and distribution of Hazel Grouse *Tetrastes bonasia* in Hokkaido, Japan, and helminth parasites in spruce grouse. Under conservation news there is a note on translocation of white-tailed ptarmigan in New Mexico. An article about the Grouse Church is found under Researchers and their Best Friend Assistants. And we continue the presentation of grouse stamps. A new book published this year in Spanish, El último urogallo (the last capercaillie), is dealing with the Cantabrian capercaillie. As usual the recent grouse literature is made in a perfect way by Don Wolfe.

One of our good colleagues has passed away. Arthur T. Bergerud, born 11th November 1930, died 27th November 2019. This issue also includes an obituary for Tom Bergerud, who may be best known for his monumental treatise with Mike Gratson entitled "Adaptive Strategies and Population Ecology of Northern Grouse", which, along with several other contributors, summarized much of what was known about grouse population dynamics at the time. This work also presented numerous theoretical and thought-provoking ideas, many of which were later proven to be true as grouse research advanced in subsequent decades.

The 15th International Grouse Symposium will be 12-19 September 2022 in Białystok, Poland. The 34th Meeting of the Prairie Grouse Technical Council is planned to be in Montana October 3-6, 2022 and the 33rd Sage- and Columbian Sharp-tailed Grouse Workshop is scheduled for August 15–18, 2022 on the campus of Utah State University in Logan, Utah. The 8th WPA International Galliformes Symposium will be in Prigen, East Java, Indonesia from 12th to 14th October 2022. In the text from the chair more conferences are listed. Abstracts from, 2021 WAFWA Sage- and Columbian Sharp-tailed Grouse Workshop, 2021 American Ornithological Society and the Society of Canadian Ornithologists-Société des ornithologistes du Canada Conference and 2021 Annual Conference of The Wildlife Society is also published under conferences.

We welcome articles, reports from projects, conservation news; abstracts from papers (if permitted by the journal) and also other things you think may be of interest to grouse people. Remember that the primary function of Grouse News is to publish interim papers, which the big journals would usually reject. Hypotheses and new techniques can be described to colleagues in the grouse world without precluding eventual publication of a completed study elsewhere.

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From the Chair

The COVID-19 situation is still a problem in the grouse world, but there are hopeful indications that life is beginning to return to normal. After 2 years of virtual conferences, there is a strong effort to resume in-person meetings in 2022. One example is the biennial Sage- and Columbian Sharp-tailed Grouse Workshop. The meeting was originally scheduled for June 2020 but was rescheduled for June 2021 with the hope that the meeting could be held in person. That turned out to be wishful thinking and the meeting had to be held virtually. In the business meeting portion of this year's workshop, attendees decided to hold the next meeting in Utah in June 2022 in a resumption of the original biennial schedule. It was interesting to listen to the comments of the attendees that were both hopeful and excited about a return to in-person meetings.

Other scientific groups and professional organizations appear to be following a similar pattern. With regularly scheduled conferences, and conferences that were postponed because of COVID-19 (see partial list below), 2022 is shaping up to be a very busy year. There are three grouse conferences scheduled including Utah (USA), Poland, and Montana (USA). The other listed conferences are general but often have grouse presentations. If a complete resumption of travel does not happen as predicted, it is not clear which of these meetings will be virtual and which will be postponed. Hopefully the conferences will take place as planned.

North American Wildlife and Natural Resources Conference: 14-18 March 2022, Spokane, Washington, USA (first in-person annual meeting since 2020)

International Conference on Human-Wildlife Conflict and Coexistence: 28–30 March 2022, Oxford, United Kingdom (rescheduled following postponement)

American Ornithological Society: 27 June-1 July 2022, San Juan, Puerto Rico (first in-person annual meeting since 2019)

North American Congress for Conservation Biology: 16-21 July 2022, Reno, Nevada, USA (first in-person biennial meeting since 2018)

Ecological Society of America: 14–19 August 2022, Montréal, Québec, Canada (first in-person annual meeting since 2019)

Western Association of Fish and Wildlife Agencies Sage- and Columbian Sharp-tailed Grouse Workshop:15–18 August 2022, Logan, Utah, USA (first in-person biennial meeting since 2018)

European Congress of Conservation Biology: 22–26 August 2022, Prague, Czech Republic (1-year delay from the typical triennial schedule)

International Society for Behavioral Ecology: 11–16 September 2022, Melbourne, Australia (2-year delay from the typical biennial schedule)

International Grouse Symposium: 12-16 September 2022, University of Białystok, Poland (1-year delay from the typical triennial schedule)

Prairie Grouse Technical Council Conference: 4-6 October 2022, Lewiston, Montana, USA (1-year delay from the typical biennial schedule)

International Galliformes Symposium: 12-14 October 2022, Prigen, East Java, Indonesia (On schedule for the typical triennial schedule)

The Wildlife Society: 6-10 November 2022, Spokane, Washington, USA (first in-person annual meeting since 2019)

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NEWS FROM GALLIFORMES SG

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NEWS FROM GROUSE GROUP

CONSERVATION NEWS

New Mexico White-tailed Ptarmigan Translocation

In late September, 2021, the New Mexico Department of Game & Fish translocated 24 White-tailed Ptarmigan from Colorado's Front Range and San Juan Mountains to the Pecos Wilderness Area in an attempt to restore site occupancy at the southern extent of the natural range of this species. Survival, habitat use, and productivity of the newly released birds will be intensively monitored over the next three years to assess the relative viability of the nascent population.

RESEARCH REPORTS

Drivers of black grouse trends in the French Alps: the prevailing contribution of climate.

Coline Canonne, Marc Montadert & Aurélien Besnard.

Introduction

In addition to the changing patterns of human land use and recreative activities, ongoing climate change is occurring faster in mountains than in plains and is expected to have a strong impact on mountain ecosystems (Scridel et al., 2018). The aim of this study was to explore the relative contribution of global changes on black grouse (Tetrao tetrix) population trends in the French Alps. The black grouse is an emblematic species of cold ecosystems, inhabiting a broad range of mountainous and boreal habitats. Despite its large global population, like all alpine Galliforms, the species is considered in need of conservation and is listed in Annex I and II of the EU Birds Directive, while still hunted. The black grouse is a particularly relevant case study for investigating the interactions and relative contribution of different global changes as the species is expected to be sensitive to pressures such as habitat fragmentation (Kurki et al., 2000), forest maturation, either shrub encroachment of alpine pastures or intensification of grazing (Strebel & Bühler, 2015), climate change (Barnagaud et al., 2010), development of recreational activities (Patthey et al., 2008) and hunting (Zbinden et al., 2018). In this study, we estimated site-specific population growth rates in a network of sites and used them to explore the spatial structure of trends. We then tested for the potential effect of selected climatic factors and recreative activities on both long-term population trends and inter-annual variation in population growth rates to investigate the relative contribution of these factors to the population dynamics of this species in the Alps.

Methods

We used counts of singing males from a network of 47 monitoring sites dispersed across the French Alps and surveyed since the 1980s or 1990s (Montadert, 2016). We defined four regions based on bio-geographic characteristics: northern pre-Alps (13 sites), northern internal Alps (16 sites), southern pre-Alps (6 sites) and southern internal Alps (12 sites). We estimated black grouse population growth rates using state space models and tested for effects of biotic and abiotic pressures on both long-term trends and inter-annual variations in these rates (Furrer et al., 2016).

Results

Our results showed that black grouse population trends were strongly heterogeneous in space, not just at a national scale, but also at a relatively small scale (Figure 1). Nevertheless, a general decline was found in the pre-Alps. While elevation and the start date of the vegetation season had a strong impact on site-specific trends, no significant effect of snowmelt dates and length of vegetation season were found (Figure 2). Climatic covariates also strongly influenced inter-annual variation in growth rates. We found no significant effect of harvesting or cable density on site-specific trends; however, there was a surprisingly positive correlation of inter-annual variation in growth rates with cable density. Finally, the impact of the number of harvested birds on inter-annual variation in growth rates differed between sites, with only a few sites showing strong negative or positive effects. Thus, during our study period, climatic conditions seemed to have had a much stronger influence than recreational activities on black grouse population growth rates in the French Alps.

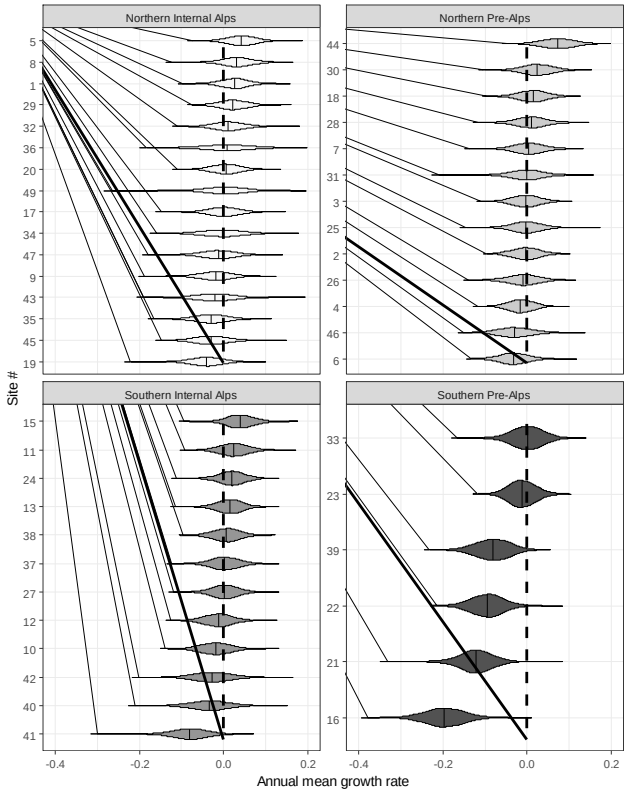

Figure 1: Violin plots of the posterior distributions of mean annual population growth rate $\overline{r_t}$ estimated with the state-space model applied on the 47 black grouse monitoring sites from 1996 to 2018. Sites are sorted by regions and according to decreasing medians (black line of each violin). Site numbers are the OGM's reference numbers.

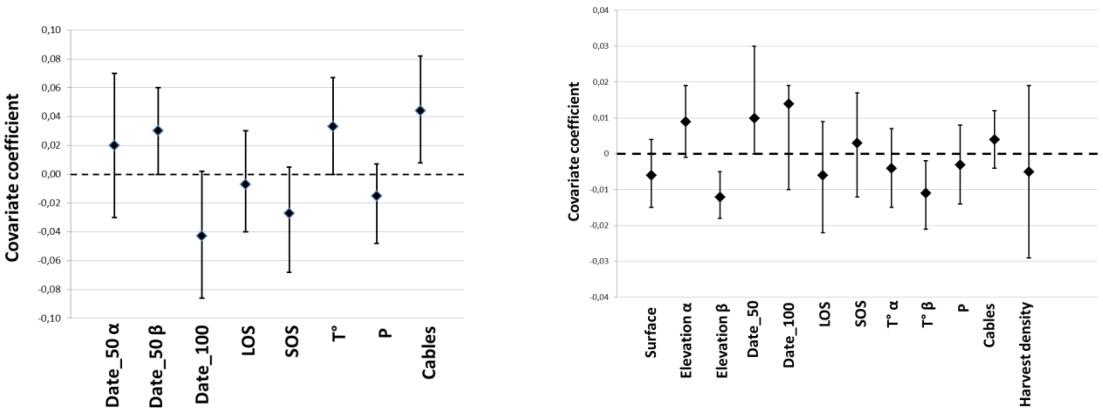

Figure 2: Regression coefficients (mean ±95%CI) of covariates' effects on inter-annual variation in growth rate on the left side, and on long term annual population growth rates on the right side. The tested covariates were the following: surface area and mean elevation of the monitoring site (Elevation and Surface), date in spring when snow cover was reduced to half of the surface area and when snow completely melted (Date_50 and Date_100), date of start and length of vegetation season (SOS and LOS), summer mean temperature and sum of precipitations (T° and P), sum of all ski cables divided by site surface area (Cables) and the number of birds harvested the previous year divided by the surface area of the site (Harvest density). Both α and β coefficients were represented for covariates for which the best model from selection was a quadratic relation.

Discussion

Our results showed that local population trends were strongly heterogeneous in space, even within the same region, with a balanced number of sites declining or increasing. This result is surprising given the overall decline of black grouse in Europe (Storch 2007). However, monitored sites we studied were not selected based on a probabilistic survey design but rather on subjective criteria, hence the overall trend is likely to be biased (Fournier et al., 2019). Unfortunately, we have no precise quantitative data about setup choice; hence, no extrapolation is feasible with these time series to get neither national nor regional trends.

Other studies on different species of grouse have observed similar strong spatial heterogeneity of population growth rates even among close populations (Cattadori and Hudson, 1999). Such strong spatial heterogeneity in population growth rates might be explained by the significant differences in local conditions even over short distances in mountains, which might overcome synchronizing drivers expected from large-scale climate patterns. Such a major role of local conditions seems to be confirmed by our study, which shows that, despite high heterogeneity in local trends, abiotic variables had a strong impact on both local trends and inter-annual variation in local population growth rates. On a given site, years with warm temperatures and early snowmelt and vegetation growth were associated with higher black grouse population growth rates, whereas we found a negative correlation between summer precipitation levels and mean annual population growth rate. Our results are in line with previous literature, warm temperatures probably favour an early start to snowmelt and the vegetative growth season (Visser et al., 2005). An early vegetation season allows hens to benefit from protein-rich vegetation during egg production, along with higher re-source availability during the chick-rearing period, factors that might improve chick body condition and in turn increase winter survival (García-González et al., 2016). Besides, high levels of precipitation and adverse climatic conditions during the hatching period and the two first weeks of a chick's life may negatively affect survival (Novoa et al., 2008). While our time series were probably too short to detect any strong signal of climatic covariates on long term trends, the strong weather signals on inter-annual variation of population size highlighted in our study suggests that ongoing and future climate change should have a strong impact on population trends.

Concerning anthropogenic activities, contrary to our expectation, cable density, used as a proxy of recreational activity near the studied sites, was not correlated to population trends, but was positively correlated to variation in local growth rates. These results are in contradiction with previous research carried out in Switzerland that showed a negative impact of ski lifts and related outdoor winter sports on black grouse abundance, after accounting for the effect of habitat type (Patthey et al., 2008). Our counterintuitive result may be explained by the fact that ski resort development in the French Alps started before World War II and continued into the 1980s, while our earliest dataset started in 1979 and most data is from the 1980s and 1990s. The impact of site-specific harvest on inter-annual variation in growth rates during our study period differed between sites, but seemed to be equally distributed around zero. Current harvest rates are considered to be very low compared to what they were before the 1990s. Today approximately 5% of the male population is estimated to be harvested each year; the number of harvested birds was about 10 times higher around 1986–88 and was 20 times higher in 1965. Today hunting quotas are also adjusted every year depending on the reproductive success of the previous year, which induce correlations within our time-series, and may even explain the positive relationship between hunting quotas and growth rates observed at some sites. The absence of strong signal of hunting in our results nevertheless do not demonstrate that the current level of hunting is sustainable at the national scale, as local harvesting may be compensated by immigration from unharvested areas (Novaro et al., 2005). Further information regarding source–sink dynamics of black grouse populations in the study area would be needed to answer this question and determine is mortality is compensatory or additive (Zbinden et al., 2018).

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Distribution of Hazel Grouse *Tetrastes bonasia* in Hokkaido, Japan

Yuzo Fujimaki1

Abstract.
A distribution map of the Hazel Grouse *Tetrastes bonasia* in Hokkaido, Japan, is presented based on the data obtained by transect and spot censuses, records in the literature and unpublished personal records. Hazel Grouse were recorded mainly in mountainous areas, where they were present in 758 out of 1,291 censused quadrats (58.7%). This density was significantly greater than that in the quadrats in plains and basins, where Hazel Grouse were recorded in 109 out of 750 censused quadrats (14.5 %). This difference is clearly evident in the distribution map provided in this study. Numerical data of occurrence rates were obtained from presence and absent data. Some vacant quadrats in distribution maps published previously were occupied, and this map might be the most detailed and accurate record of the distribution of Hazel Grouse in Hokkaido.

Key words: Distribution, Hazel Grouse, *Tetrastes bonasia*, Hokkaido.

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Potential unforeseen problems arise with translocations of spruce grouse into New York.

Angelena M. Ross

Spruce grouse (*Falcipennis canadensis*) population declines have been documented in New York since the mid-1970s. In response to these declines, the species was listed as endangered in 1999 and resources were made available to monitor populations and identify causes of the decline. By 2006, it was clear to us that spruce grouse subpopulations persisted in forest stands with younger trees and were extirpated from older-aged stands (Ross et al. 2016). In 2009, it was apparent that our shrinking subpopulations were becoming severely genetically depauperate (Kirchman et al. 2020). We subsequently developed a spruce grouse recovery plan that incorporated a population viability analysis (PVA) and outlined steps to follow to reverse the decline and ultimately, recover New York's population (Ross and Johnson 2012). Two of the most important actions proposed in the plan were to conduct habitat management and augment the New York population with individuals from more genetically diverse locations. We had begun working with private landowners in 2008 to manage forest stands for spruce grouse, and by 2013, we had completed our first year of translocations of wild-caught grouse from Ontario, Canada. Our PVA indicated that for populations to persist across the next 100 years, we had to release 50 adult grouse each year at a rate of four females to one male at 10 sites for five consecutive years.

Unfortunately, during the first few years of our translocation efforts, we grossly underestimated the time required to capture wild grouse, have them tested for diseases, and bring them home. However, we decided that it was more desirable to work through all the components of the translocations with fewer grouse, than to risk catastrophic failure with larger numbers. We needed to iron out details such as determining which transportation boxes and temporary enclosures to use to keep birds in captivity, how to effectively feed birds in captivity, the most efficient survey methods to maximize encounters, completing the necessary disease testing and veterinary visits, and getting all the paperwork together and coordinating with the US/Canada border. Each year seemed to produce a unique challenge, but finally, in 2018, we felt that we had finally achieved a smooth process. In 2019, we hit our mark of 50 adult spruce grouse successfully translocated into New York.

From 2013-2019, we released a total of 166 adult wild-caught female spruce grouse from Ontario and Maine into New York. Even though translocations took place over a continuous time frame, we view our translocations as two discrete units: 2013-2017, during which we had varying success with captures, birds escaping, and problems with disease testing; and 2018-2019, during which hang-ups were merely finding hidden pockets of spruce grouse and changing the occasional flat tire. A large contributor to the success of more recent translocation efforts is that they had the benefit of no disease testing requirements, which required only that grouse be checked visually by a veterinarian prior to translocation. Before 2018, grouse were handled multiple times, cloacas were swabbed, and birds had to live in temporary enclosures several days longer prior to being transported to New York. The extra time and handling took a notable toll on grouse survivorship.

In 2013-2017, we monitored 82 grouse via radio telemetry. During that time, we observed grouse succumb to mortality via avian predation (n=41), vehicle strikes (n=5), accidental shooting (n=8), tracheal worms (Syngamus spp.) (n=2), captures for radio change (n=2), and unknown causes (n=24) (e.g., radio failures). In 2018-2019, we monitored 56 grouse via radio telemetry and began noticing a strange pattern of mortality by which numerous grouse (n=22) were found intact, with no obvious signs of depredation. Of the 56 grouse monitored in 2018-2019, we concluded that mortality resulted from avian depredation (n=25), vehicle strikes (n=2), accidental shooting (n=1), tracheal worms (n=5), and

unknown causes (n=7). However, additional grouse (n=12) were infected with tracheal worms, but likely died from other proximate causes, such as West Nile Virus or aspergillosis. Grouse that presumably died from infection with *Syngamus* spp. had between 5 and 22 worms present in the trachea (Figure 1). Some grouse had airways that were almost completely occluded (Figure 2). Five necropsies were still pending at the time this article was written. All grouse were collected in the field and necropsies were conducted at the New York Department of Environmental Conservation Wildlife Health Unit in Delmar, New York.

*Figure 1. Eleven Syngamus trachea from a single spruce grouse (*Falcipennis canadensis*) translocated from Canada to New York in 2018 (Photo by NYSDEC Wildlife Health Unit).*

After learning about the presence of these worms, we reviewed our notes and found that some of the translocated grouse had vocalized with raspy or "gurgly" tones while they were afield or in captivity. We had never heard our resident grouse vocalize in this manner, nor had we seen a necropsy report implicate *Syngamus* spp. in the mortality of a spruce grouse prior to our translocations. When we noticed oddities such as strange vocalizations, we housed these grouse individually or with their brood in separate temporary enclosures. Temporary enclosures were 2.5 x 3 m screen tents with no bottoms (Figure 3), staked within forested habitat, allowing grouse to stand and forage on natural substrate (Figure 4). Grouse were housed from 3-10 days prior to transport. Some grouse were housed simultaneously ($n \leq 3$ adults) in enclosures, likely mixing with infected hens and broods and others were housed in the same enclosures in succession. There is no question that some of our captured spruce grouse were already infected prior to release in New York. The bigger question is whether we caused the infection of additional grouse while we housed them in the same enclosures

*Figure 2. Multiple Syngamus trachea in a spruce grouse (*Falcipennis canadensis*) almost completely occluding the airway (Photo by NYSDEC Wildlife Health Unit).*

as infected grouse, and even more importantly, what steps we could take to ensure that we do not cause additional infection of translocated grouse, thereby undermining our recovery program. Not to mention that we also could have caused undue stress to the resident population by introducing this parasite. Fortunately, *Syngamus* spp. has been noted in wild New York bird populations, but to our knowledge, it had not yet been documented in New York spruce grouse.

*Figure 3. Temporary enclosure housing spruce grouse (*Falcipennis canadensis*) in Ontario, Canada prior to translocation into subpopulations in New York (photo by A. Ross).*

Helminthic infections have been associated with reductions in productivity in geese (Vanparijs 1984) and cyclic mortality events in red grouse (*Lagopus lagopus*) (Newborn and Foster 2002). *Syngamus* spp. has been observed in willow grouse (Wissler and Halvorsen 1975) and numerous species of passerines (Campbell 1935). Treatments such as the use of medicated grits have proven effective at managing these parasites, but diligence to ensure that parasites do not become resistant to drugs is necessary. Medicated grit is readily available, has a good record of success, and could be an option while our grouse are being housed temporarily in enclosures. However, grouse are released in spruce-fir forest interiors and it would not be feasible to treat grouse at release sites post-release. A more direct approach, like topical treatment of the crop with Worm Away (Morning Bird, Inc., Morgan Hill, California) or a similar drug would be advantageous while grouse are in the hand. Another option, such as treating the water provided in enclosures may prove effective, but it may also be problematic as grouse may not drink

*Figure 4. Male spruce grouse (*Falcipennis canadensis*) inside a temporary enclosure in Ontario, Canada, highlighting vegetation structure inside (Photo by A. Ross).*

the water or they may not drink it for a long enough time frame for the drugs to be effective. To date, we have not observed any individuals drinking water from the water trays while in the tents. We suspect that birds had instead stayed hydrated by ingesting dew on the vegetation, the vegetation itself, and the provided blueberries they consume. Since we will be continuing these translocations for another four years, we ask for suggestions to help us deal with these parasites to make our translocations more successful.

We also have the questions to pose to other grouse experts:

Does anyone have experience with a topical de-wormer, and can they provide any information on its efficacy or recommend a commercially available one?

Is there any harm in treating all birds with a topical de-wormer upon capture independent of whether they show clinical signs of infection?

Is supplying the grouse with medicated grit a better option to direct application of a de-wormer to their crop while they reside in enclosures?

Is treating the vegetation and soils in between housing different cohorts of grouse feasible and if so, what could be used?

Would moving enclosures between capture cohorts be effective at preventing infection of additional grouse after previous cohorts have been vacated?

Acknowledgement

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CONFERENCES

The 15th International Grouse Symposium Białystok, Poland 2022

The 15th International Grouse Symposium will be hosted by University of Białystok (UoB), on September 12-16, 2022. The 15th IGS is co-organized by three institutions: University of Białystok, the Chapter of Polish Academy of Sciences in Białystok and Olsztyn and Directorate of Polish State Forests in Białystok.

Białystok is the largest city of North-East Poland, with a convenient connection from Warsaw by car or a fast train (2.20 h. ride). The Symposium will be held at the brand-new Campus of Natural Sciences of the UoB.

The 15th IGS will follow the format of the successful 2018 Logan Symposium, with a day of workshops, 2-3 days of talks, and post-conference fieldtrips. The scope of the conference will highlight the progress made in grouse genetics of physiology applied to conservation and population management.

The organizers will offer two post conference field trips: to the Bialowieza Forest-- UNESCO World Heritage site and the Gleboki Brod Forest District located in the Augustowska Forest- the site of the on-going program of the restitution of the lowland population of the Capercaillie.

For more information please visit the IGS15 webpage www.igs2022.uwb.edu.pl. For enquires please contact the members of the Local Organizing Committee of the 15th IGS: prof. Marek Konarzewski (marekk@uwb.edu.pl) and Dorota Ławreszuk (dorota.lawreszuk@bialystok.lasy.gov.pl).

34th Meeting of the Prairie Grouse Technical Council – October 3-6, 2022

On October 3-6, 2022, Montana is planning to host the 34th Conference of the Prairie Grouse Technical Council. During this 4-day conference, prairie grouse scientists and managers from across the continent will assemble in Lewistown to discuss contemporary research, management, and conservation issues of greater and lesser prairie-chickens, sharp-tailed grouse, and sage-grouse. Montana has not hosted the PGTC since 1991. Despite a 1 year COVID-related delay, the PGTC is excited to bring the conference back to the Treasure State.

Planning for the conference is ongoing, but please save the date and plan to join us in Lewistown, October 3-6, 2022. Abstract submissions for presentations will likely open Spring 2022. Please keep an eye on the website (link below) for updated information. Conference home page: www.prairiegrousecouncil.org

PGTC Chair and conference contact: Lance McNew, Montana State University, (406) 994-6645; lance.mcnew@montana.edu

The 33rd Sage- and Columbian Sharp-tailed Grouse Workshop

The 33rd Sage- and Columbian Sharp-tailed Grouse Workshop is scheduled for August 15–18, 2022 on the campus of Utah State University in Logan Utah. The previous meeting was virtual in June 2021 and was organized by the state of Oregon. There are preliminary plans for the WAFWA Sage- and Columbian Sharp-tailed Grouse Technical Team and the Range-wide Interagency Sagebrush Conservation Team to meet on August 15th. Research and poster presentations will take place on August 16th and 18th. A field tour to grouse habitat will be conducted on August 17th. There will be a block of rooms available at the University Inn on the Utah State University Campus (which includes complimentary breakfast), and other hotels (to be decided). The closest major airport is Salt Lake International. Updates will be posted at https://wafwa.org/workshops/grouse-workshop/ when they are available.

WPA International Symposium on Galliformes 2022

The World Pheasant Association (WPA) has announced that they expect to hold the 8th International Galliformes Symposium in Prigen, East Java, Indonesia from 12th to 14th October 2022. Such symposia are held triennially, the last having been in Vietnam in 2019. An organising committee and scientific sub-committee have been formed. Post-symposium visits to Baluran (green peafowl and junglefowl) and Sulawesi (maleo breeding grounds) are planned.

While most readers of *Grouse News* will likely have an interest in more temperate and colder regions, do note the phylogenetic position of grouse nested within phasianids, and the opportunities for contrast and comparison with other galliforms such as tropical forest partridges and megapodes.

WPA expects the symposium to go ahead as planned, though there will be Covid contingencies as necessary. Anyone interested should first contact Barbara Ingman at office@pheasant.org.uk.

Dr Geoffrey Davison, National Parks Board, Singapore, davisongwh53@gmail.com.

2021 WAFWA Sage- and Columbian Sharp-tailed Grouse Workshop

Michael A. Schroeder

The Western Association of Fish and Wildlife Agencies (WAFWA) Sage- and Columbian Sharp-tailed Grouse Workshop was held virtually on 21–24 June 2021. The Oregon Department of Fish and Wildlife (ODFW) hosted the workshop with a theme of "Pioneering Conservation". ODFW originally planned to host the biennial meeting in Bend, Oregon in June 2020 but had to delay the meeting for a year because of COVID-19. The next hosts (Utah Department of Natural Resources) intend to resume the normal biennial schedule by hosting the next meeting in 2022.

At each workshop the Robert L. Patterson Award is used to recognize exemplary contributions to sage and Columbian sharp-tailed grouse research and management over a period of at least 20 years. This year Dr. Peter Coates (USGS) and Shawn Espinosa (Nevada Department of Wildlife) were recognized with the Patterson Award. Both have contributed excellent research, management, and collaboration that benefited grouse in Nevada, and throughout the range. The Young Professional Award is used to recognize the best presentation at the workshop. The presenter must demonstrate that their work will further grouse conservation and management. This year's award recognized Benjamin Robb, who was selected from a total of 18 young presenters.

The keynote address was given by Dr. Mary Zeiss Stange, author of "Hard Grass – Life on the Crazy Woman Bison Ranch". There were 60 talks and posters at this year's meeting. The following is a list of presentations (papers and posters) and abstracts for this year's workshop (alphabetical by first author).

Management-focused habitat selection models for Gunnison sage-grouse

(C. L. Aldridge, D. J. Saher, M. S. O'Donnell, and J. H. Heinrichs):

Gunnison sage-grouse (*Centrocercus minimus*) are a threatened species, and conservation, species recovery, and habitat management efforts are needed in six isolated satellite populations which are declining (San Miguel, Crawford, Piñon Mesa, Dove Creek, Cerro Summit-Cimarron-Sims, and Poncha Pass). We developed a set of habitat selection models across satellite populations using a management-centric modeling approach to evaluate the consistency of key habitat conditions and improvement actions while allowing context-specific environmental variables and spatial scales to nuance selection responses. We used multi-scale and seasonal resource selection analyses to quantify relationships between environmental conditions and sites used by animals. All models included key habitat variables often altered through management actions. We found important similarities and differences among satellites, indicating that although some rules of thumb are generally well-grounded, the consideration of location-specific environmental differences could increase the efficiency of habitat improvement actions. Sage-grouse also had diverse responses to resource conditions at different scales, indicating that regional (e.g., landscape) and local (90 m vs. 570 m) scale conditions can differently influence expected habitat improvements and management actions. These models and approaches may benefit spatially structured populations with different environmental contexts and species with complex habitat needs and associations.

Have past sampling bias, lek count averaging, and increased sampling led to some overestimates of greater sage-grouse population declines?

(R. S. Arkle, D. S. Pilliod, M. I. Jeffries, J. L. Welty, E. Ellsworth, and A. Moser):

It is widely accepted that greater sage-grouse populations have been in decline for decades across the Intermountain West. However, preliminary findings from the examination of 70 years of data from Idaho indicate that several factors related to sampling and summarizing of lek count data could result in overestimates of decline magnitude. Evidence suggests that not all leks within a given cluster, or sub-population, are equally important and that selection by grouse, or differences in recruitment, may result in a desirability hierarchy. Along these lines, early investigators may have understandably selected the larger leks for monitoring. As concern over population trends grew around 1990, substantially more leks were sampled annually, resulting in a disproportionate number of smaller leks contributing to population estimates calculated over the last 30 years. As additional leks within sub-populations are surveyed within a given year, average male counts decline sharply, whereas the total number of males counted plateaus. This phenomenon was observed even during the 1950s and 1960s, suggesting that: 1) even when populations were most robust during the period of data collection, that both birds and researchers were selecting for certain lek types, and 2) that the widely-employed practice of averaging lek counts within sub-populations may result in declining trends if more leks are sampled over time.

Playa Restoration Project: A multiple resource restoration effort

(L. W. Ashton III, E. K. Lent, and J. Cooper):

Playas are low lying depressions with clay soils where water seasonally collects across the high desert. Playas provide limited suitable growing conditions required by some forbs and insects. These features provide important habitat to sage-grouse rearing their broods. When the west was settled, playas were altered by digging deep into the center, allowing water to collect for livestock. The water footprint then decreased in size, thus reducing the amount of forbs and insects at the playas. Because of this, the quality of brood-rearing habitat was reduced or lost completely. Over the past 10 years, the Prineville District BLM has collaborated with multiple resource specialists, grazing permittees, and partners to restore two altered playas on BLM managed lands. Within this case study planning, implementation, and lessons learned will be analyzed.

Feral horse impacts on greater sage-grouse nest site selection and success

(J. L. Beck, P. Street, J. D. Hennig, A. C. Pratt, J. D. Scasta, C. Powell, and K. T. Smith):

Burgeoning feral horses (*Equus ferus caballus*) have been identified as a potential threat to many greater sage-grouse (*Centrocercus urophasianus*) populations. Though feral horses are thought to negatively impact sage-grouse, until recently, quantitative investigation has generally focused on better understanding habitat alteration. We evaluated the potential impact of free-roaming horses on greater sage-grouse nest site selection and survival. During August 2019 we recorded horse feces along 230, 1-km transects across two study areas. We modeled nest site selection and nest survival from sage-grouse nests near Jeffrey City in central Wyoming and Adobe Town in south-central Wyoming. These two study areas were both impacted by feral horses with the highest fecal density in Adobe Town. Patterns in sage-grouse nest site selection were similar across study areas, with selection for greater big sagebrush (*Artemisia tridentata*) canopy cover. Females tended to nest in areas with greater horse fecal density, suggesting that sage-grouse and feral horses selected sites with similar resources. However, we found moderate support that sage-grouse in both study areas had lower nest success in areas with higher horse fecal densities These results contribute to a growing body of literature suggesting feral horses may be negatively impacting sage-grouse populations where populations overlap.

Molecular insights on greater sage-grouse breeding strategies in the northwestern Great Basin

(T. L. Behnke, P. A. Street, S. Davies, J. Q. Ouyang, and J. S. Sedinger):

Though sage-grouse males are fully on display during the breeding season, female mating behavior is more secretive. Genetic analysis can reveal true parentage of resulting clutches. We extracted DNA from 350 eggs in 46 clutches and feathers of putative mothers from our study site in Northwestern Nevada. We targeted 14 microsatellite loci developed for sage-grouse and one sex determination locus. Using the female feather samples, we verified maternity to examine nest parasitism, and then reconstructed possible male genotypes and looked for evidence of multiple matings. We found four clutches that had at least two distinct sires, but no evidence of nest parasitism by other females. For one clutch, the two males each sired half of the offspring. In the other three, only one or two eggs were of different parentage than the rest of the clutch. We found additional single-locus mismatches, but we cannot determine if these are

from closely related additional parents or genotyping errors. Multiple parentages in clutches may help maintain genetic diversity for the population or allow females to hedge their bets on male quality, and therefore the quality of offspring. These results provide important insights about sage grouse breeding behavior that observational studies alone cannot.

Habitat selection and survival consequences for greater sage-grouse during multiple reproductive life phases

(B. E. Brussee, P. S. Coates, S. T. O'Neil, M. A. Ricca, S. P. Espinosa, and D. J. Delehanty):

Actionable science for species of conservation concern is enhanced by models that identify environmental factors linking resource selection and demographic responses during critical life-stages. We evaluated factors influencing these responses for greater sage-grouse (*Centrocercus urophasianus*) during key reproductive phases (786 nests and 356 broods) across 19 sites within the Great Basin, 2009–2018. For each life stage, we fit macro- and micro-habitat covariates to selection and survival models while accounting for climatic conditions correlated with ecological productivity. For nesting, sage-grouse selected greater sagebrush cover and height, elevation, and herbaceous cover. We found that shrub cover increased nest survival while annual grass reduced nest survival. For brood rearing, sage-grouse selected areas with greater ecological productivity, greater proportion of shrub cover, and closer to streams and springs. During this brooding stage, burned areas elicited different survival responses to annual grass than unburned areas. At microscales, vegetative cover immediately surrounding the nest was most important to selection and survival, but functional composition varied between mesic and xeric sites. For broods, areas with greater grass and forb composition were selected. We further illustrate how application of this approach facilitates comprehensive multi-scale habitat assessment for reproductive sage-grouse. Preliminary findings are provided for best timely science.

Patterns of structural connectivity in the sagebrush biome (1985–2018)

(E. K. Buchholtz, J. A. Heinrichs, M. S. O'Donnell, and C. L. Aldridge):

Disturbances across the sagebrush biome, such as fire, invasive grasses, and human development, have modified landscape patterns and connectivity through time. Wildlife have experienced habitat loss and fragmentation, with likely impacts on patterns of movement, gene flow, and related ecosystem processes. Yet, spatial and temporal changes in connectivity across the sagebrush biome are not well understood. We used an omnidirectional circuit theory approach to classify patterns of structural connectivity in the sagebrush biome between 1985 and 2018. Results identify regions of the sagebrush biome that have lost connectivity in sagebrush cover, as well as areas of persistent connectivity and locations that are transitioning to pinch points and in danger of disconnection. These findings can help characterize opportunities for proactive conservation of remaining structural connectivity of sagebrush across the biome, as well as identify degraded areas where targeted management could increase connectivity, offering benefits to multiple species.

Early estimates of exotic annual grass percent cover in the sagebrush biome, May 2021

(S. P. Boyte, D. Dahal, S. Parajuli, M. Oimoen, and N. J. Pastick):

The USGS EROS Center plans to release a dataset titled "Early Estimates of Exotic Annual Grass (EAG) in the Sagebrush Biome, May 2021," as part of the USGS Rangeland Exotic Plant Monitoring System series. The dataset estimates percent cover of EAGs across much of the western U.S. The release continues a series that, since 2015, has estimated within-year EAG percent cover (https://www.sciencebase.gov/catalog/item/5f0ddd6e82ce21d4c4053e17. Historically, EAG datasets were developed with Moderate Resolution Imaging Spectroradiometer (MODIS) data at 250-m spatial resolution, but with recent access to new remotely sensed data (Harmonized Landsat 8 / Sentinel-2) and high-performance computing, new products have a finer 30-m spatial resolution. The study area expanded almost three times and now covers all or part of 17 states. Specific species maps of cheatgrass and medusahead have been developed in addition to a general EAG map. The maps were developed using field-based BLM Assessment Inventory and Monitoring data integrated into machine-learning software with environmental, remotely sensed, land cover, soils, and vegetation data. Preliminary model accuracy metrics indicate satisfactory results (training/test R2 = 0.94/0.67 and Median Absolute Error = 2.15%/3.16%). This timely dataset represents current estimates of ecological conditions having substantial impacts on grazing and fire management in the current year.

Free-roaming horses adversely impact greater sage-grouse population dynamics in sagebrush ecosystems

(P. S. Coates, S. T. O'Neil, D. A. Muñoz, I. A. Dwight, and J. C. Tull):

Free-roaming horse (*Equus caballus*) populations have increased in sagebrush ecosystems and surpass appropriate management levels (AMLs). Concomitantly, greater sage-grouse (*Centrocercus urophasianus*) populations have declined from loss and degradation of critical habitats. Overgrazing can degrade sagebrush communities, but evidence of horse impacts on sage-grouse population dynamics is lacking. We employed Bayesian state-space models to estimate sage-grouse population rate of change (λ) using 15 years of lek surveys in relation to horse abundance (relative to AML) and other environmental covariates. For every 50% increase in horse abundance over AML, a 2.6% annual decline in sage-grouse abundance was predicted. When horse abundance was at or below AML, sage-grouse λ estimates mirrored trends at areas with no horses. Conversely, results indicated a 75% and 99% probability of λ decline relative to controls when % AML was 200% and 300%, respectively. For context, horse herds were estimated at 405% AML in Nevada, USA during 2019. Model projections indicate ~70% declines in sage-grouse populations within horse-occupied areas by 2034 if horse population trends continue unabated. Monitoring frameworks that consider sage-grouse and other ecosystem indicator species can guide management decisions promoting wildlife-livestock coexistence within multiple-use landscapes. Findings are preliminary and provided for best timely science.

A novel approach to estimating range-wide population trends for greater sage-grouse at multiple spatial scales

(P. S. Coates, B. G. Prochazka, M. S. O'Donnell, C. L. Aldridge, D. R. Edmunds, A. P. Monroe, M. A. Ricca, G. T. Wann, S. E. Hanser, L. A. Wiechman, and M. P. Chenaille):

Incorporating spatial and temporal scales into greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) population monitoring strategies is challenging and rarely implemented. Sage-grouse populations are characterized by temporal oscillations, making trend estimation sensitive to start and stop years. Accounting for environmental and demographic stochasticity is critical to reliably estimating population trends and identifying deterministic factors on the landscape more amenable to management action. We used a range-wide standardized database of lek counts within a hierarchical Bayesian state-space model and a biologically-informed, multi-scale network of breeding populations, known as 'clusters,' to estimate trends across different spatiotemporal scales. While accounting for oscillations in population abundance, our models estimated 37.0, 65.2, and 80.7% range-wide declines across short (17 years), medium (33 years), and long (53 years) temporal scales, respectively. Recent rates of decline were greater in western portions of the range, particularly the Great Basin, where wildfire and invasive grasses are prominent. Conversely, some areas in the eastern range exhibited evidence of population growth in recent decades. This modeling framework serves as the foundation for a 'Targeted Annual Warning System' decision support tool to direct management efforts toward populations with the greatest need and may be modified to evaluate the effectiveness of conservation efforts.

Analyzing the relationship of land use and land cover change with Columbian sharp-tailed grouse populations in eastern Idaho

(D. Coats, T. Calton, T. Caughlin, J. S. Forbey, and D. Delparte):

Wildfire affects habitat quality in Southeastern Idaho which is home to 65% of the Columbian sharp-tailed grouse population of North America. In Idaho's Bannock, Oneida, and Power Counties the population of Columbian sharp-tailed grouse declined over the period of 1985 to 2018. 797 fires burned habitat in those counties over the same time period. We examined trends in nearby land cover and land use within 4 kilometers of Columbian sharp-tailed grouse leks to determine the relationship between land use and land cover with counts at lek sites. We found a significant relationship between Columbian sharp-tailed grouse counts and the rate of change in nearby sagebrush and shrub land cover types, as well as the change in burned area within 4 kilometers of a lek between 1985 and 2018. A mitigating factor in strengthening habitat near lek sites is the presence of Conservation Reserve Program lands that provide nesting and brood-rearing habitat. We have identified a connection between Conservation Reserve Program land coverage and lek counts that are unchanging to increasing over the recent decade. Bolstering the Conservation Reserve Program could provide an invaluable resource for protecting Columbian sharp-tailed grouse populations in Southeast Idaho.

Using remote sensing in rangeland management: turning an abundance of spatial data into actionable information

(M. Creutzburg):

The number of maps and spatial decision support tools for rangelands in the western US has exploded in recent years as interest in rangeland management has climbed and technological advances have opened new doors. These new products offer great opportunities to incorporate data crossing broad spatial scales and long timeframes into decision-making, but also present an overwhelming amount of new and ever-changing information for users to digest. This presentation will start with some guiding principles for how to approach the use of remotely sensed maps in rangeland management, with examples of how maps can improve efficiency and effectiveness of decision-making. It will also highlight how the Oregon SageCon Partnership has leveraged new spatial data into simplified products targeted toward specific management applications, including a set of Ecostate Time Series maps to depict change in the distribution and severity of threats to rangeland ecosystems over the last few decades, and an Invasives Geographic Strategy to guide opportunities for proactive, landscape-scale management of invasive annual grasses in the state.

Historical samples elucidate sharp-tailed grouse subspecific distributions and the genetic lineage of individuals of unknown origin in southwestern Montana

(T. B. Cross, B. D. Deeble, B. G. Larkin, and K. L. Pilgrim):

We examined the subspecific assignment of historical and contemporary sharp-tailed grouse, *Tympanuchus phasianellus*, in Montana. We had two objectives: first, to find genetic evidence for the existence of and delineation between subspecies believed to be distinct to either side of the Continental Divide; second, to identify the genetic origin of a seasonal occurrence of sharp-tailed grouse in the Centennial Valley of southwestern Montana. We compared mitochondrial DNA across three different mtDNA regions from 13 historical and 22 contemporary samples (including two from greater prairie-chicken, T. cupido) to 28 publicly available sequences representing eight different species. For T. phasianellus, we found 17 control region haplotypes, three cytochrome b haplotypes, and one cytochrome c oxidase I haplotype, some of which were geographically distinct to either side of the Divide (control region: six east, eight west, three spanning; cytochrome b: two west, one spanning), suggestive of genetic isolation resulting from the Divide. However, neither individuals on either side of the Divide nor species were monophyletic within phylogenetic trees. While the Centennial Valley sample exhibited a cytochrome b haplotype found only west of the Divide, haplotypes at other regions were not geographically distinct, and phylogenetic groupings spanned populations in eastern Idaho and northeastern Montana.

Genetic recapture identifies long-distance breeding dispersal in greater sage-grouse (*Centrocercus urophasianus*)

(T. B. Cross, D. E. Naugle, J. C. Carlson, and M. K. Schwartz):

Dispersal can strongly influence the demographic and evolutionary trajectory of populations. For many species, little is known about dispersal, despite its importance to conservation. The greater sage-grouse (*Centrocercus urophasianus*) is a species of conservation concern that ranges across 11 western U.S. states and 2 Canadian provinces. To investigate dispersal patterns among spring breeding congregations, we examined a 21-locus microsatellite DNA dataset of 3,244 greater sage-grouse sampled from 763 leks throughout Idaho, Montana, North Dakota, and South Dakota, USA, across 7 yr. We recaptured ~2% of individuals, documenting 41 instances of breeding dispersal (median dispersal distance = 15 km), with seven dispersal events of >50 km, including one of 194 km. We identified 39 recaptures on the same lek up to 5 yr apart, which supports the long-held paradigm of philopatry in lekking species. We found no difference between the sexes in breeding dispersal distances or in the tendency to disperse vs. remain philopatric. We also documented movements within and among state-delineated priority areas of conservation importance, further supporting the need to identify movement corridors among these reserves. Our results can be used to inform the assumptions of count-based population models and the dispersal thresholds used to model population connectivity.

Network and resistance modeling reveal priority corridors for functional connectivity conservation of greater sage-grouse

(T. B. Cross, J. D. Tack, K. E. Doherty, S. J. Oyler-McCance, and B. C. Fedy):

Connectivity among populations is paramount to conservation. Of primary concern is identifying corridors that conserve functional connectivity. We integrated two published models of functional connectivity—a landscape resistance model and a network model—to identify, prioritize, and characterize corridors connecting greater sage-grouse lek complexes range wide. Using the network model minimum spanning tree (MST – the minimum subset of total network connections required to connect all nodes, without cycles, with the maximum possible edge weight [genetic covariance]) we identified leks connected by the greatest genetic exchange, prioritized those connections based on betweenness (the total number of pairwise network connections fostered by a given connection), then modeled corridors among connected leks by thresholding current maps based on a circuit theory analysis of the landscape resistance model. Out of 457 MST connections among 458 nodes, we identified 92 connections within the top 25% of betweenness, and thresholded the corresponding pairwise current maps to the top 0.5% of current, resulting in 6725 km^2 corridors for functional connectivity. Many of these priority corridors were central to the species range, were largely encompassed within priority areas for conservation (62% of total corridor area), and were composed of high quality breeding habitat (50% ≥65% HSI) and high sagebrush cover (60%). Nevertheless, on average, 61% of corridor area was classified as moderately resistant and resilient, 44% as moderately human disturbed, and 23% as at moderate risk of conversion to tillage agriculture.

Comparison of songbird population trends to sage-grouse lek trends: assessing sage-grouse core areas and umbrella species concept

(J. B. Dinkins and J. L. Beck):

Many conservation strategies promote the potential of multiple species benefitting from protection of large areas necessary for the continued viability of one species. One prominent strategy in western North America is Wyoming's sage-grouse Core Area Policy, which was designed to conserve greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) breeding habitat, but may also serve as an umbrella to conserve other sagebrush (*Artemisia* spp.) obligate wildlife, including songbirds. Sagebrush-obligate songbirds and sage-grouse have undergone population declines attributed to similar habitat issues. We compared trends of sagebrush-obligate songbirds from the Breeding Bird Survey and sage-grouse lek counts in two sage-grouse populations in Wyoming (Powder River Basin and Wyoming Basins), 1996–2013. Our evaluation focused on similarities among population performance of the potential umbrella species and species under that umbrella. Trends of sagebrush-obligate songbirds were not parallel or consistently similar in trajectory to sage-grouse in either Core or non-Core Areas, respectively. Our results indicated Core Areas were successful at maintaining higher sage-grouse trends compared to areas not protected under the Core Area Policy. However, sagebrush-obligate songbird trends did not follow the same pattern. This suggests that protection of only the best sage-grouse habitat may not be a sufficient conservation strategy for other sagebrush-obligate birds.

Expanding abundance of a native predator, common raven, within the habitat of two sensitive native prey species, greater and Gunnison sage-grouse

(J. B. Dinkins, L. R. Perry, J. L. Beck, and J. D. Taylor):

Common raven (*Corvus corax*; hereafter, raven) abundance has increased throughout western North America during the past century. Human subsidies have allowed ravens to maintain higher annual survival and reproduction than with natural resources alone in greater (*Centrocercus urophasianus*) and Gunnison (*C. minimus*) sage-grouse habitat. Using Breeding Bird Survey data, 1995–2014, we evaluated raven abundance and expansion into sagebrush ecosystems focusing on the seven sage-grouse Management Zones (MZs). We assessed the effects of numerous land cover and anthropogenic features on instantaneous growth rate or carrying capacity of ravens. Abundance of ravens in western and southeastern MZs was greater than northeastern MZs within the greater sage-grouse range; however, percent increase was high in all MZs. High abundance in MZ VII indicated Gunnison sage-grouse have been exposed to higher raven abundance for many years. Higher numbers or instantaneous growth of ravens was positively associated with transmission line density, proportion urban land cover within 25 km, and burned area within 3 km and negatively related to proportion forest land cover within 15 km. Our findings suggest ravens have capitalized on human subsidies to increase abundance and expand into sagebrush ecosystems, which likely has ramifications for sensitive species that inhabit sagebrush ecosystems.

Prioritizing restoration areas to conserve multiple sagebrush-associated wildlife species

(C. J. Duchardt, Adrian P. Monroe, Julie A. Heinrichs, Michael S. O'Donnell, David R. Edmunds, and Cameron L. Aldridge):

Habitat degradation in the sagebrush steppe has been linked to declines in many species, making sagebrush restoration a management priority. However, limited funding, spatiotemporal variation in restoration success, and the need to manage for diverse wildlife species makes decision-making regarding restoration actions challenging. We developed the Prioritizing Restoration of Sagebrush Ecosystems Tool (PReSET) to address this challenge. This decision support tool uses the prioritizr package in program R and an integer linear programming algorithm to select parcels representing both high biodiversity value and high probability of restoration success. We tested PReSET on a sagebrush steppe system within southwestern Wyoming using distributional data for greater sage-grouse (Centrocercus urophasianus) and 5 other wildlife species and a spatial layer of predicted sagebrush recovery times to identify restoration targets at landscape and local scales. While the broad-scale portion of our tool outputs can inform policy, local-scale results can be applied directly to on-the-ground restoration. We noted tradeoffs, including that restoring for habitat connectivity may require restoration in areas with lower probability of success. Future applications of PReSET will draw from emerging datasets, including spatially-varying economic costs of restoration, animal movement data, and additional species, to further improve our ability to target effective sagebrush restoration.

Sage-grouse response to wildfire: Analyses of range-wide effects and relationships between sage-grouse demography and underlying post-fire sagebrush recovery processes

(I. A. Dwight, P. S. Coates, C. L. Roth, B. G. Prochazka, M. P. Chenaille, M. A. Ricca, C. L. Aldridge, D. S. Pilliod, and M. Rigge):

Wildfire has long-term adverse impacts on greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) population persistence within the Great Basin. However, chronic effects of wildfire may vary across the entire distributional range of sage-grouse based on regional variation in climate and ecological properties related to sagebrush (*Artemisia* spp.) ecosystem resilience and resistance to invasive annual grasses. We extend previous methods of modeling sage-grouse population rate of change (λ) in the Great Basin to a range-wide study extent and developed an advanced sagebrush recovery model using back-in-time classification of satellite imagery in burned areas over the past 34 years. Specifically, we employed a Bayesian state-space model framework, which relates variation in λ to changes in cumulative burned area around leks, while accounting for environmental covariates and density dependent mechanisms (Gompertz). Across the range of sage-grouse, we found support for an interaction between cumulative burned area and a one-year lag effect for summer precipitation on lambda. However, the positive influence of precipitation was negated by long-term negative impacts of wildfire, yet the strength of this effect varied among regions. Understanding patterns of variation among broad-scale regions can elucidate wildfire impacts across a large ecological gradient. Findings are preliminary and provided for timely best science.

Linking microhabitat, home range, reproductive stage, and behavior in greater sage-grouse during brood-rearing season

(E. L. Gelling, A. C. Pratt, and J. L. Beck):

We linked reproductive stage, behavioral state, microhabitat selection, and home range for brood-rearing and broodless greater sage-grouse (*Centrocercus urophasianus*) to more comprehensively understand habitat selection by all females during brood-rearing. We used GPS location and accelerometer data collected every 5 min from female sage-grouse in Carbon County, Montana, and Park County, Wyoming during 2018–2019. We sampled microhabitat for 36 females at 276 bird-use and random locations, estimated home ranges for 38 females, and measured activity levels of 43 females spanning 1,317 bird-days. Broods 0–2 weeks selected microhabitat characteristics at night roosts, broods 3–5 weeks selected microhabitat features at foraging locations and night roosts; however, we did not detect significant microhabitat selection by broodless females. Broods 0–2 weeks had the smallest daily home range (0.027 km^2) compared with broods 3–5 weeks (0.038 km^2) and broodless females (0.035 km^2) and the smallest seasonal home range (0.211 km^2) compared with broods 3–5 weeks (0.363 km^2) and broodless females (0.435 km^2). Each reproductive stage differed in daily activity patterns. Our results indicate research and management decisions should consider the importance of reproductive stage and behavioral state to account for habitat and space required by all individuals in a population.

Sage-grouse seasons, home ranges and habitats, what are they and how many are there?

(R. T. Haynam, L. B. McNew, M. J. Borgreen, and J. C. Carlson):

Wildlife-habitat responses are typically inferred from population-level survival or resource selection models without regard for detailed individual- or population-level movement patterns. Improved spatial generality of inferences may be gained by linking habitat response associations with specific behaviors or activity signatures derived from movement data and expert knowledge. Any movement or phenological stage (e.g., laying, incubating, roosting, transit, exploratory, winter-ranging) may be used to define a functional habitat type. Our primary goal was to quantify sage-grouse space- and time-use signals relevant to management and parse variability in these signals into components due to spatial (landscape elements) and temporal (seasonality) characteristics, while accounting for individual-level variation. We attached a 22-g solar powered Global Positioning System (GPS) Platform Transmitting Terminal to 86 female sage-grouse in north-central Montana. We monitored females and analyzed movement behaviors using a combination of field observations, nonlinear-regression movement models, multivariate clustering techniques, and a time-local convex hull approach. Time-local convex hulls can be thought of as many brief-duration home ranges from which time- and space- use metrics can be calculated. We will present results from our north-central Montana sage-grouse movement ecology research including migration patterns, diversity of movement modes, seasonal space- and time-use patterns, and seasonal landscape-element associations.

Trade-offs in managing fire, invasion, and disturbance impacts in the greater sage-grouse landscape

(J. A. Heinrichs, E. Buchholtz, H. Sofaer, J. Kreitler, M. Crist, D. Shinneman, C. Aldridge, C. Jarnevich, D. Manier, B. Tarbox, N. Van Schmidt, J. Shyvers, J. Saher, and additional research partners):

Several landscape-level changes influence greater sage-grouse (*Centrocercus urophasianus*) habitats and populations. Increasing fire, proliferating invasive annual grasses, land-use change and disturbances impact landscapes and populations in many ways. There is increasing need to understand the combined effects of these changes and design management interventions that consider multiple threats and actions taken to address them. In this talk, we synthesize key findings from a range of research projects that model the implications of fire, plant invasion, and management actions on the sagebrush ecosystem. Results from individual studies identify multiple different management opportunities, but sometimes conflicting recommendations that require researchers and managers to balance ecological trade-offs. Syntheses among multiple projects highlights opportunities for greater integration among projects and people. We highlight specific needs for collaborative research and action, modeling approaches that integrate different kinds of information, and communication of results beyond scientific repositories.

Resource selection and occurrence overlap between feral horses, pronghorn, and greater sage-grouse

(J. D. Hennig, J. D. Scasta, A. C. Pratt, C. Powell, and J. L. Beck):

Feral horse (*Equus ferus caballus*) populations on western rangelands continue to increase, potentially impacting co-occurring wildlife, particularly greater sage-grouse (*Centrocercus urophasianus*) and pronghorn (*Antilocapra americana*). Sage-grouse and pronghorn range overlap with horses is greatest in Wyoming; therefore, evaluation of horse influence on these species within the state has population-wide implications. While ranges overlap, we lack understanding of comparative resource selection and space use between these species, but this information is critical to implement successful management strategies. To address this knowledge gap, we attached global positioning system (GPS) transmitters to female horses (n = 30), sage-grouse (n = 46), and pronghorn (n = 30) within the Bureau of Land Management–Adobe Town Herd Management Area in southern Wyoming between 2017 and 2021 to evaluate seasonal resource selection and predicted proportion of occurrence overlap between these species. We found comparative resource selection was most similar between pronghorn and horses, consequently these species displayed a high degree of predicted occurrence overlap in both summer (0.84) and winter (0.90). Occurrence overlap was lowest between horses and sage-grouse during the breeding (0.68) and winter (0.62) seasons, but selection by both species for closer proximity to water and herbaceous cover resulted in a high degree of occurrence overlap (0.91) in summer. Our results suggest that pronghorn face potential competition with horses year-round in this area, while the threat of decreased habitat quality, as influenced by feral horses, is most prevalent for sage-grouse during late brood-rearing. Our work can guide consideration of potential management actions, whereas future research should examine links between feral horse effects and fitness metrics of pronghorn and sage-grouse.

Understanding the effects of 50-years of Wyoming vehicular traffic on sage-grouse populations

(R. D. Inman, M. O'Donnell, B. S. Robb, A. P. Monroe, J. A. Heinrichs, E. K. Buchholtz, and C. L. Aldridge):

Road networks and their associated vehicular traffic may negatively impact populations of many terrestrial species due to noise, barriers to movement and direct mortality from collisions. Documented declines and extirpation of greater sage-grouse (*Centrocercus urophasianus*) at lek sites near major highways have been observed but not well studied. Further, recent decades have seen increased truck traffic associated with energy development such as oil and gas drilling, which can elevate stress hormones, change lekking behavior, and increase mortality. However, the cumulative and long-term impacts of vehicular traffic on sage-grouse populations are largely unknown. We address this knowledge gap by developing estimates of yearly traffic volume on Wyoming Department of Transportation's network of paved roads using a novel machine learning method (XGBoost). We show how spatial patterns of vehicular traffic on these roads have changed through time and use these estimates to assess how traffic has impacted sage-grouse population trends within a hierarchical modeling framework. We also highlight future efforts of estimating annual traffic volume on unpaved roads and demonstrate the utility of incorporating estimates of traffic volume when assessing cumulative impacts on sage-grouse populations.

Piceance Basin restoration for wildlife

(D. B. Johnston, M. Garbowski, A. Monty, C. S. Brown, and P. L. Chapman):

The Piceance Basin in northwest Colorado provides critical habitat for mule deer and greater sage-grouse, and is also impacted by natural gas development. With elevations of 5,000-8,000 feet, sagebrush communities vary from Wyoming big sage with a cheatgrass understory to Mountain big sage with a diverse native understory. In 2008, Colorado Parks and Wildlife (CPW) set up 6 sagebrush restoration experiments at 12 sites spanning the elevation range. Monitoring continued through 2019. Key findings emphasize the importance of controlling cheatgrass dispersal and seed density within disturbances at all elevations. Cheatgrass dispersal and seed density are lessened when barriers to seed movement are provided, and this allows lighter use of herbicides and competitive grasses, both of which hinder sagebrush establishment. Sagebrush seed collected near restoration sites is essential, as sagebrush is site-adapted at a fine scale. Replacing dead sagebrush skeletons back on restoration sites slightly but consistently improves sagebrush establishment. With the suite of tools now available, including dispersal control, herbicides, forb/shrub-heavy seed mixes, local sagebrush seed, and shrub skeletons, disturbances within degraded sagebrush communities should be viewed as an opportunity to improve habitat. Findings are synthesized in CPW technical publication #57, Piceance Basin Restoration for Wildlife.

The response of greater sage-grouse to the reclamation of an oil and gas development landscape

(C. P. Kirol and B. C. Fedy):

Habitat selection studies at an individual level can reveal patterns in selection that are not apparent when using a population-level approaches. We explored individual-level movements, space use (e.g., home ranges) and habitat selection of female greater sage-grouse (*Centrocercus urophasianus*) that raised chicks (brood-rearing sage-grouse) in an established oil and gas production area. We used integrated step selection analysis (iSSA) that permit the quantification of the effects of environmental and anthropogenic covariates on the movement and selection process simultaneously. On average, brood-rearing female sage-grouse established home ranges in areas with a majority of the home range comprised of sagebrush landcover (mean = 77.4%) and a minimal proportion of the area comprised of anthropogenic surface disturbance (mean = 3.5%). Brood-rearing females consistently selected for natural vegetation and avoided disturbed surfaces, both active and reclaimed surfaces, at fine spatial scales. Power line visibility generally led to avoidance behavior; however, much shorter (3m) wells structures generally did not. We found that individual variability was partially explained by age (adult or first year), or previous experience of the landscape. Adults were more likely than first year females to demonstrate avoidance of energy features and adults were also less likely than first year females to establish home ranges in areas with energy infrastructure. Our results reiterate the importance of accounting for, or at least recognizing, individual variability in population-level modeling efforts.

Brood habitat quality predicts lek occurrence and male lek attendance in Columbian sharp-tailed grouse

(J. D. Lautenbach, J. L. Beck, and A. C. Pratt):

The lek hotspot hypothesis predicts that leks will be located in areas more frequented by females. To identify if leks are placed in areas more likely to be frequented by female Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*), we evaluated habitat selection and quality (modeled by nest, brood, and adult female winter survival) for nesting, brood-rearing, and wintering female sharp-tailed grouse in south-central Wyoming (2017-2019). We compared habitat selection and quality across life-history stages for 213 VHF-marked females to 24 known lekking locations to evaluate whether habitat selection or quality influenced lek occurrence and male lek attendance. Female habitat selection and survival were influenced by vegetation and topographic conditions—we used influential covariates from each model to generate predictive surfaces of habitat selection and quality for each life-history stage. Lek locations and male lek attendance were best predicted by brood-rearing habitat quality within 400- and 800-m of leks, respectively, with an increasing proportion of high-quality brood-rearing habitat indicating a higher probability of lek occurrence ($\beta = 2.5$) and increased male lek attendance ($\beta = 11.5$). Our findings suggest quality of brood-rearing habitat helps predict lek occurrence and male lek attendance and supports Columbian sharp-tailed grouse population and habitat monitoring near leks.

Nesting, brood rearing, and summer habitat selection by translocated greater sage-grouse in North Dakota, USA

(K. Lazenby, P. Coates, S. O'Neil, J. Kolar, M. T. Kohl, and D. Dahlgren):

Human enterprise has led to large-scale changes in landscapes and altered wildlife population distribution and abundance, necessitating efficient and effective conservation strategies for impacted species. Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are a widespread sagebrush (*Artemisia* spp.) obligate species that has experienced population declines since the mid-1900s resulting from habitat loss and expansion of anthropogenic features into sagebrush ecosystems. Habitat loss is especially evident in North Dakota, USA, on the northeastern fringe of sage-grouse distribution, where a remnant population remains despite recent development of energy-related infrastructure. Resource managers in this region have determined a need to augment sage-grouse populations using translocation techniques that can be important management tools for countering species decline from range contraction. Although translocations are a common tool for wildlife management, very little research has evaluated habitat following translocation, to track individual behaviors such as habitat selection and fidelity to the release site, which can help inform habitat requirements to guide selection of future release sites. We provide an example where locations from previously released radio-marked sage-grouse are used in a resource selection function framework to evaluate habitat selection following translocation and identify areas of seasonal habitat to inform habitat management and potential restoration needs. We also evaluated possible changes in seasonal habitat since the late 1980s using spatial data provided by the Rangeland Analysis Platform coupled with resource selection modeling results. Our results serve as critical baseline information for habitat used by translocated individuals across life stages in this study area, and will inform future evaluations of population performance and potential for long-term recovery.

Brood translocations are more effective and efficient than translocation of pre-nesting females

(S. R. Mathews, M. B. Meyerpeter, P. S. Coates, B. G. Prochazka, K. D. Lazenby, D. K. Dahlgren, J. L. Kolar, and D. J. Delehanty):

Greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) translocations are often employed without adequate monitoring of impacts on source populations. Moreover, translocated sage-grouse frequently fail to reproduce post-release resulting in a net loss to population restoration. We translocated females with chicks, a novel method referred to as 'brood translocation', and pre-nesting females, a more conventional method, across two distinct sage-grouse translocation projects in California and North Dakota (2017–2020). Using integrated population models, we estimated recruitment by translocated pre-nesting and brood-rearing females, and we estimated the impact of translocation on population growth rates (λ) at both source and restoration sites. Recruitment at restoration sites was substantially higher following brood translocations compared to the conventional method of using pre-nesting females, and population growth rates from brood translocations were 11–30% higher than those of pre-nesting translocations. While brood translocations resulted in slightly lower λ at source sites compared to pre-nesting methods, brood translocations demonstrated a greater net positive cost-benefit ratio in overall abundance after considering impacts to both restoration and source sites. These results

indicate that brood translocation is a more efficient method for restoring sage-grouse populations than the established pre-nesting method. Findings are preliminary and provided for best timely science.

Field methods for translocating female greater sage-grouse with their broods

(M. Meyerpeter, K. Lazenby, P. Coates, M. Ricca, S. Mathews, S. Gardner, J. Kolar, D. Dahlgren, and D. Delehany):

Greater sage-grouse (*Centrocercus urophasianus*) have experienced significant range contraction and reduced abundance within their range in response to habitat loss and degradation. Translocation is a conservation action used to reintroduce extirpated populations or augment existing populations, but current translocation strategies have had limited success in restoring viable populations of sage-grouse. There is a need for translocation strategies that increase site fidelity and reproduction of translocated individuals, the lack of which is often cited as a reason for the limited success of sage-grouse translocations. To improve on previously used methods, we translocated female sage-grouse with their broods to promote fidelity to the release site by both females and their young. We developed a novel protocol to release sage-grouse with chicks using a delayed-release system including a custom release box and acclimation pen designed to promote brood cohesion and prevent chick abandonment. We translocated 39 females with 208 chicks during two separate translocation projects in North Dakota and California and successfully released 88.9% of translocated females with their broods using this protocol. We demonstrate that this release method can be used to successfully release sage-grouse and their broods with minimal chick abandonment. We encourage the use of this protocol in future translocation efforts of sage-grouse as well as additional research on the post-release movement and survival of translocated broods.

At what scales do sage-grouse populations respond to sagebrush cover in landscapes?

(A. P. Monroe, J. H. Heinrichs, C. L. Aldridge, M. S. O'Donnell, and D. R. Edmunds):

The scales at which Greater sage-grouse (*Centrocercus urophasianus*) respond to features within landscapes have important implications for managing this species under multiple use mandates. While several scales have been posited based on nesting distribution and within-season movements, scales of effects can vary with landscape context and response type. We therefore applied a scale selection approach to identify the scale of effect of sagebrush for sage-grouse population trends using counts from 365 leks in southwest Wyoming (2003–2019) and annual estimates of sagebrush cover from a remote sensing product. This approach allowed us to jointly estimate the most relevant scales for sagebrush cover (with error estimates), temporal lags, and the effect of sagebrush cover while accounting for variation in detectability during lek counts. Preliminary results suggest a positive response to mean sagebrush cover up to 4.3 km from leks and lagged by three years. With increasing availability of data from standardized lek count datasets, back-in-time sagebrush estimates, and other landscape features across much of the sage-grouse range, our approach can be readily applied elsewhere to identify scales relevant to each population, and to other responses such as demography and movement.

Identifying greater sage-grouse population structures to inform a hierarchical monitoring framework

(M. S. O'Donnell, D. R. Edmunds, C. L. Aldridge, J. A. Heinrichs, A. P. Monroe, P. S. Coates, B. G. Prochazka, S. E. Hanser, and L. A. Wiechman):

Population monitoring is important to wildlife and land management agencies, but analyses of population data rarely account for processes occurring across spatial and temporal scales. We present a multi-scaled framework to inform long-term monitoring and population trend assessments of sage-grouse across the western United States. First, we defined population structure uniquely using an amalgamation of factors that encompassed dispersal capabilities, seasonal habitat conditions, dispersal distances informed from genetic flow, and functional processes (scale effects) affecting movements. Second, we assessed multi-scaled habitat selection needs with constraint-based rules of connectivity (population structure) using a landscape partitioning approach known as the Spatial "K"luster Analysis by Tree Edge Removal clustering algorithm (SKATER). This unique combination of methods provided a biologically-informed methodology of grouping breeding populations at multiple nested scales. We evaluated the hierarchical framework (13 cluster levels) based on its assumption of closed populations using >1.7 million telemetry locations (2006–2021) and 2,821 unique birds (fine-scaled clusters captured 92% of birds' time). The resulting population structure is intended to support numerous needs, including a hierarchical and spatially balanced framework for population monitoring and a Targeted Annual Warning System that can provide wildlife managers an adaptive management tool.

Simulation of soil moisture budgets: spatially refined projections of sagebrush ecosystem potential

(M. S. O'Donnell and D. J. Manier):

Soil conditions, such as moisture availability, have important effects on plant distributions, growth rates, and habitat conditions. Existing soil moisture data are often inadequate to explain variability in vegetation patterns and habitat conditions. While soils are perceived as being slow to change – compared to vegetation, for example – soil moisture conditions that affect plant growth can change rapidly. Building on existing data and models, we developed a framework that uses spatially explicit estimates of climate, soil properties, microtopography, and snowmelt in a monthly soil-water accounting system (Newhall soil simulation model). Our simulation currently uses 1981–2010 climate normals for temperature and precipitation, but the framework permits easy substitution for future analyses. Analyses (generalized additive models) for correlations between soil-climate estimates and sagebrush cover, bare ground, and annual herbaceous cover confirmed strong relations. The detailed spatial information coupled with attribution describing important relationships with habitats, desirable vegetation (sagebrush) or risk of undesirable conditions (annual herbaceous dominance or excessive bare ground) will facilitate management by connecting habitat conditions to detailed soil-climate maps. The continuous estimates of soil moisture also offer novel information as environmental predictors for habitat and wildlife population models and sagebrush restoration and recovery.

Rebuilding sagebrush habitat: using state-transition simulations to project post-fire restoration and habitat recovery efficacy for greater sage-grouse

(E. K. Orning, J. A. Heinrichs, and C. L. Aldridge):

Restoring naturally and anthropogenically disturbed areas is a critical conservation challenge for land managers across the sagebrush biome. Managers need assessments of post-fire revegetation influence on species-specific habitat restoration and the scope and scale of efforts producing habitat improvement for key wildlife. Additionally, a means of selecting efficient design strategies applicable over temporal scales that allow sagebrush obligate species to persist is essential. We used recent fire events and empirical data on post-fire sagebrush recovery to develop a spatially explicit state-and-transition simulation modeling (STSM) framework that explores habitat recovery as a function of restoration action. We explored scenarios over the Great Basin and examined post-fire restoration outcomes that included (a) type of action (natural regrowth, seeding, planting), (b) duration of effort (single, multi-year), and (c) amount of effort (proportion of burned area mitigated). We then used simulated outcomes to evaluate whether sage-grouse habitat requirements were met by management actions and the feasibility of restoration achieving species-specific recovery goals, in addition to sagebrush revegetation objectives. Our simulated results provide insight into the scope of post-fire restoration effort required to restore sagebrush habitat for sage-grouse across large landscapes. Our flexible framework can aid regional restoration decisions targeting other obligate species or communities.

Identifying population genetic structure and effective migration across the range of greater sage-grouse

(S. J. Oyler-McCance, T. B. Cross, and B. C. Fedy):

Conservation efforts for Greater sage-grouse require an understanding of population structure, gene flow, and connectivity across the species range. Our objectives were to describe large-scale patterns of population genetic structure and gene flow across the range and characterize genetic population kernels—those areas that serve as spatio-genetic centroids of genetic differentiation—across the range. We used samples from 2134 individuals from 927 leks and genotyped them at 15 microsatellite loci. We used a variety of spatial genetic analyses to evaluate population genetic structure and effective gene flow. Using standard STRUCTURE analysis as well as spatial principal components analysis, we found six main areas of large-scale genetic differences. Additionally, a new analysis involving a spatial iterative bifurcation process identified 12 subpopulation kernels of differentiation. Gene flow was generally higher and differentiation lower in areas of contiguous habitat (eastern Montana, most of Wyoming, much of Oregon, Nevada, and parts of Idaho). Fragmented areas in Utah had the greatest differentiation (6 kernels) and lowest effective migration. Comprehensive management of sage-grouse includes monitoring programs that arguably should include genetic data. The data and analyses presented here provide a baseline for monitoring future changes in connectivity and genetic diversity resulting from landscape changes.

Analysis of six years of native seedling monitoring from post-fire restoration efforts in southwest Idaho

(K. L. Pappani and M. B. Young):

It is widely acknowledged that locally adapted and source-identified native plant materials are necessary for restoration of functional sagebrush steppe ecosystems and associated greater sage-grouse habitat. Monitoring of post-fire restoration treatments is critical to gathering insight on how best to improve restoration success. Our program fills both of these needs by collecting locally adapted native seed for use in restoration plantings and by monitoring seedling growth, establishment, and survival. This research tracks short-term growth and survival of a random subset of out-planted seedlings across 30 sites in southwest Idaho occurring from 2016-present. 2,680 seedlings were monitored including 250 low sagebrush, 1,276 big sagebrush, 1,104 bitterbrush, and 50 saltbush during the spring and fall of these years. Preliminary results indicate that nursery seedling quality, season of planting, and soil type have a combined effect on survival of bitterbrush and sagebrush seedlings. Higher quality seedling stock has a higher probability of survival to the establishment phase at year two. Bitterbrush survives better when planted in the spring and sagebrush when planted in the fall. Bitterbrush survival and height are greater on clayey/loamy sites. Big sagebrush survival and height are greater on sandy/granitic sites. Future analysis will delve into microsite climatic factors.

Behavioral-state dependent habitat selection in translocated greater sage-grouse in North Dakota, USA

(S. Picardi, P. Coates, J. Kolar, S. Mathews, S. O'Neil, and D. Dahlgren):

Post-release monitoring is important to inform future translocation protocols. For example, habitat selection of translocated individuals can inform the choice of future release sites. However, translocated animals undergo post-release behavioral modification and may select for different habitat characteristics when exploring their new environment versus after settlement. We investigated the effect of behavioral state on habitat selection of female greater sage-grouse translocated from Wyoming to North Dakota. We used a Hidden-Markov Model to segment individual trajectories into exploratory and restricted behavioral states. Then we used Integrated Step Selection Analysis to quantify habitat selection within each behavioral state, accounting for reproductive status and seasonality. In exploratory state, sage-grouse selected for high sagebrush cover in all seasons; during winter, they also selected for gentle slopes and avoided roads. In restricted state, females with broods selected for high herbaceous cover and roads. When they did not have a brood, sage-grouse in restricted state selected for gentle slopes year-round and otherwise used resources in proportion to their availability. These results demonstrate that sage-grouse adjust their habitat selection to their current internal state, and indicate the need to account for behavior when estimating habitat selection to inform the choice of future release sites.

A range-wide multi-scale assessment of greater sage-grouse population performance using a targeted annual warning system

(B. G. Prochazka, P. S. Coates, M. S. O'Donnell, C. L. Aldridge, D. R. Edmunds, A. P. Monroe, M. A. Ricca, G. T. Wann, S. E. Hanser, L. A. Wiechman, and M. P. Chenaille):

In the absence of local perturbations, greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) populations exhibit short-term fluctuations in abundance, governed by environmental and demographic stochasticity, and long-term oscillations in response to large-scale climatic patterns. Multi-scale spatiotemporal fluctuations in abundance can hinder population performance assessments when additional information regarding the metapopulation structure is absent. By utilizing a hierarchical population monitoring framework previously developed for sage-grouse across their range, we made intra-annual comparisons of population performance across multiple spatially nested scales. Log odds ratios developed from local and broad-scale population growth rates served as a within-year performance metric, which captures local-scale declines that outpace the broad-scale. Multi-year assessments of log odds ratios accounted for environmental and demographic stochasticity, as well as observation error, and identified populations exhibiting strong evidence of aberrant decline. Post hoc analyses identified optimal thresholds for log odds ratio indices by assessing when populations reached broad-scale stability from simulated management intervention. Using this framework, we identified population declines that are likely attributable to disturbances on the landscape rather than environmental stochasticity or intrinsic factors across broader regions, which can help immediately inform when and where increased monitoring or direct management intervention may be needed to reverse negative trends.

Greater sage-grouse landscape connectivity prioritization when data is limited: a case study in systematic conservation planning

(M. Racioppa and B. Fedy):

Systematic conservation planning (SCP) aims to address research-implementation gaps in ecology by providing a framework for better engagement with stakeholders. In SCP, decision support tools are used to quantify conservation goals as optimization problems, generating solutions to identify areas suitable for specific management actions. The Rock Springs Field Office is a 3.6-million-acre management area located in southwestern Wyoming tasked with addressing the conservation of greater sage-grouse (*Centrocercus urophasianus*) by producing future visions of the landscape considering environmental, social, political, and economic land uses. We used bootstrap and sensitivity analysis approaches to investigate the how integrating costs, other species' distributions, feature weights, expert opinion, and constraints can impact solution quality. We used prioritizr to run our prioritizations and assessed solutions with metrics including irreplaceability, a relative score assigned to each planning unit, ROI, and contiguity. Using development potential surfaces to predict threat and inform our costs, led to an increase in irreplaceability values and a decrease in contiguity of the solutions. Feature weights successfully increased the representation of target features in the solutions and through consultation and strategic application, they can be applied to mitigate potential trade-offs built into the conservation problem or weaknesses in the existing protected areas.

Timestamping Wyoming anthropogenic disturbances to inform wildlife studies in sagebrush ecosystems

(B. S. Robb, D. R. Edmunds, M. S. O'Donnell, R. Inman, A. P. Monroe, M. J. Holloran, N. Graf, and C. L. Aldridge):

Greater sage-grouse (*Centrocercus urophasianus*) populations in Wyoming are managed by the Core Area strategy, whereby surface disturbances are limited to a 5% threshold. The Density and Disturbance Calculation Tool (DDCT) estimates density of surface disturbance within Core Areas using mapped disturbances compiled through the Wyoming Habitat Protection program. However, 89% of DDCT data lack temporal context. Understanding the mechanistic effects of disturbance on wildlife population trends depends on temporally accurate data. Using DDCT mapped disturbances and back-in-time sagebrush fractional components (1985–2018), we timestamped disturbances by identifying the year of greatest change in loss of sagebrush cover. Comparing the estimated year of sagebrush loss to a subset of disturbances with a reported year of disturbance, we found we could accurately estimate disturbance dates for oil and gas well pads 0.037 years after (SD 5.976, n = 2868) and wind turbines 0.686 years before (SD 6.162, n = 398) the reported disturbance year, on average. We are applying this approach to disturbances throughout Wyoming, limited to post-1985 disturbances and areas with temporal sagebrush estimates. Estimating timestamps for disturbance layers will let us assess how disturbances affect population trends for sage-grouse and mule deer (*Odocoileus hemionus*) at broad spatio-temporal scales.

Quantifying the temporal stability in seasonal habitat for sage-grouse using regression and ensemble tree approaches

(J. R. Row, M. J. Holloran, and B. C. Fedy):

Identifying and quantifying the extent to which landscape-level habitat variables drive the spatial distribution of individuals across a region can provide fundamental insights into a species ecology and be essential to wildlife management and conservation plans. Although the preferences for habitat resources and the resources themselves are not static over time, most research at large spatial scales does not consider seasonal effects nor quantify annual temporal variability in the spatial distribution of habitat resources. In this study, we used and compared a machine learning (boosted regression trees; BRT) and mixed-model (GLMM) approach to quantify seasonal habitat selection across three life-stages (nest, late brood and winter habitat) of sage-grouse and estimated annual stability across a 13 year dataset in south-central Wyoming. GLMM models had high AUC values, but were consistently outperformed by the BRT models for all seasons. We assessed annual variation by predicting the BRT models across years and we found significant spatial trends in the distribution of nesting habitat, with general decreases in the relative probability of use across the core of the study area and corresponding increases in selection on the periphery, suggesting birds were shifting out of preferable ranges over the course of our study. The annual dynamics of habitat selection are seldom addressed in large-scale research but can have potentially dramatic influences on our identification of preferred habitats.

The cheatgrass challenge: a proactive strategy for tackling invasive annual grasses

(C. Sandford, J. Maestas, J. Eller, J. Uriarte, C. Martin, S. Palazzolo, S. Jirik, J. Pyron, B. Brazee, D. Tilley, J. Laney, B. Jacobson, B. Richards, and D. Twidwell):

Cheatgrass increases wildfire size and frequency and is a primary threat to greater sage-grouse and sagebrush ecosystems, particularly in the Great Basin. Efforts to control invasive annual grasses are often reactive and uniformed by landscape context. Science shows that invasive species control is more effective and cost-efficient when done early, before infestations become widespread, and when management is informed by what's going on in the surrounding landscape. Idaho partners have come together to develop and implement a new proactive state-wide strategy to halt conversion of sagebrush habitats to annual grasslands. With the aid of technology provided by the Rangeland Analysis Platform (RAP), partners mapped three coarse region types across the state: 1) Core - representing regionally intact rangelands characterized by relatively low cover of annuals, 2) Annual Grass Region - large areas dominated by moderate-to-high cover of annuals, and 3) Transition Zones - areas between core and annual grass region. A spatial strategy for prioritizing management was then devised: defend the core, grow the core, and mitigate impacts. The Cheatgrass Challenge provides a proactive, rather than reactive, alternative to preventing further loss of intact sagebrush ecosystems to the cheatgrass-fire cycle and serves as a model for other western states.

Potential impacts of wildfires on sharp-tailed grouse and greater sage-grouse in Washington state

(M. A. Schroeder, M. Atamian, J. Heinlen, E. Braaten, D. J. Peterson, and D. Stinson):

Wildfires have increased in both frequency and extent throughout western North America. In the state of Washington, the record for the largest wildfire was set in 2014 (256,000-acre Carlton Complex), then broken in 2015 (305,000-acre Okanogan Complex), and broken again in 2020 (410,000-acre Cold Springs Canyon/Pearl Hill). All three of these wildfires, along with other smaller wildfires, have impacted both sharp-tailed grouse and greater sage-grouse habitat. Twenty six of 58 sharp-tailed grouse leks and 13 of 29 greater sage-grouse leks active between 2008 and 2021 were within a wildfire perimeter at least once between 2012 and 2020. Lek counts at 'impacted' sharp-tailed grouse leks dropped 82% in the year following the wildfire while leks outside the wildfire perimeters dropped 6%. In contrast, the 1-year declines for sage-grouse were 16% inside and 12% outside the fire perimeters. Examination of long-term impacts to sharp-tailed grouse suggest that post-fire recovery takes about 6 years. Because most of the potential sage-grouse impacts occurred between 2020 and 2021, no long-term trends could be examined. Some of the observations include: (1) fire impacts may extend beyond the fire perimeter; (2) sage-grouse and sharp-tailed grouse appear to respond differently to burned habitat on a lek site; and (3) unburned refugia may be critical for recovery of habitats and populations.

Temporal changes in greater sage-grouse seasonal habitat selection in response to large-scale wildfire

(E. M. Schuyler, C. A. Hagen, C. R. Anthony, L. J. Foster, and K. M. Dugger):

We modeled seasonal habitat use by female greater sage-grouse (*Centrocercus urophasianus*) in the Trout Creek Mountains of Oregon and Nevada, USA, to identify landscape characteristics that influenced sage-grouse habitat selection and to create predictive surfaces of seasonal use 1 and 7 years after a large wildfire (>180,000 ha). We developed resource selection function models using GPS location data from 2013 – 2019 for each of 3 biologically distinct seasons (breeding, n = 149: 8 Mar – 12 Jun, summer, n = 140: 13 Jun – 20 Oct, winter, n = 94: 21 Oct – 7 Mar). For all seasons, by year 4-5 post-fire, sage-grouse selected for unburned patches more than all other burn severity patches. Generally, use of unburned areas relative to burned areas increased through time. Seven years post-fire (2019), the area predicted to have high probability of use in each seasonal range decreased (breeding: 16.4%, summer: 12.2%, winter: 4.2%) while the area predicted to have low or low-medium probability of use increased (breeding: 14.5%, summer: 22.5%, winter: 22.8%) when compared to 1-year post wildfire (2013). Our results showed that sage-grouse continued to avoid burned areas 7 years post-fire, and may limit populations if available habitat recovery lags behind.

Optimizing spatial application of habitat management actions for the Gunnison sage-grouse satellite populations

(J. E. Shyvers, N. D. Van Schmidt, D. J. Saher, J. A. Heinrichs, and C. L. Aldridge):

The Gunnison sage-grouse (*Centrocercus minimus*) is a species of conservation concern that is currently listed as threatened under the federal Endangered Species Act (1973). The species has experienced substantial and continuing declines in range-wide abundance and distribution, primarily due to loss of

habitat. Gunnison sage-grouse are predominantly restricted to seven populations in southwest Colorado, six of which are small, isolated satellites where numbers are currently declining or significantly below conservation objectives. We assessed the potential for habitat management actions to improve habitats for these satellite populations using newly developed, population-specific Resource Selection Function maps. Our approach was to 1) estimate the habitats likely to be most responsive to management actions that improve suitability for Gunnison Sage-grouse, 2) apply representative habitat improvement scenarios based on the Bureau of Land Management's current habitat actions for sage-grouse to gauge the benefits of different types of actions, and 3) assess a suite of targeted actions that most improve sage-grouse habitat in each satellite population. We demonstrate how this information can be used to optimize local habitat management efforts within these satellite populations.

Thinking outside the box for at risk species: mitigation 101

(C. Sime, K. Andrle, N. Seidel, T. Elm, and A. Waring):

The greater sage-grouse (GRSG) is an at-risk species, having been considered for Endangered Species Act (ESA) protections eight times. Population status and trends, regulatory mechanisms, and habitat loss are key drivers in U.S. Fish and Wildlife Service determinations about whether ESA protections are warranted. Mitigation is a market-driven, proactive way to address and ameliorate threats to at-risk species before a species is listed. Mitigation after a species is listed offers fewer options with limited effectiveness and has not been widely successful in species recovery. Mitigation for impacts to GRSG habitat was incorporated into federal land use plans and state conservation strategies, respectively, to proactively address threats. Mitigation for impacts from known, identified threats attributed to anthropogenic disturbance was foundational to the 2015 finding that listing was not warranted range wide. Mitigation motivates developers to avoid, minimize, reclaim, and compensate for impacts by siting and implementing projects in ways that are least impactful. Developers are incentivized to design and site projects to keep mitigation obligations and costs low. In some cases, mitigation obligations would have been so high that the project was never implemented. State and federal mitigation policy approaches and impact quantification methods vary, but endeavor to offset impacts using common, universal principles. Mitigation must be timely, adequate, and effective to offset habitat impacts and losses. This talk will provide an overview of mitigation principles and give examples of how mitigation can be a beneficial tool to squarely address habitat loss and fragmentation for GRSG so that anthropogenic development is balanced with conservation.

Response of greater sage-grouse to habitat treatments in Wyoming big sagebrush

(K. T. Smith, J. R. Levan, A. D. Chalfoun, T. J. Christiansen, S. R. Harter, S. Oberlie, and J. L. Beck):

Sagebrush (*Artemisia* spp.) often has been treated through chemical application, mechanical treatments, and prescribed burning to increase herbaceous forage species released from competition with sagebrush. We initiated a 9-year (2011–2019) study in central Wyoming to better understand how greater sage-grouse (*Centrocercus urophasianus*) respond to vegetation treatments in Wyoming big sagebrush communities. We used a Before-After Control-Impact study design to evaluate the influence of 2 common sagebrush treatments on greater sage-grouse demography and resource selection. Our results generally suggested neutral demographic responses and slight avoidance by greater sage-grouse in response to Wyoming big sagebrush treated by mowing and tebuthiuron. Perennial grass cover and height, and forb cover and species richness varied temporally, yet did not vary systematically between treatment and control plots. We also found no evidence that perennial grass cover, perennial grass height, forb cover, or forb species richness was greater in mowed or tebuthiuron treated areas that received grazing rest compared to areas that received no grazing rest. Finally, forb and invertebrate dry matter did not differ between treated plots and control plots in any years following treatments. Results from our study support a developing paradigm that sage-grouse in Wyoming big sagebrush do not respond positively to sagebrush treatments.

Management recommendations for greater sage-grouse winter concentration areas

(K. T. Smith, A. C. Pratt, and J. L. Beck):

Our goal was to generate management recommendation guidelines for greater sage-grouse (*Centrocercus urophasianus*) winter concentration areas in Wyoming. Phase 1 of our research utilized data from female sage-grouse equipped with GPS transmitters (~877,000 year-long locations from 536 females) throughout Wyoming. We assessed variables within circular regions (0.1–10.0 km) to identify scales in which sage-grouse selected winter home ranges and habitat within winter home ranges. Median date of arrival and departure from winter range was 7 November and 13 March, respectively. We observed regional variation but sage-grouse generally selected habitat with gentle topography, close to breeding habitat, and

dominated by sagebrush (*Artemisia* spp.) land cover absent of juniper (*Juniperus* spp.). Sage-grouse avoided surface disturbance within circular regions ≤3.2 km, but there were nuances relative to types of disturbance and region. Across all disturbance types and circular regions, mean surface disturbance at sage-grouse locations did not exceed ~6%. Trends were more variable for avoidance of disturbance within winter ranges, so selection was likely more important at the larger scale when grouse selected home ranges. Phase 2 will assess the effectiveness of the guidelines developed applied to a novel area located in southern Wyoming where we collected GPS location data from 2018–2021.

There's more than one way to conserve a grouse: a contextualization of greater sage-grouse management plan development

(M. E. Smith and A. Gregory):

Wildlife management agencies are tasked with the difficult prospect of managing wildlife species in light of ongoing anthropic pressures and stakeholder involvement. This project examines how management agencies orchestrate actions that balance wildlife needs and human stakeholder desires in effective management policies. Using greater sage-grouse (*Centrocercus urophasianus*) as a case study, we evaluate the relative contributions of socio-political and ecological factors driving state management plan development and structure in six western states. Socio-political factors will include social, ecological, and economic value of sage-grouse conservation as derived from interviews and surveys. Ecological factors will include precipitation extremes, temperature extremes, sagebrush percent cover, lambda, and R2 as derived from existing climatological data and state lek counts. Through the use of mixed methods analysis and Random Forest machine learning algorithms, each factor will be given a weighted importance score. These weights will be used to understand the degree to which these factors influenced the development of management plan-stipulated goals.

Productivity and abundance of Columbian sharp-tailed grouse in Idaho: multi-scale effects of weather, habitat, and disturbance

(B. S. Stevens, C. J. Conway, J. M. Knetter, J. P. Donnelly, and S. B. Roberts):

The distribution of Columbian sharp-tailed grouse (CSTG) has contracted dramatically, yet Idaho remains a stronghold for CSTG populations (>60% of the remaining birds are found in this state). We used long-term monitoring data to assess patterns of CSTG productivity and relative abundance in Idaho and evaluated the effects of weather, habitat, and disturbance variables (e.g., fire frequency data) on demographic traits. We used 20 years of age-ratio data collected from hunter harvested birds (10,281 wings collected from 2000-2019) to assess patterns of CSTG productivity and 26 years of lek count data (6,114 surveys at 573 leks from 1995-2020) to assess patterns of relative abundance. We used generalized linear mixed-effects regression models to explore the relationships between productivity and abundance data and covariates measured over multiple spatial and temporal extents. We used model selection to identify the optimal spatial-temporal scales of effect for each covariate and to evaluate relative support for each covariate concurrently in multi-scale regression models. Our results provide the first large-scale assessment of drivers of productivity and abundance for CSTG populations across Idaho and consequently will provide important insights for management and conservation of CSTG.

Functional responses in greater sage-grouse habitat selection in response to large-scale disturbance

(B. S. Stevens, S. B. Roberts, D. K. Englestead, and C. J. Conway):

Habitat selection studies are ubiquitous in wildlife ecology, yet statistical inference about preferred habitat is conditional on the habitat available to the study population. Consequently, patterns in selection can change over time as natural or anthropogenic disturbances alter habitat composition. Assessing functional responses allows investigators to quantify how selection changes in response available habitat, and we used this framework to assess changes in greater sage-grouse habitat selection in response to a wildfire in southeastern Idaho. We monitored >300 female sage-grouse with satellite transmitters in high-elevation mountain big sagebrush communities. This study spanned a 6-year period that included observations both before and after a high-intensity burn that covered >40,000 hectares. We tested for functional responses in nest-site and brood-rearing habitat selection and assessed the consistency of responses across spatial scales. We also built generalized resource selection functions that incorporate functional responses and optimally predict habitat selection in response to changes in availability. We found that functional responses in were common and relationships were often consistent across spatial scales. Our results demonstrate the importance of understanding functional responses and also provide a generalized model for predicting sage-grouse habitat selection in the presence of large-scale changes in the composition of sagebrush steppe communities.

Impacts of non-native grazers to vegetation structure results in cascading effects for native species

(P. A. Street, T. L. Behnke, and J. S. Sedinger):

Competition among livestock, feral horses, and Greater Sage-grouse has been the subject of numerous legal actions and management policies, yet, data documenting the details of this competition are lacking. Using fecal abundance as an index of livestock and feral horse use, we evaluated whether these non-native grazers were impacting the habitat and if greater sage-grouse could compensate by choosing where to nest and brood their chicks. We found greater sage-grouse were choosing sites with higher percentages of perennial grasses and forbs to build their nests, and even higher percentages to brood their chicks. As livestock increased, we observed decreases in perennial grasses, forbs that are known to be consumed by Greater Sage-grouse chicks, all other forbs, cheatgrass, and documented increases in the amount of bare ground. These effects were consistent at all sites. We observed similar results at available sites with high predicted horse use, but at sites chosen by females to nest and brood their chicks, we observed substantial increases in the amount of cheatgrass as horses increased. These results suggest that non-native ungulates are resulting in impacts on the herbaceous plants associated with greater sage-grouse reproduction, and likely population dynamics.

Modeling sagebrush recovery across the sage-grouse range using three decades of remotely-sensed vegetation estimates

(B. C. Tarbox, A. P. Monroe, C. L. Aldridge, M. S. O'Donnell, J. A. Heinrichs, D. S. Pilliod, and P. S. Coates):

Imperiled species such as the greater sage-grouse (*Centrocercus urophasianus*) depend on sagebrush, yet habitat continues to be lost. Effective sagebrush restoration is needed to reverse this trend, but understanding the conditions that determine when, where, and at what rate, sagebrush recovery will occur is a pressing research need for prioritizing and implementing restoration efforts across this vast landscape. We have developed a framework for modeling and predicting sagebrush recovery using datasets that catalog land management treatments and sagebrush cover across the sagebrush biome over time (e.g., Land Treatment Data Library and Rangelands Condition Monitoring Assessment and Projection). We are assessing the influence of environmental factors (e.g., soil moisture availability), disturbance types (e.g., wildfire, brush removal), and restoration treatments (e.g., herbicide application, aerial seeding) on recovery rates of sagebrush cover. Our results will facilitate stewardship of the sagebrush biome and the species that depend on it by providing a variety of spatially explicit predictions and projections of sagebrush recovery to inform regional planning and on-the-ground restoration efforts. These analyses will also support other on-going efforts including economic cost-effectiveness analyses, restoration responses to wildfires, and restoration prioritization tools that optimize management efforts targeted at wildlife species of conservation concern.

Prioritizing the placement of conifer removal projects for concurrent multi-species management

(N. J. Van Lanen, A. P. Monroe, and C. L. Aldridge):

The removal of conifers from the sagebrush and pinyon-juniper ecotone is an increasingly popular alternative for enhancing greater sage-grouse habitat, with over 1,400km^2 recently cleared in the western United States. These treatments likely result in mixed effects for wildlife species and responses may vary across space. Declining populations of both sagebrush and pinyon-juniper associated species highlight the need for tools which guide conifer management across the sagebrush ecosystem. To address this need, we developed hierarchical habitat-relationship models of true abundance using avian point count data collected under the Integrated Monitoring in Bird Conservation Regions program. Leveraging these habitat-relationships will allow us to predict abundance for sagebrush and pinyon-juniper associated species across the landscape; given both current conditions and expected conditions following conifer removal. Our optimization framework allows predictions to be weighted based upon management objectives and species' conservation priorities, to assess utility of planned conifer removal at specific locations. The predicted abundance surfaces will map high-quality habitat for these species of interest and can be used to identify core habitat areas. The optimization framework can appropriately prioritize areas for future conifer removal, to maximize conservation outcomes for sage-grouse and minimize negative effects on other pinyon-juniper associated species.

Gunnison sage-grouse habitat vulnerability to climate change, development, and fire in the 21st century

(N. D. Van Schmidt, J. E. Shyvers, D. J. Saher, J. A. Heinrichs, and C. L. Aldridge):

Gunnison sage-grouse are a federally-listed endangered species, with only eight extant populations localized largely to southwestern Colorado. Already in serious decline, ongoing climate change and land-use change processes may worsen habitat conditions for the species. We adapted a scenario-based risk assessment framework from the Fish & Wildlife Service's conservation planning into a spatially explicit projection of the landscape's future risk to future change by 2070. Our approach integrated projections of fire risk, development, and shifts in sagebrush habitats, pinyon-juniper encroachment, and mesic habitat due to climate change. This resulted in 30-m maps of risk to sage-grouse habitats under three scenarios: pessimistic (hot and dry future climate, high development), continuation (moderately hot, moderate development) and optimistic (warm & wet, low development). By intersecting the risk maps with sage-grouse habitat use models and a database of management interventions, we identified the degree to which each subpopulation and set of management actions are imperiled by each threat over the next half-century.

A regionally varying habitat suitability model to identify areas for greater sage-grouse persistence

(G. T. Wann, C. L. Aldridge, N. D. Van Schmidt, J. E. Shyvers, B. C. Tarbox, M. M. McLachlan, A. J. Titolo, M. S. O'Donnell, J. A. Heinrichs, P. S. Coates, A. P. Monroe, and D. R. Edmunds):

Modeling species habitat suitability over large spatial distributions is challenging because local populations may respond differently to similar habitats in different geographic contexts. We used a recently compiled lek database to model greater sage-grouse (*Centrocercus urophasianus*) lek persistence across their U.S. distribution to help the Bureau of Land Management (BLM) assess habitat suitability. We estimated relationships between lek persistence (active and inactive leks) and landscape characteristics summarized at varying spatial scales (1–30-km radii buffers of leks) using logistic regression. We treated 24 mid-scale regions (representing a second order habitat process) delineated by the BLM as random intercepts and slopes which allowed for regional variability in model predictions and estimated habitat relationships. Preliminary results indicated our model had reasonable predictive capacity (area under curve = 0.708). We developed habitat bins based on probabilities associated with targeted model sensitivities (percentage correctly classified active leks) for mapping purposes, and identified levels of landcover change (pinyon-juniper encroachment) and densities of point and line disturbance above which leks are predicted to go inactive. Our model provides a range-wide layer that can be used to identify sage-grouse habitats and disturbance thresholds that are specific to each mid-scale assessment area considered by the BLM.

Assessing impacts of common raven (*Corvus corax*) density on greater sage-grouse (*Centrocercus urophasianus*) to develop science-driven adaptive management strategies

(S. C. Webster, P. S. Coates, S. T. O'Neil, B. E. Brussee, S. J. Dettenmaier, C. L. Roth, J. C. Tull, M. A. Ricca, P. J. Jackson, J. B. Dinkins, A. M. Moser, L. J. Foster, and D. J. Delehanty):

The common raven (*Corvus corax*) is a behaviorally flexible predator with drastically increasing populations that negatively impact sensitive prey species, including greater sage-grouse (*Centrocercus urophasianus*). Accurate estimates of raven density remain difficult to obtain, and effective, adaptive management protocols are needed to mitigate negative impacts of surging raven populations. We mapped raven density across the Great Basin, USA, and evaluated effects of density on sage-grouse nest survival in order to estimate a critical raven density that can serve as a predator-prey conflict threshold for sage-grouse. We found density adversely impacted sage-grouse nest survival, and we identified a threshold of ~0.40 ravens km^2. Importantly, average raven density across study extent was 0.54 ravens km^2 (95% CI = 0.42–0.70). We used underlying data to demonstrate a science-based adaptive approach to inform management of ravens in western landscapes with emphasis on sage-grouse habitats. We also developed a map that delineated areas used by breeding versus non-breeding ravens as management options could vary across these areas. Our strategy is amenable to different management objectives and is a valuable resource for managers wanting to ameliorate impacts of ravens on sage-grouse and other sensitive species. Findings are preliminary and provided for best timely science.

Gunnison sage-grouse recovery tracking: conservation efforts database v3.0

(L. A. Wiechman, J. L. Welty, M. M. Heller, J. Long, A. Urpsis, S. P. Finn, J. Lindstrom, and G. Montgomery):

Natural and anthropogenic disturbances that are detrimental to fish, wildlife, plants, and ecosystems are the focus of conservation. While the intensity and extent of these impacts may be well documented, the conservation actions applied by resource management agencies and organizations and their effectiveness to address environmental impacts are often poorly and inconsistently documented. Even when conservation actions are documented, it can be difficult to determine the short- and long-term effects on targeted species or habitats because of poor record organization and lack of post-action monitoring. The Conservation Efforts Database (CED) is a secure, on-line web app that collects and summarizes spatially explicit information related to conservation and restoration actions into a comprehensive database. The CED Team worked with a diverse group of stakeholders to develop a module designed to collect information related to recovery actions implemented for the threatened Gunnison sage-grouse. This new module will build upon the existing CED web-based services, to allow stakeholders to summarize recovery efforts across populations and management jurisdictions and evaluate the conservation benefit achieved from conservation and restoration efforts. Spatial data displayed in the CED provides useful context for planning and siting of future conservation efforts, fostering collaborative conservation across the species' range.

Multi-scale resource selection functions controlling for differences in habitat availability perform best when transferred to a novel site

(K. J. Winiarski1, J. R. Row, M. J. Holloran, C. P. Kirol, J. L. Beck, and B. C. Fedy):

Identifying important habitats via methods such as resource selection functions (RSFs), is often necessary over relatively short timeframes. If data are absent, then it is necessary to develop RSFs by either i) collecting new data or ii) using data from an alternative site(s). Unfortunately, RSF predictions can be inaccurate if data are collected over a short timeframe or if RSFs are transferred from a site(s) not representative of the novel site. Using Greater Sage-Grouse as a case study, we compared the performance of multi-scale RSFs developed using available data from an alternative site(s) to an RSF developed using data from the focal site to assess RSF transfer performance using telemetry data from 8 different sites. We fit RSFs developed using nest location data using a generalized functional response (GFR) RSF and the mean of a local and non-local RSF. The GFR RSF consistently transferred well to novel holdout sites, with much less consistency found with the other approaches. Importantly, GFR RSFs, frequently performed better than the focal site RSF. Our results highlight the accuracy and flexibility of the GFR RSF and the potential shortcomings with RSF predictions developed using i) data from an alternative site(s) (without controlling for habitat availability) or ii) data collected at the focal site over a relatively short timeframe.

Genetic diversity within a hierarchical monitoring framework as an early indicator of population decline in greater sage-grouse

(S. J. Zimmerman, C. L. Aldridge, M. S. O'Donnell, D. Edmunds, P. S. Coates, and S. J. Oyler-McCance):

Wildlife population monitoring typically occurs at one arbitrary scale and does not include genetic information, despite the known importance of genetic variation to population fitness and potential follies of mismatch between spatial scale and monitoring. Recently developed methods generating hierarchically nested monitoring units (clusters) for greater sage-grouse (*Centrocercus urophasianus*) have identified population trend declines across spatiotemporal scales. The same clusters used as proxy for spatial scale can detect local units (i.e., neighborhood-scale) with low genetic diversity, further facilitating identification of management targets; providing a local signal of decline that is less sensitive to stochasticity than population trend. We defined genetic diversity thresholds for conservation concern, developed a model to robustly estimate genetic diversity, and used previously developed clusters to identify management-relevant areas within in the greater sage-grouse range based on genetic diversity levels. We found strong, cross-scale indications of decline in the small and isolated Washington population unlikely to respond to typical local management actions. Importantly, we found 36 neighborhood-scale clusters as potential targets of conservation action; many of which correspond to documented local trend declines. Our findings could facilitate conservation action prioritization in combination with population trend assessments and act as baseline of genetic diversity for future comparison.

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2021 American Ornithological Society and the Society of Canadian Ornithologists-Société des ornithologistes du Canada Conference

Michael A. Schroeder

The American Ornithological Society (AOS) and the Society of Canadian Ornithologists-Société des ornithologistes du Canada (SCO-SOC) held a virtual joint meeting during 9–13 August 2021. This was the 139th annual meeting of AOS and the 39th annual meeting of SCO-SOC with a theme of "Birds of many feathers flock together". There were approximately 560 plenaries, workshops, symposiums, and contributed posters and papers. Although grouse are never the focus of this meeting, there were 10 talks and posters focused on grouse. The AOS is planning their next annual meeting for 27 June – 1 July 2022 in person in Puerto Rico.

Grouse alumni Kathy Martin was a recipient of this year's prestigious William Brewster Memorial Award recognizing her exceptional body of work on birds of the Western Hemisphere. The AOS put together the following description of Kathy Martin's work: "Dr. Kathy Martin is a professor in the Department of Forest and Conservation Sciences at the University of British Columbia, and Research Scientist Emeritus with Environment and Climate Change Canada. For more than 40 years, Dr. Martin has contributed significantly to two major areas of ornithological research in the Western Hemisphere: ecology and life history of arctic and alpine birds, and the community dynamics of cavity-nesting birds and how they are affected by forestry and natural disturbances. Dr. Martin served as AOS President and has been previously recognized by the Society for excellence in ornithological research as an AOS Elective Member and Fellow." Although grouse were not specifically mentioned in this description, the Grouse World recognizers her many contributions. Congratulations Kathy.

The following is a list of presentations (papers and posters) and abstracts for this year's AOS and SCO-SOC conference (alphabetical by first author).

Translocated lesser prairie-chicken lek dynamics and female space use

(C. Aulicky, D. Haukos, K. Fricke, L. Rossi, J. Reitz, and K. Schultz):

Translocation of lek-breeding prairie grouse offers unique challenges and considerations. Translocation efforts are considered successful with lek persistence, but the focus on translocating males first to bolster or form leks is based on untested assumptions about how lek breeding species disperse and navigate new landscapes. This approach assumes males are the dispersing sex, despite increasing evidence of long-distance movement by females. Female-driven dispersal implies that males form leks following female space use and habitat constraints in accordance with the hotspot hypothesis. We tested the hotspot hypothesis in shaping lek formation and stability of translocated lesser prairie-chickens (*Tympanuchus pallidicinctus*) in the Sand Sagebrush Prairie Ecoregion using the spatial movements of 32 GPS- and 24 VHF-equipped females. We used ArcGIS optimized hotspot analysis to identify significant clusters of female locations and evaluated where translocated males formed leks and the persistence of those leks. We found the spatial use of female lesser prairie-chickens drove the dynamics of leks as expected under the hotspot hypothesis and leks formed in location clusters. We found the number of nesting attempts by females within a 5 to 2 km distance had the greatest influence on the persistence of formed leks into a subsequent year. Based on our findings, future translocation efforts should focus on creating nesting habitat to sustain long-term nest site selection prior to releasing birds, rather than methodology focused on creating or bolstering leks without accounting for female behavior.

Conserving Alberta greater sage-grouse (*Centrocercus urophasianus*) populations: an assessment of translocation recovery using genetic markers

(B. A. Graham, J. Nicholson, M. Klem, E. Spilker, S. J. Oyler-McCance, and T. M. Burg):

Since 2011, the greater sage-grouse (*Centrocercus urophasianus*) recovery project has translocated 118 individuals (3 males, 115 females) from Montana to southern Alberta to augment declining local populations. Although survival of translocated individuals is comparable to local birds, recruitment may be lower because of nest site selection and anthropogenic disturbances. In this study we quantify the impact of translocated birds on genetic diversity for local Alberta populations. We collected samples over a ten-year period (2010 to 2020) and genotyped 450 individuals at 14 variable microsatellite loci and the mitochondrial control region and compared contemporary genetic patterns to genetic patterns from pre-2005. We found that although some measures of genetic diversity (allelic richness) have decreased in the AB populations, others (both observed and expected heterozygosity, and haplotype diversity) are comparable to historic levels. Analyses based on mtDNA markers indicate that mtDNA haplotype frequencies have changed from pre-2005 levels, and we detected several new haplotypes in AB that were previously found in MT showing the translocated birds successfully reproduced. Our study suggests the

current recovery techniques, such as translocations, are having a positive impact on the native sage-grouse population. Further analyses will provide greater insights into the genetic makeup of wild Alberta sage-grouse populations and assist with the recovery across their former range.

To the beat of their own drum: temporal and environmental factors influence drumming display activity in the ruffed grouse (*Bonasa umbellus*)

(M. J. Martin, E. C. Déaux, and A. N. Iwaniuk):

The ruffed grouse is a widespread gamebird species that is heavily managed in many regions, but its cryptic coloration and behavior makes it difficult to census. Frequently, ruffed grouse population estimates are therefore derived from counting the number of males actively drumming: a wing-beating display that generates a loud, low frequency sound. While drumming surveys have been used for over 60 years, the timing of surveys relative to drumming activity and the effects of weather on drumming activity remain unclear. We analyzed drumming activity across several years and used generalized additive mixed models to determine the relationship between drumming activity and time of day, date, temperature, and precipitation. The dates of peak activity were similar across years, despite inter-annual variation in weather patterns. The hourly drumming activity model yielded two activity peaks: a large peak at 1.5 hours before dawn and a second, smaller peak 1 hour before sunset. Temperature range formed a u-shaped curve relative to drumming activity with low and high temperature extremes associated with increased activity. Minimum temperature was not associated with changes in drumming activity, but drumming activity increased gradually with higher daily maximum temperatures. These results suggest large temperature increases and decreases throughout the day and high daily maximum temperatures increase daily drumming activity rates. In addition, morning drumming surveys should begin 2 hours prior to sunrise, and evening drumming surveys could be a useful addition to accurately census ruffed grouse populations.

A genus at risk: Predicted current and future distribution of all three *Lagopus* species reveal sensitivity to climate change and efficacy of protected areas

(D. Scridel, M. Brambilla, D. de Zwaan, N. Froese, S. Wilson, P. Pedrini, and K. Martin):

Cold-adapted species are considered vulnerable to climate change. However, our understanding of how such sensitivity will influence habitat suitability remains poorly understood, particularly for species at high latitudes or elevations. Using community science observations from 1970–2020, we built distribution models for ptarmigan (*Lagopus* spp.) across British Columbia, a globally unique region harbouring all the species belonging to this genus. White-tailed ptarmigan (*L. leucura*) and rock ptarmigan (*L. muta*) were associated with colder temperatures and tundra-like open habitats, and willow ptarmigan (*L. lagopus*) with open, shrub habitats. Future projections based on climate and vegetation scenarios indicated marked losses in suitable habitat by the 2080s (RCP +8.5 W/m²), with range declines of 85.6% and 79.5% for white-tailed and rock ptarmigan, respectively, and of 61.3% for willow ptarmigan. Predicted current and future suitable habitat occurred primarily outside of current protected areas ('Pas'; 67–82%), yet range size declined at a less pronounced rate within PAs suggesting a capacity to buffer habitat loss. Ptarmigan are predicted to persist at higher elevations and latitudes than currently occupied, with the magnitude of elevation shifts consistent with trends observed elsewhere in the Holarctic. Our spatially explicit assessment of potential current and future distributions of ptarmigan species provides the first comparative evaluation of climate change effects on the distribution of three congeneric, cold-adapted species with different habitat preferences and life-history traits. We also highlight the potential role of PAs in preserving suitable sites for these and other climate-sensitive species in the future.

Seeking shelter: winter weather constrains the behavioral flexibility of a winter-adapted bird

(A. A. Shipley and B. Zuckerberg):

Behavioral flexibility is an important pathway by which animals respond to rapidly changing environmental conditions. Seeking out and accessing microrefugia is an important behavior that can protect animals from inclement weather, predation, and periods of rapid environmental change. During winter, snow serves as a seasonal microrefugium that provides thermal insulation and protects overwintering species from predators. However, snow depth and quality can be highly variable throughout the winter, and it is unclear how species that use snow cover as a microrefugium adjust their behavior with changing climatic conditions and in complex landscapes. We documented roosting behavior of a winter-adapted bird, the ruffed grouse (*Bonasa umbellus*), and found significant non-linear relationships between roosting behavior and snow conditions: grouse were more likely to use snow

burrows when snow was deep and powdery. Further, grouse experienced warmer temperatures in snow burrows than in other roost types. Contrary to our predictions, cover types did not influence snow roosting behavior, and grouse were not more likely to use snow burrows at colder temperatures, potentially because snow roosting may serve to protect grouse from predators in addition to serving as thermal refugia. However, both the snow conditions necessary for snow roosting, and the occurrence of snow roosting behavior, were relatively rare and declined over the course of our study. Loss of winter microrefugia due to snow cover loss and climate change may severely limit the use of behavioral flexibility for winter-adapted species.

Maternal adjustment of offspring sex allocation in greater sage-grouse

(K. L. Smith, E. F. Tymstra, S. R. Mathews, P. S. Coates, and G. L. Patricelli):

Greater sage-grouse (*Centrocercus urophasianus*) is a species of conservation concern that is widely used as a model for lek breeding. Females of lekking species may invest asymmetrically in male and female offspring in favor of the sex that is predicted to have the highest reproductive potential. This is typically achieved by either producing more offspring of one sex or adjusting the distribution of resources and parental care. Though the physiological mechanisms underlying offspring sex biasing have been examined in other taxa, they have yet to be studied in greater sage-grouse. I measured stress endocrinology, morphometrics, and age of female sage-grouse to determine the predictive power that maternal condition and experience have over biases in offspring sex ratio. Quantifying this relationship will elucidate the strategies of brood demographics and through this understanding, the population implications of anthropogenic stressors.

You are what you eat: connecting foraging and breeding behavior in lekking greater sage-grouse

(E. F. Tymstra, J. Forbey, and G. L. Patricelli):

Economic models of negotiation provide useful frameworks to understand courtship and mating behavior and the processes that underlie behavior on leks. Mate choice can be viewed as a series of negotiations that occur between buyers and vendors (females and males, respectively) in a marketplace. Males must choose a territory location that maximizes mating opportunities and minimizes predation and competition from other males. In order to afford valuable locations within the marketplace, males must be able to pay 'rent'. Previous work on lek-settlement has focused on using economic models in relation to female home ranges, habitat characteristics, and predation. Yet, we do not know how male display territory placement is affected by the physiological condition (endogenous factor of rent) of territorial males in relation to diet choice. During the lekking season, male greater sage-grouse maintain lek territories, which vary in female visitation rate and thus mating potential. Males engage in aggressive encounters with neighbors, presumably to maintain territory boundaries. Since territories differ in value, males on different parts of the lek pay different costs (i.e. 'rent'). Successful males maybe those who can afford these costs due to higher endogenous energy gained from higher-quality diets (higher income). In this study, I examine how dietary quality relates to territory quality on the lek. I will use biomarkers of diet quality (glucuronic acid) and measurements of diet diversity taken from territories of high and low value across study leks. This will provide data on how habitat quality may influence lek dynamics and will further support the links between foraging, habitat quality, and reproductive behavior.

Impacts of conifer removal on sagebrush songbirds

(E. C. Zarri and T. E. Martin):

Conifers have encroached into shrubland habitats across the western United States, contributing to the degradation of sagebrush habitat quality. Conifer removal has become a common restoration strategy and is often done to increase habitat quality for greater sage-grouse. Sage-grouse clearly benefit from tree removal through increases in abundance and reproductive success. Other sagebrush associated species are assumed to benefit similarly, but these assumptions are often based on minimal or no data. This study aims to test how conifer removal impacts the abundance and reproductive success of sagebrush songbirds, including sagebrush-obligate, sagebrush-associated, and generalist species. Removal of conifers could result in ecological traps for songbirds due to high spillover nest predation from conifer habitats. I monitored nests and created territory maps of seven species between conifer removal and control areas in montane sagebrush habitat in southwest Montana. Sagebrush-obligate species including Brewer's sparrow and sage thrasher have higher abundance and nest success in conifer removal areas. Sagebrush-associated and generalist species show mixed responses. Vesper sparrows are more abundant in removal areas, whereas green-tailed towhees, dark-eyed juncos, chipping sparrows, and white-crowned sparrows are more abundant where conifers remain. Additional data is required to clarify patterns of nest success for

these species. However, initial results indicate that conifer removal is beneficial for declining species of sagebrush-obligate songbirds.

Toward an understanding of the relationship between environment and genetic divergence in white-tailed ptarmigan

(S. J. Zimmerman, C. L. Aldridge, K. M. Langin, G. T. Wann, R. S. Cornman, and S. J. Oyler-McCance):

Rapid changes to the alpine resulting from a warming climate will expose alpine-adapted species to novel environmental conditions, forcing one of three responses: shift distribution, acclimate, or adapt genetically to a new climate. Suitable alternative habitat for alpine-specialist species is limited, and the long-term capacity for acclimation will likely be tested, but adaptive genetic variation may provide the raw ingredients for species to adapt to this changing environment. Here, we use a genomic approach to characterize putatively adaptive divergence patterns in an alpine-obligate species, the white-tailed ptarmigan (*Lagopus leucura*). The species is distributed from Alaska to New Mexico, across an environmentally-variable geographic range. Previous work identified genetic structure and morphological, behavioral, and physiological differences across the species' range; however, those studies were unable to determine the degree to which populations have adapted genetically to local variation in environmental conditions. We used a single nucleotide polymorphism (SNP) dataset generated from 95 white-tailed ptarmigan distributed throughout the species' range and genotype-environment association analyses to identify candidate adaptive loci. We detected associations between multiple environmental gradients and candidate adaptive loci, suggesting ptarmigan populations may be locally adapted to the plant community composition, local climate, and the seasonality of the environment. Overall, our results suggest there may be groups within the species' range with genetic variation that may be essential for adapting to a changing climate.

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2021 Annual Conference of The Wildlife Society

Michael A. Schroeder

The Wildlife Society (TWS) held its annual conference as a virtual meeting during 1–5 November 2021. This was the 28th annual conference of TWS and included plenaries, workshops, symposiums and hundreds of posters and papers. TWS plans to resume in-person conferences during 6–10 November 2022 in Spokane, Washington, USA. The following is a list of 40 presentations (papers and posters with their abstracts) that directly and indirectly focused on grouse at this year's conference (alphabetical by first author).

Effects of forest management on early-successional avian species in the Southern Blue Ridge Ecoregion

(M. Adams, B. Ross, A. Tegeler, M. Hook, and M. Small):

Early-successional habitats are a critical habitat type for ruffed grouse (*Bonasa umbellus*) and golden-winged warblers (*Vermivora chrysoptera*). In the southern Blue Ridge Ecoregion, early-successional habitats have declined over the last 70 years, and the extent of which ruffed grouse and golden-winged warblers occupy these habitats at the edge of their ranges is unknown. The goal of this project was to assess the status and distribution of golden-winged warblers and ruffed grouse in the southern Blue Ridge Ecoregion. We also aimed to determine how management of early-successional habitats influences presence/absence of ruffed grouse and golden-winged warblers on public lands, and to evaluate the use of Autonomous Recording Units (ARUs) to detect and monitor both species. Using a conditional occupancy design, we surveyed for ruffed grouse (March 15th – April 30th 2020 and 2021), golden-winged warblers, and associated indicator species (May 5th – June 30th 2020 and 2021) at sites representing varying degrees of timber harvest management and controlled burning intensity. ARUs were placed at sites with and without positive detections of our target species. In 2020, ruffed grouse were detected at one site. In 2021, ruffed grouse were detected at seven sites. In 2020, prairie warbler occupancy was the greatest among indicator species ($\Psi = 0.976$). Our models failed to converge due to their nearly ubiquitous occupation of study sites. Field sparrow occupancy was estimated at $\Psi = 0.656$ and was positively influenced by shrub cover and visual obstruction yet negatively influenced by perimeter-to-area ratio of the occupied patch. Common yellowthroat warbler had the lowest occupancy estimate among indicator species ($\Psi = 0.334$)

and this estimate was positively influenced by percentage of grassland at the 1-kilometer scale. This project will help inform habitat management and conservation of early-successional species and provide guidelines for future monitoring protocols.

Role of female space use in lek dynamics of translocated lesser prairie-chickens

(C. Aulicky, D. Haukos, L. Rossi, K. Fricke, J. Reitz, and K. Schultz):

Translocation of male prairie grouse prior to releasing females is believed to retain birds at desired sites by bolstering or forming new leks. However, this method is based on an untested assumption that males are the dispersing sex in a lek breeding species despite increasing evidence indicates widespread, long-distance movement by females. Female-driven dispersal implies a different mechanism such as the hotspot hypothesis, which postulates males form leks following female space use and habitat constraints. We tested the hotspot hypothesis in shaping lek formation and stability of translocated lesser prairie-chickens (*Tympanuchus pallidicinctus*) in the Sand Sagebrush Prairie Ecoregion of Kansas and Colorado, USA, using the spatial movements of 72 GPS and 44 VHF equipped females. We used ArcGIS optimized hotspot analysis to identify significant clusters of female locations and evaluated where translocated males formed leks and the persistence of those leks. We found that intensity of space use by female lesser prairie-chickens drove lek size and leks formed in location clusters. We found the number of nesting attempts by females within a 5- to 2-km distance had the greatest influence on the persistence of leks into a subsequent year. Our findings show that visual obstruction constraints for quality nesting habitat and female space use drive placement and stability of leks, as expected under the hotspot hypothesis. Future translocation efforts should focus on female habitat constraints by creating quality nesting habitat to sustain long-term nest-site selection prior to releasing birds in order to encourage lek formation and persistence after translocation.

Greater sage-grouse use of thermal refugia on their southern range margin

(A. Beers and N. Frey):

Climate change is likely to drive widespread species range shifts and extirpations, especially on warm range edges. That range edge tends to have lower quality habitat and lower population density. In the Intermountain West, climate change is likely to reduce sagebrush steppe habitat. Among the species potentially threatened is the Greater sage-grouse (*Centrocercus urophasianus*), as they depend on sagebrush for forage and shelter. Other gallinaceous birds are sensitive to thermal stress and exploit refugia to limit it, but sage-grouse response to temperature is not well studied. We deployed 75 data loggers in two valleys in southern Utah and Nevada and used 27 months of data to derive metrics of seasonal temperature extremes, then used random forest models to test the impacts of temperature, land cover, and topography on sage-grouse habitat selection. We found that temperature informed selection in all seasons and both sites, but unevenly improved model performance. In Utah, sage-grouse used areas near trees during the summer and winter, likely to avoid extreme heat and cold, respectively. In autumn and spring extremes were rarer and sage-grouse avoided trees. Conversely, sage-grouse in Nevada, the colder site, selected large and contiguous patches of sagebrush in extremes temperatures and selected habitat near trees only in winter cold. Our findings show that extreme temperatures drive sage-grouse to select habitat near trees despite the risk posed by avian predators. The difference between our Utah and Nevada sites suggests that sage-grouse likely prefer to use sagebrush as thermal shelter but that it may be inadequate shelter during the hottest times, forcing riskier selection. These models point towards a more mechanistic understanding of how sage-grouse respond to temperature on warm range margins. This will refine our understanding of seasonal habitat requirements and inform management decisions to prioritize thermal refugia for an imperiled species of conservation concern.

Quantifying population drivers using historical prairie grouse monitoring data

(J. Carroll, J. Lusk, D. Berger, and L. A. Powell):

Population monitoring data collected by state and federal agencies provide a long-term record of abundance trends, but protocols are not explicitly designed to quantify drivers of those trends. Knowledge of population drivers is critical to the mechanistic understanding of population dynamics that underpins vital rate-focused conservation and management practices. However, longitudinal studies designed to address population drivers are rare. Historical monitoring data could potentially be leveraged to provide information on population drivers if combined with long-term data sets that describe environmental covariates at similar spatial and temporal scales. Greater prairie-chickens (*Tympanuchus cupido pinnatus*) and sharp-tailed grouse (*Tympanuchus phasianellus jamesi*) are both species of conservation concern because of drastic population declines throughout their respective ranges. In the Sandhills of Nebraska, the birds occupy shared range, necessitating co-management. Using sixty-four years or prairie grouse breeding ground count data combined with indices describing predation pressure, land use change and

climate, we attempted to quantify drivers of species-specific population growth rates in the Sandhills. We used a Ricker population process model in a Bayesian state-space framework to explore the relationship between species-specific count data and environmental covariates with a one-year time lag. To draw out the covariates with the strongest influence on population trends, we used a variable selection technique. The top models for prairie-chickens and sharp-tailed grouse included different environmental covariates, suggesting that prairie grouse are subject to species-specific population drivers. Management strategies in shared range must address species-specific resource needs to ensure the persistence of both greater prairie-chickens and sharp-tailed grouse. Our study provides a framework for wildlife managers to use existing count-based monitoring records and free, publicly available environmental data to explore population drivers in addition to abundance trends.

Collaborative approach to profitable ranching & conservation in the Nebraska Sandhills

(C. Christiansen):

The Sandhills of Nebraska are a unique grassland ecosystem consisting primarily of rolling grasslands and wet meadow habitats. Identified as a largest stabilized grassland in the western hemisphere, the Sandhills provides home to a wide range of wildlife including a handful of federally endangered species. This area is also well-known as one of the top cattle-producing regions in the country. However, Sandhill's ranchers are not immune to threats to their operations. Through collaborative efforts with multiple entities, Landowners are able to address threats to their operations while maintaining or creating high quality habitat for wildlife. This results in keeping ranchers profitable and on the landscape and promoting long-term sustainable operations while maintaining or improving habitat for wildlife on their operations.

Managing wildlife openings to benefit game and non-game bird species in central Appalachian forests

(H. Clipp, C. Rota, and P. Wood):

In forested landscapes of the Central Appalachians, wildlife openings are created and maintained by land managers to provide early-successional habitat (e.g., areas of herbaceous ground cover, shrub-scrub, or young forest) for three regionally-important game birds — wild turkey (*Meleagris gallopavo*), ruffed grouse (*Bonasa umbellus*), and American woodcock (*Scolopax minor*). These wildlife openings can also benefit a myriad of non-target (i.e., non-game) avian species and guilds, depending on local habitat features and landscape-level factors. Yet little effort has been made to investigate how to optimally manage wildlife openings to attract a full spectrum of avifauna throughout spring and summer and maximize richness across habitat guilds. Therefore, the purpose of this study is to examine the sympatric use of wildlife openings by game birds, breeding songbirds, and post-breeding songbirds in response to site- and landscape-level wildlife opening characteristics. Our objectives are to determine how local habitat attributes, opening size, management actions, and landscape context relate to (1) avian guild richness, (2) occupancy of specific game birds, breeding songbirds, and post-breeding songbirds, and (3) abundance of specific early-successional, edge-associated, and forest-interior breeding songbird species in wildlife openings. In April–August 2019–2021, we used species-specific and community-wide point count surveys, acoustic recording units, game cameras, and transect surveys to sample the avian communities of nearly 300 wildlife openings within the Monongahela National Forest in eastern West Virginia. Results from multi-species occupancy and n-mixture models indicate vegetative cover and opening size influence avian guild richness and occupancy/abundance of certain focal species. Ultimately, these results will assist in the design and management of wildlife openings that simultaneously support target game bird populations and promote a diverse suite of songbirds.

Efficacy of common raven reproduction manipulations at conserving sensitive prey species: three case studies

(D. Delehanty, C. Sanchez, B. Brussee, P. Coates, K. Holcomb, S. Harju, T. Shields, M. Vaughn, B. Prochazka, S. Mathews, S. Cornell, and C. Olsen):

Expansion of human enterprise has resulted in the availability of anthropogenic subsidies to generalist species which has led to expansion in populations across landscapes that were previously less suitable for generalists' current rates of survival and recruitment. Of particular concern is growing populations of common ravens (*Corvus corax*, raven), because raven predation is linked to depressed vital rates and population declines of several sensitive species. Recent management strategies intended to both limit raven recruitment and decrease predation by ravens on sensitive species are focused on manipulating raven populations during the breeding season. These strategies include oiling raven eggs, which causes

embryonic development to fail, and removing raven nests in targeted areas, which prevents or terminates raven reproduction. We present three case studies, each with the objective of examining how manipulation of raven reproduction during the breeding stage influences demographic rates of two sensitive prey species. Methods include oiling raven eggs or removing raven nests within greater sage-grouse (*Centrocercus urophasianus*) nesting ranges across Wyoming, California, and Nevada and detecting changes in sage-grouse nest survival within control and raven treatment sites to determine a treatment effect. Additionally, raven egg-oiling treatments were applied in California, where Mojave desert tortoise (*Gopherus agassizii*) decoys paired with Passive Infrared (PIR) triggered trail cameras were used to examine the effects of treatment on raven depredation rates of juvenile desert tortoises. Results in all three case studies were consistent in showing that manipulating the reproductive success of nesting ravens, through egg-oiling or nest removal, reduces their predation impacts on prey. Along with new technologies that can make both techniques more feasible, these findings suggest that egg-oiling and nest removal are viable tools for managing ravens, especially in areas where breeding ravens have negative impacts on sensitive prey species. Findings are preliminary and provided for timely best science.

A science-driven actionable adaptive management framework for common ravens

(S. Dettenmaier, P. Coates, S. Webster, C. Roth, S. O'Neil, J. Tull, and P. Jackson):

Large-scale increases and expansion of common raven (*Corvus corax*) populations are occurring across much of North America resulting in increased negative consequences for livestock and agriculture, human health and safety, and sensitive species conservation. Most raven control efforts have focused on lethal removal without post-treatment monitoring. This approach has led to management plans that often fail to consider alternative actions that may be more effective for achieving long-term goals. We describe a science-based adaptive management framework for addressing overabundant raven populations that explicitly incorporates scientific products. The framework comprises five steps: (1) desktop analysis; (2) field assessments; (3) comparison of raven density estimates to an ecological threshold; (4) prescribing management actions using a 3-tiered process; and (5) post-management monitoring. For the benefit of state and federal resource managers, we include the available scientific products within the framework to guide the development of raven management plans. The adaptive management framework is applied using our off-the-shelf Science-based Management of Ravens Tool (SMaRT). SMaRT is a web-based application with a user-friendly interface that guides managers through the steps of the framework to develop a fully customized adaptive plan for raven management. In the SMaRT interface, users can: (1) interact with current existing maps of raven occupancy and density, and input areas of interest or upload pre-defined polygons for target species within the Great Basin to delineate their proposed survey or treatment sites; (2) generate raven densities using a rapid assessment function; (3) compare site-level density to an identified ecological threshold; and (4) produce a list of potential management actions for their consideration. SMaRT supports decision-making by operationalizing science within raven management and facilitates meeting diverse goals including sensitive species conservation, protection of livestock and agriculture, safeguarding human health, and addressing raven overabundance and expansion. Findings are preliminary and provided for timely best science.

A range-wide, long-term greater sage-grouse monitoring database to inform management across eleven western states, USA

(D. Edmunds, A. Moser, M. O'Donnell, T. Remington, C. Aldridge, T. Runia, J. Heinrichs, L. Schreiber, A. Monroe, M. Schroeder, P. Coates, S. Stiver, B. Prochazka, N. Whitford, S. Hanser, and C. Wightman):

Long-term monitoring of natural resources is imperative for increasing our understanding of ecosystem processes, services, and how to manage those ecosystems to maintain or improve function. Challenges with using these data may occur because methods of monitoring changed over time, multiple organizations collect and manage data differently, and monetary resources fluctuate, affecting many aspects of data (e.g., more or less monitoring on an annual basis depending on level of funding). We demonstrate the methods and challenges for acquiring, uniting, and standardizing a range-wide greater sage-grouse (*Centrocercus urophasianus*) lek count database (lek is a breeding site where males compete for ability to mate with visiting females). The database was comprised of long-term lek count monitoring data, which we compiled using data provided by all 11 western USA states where greater sage-grouse occur and dated back to the 1950's in some of these states. We used automated and repeatable methods to standardize data via custom open-source software (grsg_lekdb) to improve the scientific integrity of future sage-grouse population assessments within and among states. Data standardization included reconciling uses of different terminology and expunging unusable data, resulting in the removal of 26% of data records due to database insertion errors and modifications to >1 million values to correct formatting and typing errors. We used the data to inform population monitoring and modeling needs,

including a range-wide population trends analysis based on hierarchical, nested lek clusters (multi-scaled monitoring framework) and a Targeted Annual Warning System (TAWS) to inform managers of leks and populations in decline. Our approaches corrected spatial and aspatial data errors, maximized inclusion of usable data, and supported applications of ecoinformatics that identified data to inform detection probabilities, population trends, and monitoring guidelines. We show the importance of data management and how ecoinformatics can improve the usefulness of data for future research needs.

Greater prairie-chicken habitat selection within a mosaic burning regime on Fort Riley Military Reservation, Kansas

(J. Gehrt, D. Haukos, and D. Moon):

Greater prairie-chickens (*Tympanuchus cupido*) face large-scale disturbances in the form of habitat loss and conversion of the prairies in which they reside. Even large tracts of remaining grasslands, such as the Flint Hills ecoregion, are not free from disturbances caused by contemporary land management practices such as ranching. Some ranching practices implement annual burning or intensive grazing regimes that may decrease habitat availability for Greater Prairie-chickens. Fort Riley Military Reservation in Riley and Geary counties, KS may prove to be a refuge for Greater Prairie-chickens as grazing is not allowed and burn regimes are characterized as a mosaic style, leaving a heterogeneous matrix of vegetation on the landscape. This heterogeneous landscape prompted us to assess relative use of available habitat types by Greater Prairie-chickens on the reservation. We tracked the movements and space use of 38 females from April-August 2019 and 2020. Females predominately selected for frequently burned areas (every 1 to 2 years). We also found used and nest locations to be in similar areas on the landscape in 2019 and 2020 despite annual shifts in burn frequencies in those areas. This shift in burn frequencies led to a significant difference in nest success between frequently and moderately (every 2 to 4 years) burned areas (9% and 21% respectively). Information on the influence of the mosaic burning regime on habitat selection by Greater-Prairie chickens will aid in the development of specific management recommendations for the conservation of Greater Prairie-chickens on Fort Riley Military Reservation.

Variance in clutch size and egg morphology of lesser prairie-chickens across a climate gradient

(B. Grisham, C. W. Boal, S. Morrise, and D. Haukos):

Lesser prairie-chickens (*Tympanuchus pallidicinctus*) are distributed from southeast New Mexico to south-central Kansas. This range encompasses a temperature and precipitation gradient that is hotter and drier in the southwest to cooler and wetter in the northeast. We hypothesized lesser prairie-chickens may vary clutch sizes or egg morphology as an adaptation to local environmental conditions. We compared clutch sizes and morphometric characteristics of lesser prairie-chicken eggs from among study areas in Texas and Kansas. We used analysis of variance tests to compare clutch sizes, and egg metrics of length, width, volume, surface area, deviation from an ellipse, and mass. We also compared egg coloration and extent of speckling. Lesser prairie-chickens in Texas set significantly fewer eggs per clutch (mean 6.7 ± 1.75 SD) compared to those in Kansas (mean 10.3 ± 2.36 SD). We found eggs from the Texas study area were larger, with greater volume than any of the Kansas study areas, and had a greater mass than two of three Kansas study areas. Texas prairie-chicken eggs also had greater deviation from an ellipse than two Kansas study areas. Visual appearance also differed; Texas eggs were lighter toned in shell color but had a greater frequency of speckling than Kansas eggs. Our results suggest that lesser prairie-chickens in Texas put greater investment in fewer but larger eggs per clutch. The lower surface to volume ratios of larger eggs translates to reduced evapotranspiration loss of moisture and reduced heat gain compared to smaller eggs. The diffuse darker speckling against a lighter background may serve to improve camouflage of eggs while reducing heat absorption compared to darker toned eggs. It appears that lesser prairie-chickens in the southwestern extent of their distribution may be responding to the hotter and drier climate through modification of clutch sizes and egg morphology.

Lesser prairie-chicken space use following megafire in the mixed-grass prairie

(C. Hagen, N. Parker, D. Sullins, D. Haukos, and K. Fricke):

Fire was a key ecological driver in the formation of the Great Plains of North America and helped maintain diverse and heterogeneous grasslands benefiting grassland-dependent wildlife, such as the lesser prairie-chicken (*Tympanuchus pallidicinctus*). Decades of fire suppression in parts of the Great Plains has reduced species diversity and facilitated woody plant encroachment, further fragmenting remaining lesser prairie-chicken habitat. Fire suppression, combined with effects of climate change, has led to an increase in size and severity of wildfires in the Great Plains. While wildfires may benefit some aspects of lesser prairie-chicken habitat, fires of this size (>40,000 ha) and intensity have not been recorded in recent

history and lesser prairie-chicken response to such fires in modern, fragmented grasslands is unknown. We compared space use and resource selection by lesser prairie-chickens marked with GPS transmitters in the mixed-grass prairie of Kansas before (2014-2016) and after (2018-2020) a 2017 wildfire (252,000 ha). We used Brownian bridge movement models to estimate 95% isopleth home ranges and found no difference in overall lesser prairie-chicken space use before (828 ± 110 ha) and after (719 ± 101 ha) the fire. However, home ranges included 5 times more percent cover of Conservation Reserve Program (CRP) fields after the fire compared to before, suggesting CRP/cropland landscapes with disjointed fire fuel availability can provide refuge during extreme events. Step selection revealed lesser prairie-chickens strongly avoided wooded areas before and after the fire, indicating that although we did see mortality of woody species, areas did not become available for use by lesser prairie-chickens. Furthermore, lesser prairie-chickens avoided burned areas post-fire, suggesting limited habitat availability post-fire and emigration from the study site. Our results point to the need for multiple management strategies (e.g. prescribed fire, CRP enrollment) to manage lesser prairie-chicken habitat and limit future megafires.

Assessing range-wide population performance of greater sage-grouse using a targeted annual warning system

(S. Hanser, L. Wiechman, M. Chenaille, B. Prochazka, P. Coates, M. O'Donnell, C. Aldridge, D. Edmunds, A. Monroe, M. Ricca, and G. Wann):

When local perturbations are absent, greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) populations exhibit long-term oscillations in abundance, which are driven by large-scale climatic patterns. Concurrent to long-term oscillations is short-term "noise", which is governed by environmental and demographic stochasticity. Multi-scale spatiotemporal fluctuations in abundance make population performance assessments difficult, especially when additional information regarding metapopulation structure is absent. By incorporating metapopulation structure into a Bayesian hierarchical population monitoring framework developed for sage-grouse across their range, we were able to identify moments of aberrant decline at lek sites (i.e., traditional breeding grounds) and local populations defined as clusters of leks. Within this framework we defined aberrant decline at these scales as a negative trend that is also declining at a rate below the estimated trend at a much broader spatial scale. Multi-year assessments of aberrant decline accounted for environmental and demographic stochasticity, as well as observation error, and identified populations exhibiting strong evidence of climatically corrected negative trends. Post hoc analyses that simulated management intervention at the local scale used metapopulation stability as a target for identifying optimal management intervention thresholds. Using this framework, we identified population declines that are likely attributable to disturbances on the landscape rather than environmental stochasticity or intrinsic factors across broader regions, which can help immediately inform when and where increased monitoring or direct management intervention may be needed to reverse negative trends.

Targeted brush removal to benefit prairie grouse and cattle operations

(D. Haukos, C. Hagen, KC Olson, K. Harmoney, and D. Sullins):

Strategic habitat conservation relies on iterations of planning, evaluation, and implementation as cogs in a wheel that can be effective and adaptive when managing for species of concern. At broad scales, conservation is often halted at the implementation stage, particularly when reliant on voluntary participation from private landowners and producers. In such situations, an evaluation of socioeconomic factors that constrain conservation action may become as important as identifying best management practices for wildlife. We provide an example of a potential win-win solution that could benefit both lesser prairie-chickens (*Tympanuchus pallidicinctus*) and cattle operations in Kansas based on a comprehensive evaluation of habitat requirements, habitat availability, and socioeconomic factors. We first estimated the distribution of lesser prairie-chickens using data from individuals marked with GPS transmitters in Kansas and Colorado, USA, and empirically derived relationships with anthropogenic structure densities and grassland composition. We then used our estimated species distribution to provide spatially explicit prescriptions for tree removal in locations most likely to benefit lesser prairie-chickens. Strategic application of tree removal has the potential to restore 1,154 km2 of lesser prairie-chicken habitat. Based on published tree removal rates, it would cost approximately $32.6 million to remove trees in this area. Assuming that grassland forage ceases to exist when tree cover is >50%, preliminary estimates suggest that strategic removal of tree cover would provide forage for 3,360 steers at a stocking rate of 2 hectares per head and provide an additional $308,000 annually for private landowners. Our estimated benefits are conservative and do not account for greater water for herbaceous growth and direct consumption by cattle, nor the long-term benefits of proactive tree removal. Overall, mechanical tree removal may be more costly than short-term gains in cattle production, however, both cattle and lesser prairie-chickens can benefit long-term when future encroachment is prevented.

Fuel break effectiveness linked to accessibility, environmental conditions, and treatment type in a retrospective assessment of wildfires across the western United States

(J. Heinrichs, B. Brussee, P. Coates, C. Roth, M. Ricca, C. Aldridge, M. Crist, D. Shinneman):

Accelerated cycles of wildfire and annual grass invasion are threatening iconic sagebrush ecosystems of the American West and the species that inhabit them. Therefore, wildfire management is at the core of conservation plans for the sagebrush ecosystem, especially critical habitat for species of conservation concern such as the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse). Fuel breaks are a key component wildfire suppression and may minimize catastrophic losses of sagebrush by disrupting fuel continuity, reducing hazardous fuel loads, and facilitating staging fire suppression operations, but an extensive evaluation of effectiveness at broad spatiotemporal scales is lacking. We compiled a comprehensive database of fuel breaks across sage-grouse range and intersected them with wildfire perimeters from the Monitoring Trends in Burn Severity and GeoMAC databases from 1984–2018. We coupled fuel break fire events with environmental data characterizing topography, fuels, fuel break condition and accessibility, and weather in a retrospective analysis to identify conditions related to fuel break effectiveness using a binomial mixed model within a Bayesian framework. We found that fuel breaks with greater contact with larger fires were less likely to be successful. In addition, we identified variation in the effectiveness of fuel break treatments based on the ecosystem's ability to resist annual grass invasion and recover from wildfire (i.e., resilience). We also found that fuel continuity and fuel break accessibility influenced success. Specifically, greater continuity of fine fuels decreased probability of fuel break success, whereas fuel breaks closer to roads were more likely to be successful. These results can help managers identify areas for fuel break installations and manage tradeoffs between fire suppression and sagebrush disturbance, such as habitat fragmentation caused by fuel breaks. Findings are preliminary and provided for timely best science.

Understanding the effects of 50-years of Wyoming vehicular traffic on sage-grouse populations

(J. Heinrichs, E. Buchholtz, M. Holloran, C. Aldridge, R. Inman, M. O'Donnell, B. Robb, and A. Monroe):

Road networks and their associated vehicular traffic may negatively impact populations of many terrestrial species due to noise, barriers to movement and direct mortality from collisions. Documented declines and extirpation of Greater sage-grouse (*Centrocercus urophasianus*) at lek sites near major highways and other transportation infrastructure have been observed but not well studied. Further, recent decades have seen increased truck traffic associated with energy development such as oil and gas drilling, which can elevate stress hormones, change lekking behavior, and increase mortality. However, the cumulative and long-term impacts of vehicular traffic on sage-grouse populations are largely unknown. We address this knowledge gap by developing estimates of yearly traffic volume on Wyoming Department of Transportation's network of paved roads using a novel machine learning method (XGBoost). We show how spatial patterns of vehicular traffic on these roads have changed through time and use these estimates to assess how traffic has impacted sage-grouse population trends within a multi-scale hierarchical modeling framework. We also highlight future efforts of estimating annual traffic volume on unpaved roads and demonstrate the utility of incorporating estimates of traffic volume when assessing cumulative impacts on sage-grouse populations.

Development of a dusky grouse population monitoring program

(S. Landry-Giavotella and D. Dahlgren):

Dusky grouse (*Dendragapus obscurus*) are an understudied gallinaceous species that are harvested across their range in western North America. Currently, 7 of the 10 states where dusky grouse are found collect harvest data via wing collections and/or hunter harvest surveys, yet no state currently conducts breeding or brooding surveys to monitor population changes over time. A recent study in the Bear River Range of Utah was completed where forest grouse breeding surveys were implemented over two consecutive seasons (2017–2018) to estimate occupancy and detection probabilities and to refine sampling protocols for dusky and ruffed grouse (Bonasa umbellus). We implemented similar breeding survey protocols for dusky grouse in the Great Basin 'sky island' ranges of east-central Nevada, where we performed over 350 point-count surveys across four springs (2018–2021) to estimate annual abundance of breeding dusky grouse and to assess breeding habitat selection. We used a combination of hierarchical modeling methodology in each survey, including distance sampling, time-to-detection, and N-mixture, then used those data to design a monitoring protocol and a hierarchical relative abundance model that Nevada Department of Wildlife biologists can use to track trends in dusky grouse populations over time. We will

illustrate how to test our model using the Utah data to determine its compatibility with other regions. If the model converges well, then the same protocol and model can be used for dusky grouse monitoring in Utah; otherwise, we will adjust analyses to determine the top model that is specific to Utah populations. Ultimately, these model(s) and protocol(s) will be made available for testing with other dusky grouse populations to determine if there is a one-size-fits-all model or if the model should be modified by state or region to better estimate dusky grouse abundances throughout their range.

Brood-habitat quality predicts lek occurrence and male lek attendance in sharp-tailed grouse

(J. Lautenbach, J. Beck, and A. Pratt):

Understanding why leks occur at certain sites over others has important conservation implications, especially in lekking grouse species where habitat and population management centers on lek locations. The lek hotspot hypothesis predicts that leks will occur in areas more frequented by females and offers a theoretical framework to explore why leks occur where they do. To identify whether leks are placed in areas more likely to be frequented by female sharp-tailed grouse (*Tympanuchus phasianellus*), we evaluated habitat selection and quality (as modeled by nest, brood, and female winter survival) based on multiple vegetation and topographic metrics from locations of 213 VHF-marked female sharptails during nesting, brood-rearing, and winter in south-central Wyoming from 2017–2019. We then compared predicted habitat selection and quality across life-history stages to 24 known leks to evaluate whether habitat selection or quality influenced lek occurrence and male lek attendance. Lek locations and male lek attendance were best predicted by brood-rearing habitat quality within 400 and 800 m of leks, respectively, with an increasing proportion of high-quality brood-rearing habitat indicating a higher probability of lek occurrence ($\beta = 2.5$; 95% CI 1.4–3.9) and increased male lek attendance at ($\beta = 11.5$; 95% CI 4.5–18.4). Although nest, brood-rearing, and winter habitat selection and nesting and winter habitat quality were not the top models, they did predict lek occurrence, but not male lek attendance; these models showed that the probability of lek occurrence increased with increasing probability of selection or quality. Our results suggests that sharp-tailed grouse leks occur in areas with more abundant brood habitat surrounding them and that lek attendance increases in areas with greater production potential. Our results support monitoring sharp-tailed grouse populations by conducting lek surveys and suggest that population changes might be due to varied brood success.

Why didn't the chicken cross the road? Effects of linear features on greater prairie-chicken space-use and landscape connectivity

(D. Londe, D. Elmore, C. Davis, S. Fuhlendorf, and T. Hovick):

Landscapes across the globe are becoming increasingly fragmented by anthropogenic activities. In particular, many landscapes are divided by linear features such as roads or power lines used to power human settlements. These structures can have important implications for wildlife populations as they may create barriers to movement for individuals. This can reduce the flow of genes and individuals across the landscape potentially increasing the risk of local extinctions for some populations. Our first objective in this study was to assess if greater prairie-chickens, a species of conservation concern in the Great Plains of North America, alter their movement behaviors (speed or direction of travel) or their selection patterns relative to linear features such as power lines, or roads using integrated step selection analysis (iSSA). Our second objective was to determine if changes in movement or selection behavior influenced the frequency at which greater prairie-chickens crossed linear structures. We assessed crossing rates by comparing the number of movements in observed greater prairie-chicken movement tracks that crossed these features to the number of movements that crossed these features in simulated movement tracks. Based on the iSSA analysis, we found that greater prairie-chickens avoided power lines, and roads in both seasons, but found little evidence for changes in speed or direction of travel at the population level. Further, prairie-chickens crossing roads and power lines at much lower rates than expected. Consistent avoidance of development in both seasons resulted in indirect habitat loss for greater prairie-chickens. Additionally, the avoidance of linear features has the potential to reduce connectivity across the landscapes. By considering both movement and selection we were able to develop a clearer picture of how increasing human activity may influence the space-use of species of conservation concern.

Reproduction and habitat selection of reintroduced, translocated, Columbian sharp-tailed grouse

(S. Mathews, P. Coates, B. Brussee, S. O'Neil, S. Espinosa, and D. Delehanty):

Resource managers have determined a need to augment Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*; hereafter, sharp-tails) populations using translocation techniques. Although translocation is a common management practice, little research has evaluated breeding habitat requirements in selection and survival models of translocated sharp-tails. Spatially explicit maps can quantify suitable habitat at a release site and identify breeding areas that inform management decisions and potential release locations. Furthermore, evaluation of microhabitat characteristics within these areas can inform specific vegetation requirements that further promote breeding success. We translocated 215 sharp-tails to Nevada as a species reintroduction project and documented all nest and brood attempts by translocated individuals. Using Bayesian regression and shared-frailty models, we quantified selection for microhabitat factors at nests and brood locations, respectively, and analyzed which factors had the largest impact on nest and brood survival while accounting for spatial correlation to the release location. In Nevada, translocated females avoided mountain shrubs within 25 m of their nest bowl (β = -0.97, 95% credible interval [CRI]-2.14 – -0.08), and strongly selected nests with taller residual grasses (β = 0.81, 95% CRI= 0.22 – 1.49). Tall perennial forbs however, had the largest impact on nest survival (β=-0.56, 95% CRI = -1.05–0) wherein taller forbs substantially reduced the probability of nest failure. Translocated females with broods avoided higher percentages of shrub (β = -0.61, 95% CRI = -0.92 – -0.30) and selected locations with taller sagebrush (β = 0.54, 95% CRI = 0.26 – 0.84) and increased percentages of horizontal cover (β = 0.51, 95% CRI = 0.20 – 0.83) with minor effects on the probability of brood survival. Finally, we mapped habitat selection and survival on a macro scale to identify potential future release sites that could maximize reproduction by translocated individuals. These findings are preliminary and provided for timely best science.

Evaluating the role of NDVI-based phenology metrics in lesser prairie-chicken nest-site selection

(A. Messier, D. Sullins, D. Haukos, and C. O'Meilia):

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is an at-risk grassland obligate species that relies on healthy, intact grasslands to reproduce. The ability to monitor and identify broad-scale habitat availability for this species is important for future conservation efforts, yet also difficult given the large area needed to sustain populations (~8,000 ha). Fortunately, continuing advancements in remote sensing technology may make broad-scale monitoring feasible. Remotely sensed vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and associated phenology metrics (amplitude, duration, maximum NDVI, etc.) can provide information about the productivity and health of grasslands. These metrics may also yield inferences about the availability of lesser prairie-chicken reproductive habitat at relevant spatial scales. We evaluated the potential role of NDVI-related phenology metrics in nest-site selection by lesser prairie-chickens. Using cloud-free Landsat 8 scenes and yearly MODIS Aqua phenology scenes, snapshot NDVI estimates and yearly phenology estimates were derived at >70 lesser prairie-chicken nest locations and two paired random points at two study sites in Kansas. Using an information theoretic approach, we fit multiple resource selection functions based on NDVI and related phenology metrics to predict nest site selection. Based on AICc, none of our candidate models outperformed the null model, and none of the phenological relationships were informative predictors. Preliminary results suggest that phenology metrics alone may not be a reliable predictor of lesser prairie-chicken nest-site selection. This may be due to the resolution of the phenometric images, limiting landscape features such as avoidance of anthropogenic and woody features, or other hierarchical processes. Hereafter, we plan to evaluate the influence of NDVI and NDVI-based phenology metrics on lesser prairie-chicken brood habitat.

Changes in spatial distribution decoupled from abundance for greater sage-grouse in Bi-State Distinct Population Segment

(M. Milligan, P. Coates, M. Ricca, B. Prochazka, S. O'Neil, J. P. Severson, S. Mathews, S. Espinosa, S. Gardner, S. Lisius, and D. Delehanty):

Changes in distribution or abundance are frequently used independently to evaluate trends and status of wildlife populations. It is often assumed, although not explicitly stated, that these measures are correlated. However, if population distribution and abundance become disconnected, such as when changes in a subpopulation drive overall population trends, then focusing on a single indicator, such as abundance, can mask important losses in distribution. We evaluated changes in both population abundance and distribution from 1995 to 2021 for greater sage-grouse (*Centrocercus urophasianus*) in the Bi-State

Distinct Population Segment, a genetically distinct and isolated population straddling the border of Nevada and California on the edge of the sage-grouse geographic range. First, we used an integrated population model incorporating lek counts and demographic data to predict annual population abundance across all sub-populations (i.e., lek complexes). Second, we used telemetry data to develop phenological and reproductive life-stage resource selection functions to map predicted habitat. Finally, we used predicted abundances to estimate a weighted utilization distribution of space use that, with the predicted habitat maps, allowed us to evaluate changes in population distribution over time. Although overall population abundance remained stable over both the short- (λ = 0.99, 95% CRI = 0.70-1.30) and long-term (λ = 1.02, 95% CRI = 0.74-1.42), the distribution of occupied habitat declined. This was due to significant losses among 3 sub-populations, while one larger subpopulation expanded, translating to a loss of total area over time and a 77% probability that the range of any given subpopulation contracted. The contractions in distribution combined with stable population trends suggests long-term patterns in redistribution of sage-grouse among subpopulations, with peripheral subpopulations declining while the largest core population increased. This decoupling between trends of abundance and distribution could have implications for metapopulation persistence as peripheral populations become more vulnerable

A novel approach to estimate range-wide population trends for greater sage-grouse at multiple spatial scales

(A. Monroe, M. Ricca, G. Wann, S. Hanser, L. Wiechman, M. Chenaille, P. Coates, B. Prochazka, M. O'Donnell, C. Aldridge, and D. Edmunds):

Incorporating spatial and temporal scales into greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) population monitoring strategies is challenging and rarely implemented. Sage-grouse populations are characterized by temporal oscillations, making trend estimation sensitive to start and stop years. Accounting for environmental and demographic stochasticity is critical to reliably estimating population trends and identifying deterministic factors on the landscape more amenable to management action. We used a standardized database of lek counts within a hierarchical Bayesian state-space model and a biologically-informed, multi-scale network of breeding populations, known as 'clusters,' to estimate trends across different spatiotemporal scales. While accounting for oscillations in population abundance, our models estimated 37.0, 65.2, and 80.7% range-wide declines across short (17 years), medium (33 years), and long (53 years) temporal scales, respectively. Models also predicted 12.3, 19.2, and 29.6% of populations (defined as clusters of neighboring leks) consisted of over 50% probability of extirpation at 19, 38, and 56-year projections from 2019, respectively, based on averaged annual rate of change in apparent abundance across two, four, and six oscillations (average period of oscillation is 9.6 years). At the lek level, models predicted 45.7, 60.1, and 78.0% of leks with over 50% extirpation probabilities over the same time periods, respectively, mostly located on the periphery of the species' range. Recent rates of decline were greater in western portions of the range, particularly the Great Basin, where wildfire and invasive grasses are prominent. Conversely, some areas in the eastern range exhibited evidence of population growth in recent decades. This modeling framework can serve as the foundation for a 'Targeted Annual Warning System' decision support tool to direct management efforts toward populations with the greatest need and may be modified to evaluate the effectiveness of conservation efforts.

Biome-scale woody encroachment threatens conservation potential and sustainability of U.S. rangelands

(S. Morford, B. Allred, D. Twidwell, M. Jones, J. Maestas, and D. Naugle):

Woodland expansion is a dominant threat to the economic sustainability of working rangelands. Applying new satellite technology, we show that a quarter of U.S. rangelands are experiencing tree cover expansion and that tree cover in these areas has increased by 50% over the past 30 years. Combining satellite and USDA economic data reveals that forage production losses to tree encroachment have cost producers some $5 billion in revenue since 1990, with annual losses now topping $300 million. Identifying where tree encroachment contributes to ranch-level forage and revenue losses provides a mechanism to focus private-land conservation efforts to promote economically sustainable outcomes in U.S. working lands. To this end, we share a web-based application that allows users to investigate recent woody encroachment and herbaceous production loss at any location in the western U.S. These data and tools are freely available from the Rangeland Analysis Platform and are being used to guide the Great Plains and Sagebrush Biome Frameworks for Conservation Action developed by the NRCS.

Free-roaming horses adversely impact greater sage-grouse population dynamics in sagebrush ecosystems

(S. O'Neil, P. Coates, D. Munoz, I. Dwight, and J. Tull):

Free-roaming horse (*Equus caballus*) populations have increased in sagebrush ecosystems and have exceeded maximum appropriate management levels (AMLmax) designated by the Bureau of Land Management for more than a decade. Concomitantly, greater sage-grouse (*Centrocercus urophasianus*) populations have declined from loss and degradation of critical habitats. Overgrazing can degrade sagebrush communities, but the effects that feral horses have on sage-grouse population dynamics are largely unknown. We employed Bayesian state-space models to estimate sage-grouse population rate of change (λ) using 15 years of lek surveys in relation to horse abundance (relative to AMLmax) and other environmental covariates such as sagebrush cover, wildfire, and precipitation indices. Additionally, we employed a post-hoc impact-control design to validate existing AMLmax values in relation to sage-grouse population responses that help control for environmental stochasticity and broad-scale oscillations in sage-grouse abundance. For every 50% increase in horse abundance over AMLmax, a 2.6% annual decline in sage-grouse abundance was predicted. When horse abundance was at or below AMLmax, sage-grouse λ estimates mirrored trends at areas with no horses. Conversely, results indicated a 75%, 97%, and 99% probability of λ decline relative to controls when horse abundance relative to AMLmax was 200%, 250%, and 300%, respectively. For context, horse herds were estimated at 405% AMLmax in Nevada, USA during 2019. Model projections indicate ~70% declines in sage-grouse populations within horse occupied areas by 2034 if horse population trends continue unabated, compared to 18% declines in areas not currently occupied by horses. Monitoring frameworks that consider sage-grouse and other ecosystem indicator species can guide management decisions that promote co-occurrence of horses with sensitive wildlife and other managed livestock within multiple-use landscapes. Findings are preliminary and provided for best timely science.

Sage-grouse response to wildfire: analyses of range-wide effects and relationships between sage-grouse demography and underlying post-fire sagebrush recovery processes

(D. Pilliod, M. Rigge, I. Dwight, P. Coates, C. Roth, B. Prochazka, M. Chenaille, M. Ricca, C. Aldridge, and A. Monroe):

Wildfire has long-term adverse impacts on greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) population persistence within the Great Basin. However, chronic effects of wildfire may vary across the entire distributional range of sage-grouse based on regional variation in climate and ecological properties related to sagebrush (*Artemisia* spp.) ecosystem resilience and resistance to invasive annual grasses. These properties drive variation in sagebrush recovery after disturbance and are expected to influence changes in sage-grouse population abundance. We extended on previous methods of modeling sage-grouse population rate of change () in the Great Basin to a range-wide study extent and developed an advanced sagebrush recovery model using time series satellite imagery in burned areas over the past 35 years. Specifically, we employed a Bayesian state-space model framework, which relates variation in to changes in cumulative burned area around leks, while accounting for environmental covariates and Gompertz density dependence. Across the range of sage-grouse, we found support for an interaction between cumulative burned area and a one-year lag effect on summer precipitation. Although the strength of the effect varied among regions, which we delineated by broad-scale clusters of leks grouped by shared climatic conditions, the positive influence of precipitation was typically reduced as the proportion of burned area around leks increased. We then used models to project over the course of 35-years under different management action scenarios to inform specific actions that reduce cumulative burned areas and neutralize negative impacts of habitat loss. Understanding patterns of variation among broad-scale regions can elucidate wildfire impacts across a large ecological gradient. Findings are preliminary and provided for timely best science.

Winter microhabitat selection and greater sage-grouse response to weather severity

(C. Powell, J. Beck, K. Smith, and A. Pratt):

Winter habitat used by greater sage-grouse (*Centrocercus urophasianus* 'hereafter, sage-grouse') is characterized by moderate topography within a mosaic of sagebrush (*Artemisia* spp.) of differing height and cover. This mosaic ensures access to forage and shelter among variable snow depths. How sage-grouse select winter habitat in response to severe weather is less understood. Our objective was to evaluate predictors of sage-grouse microhabitat selection in response to severe weather in Wyoming's Red Desert. We monitored 52 adult female sage-grouse equipped with GPS transmitters during winters

2018/2019 and 2019/2020. When weather was severe, we expected less movement resulting in smaller daily home ranges. We calculated a winter severity index (WSI) within daily home range polygons that incorporated multiple weather metrics (snow depth, temperature, wind velocity, precipitation) using SnowMet at 30-m resolution. We employed a resource selection function modeling to evaluate whether sage-grouse selected areas with lower WSI values. To quantify microhabitat structure, we identified 90 grouse locations, 90 randomly-generated locations within home ranges, and 90 locations at the population range scale, encompassing winter 2019/2020. During summer 2020, we sampled winter microhabitat structural characteristics along 50 x 50 m transects at these 270 locations to record canopy cover, density, and height for each shrub species as well as visual obstruction. To model sage-grouse winter microhabitat selection, we paired each use location with a home range and population range random location (dependent variables) and regressed these against shrub community structure along each transect and the WSI value from the day of bird use. When weather was severe, we expected sage-grouse to mediate weather severity by selecting greater shrub concealment at the microhabitat scale. Information on microhabitat that sage-grouse select to maximize their survival during severe winter conditions will better inform conservation of critical wintering habitats to promote population persistence under changing climatic conditions.

Common ravens disrupt greater sage-grouse lekking behavior in the Great Basin

(M. Ricca, J. Atkinson, P. Coates, B. Brussee, and I. Dwight):

Expansion of human enterprise has contributed to increased abundance and distribution of common ravens (*Corvus corax*; hereafter, raven) across sagebrush ecosystems within western North America. Ravens are highly effective nest predators of greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse), a species of high conservation concern. Sage-grouse population trends are estimated using count survey data of males attending traditional breeding grounds, known as leks. We sought to investigate associations of ravens to sage-grouse lek sites and document interactions between the sage-grouse and ravens, as well as predators of adult sage-grouse. First, we used extensive raven point counts and lek count data collected across Nevada and California to evaluate spatial associations between sage-grouse and ravens while accounting for other environmental covariates. We found that ravens were more likely to be observed closer to lek sites, especially as leks increased in size. Second, we used a subset of the lek dataset to describe behavioral changes of male sage-grouse in the presence of ravens and other predators. While golden eagles (*Aquila chrysaetos*) and other raptors elicited stronger disruptive responses, our models indicated ravens also decreased the probability of sage-grouse displaying and increased the probability of sage-grouse flushing from leks. These results collectively suggest that sage-grouse perceive non-lethal ravens as a reason to alter breeding activity, and lek counts could be biased low if raven presence during surveys is not accounted for when used in modeling trends in population abundance. Findings are preliminary and provided for timely best science.

Using conservation planning software to optimize conifer treatment in sage-grouse habitat within the Great Basin

(C. Roth, P. Coates, M. Ricca, and B. Brussee):

The expansion and infill of pinyon (*Pinus monophyla*) and juniper (*Juniperus osteosperma*, *J. occidentalis*; hereafter conifer) woodlands threatens the imperiled sagebrush (*Artemisia* spp.) ecosystems of the Great Basin by degrading habitat for sagebrush obligates like the greater sage-grouse (*Centrocercus urophasianus*). Increased conifer cover reduces sage-grouse habitat use and sage-grouse that use these impacted areas have relatively higher mortality rates. Thus, conifer-impacted areas that remain dominated by sagebrush may act as ecological traps, as studies found negative impacts to sage-grouse occupying habitat with as little as 2.5% conifer cover. Therefore, managers require tractable, science-based tools to optimize the ecological and economic effectiveness of proposed efforts to remove conifers and restore sage-grouse habitats. Using a multi-stage modeling approach, we extended and improved a spatially-explicit conservation planning tool that evaluates areas targeted for conifer removal by predicting effectiveness of treatment relative to sage-grouse habitat suitability. Specifically, our conservation planning tool: 1) simulates conifer removal within user-defined treatment polygons using a high resolution (1-m2) conifer map developed from object-based image analysis; 2) predicts recovery success by quantifying spatial variation in understory dynamics like sagebrush community type, dominance, and annual grass invasion using maps of resilience (i.e. ability to recover from disturbance) and resistance to invasion derived from soil moisture and temperature data; and 3) predicts response surfaces derived from models of sage-grouse selection, use, and survival to calculate improvements in post-treatment habitat suitability. The tool is fully automated within a web-based application and provides a user-friendly interface. The outputs include pre- and post-treatment seasonal habitat suitability surfaces for sage-grouse and ranks proposed treatment sites by cost-effectiveness. This framework can be

expanded to include other disturbances (e.g., wildfire) and active restoration scenarios (e.g., seeding and transplanting). Findings are preliminary and provided for timely best science.

Assessing impacts of common raven density on greater sage-grouse to develop science-driven adaptive management strategies

(C. Roth, J. Tull, M. Ricca, P. Jackson, J. Dinkins, A. Moser, L. Foster, D. Delehanty, S. Webster, P. Coates, S. O'Neil, B. Brussee, and S. Dettenmaier):

The common raven (*Corvus corax*; hereafter raven) is a behaviorally flexible predator with drastically increasing populations that negatively impact sensitive prey species, including greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse). Accurate estimates of raven density remain difficult to obtain, and effective, adaptive management protocols are needed to mitigate negative impacts of increasing raven populations. We mapped raven density across the Great Basin, USA, and evaluated effects of density on sage-grouse nest survival in order to estimate a predator-prey conflict threshold for sage-grouse. We found increasing raven density adversely impacted sage-grouse nest survival, especially above a threshold of ~0.40 ravens km2. Importantly, average raven density across our study extent was 0.54 ravens km2 (95% CI = 0.42–0.70). We used underlying data to demonstrate a science-based adaptive approach to inform management of ravens in western landscapes with emphasis on sage-grouse habitats. We also developed a map delineating areas used by breeding versus non-breeding ravens (i.e. resident or non-resident, respectively) as local management options could vary based on raven breeding status. Our science application is amenable to different management objectives and is a valuable resource for managers wanting to ameliorate impacts of ravens on sage-grouse and other sensitive species. Findings are preliminary and provided for best timely science.

Tallgrass prairie restoration on the campus of Missouri Western State University, Saint Joseph, Missouri

(J. Rushin, M. Mills, J. Powelson, and C. Chevalier):

We have initiated a long-term prairie restoration project on the campus of Missouri Western State University (MWSU), St. Joseph, MO. Previously, the site consisted of mostly hay fields and three wooded acres surrounding a small pond. In 2019 we applied two herbicide applications coupled with mowing to remove nonnative plants and to prepare the site for planting in January 2020. We used a seed mixture of approximately 150 species of prairie forbs and grasses donated by The Nature Conservancy's Dunn Ranch near Eagleville, MO, with additional seed provided by the Missouri Department of Conservation (MDC). The current plan calls for a 25-acre prairie unit that will consist of a mixture of warm-season grasses (e.g., Little Bluestem, Side-oats Grama, and Prairie Dropseed) and wildflowers. Pollinator plots totaling 3.9 acres will receive plantings of pollinator-friendly plants with an emphasis on species preferred by monarch butterflies. Five acres adjacent to the wooded area were planted in Sept. 2020 with a variety of hardwood trees (e.g., various oaks, hickory, black cherry, and walnut) spaced 40-60 feet apart to create a savannah. We established three 6900 m2 experimental plots, each with a drift fence array with pit-fall traps, and have begun to plant a wheelchair-accessible interpretive prairie garden near the parking lot. Additional plans include creating a GIS database, continuing to sample the flora and fauna, and conducting controlled burns next spring (2022). This prairie site will serve students and faculty of MWSU as an area for laboratory exercises and undergraduate research projects. Additionally, the MWSU cross country course runs through the prairie. The prairie will also be open to public groups such as K-12 classes, scout troops, and other community groups.

AI meets UAV: an autonomous egg-oiling drone

(T. Shields and W. Boarman):

Egg oiling via drone is becoming a standard tool for raven management for both Mojave Desert Tortoise (*Gopherus agassizii*) and Greater Sage Grouse (*Centrocercus urophasianus*) conservation in California and Nevada. This includes nests found high in utility transmission towers and other artificial structures, as well as in cliff faces. As currently practiced, especially when raven nests are in tower structures, it requires highly skilled, and consequently expensive, drone pilots. In an effort to reduce costs, expand the number of problem avian species treated and improve ease of operation our team (Hitron Technologies, Boardwalk Consulting Services, University of South Carolina and Hardshell Labs) under a contract with the Department of the Navy, is developing the Independent Remote Egg Oiling System (IREOS), a semi- or fully autonomous drone capable of independent navigation to a target nest for the treatment of eggs therein. This will require obstacle avoidance and the ability to recognize nests and to identify eggs of many different species, as well as positioning for oiling and the hardware necessary to accurately deliver that oil. We will describe the many technical challenges that confront us in this ambitious effort,

including configuring the drone, acquisition of imagery of several species for training the image-object recognition programs needed, and integration of system components. The ultimate goal is a machine capable of relatively independent operation to facilitate the wider use of egg oiling as a management tool for problematic avian species and we will describe our path to that goal.

Optimizing spatial application of habitat management actions for the Gunnison sage-grouse satellite populations

(J. Shyvers, N. Van Schmidt, D. J. Saher, J. Heinrichs, and C. Aldridge):

The Gunnison Sage-Grouse (*Centrocercus minimus*) is a species of conservation concern that is currently listed as threatened under the federal Endangered Species Act (1973). The species has experienced substantial and continuing declines in range-wide abundance and distribution, primarily due to loss of habitat. Gunnison Sage-grouse are predominantly restricted to seven populations in southwest Colorado, six of which are small, isolated satellites where numbers are currently declining or significantly below conservation objectives. Our objective was to assess the potential for targeted habitat management actions to improve habitats for these satellite populations using newly developed Resource Selection Function models mapped to each population. Our approach was to 1) identify the habitats likely to be most responsive to management actions that improve suitability for Gunnison Sage-grouse, 2) apply spatially representative habitat improvement scenarios based on the Bureau of Land Management's current habitat actions for sage-grouse to gauge the benefits of different types of actions, and 3) recommend a suite of realistic, spatially-targeted actions that most improve sage-grouse habitat in each satellite population. Preliminary results show a wide range of sensitivity and expected responsiveness to habitat improvement actions, even among local site choices. This indicates that spatial targeting could increase the potential for return on conservation investments and demonstrates how local habitat management actions can be optimized for each satellite population to provide the most benefit given limited management resources.

Evaluating habitat suitability for lesser prairie-chicken reintroductions in the mixed-grass prairie ecoregion

(M. Solomon and L. McNew):

Populations of lesser prairie-chickens (*Tympanuchus pallidicinctus*) in the mixed-grass prairie ecoregion of the southern Great Plains are projected to go extinct in the next 100 years unless targeted conservation efforts are implemented to increase the size and connectivity of subpopulations through either translocation or habitat restoration. As lesser prairie-chickens are generally a residential species and thus vulnerable to environmental and demographic stochasticity, identifying potential suitable habitat and potential connective corridors to facilitate movement between subpopulations is crucial for lesser prairie-chicken persistence. Our objectives were to 1) develop and validate a spatially explicit habitat suitability model for areas currently occupied by lesser prairie-chickens in the mixed-grass prairie ecoregion, 2) identify areas of unoccupied habitat potentially suitable for lesser prairie-chicken reintroductions, and 3) identify potential corridors that connect current subpopulations of lesser prairie-chickens to unoccupied suitable habitat. We developed habitat suitability models using resource selection functions and Random Forest classification trees to compare landscape-level habitat conditions within 5 km of 273 lek locations (used) and 5,460 random points (available). Habitat conditions were measured in GIS and included both biotic and abiotic characteristics known to affect lesser prairie-chicken habitat use and survival. We then extrapolated our habitat suitability model to the historical range of lesser prairie-chickens to identify contiguous patches of suitable habitat for reintroductions. We used a least-cost path analysis to identify potential corridors connecting potentially suitable habitat to current subpopulations. We will present results on how well each model performed and identify potential areas for targeted habitat restoration efforts and translocation of birds. Our habitat suitability models should assist future reintroduction and habitat restoration plans by identifying habitat conditions that predict the presence of lesser prairie-chicken leks in the mixed-grass prairie ecoregion.

After the dust settles: survival, space use, and resource selection of translocated lesser prairie-chickens

(E. Teige, L. Berigan, C. Aulicky, D. Haukos, K. Fricke, L. Rossi, K. Schultz, and J. Reitz):

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) has experienced severe population declines over the last century. The current lesser prairie-chicken range is limited to four ecoregions including Short-Grass Prairie/CRP, Mixed-Grass Prairie, Sand Shinnery Oak Prairie, and Sand Sagebrush Prairie. Although >70% of the current population occurs within the Mixed-Grass Prairie and Short-Grass Prairie/CRP ecoregions, the Sand Sagebrush Prairie of southwestern Kansas and southeastern Colorado historically supported the largest density, with estimates as high as 86,000 birds in the 1970s. By 2016,

populations decreased 98% across the ecoregion, with only an estimated 1,479 birds remaining. To supplement this population, 411 lesser prairie-chickens (204 males and 207 females) were translocated during 2016-2019, from the Shortgrass/CRP Ecoregion of northwestern Kansas to the Cimarron and Comanche National Grasslands in Kansas and Colorado, respectfully, which provide ~224,000 ha of Sand Sagebrush Prairie habitat. We deployed 279 VHF collars from 2016-2019 and 115 SAT-PTT transmitters from 2018-2019 on translocated lesser prairie-chickens. Post dispersal, female breeding season survival was similar between native (0.52, 95% CI = 0.47-0.57) and translocated (0.45, 95% CI = 0.39-0.51) birds but differed during the nonbreeding season with native survival of 0.73 (95% CI = 0.66-0.78) and translocated of 0.50 (95% CI = 0.41-0.58). After dispersal, home range areas were comparable with ecoregion native populations but varied between sexes. Resource selection functions indicate translocated birds use Conservation Reserve Program (CRP) land more than what is available on the landscape. National Grassland use overall was low as most birds dispersed following release; however, Comanche was used more than Cimarron. The opportunity to study the survival, home range development, and resource selection of a translocated and native population provides a unique opportunity to assess translocations as a viable management tool for lesser prairie-chickens in the Sand Sagebrush Prairie Ecoregion.

Spatiotemporal variation and individual heterogeneity in resource selection by lesser prairie-chickens

(B. Verheijen, D. Haukos, and D. Sullins):

Patterns in resource selection are rarely uniform within a species, instead varying with spatiotemporal variation in resource availability and individual heterogeneity in resource needs. Because of its direct link with fitness and distribution of animals, variation in resource selection has important consequences for local population dynamics and carrying capacity. Understanding this variation is especially important for species of conservation concern where active management of species should be guided by local habitat needs. Since European settlement, the lesser prairie-chicken (*Tympanuchus pallidicinctus*), a species of non-migratory prairie grouse, has declined ~90% from its historically occupied range and abundance. Occurring in four distinct ecoregions, lesser prairie-chickens show range-wide similarities in resource selection as well as variation among ecoregions, sexes, and biological seasons. We tested the extent and strength of this variation by tracking lesser prairie-chickens at five sites in Kansas and Colorado, representing the three northernmost currently occupied ecoregions. Although lesser prairie-chickens selected greater amounts of grass cover on the landscape (>60% in 5-km buffer), grassland patches with lower perimeter to area ratios, and intermediate amounts of forb cover (20–40%), relative strength of selection varied among sites based on the proportion of available grassland. Lesser prairie-chickens strongly avoided trees and minor roads, but only when those features were close (< 3 km), selected areas with greater shrub cover or taller vegetation at western sites, where low amounts of precipitation limit vegetation growth, and more intermediate vegetation heights at eastern sites. During the breeding season, females selected sites with taller vegetation, at lower elevations, and that were further away from trees than males, while patterns were weaker and more similar between sexes during the nonbreeding season. Observed variation in resource selection among sites and between sexes further supports the need to adapt management plans to local resource availability and needs of lesser prairie-chickens.

Assessing long-term changes in lesser prairie-chicken habitat quality across the sand sagebrush prairie ecoregion

(M. Vhay, D. Haukos, and D. Sullins):

Lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations have declined by an estimated 90% in recent decades, with the lowest contemporary population estimates occurring in the Sand Sagebrush Prairie Ecoregion of the southwestern Great Plains. Drivers contributing to these declines are unclear, but include conversion of native prairie to row-crop agriculture, increased anthropogenic disturbance, and overall reduction of habitat quality throughout the lesser prairie-chicken's range. We hypothesize that recent changes in habitat quality, rather than quantity, are the main drivers of lesser prairie-chicken declines. Our objective is creation of a comprehensive overview of landscape-scale changes in the Sand Sagebrush Prairie Ecoregion since the contemporary high lesser prairie-chicken population of the mid-1980s. We reconstructed landcover change and delineated patch types in the ecoregion using satellite imagery and aerial photography in three- to five-year intervals. Using FRAGSTATS, we measured landscape- and patch-scale metrics including number of patches, edge, and contagion. We summarized the number of anthropogenic structures and trees throughout the ecoregion for the same time period. We anticipate finding a loss of native prairie, increased fragmentation of remaining prairie, decreased optimal densities of sand sagebrush, increased density of both anthropogenic features and trees throughout the ecoregion, and increased fragmentation of remaining native prairie. Our study will provide insight into

aspects of marked change in habitat quality for lesser prairie-chickens in the Sand Sagebrush Prairie Ecoregion, providing a basis for investigation into finer-scale changes.

Effects of cover type on seasonal movement patterns in ruffed grouse in northern Wisconsin

(A. Weisbeck, Z. Cason, B. Roberts, C. Johnson, and J. Riddle):

Effects of Cover Type on Seasonal Movement Patterns in Ruffed Grouse in Northern Wisconsin Ruffed Grouse (*Bonasa umbellus*) are an important game bird in the Great Lakes region that relies heavily on young forest with high stem density. Males perform a unique drumming display atop fallen logs to attract females and maintain their territory throughout the spring. Following their breeding season, this territory may change as a result of altered needs. We aim to evaluate the relationship of Ruffed Grouse movement patterns to cover types in Northern Wisconsin as part of a UW-Stevens Point Wildlife Society undergraduate research project. Male Ruffed Grouse were captured with mirror box traps placed on active drumming logs between March and May of 2019 and 2021. Telemetry was conducted between March and August of 2019 and 2021. We hypothesize that cover type may be affecting seasonal movement patterns. Land cover was examined within grouse home ranges using Locate 3.11 and ArcMap with the two years of data. Using these methods, we aim to determine whether Ruffed Grouse use different resources and land cover types seasonally. A preliminary study with data from only one year suggested that there may be selection for aspen cover type during the mating season, but this was not statistically significant. This information can be used to influence habitat management decisions on the Treehaven property and other Ruffed Grouse management areas.

Greater sage-grouse population structures and a hierarchical monitoring framework to inform management

(L. Wiechman, M. O'Donnell, D. Edmunds, C. Aldridge, J. Heinrichs, A. Monroe, P. Coates, B. Prochazka, and S. Hanser):

Population monitoring is important to wildlife and land management agencies, but analyses of population data rarely account for processes occurring across both spatial and temporal scales. We present a multi-scaled framework to inform long-term monitoring and population trend assessments of greater sage-grouse (*Centrocercus urophasianus*) across the western United States. Using a newly developed standardized database of sage-grouse leks (breeding sites), we defined population structure (connectivity) with least-cost paths between neighboring leks while relying on a resistance surface to identify the smallest cost-weighted distance path between leks. We then uniquely incorporated various factors that encompassed dispersal capabilities, seasonal habitat conditions, dispersal distances informed from genetic flow, and functional processes (scale effects) of habitat selection to decompose the least-cost paths into sub-populations. Lastly, we assessed multi-scaled habitat selection needs with constraint-based rules of connectivity (reflected as sub-populations) using a landscape partitioning approach known as the Spatial "K"luster Analysis by Tree Edge Removal clustering algorithm (SKATER). This unique combination of methods provided a biologically-informed methodology of grouping breeding populations at multiple nested scales (clusters). We evaluated the resulting hierarchical framework (13 cluster levels) based on the assumption of closed populations using >1.7 million telemetry locations (2006–2021) and 2,821 unique birds. We found that fine-scaled clusters captured 92% of birds' time spent within their home cluster. The hierarchical framework is intended to support numerous needs, including a hierarchical and spatially balanced framework for population monitoring, demarcation of multi-scaled units for assessing population trends, and a newly developed Targeted Annual Warning System (TAWS) that identifies leks and population clusters undergoing noticeable population declines relative to regional trends.

Impacts of conifer removal on sagebrush songbirds

(E. Zarri and T. Martin):

Conifers are encroaching into sagebrush habitats across the western United States, contributing to habitat loss and degradation for sagebrush associated species. Conifer removal is a common restoration technique and is often implemented to improve habitat quality for greater sage-grouse. Benefits of tree removal to sage-grouse have been well studied and sage-grouse populations increase without trees on the landscape. Other sagebrush associated species are assumed to benefit similarly, but these assumptions are rarely tested. Understanding how habitat modifications, such as conifer removal impact all species in the community is essential for informed management. This study investigates the impacts of conifer removal on the abundance and reproductive success of sagebrush songbirds, including sagebrush-obligate, sagebrush-associated, and generalist species. Removal of conifers could result in ecological traps for songbirds due to high spillover nest predation from conifer habitats. I monitored nests and mapped

territories of seven songbird species between conifer removal and control areas in montane sagebrush habitat in southwest Montana. Sagebrush-obligate species including Brewer's sparrow and sage thrasher are more abundant and have higher nest success in conifer removal areas. Sagebrush-associated and generalist species show mixed responses. Vesper sparrows are more abundant in removal areas, whereas green-tailed towhees, dark-eyed juncos, chipping sparrows, and white-crowned sparrows are more abundant where conifers remain. Additional data is required to clarify patterns of nest success for these species. However, initial results indicate that conifer removal is beneficial for declining species of sagebrush-obligate songbirds.

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NEW BOOKS

El último urogallo

Manuel A. González (ed)

The Cantabrian capercaillie *Tetrao urogallus cantabricus* is critically endangered, and only living in the Cantabrian Mountains in NW Iberian Peninsula. This book, written in spanish, offer us a walk through the last four decades studying this grouse, an approach to the current situation and dare to venture their possible future in Spain. All this with many photographs (most of them unpublished) of high historical and scientific value, graphics and illustrations. Will the grouse continue to give us its song in the future? A work that cannot be missing in the library of any bird fan. The book on the Cantabrian capercaillie is written by the most reputable scientists and authors in the knowledge of this very representative bird, Francisco J. Purroy, Vicente Ena, Rafael de Garnica, Emilio de la Calzada, Luis Fernández, Javier Purroy, Benito Fuertes, Mario Quevedo, María José Bañuelos, Luis Costa María Cano, María Morán-Luis, Beatriz Blanco-Fontao, Rolando Rodríguez -Muñoz and Alberto Fernández-Gil, with the presentation of Antonio Laborda and edited by Manuel A. González.

Manuel A. González 2021 (ed). El último urogallo. University of León, León, Spain, 406 pages, Hardcover, 20,00 €. ISBN: 9788418490125. In Spanish.
https://www.universitarialibros.com/libro/el-ultimo-urogallo_146353.

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For a complete bibliography on grouse, go to: http://www.suttoncenter.org/about/publications/

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RESEARCHERS AND THEIR BEST FRIEND ASSISTANTS

The Grouse Church - the researcher, the grouse and the dog

Torstein Storaas

Jack Connelly told his student Dave Dahlgren that no one could be a *grouse biologist* without having bird dogs. Personally, I came to grouse through dogs. As a boy, I loved birds. The love was perhaps old fashioned, in the beginning I identified birds, then shot birds for taxidermy work, and collected eggs (never more than one from each nest). After becoming a member of the Norwegian Ornithological Society my activities became more scientifically meaningful. Then, I acquired my first wirehaired German pointer. The wirehaired was not interested in sparrows and buntings, grouse and ptarmigan completely filled its head, and soon mine. When Per Wegge took me as a student on the Woodland Grouse Project at Varaldskogen, Norway, I was in heaven. My dogs became my main tools for research, and I got permission to keep dogs at the dormitory and students' office. The dogs located nests and chicks, and helped census populations. When I understood how many days of fieldwork were needed to obtain a single data point, I realized that grouse biologists must be crazy. When I met other grouse biologists at international grouse symposia, I realized that grousers are wonderful people and include fascinating members of the "Grouse Church." These individuals believed field work with dogs was Christmas and Easter, bird hunting was heaven and The Holy Sacrament involved hunting and eating grouse and drinking French wine.

After thinking about grouse, dogs, and research, I developed four hypotheses: 1) Grousers started to study grouse as an excuse to use their dogs in fieldwork. 2) Without dogs and hunting experience, it would be impossible to conduct exceptional grouse-research. 3) Non-hunting researchers without pointing dogs write many more and boring papers because they sit by the computer and do not struggle for their own data. 4) You need to have a bird dog to be a real grouse biologist.

Methods

I asked all recipients of Grouse News to answer a few questions and provide some comments. I received 21 answers, too few for statistical analysis. Therefore, I employed the Torstein-method to analyse the data. In other words, I examined at data and subjectively selected what I wanted.

Results

A large proportion of the grousers did not own a dog before starting grouse research (Table 1). Clait Braun even stated that he is not a dog person. A small majority were, are, and will be grouse hunters. Kerry and Jack strongly objected to other people hunting in their secret spots. A few respondents did not support grouse hunting, while others tolerated hunting as a means of encouraging hunters to advocate for grouse habitat and grouse interests as well as provide information on grouse.

Table 1. Grousers obsession with dogs and hunting (N=21).

	Yes	No	Yes and no
Had bird dog before	13 (62%)	8 (38 %)	
Hunted before	12 (57 %)	9 (43 %)	
Used dog in research	15 (71 %)	6 (29 %)	
Hunted after	9 (43 %)	12 (57 %)	
Would like to hunt grouse	12 (57 %)	9 (43 %)	
Hunting OK	12 (57 %)	2 (10 %)	7 (33 %)

Most (71 %) have used dogs in their grouse research and some have been dependent on dogs. I selected comments from Maria, Dave and Rocky:

Maria Hörnell Willebrand: *"I have had many dogs (German and English pointers) and they have all been critical for my research. Without my own dogs it would have been impossible to catch all the birds needed in my research projects (they have to be specially trained). My all time best dog was Bart (an English pointer) that was outstanding at finding rock ptarmigans. I succeeded to get the first Swedish rock ptarmigan project because I could guarantee catching ptarmigan with this dog. I have had many other good dog used in my research (Bremer, Prada, Leo, Sigge, Ymer, Ypsilon, Mackan, Hasse), but Bart was by far the best dog I had and I have never met anyone with a better English pointer."*

Dave Dahlgren: *"I was told early in my career that no one could really be a "grouse biologist" without having bird dogs. HA! Of course, my early mentor was Jack Connelly, so that should explain it. As I look back on many years of field research, but especially my 6 years of graduate work where I was in the field on a daily basis during the field season conducting telemetry-based studies and also having my dogs with me most days, I realize that I learned as much about grouse from my dogs as I did from using my telemetry gear. Once a person really understands their dogs, the way they communicate through body language, that unspoken messaging that occurs between a handler and the dog, there is an almost subconscious gathering of information that happens for a grouse researcher or a bird hunter. The best way I can describe it is a sense you receive, as if the dog and their scenting/detecting abilities become an extension of the handler's own senses. When that connection becomes solidified between a dog and a handler maybe that's when a person conducting grouse research truly becomes a "grouse biologist"?"*

Rocky Gutiérrez: *"I first used a dog to locate mountain quail for subsequent direction behavioral observations. However, this is the only dog I have ever seen that could find mountain quail, point them, and then back off to allow me to follow and watch them. Consequently, a well trained dog allowed me to conduct the first PhD research completed on this species. With respect to grouse, I used dogs exclusively to locate birds for collecting scientific (genetic and museum specimens) specimens."*

"To me, dogs greatly enhanced the retrieval probability of wounded birds. They also made the location and subsequent collection orders of magnitude easier than not having a dog. Thinking back on this, I am not sure that I ever lost a grouse in the field when I had one of MY dogs. I have also used dogs to locate areas for potential grouse study sites because a good dog can allow you to determine if the local population is of adequate size (independent of cycles or up and downs in annual numbers) for study. In North America, there are some species that are relatively difficult to find even if killed with a single shot owing to the dense structure of their forest, shrub, or grassland habitats (ruffed grouse, blue grouse, prairie chickens, sharp-tailed grouse). So I had never pondered this question of retrieval success with and without a dog with respect to my personal research studies until you posed this question - except in the general sense that EVERYONE knows dogs are much better at finding dead or wounded birds than a human is."

Some researchers depended on dogs to obtain critical information.

Emmanuel Menoni: *"Grouse studies in France were initiated By Larry Ellison. He put together a small team (Ariane Bernard-Laurent, Yann Magnani, Patrick Léonard, Marc Montadert and myself of which 4 used dogs for counting the birds, estimating the breeding success, catching chicks for telemetry, etc. Since the European Union asked us to provide estimations of population size, breeding performance, range etc. at mountain range scale, a network has been set up by ourself gathering hunters associations, National Parks, Nature Reserves, Foresters, Departmental service on National Office of Hunting and wildlife (now recast in National Office of Biodiversity). In summer time, more than 300 people and their*

pointing dogs are involved in counting a sample of several hundred of plots of 20-40 ha since more than 20 years. We can thus calculate the reproduction indices of 3 grouse species at different scales in the French Alps and Pyrenees. Following this, Spanish and Italian biologists spread it in their mountains."

Still Olafur Nielsen of Iceland claimed *"that it is mainly disbelief of foreign colleagues in grouse research that grouse work is possible without the aid of dogs"*. It is obvious that Olafur works with rock ptarmigan in Iceland, not with capercaillie at Varaldskogen. However, there are other uses of dogs, including personal protection:

Rocky: *"Dogs with fierce hearts can also be protectors in the field. One of my GSPs even attacked bears when we came upon them or they came too close to us. She continued this behavior even after suffering a broken clavicle and a total linear raking of claws down her back in separate fights. Perhaps she even became obsessed with them because she backed off a grizzly while I was fumbling to put slugs in my shotgun - clearly her obsession precluded adaptive judgment on her part. My wife and I always felt comfortable collecting grouse throughout North America knowing this dog would not allow a bear either to investigate us or our camps."*

Dogs may also be useful when you hunt with sons of famous writers.

Jack Connelly: "*I got into quite an argument one time with Jack Hemingway (son of Ernest Hemingway and father to actresses Margo and Muriel). Jack had shot a sharp-tailed grouse and his little Brittany could not find it. I brought my springer spaniel over and she immediately took off in the opposite direction of the spot where Jack said the bird fell. Jack had some not very complimentary things to say about my dog and its ability to find wounded birds. I told him she knew what she was doing. Jack looked a lot like his father and I felt like I was arguing with the great writer himself. Five minutes later my dog returned with Jack's bird. A Hemingway had to eat his words.*"

Maria noted the importance of using well-trained dogs.

Vero Braunisch: *"Some chicks are sometimes killed by dogs, but it is negligible comparing the benefit got." It may also be dangerous for the dog. My own dog was bitten by a viper during census work in August last year. Moreover, Kerry Reese: "3 times, my dogs were bitten by a viper, and one died."*

Not only dogs may be a danger to chicks, and vipers to dogs.

Marc Montadert: *"When I used my results obtained with our dogs to limit hunting bags by means of quotas, my dog was killed, and I found it with a message: dog=counting=restriction. But nowadays, the quotas are generally well accepted."*

Finally Torfinn Jahren states: "*Dogs can be very valuable during field work and field work is more fun with dogs."*

In addition, Robert Moss claims "*dogs are more fun than mobile phones*".

There is some variation in preference for dog breeds. I prefer Wirehaired German pointers, but most grousers are flexible and prefer good dogs of any breed. Because of Editor Tor's time limit, I do not have time to obtain data on the hypothesis addressing the connection between dogs and publications. However, two great and productive grouse biologists, Ilse Storch and Robert Moss, do not have bird-dogs.

Discussion

I am very sorry that I have to discard the hypotheses on which I have some kind of evidence. A large proportion of grouse researchers did not study grouse to be able to use their dogs. Excellent work is done without the use of dogs, and it is impossible for me to think or say that Ilse and Robert are not "real grouse biologists". However, it is still possible that people with dogs spend more time being outside with the dogs to collect data and thus publish fewer, but better papers. I am impressed by Per Wegge, who always wore rubber boots, took his dog and collected his own data – and then published his findings.

However, non-dog owners like Robert and Olafur spend enormous amount of time in the field conducting excellent research. Thus, I have to discard all my prejudices.

Still, there is a small Grouse Church. The physical church is Nature, where members worship alone with or without dog. The members gather each third year at the International Grouse Symposium, where hunters, dog owners, non-hunters and not dog-people come together to discuss grouse and grouse conservation.

There is no doubt that well-trained bird dogs are useful. Several theses are based on dog work. The European Union would not get their needed grouse density information without bird dogs. Norwegian willow ptarmigan would probably remain on the Red List if we did not have a voluntary grouse census based on the efforts of thousands of dog and dog owner's days. Dog owning hunters are eager to hunt birds, but also protect populations for future use. Moreover, throughout much of the world, it is great to explore splendid natural areas with the dog and find grouse. Bird-dog work is more fun than mobile phones, freely citing Robert.

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SNIPPETS

Grouse on Stamps
Ladislav Paule

The topic of Galliformes on postal stamps was rather rare and the Postal authorities sporadically issued stamps or stationaries with this topic. Situation changed in 2021.

The PostEurop – agency established in 1991 and governing 57 member Postal authorities within Europe – decided to devote the Europa 2021 series the stamp issues to the common topic "Endangered national fauna". There were so far published 116 stamps by 62 postal authorities showing a broad spectrum of different species endangered by extinction from insects, amphibians and fish to birds of prey, game species and large carnivores (wild cat, lynx, brown bear and leopard).

By coincidence, four Postal authorities – Bosnia and Herzegovina (Mostar), Croatia, Slovenia and Slovakia – decided to issue a stamp showing capercaillie as a representative of endangered species. While Slovakia issued only a single stamp, Croatia and Slovenia issued two stamps each, combining it with endangered carnivore species – lynx (Croatia) and wild cat (Slovenia). Bosnia and Herzegovina issued also a pair of two stamps – male and female capercaillie. However, an error appeared and instead of the female capercaillie, the stamp shows a male hazel grouse. Unfortunately, it happened in Bosnia and Herzegovina also in 2005, when instead of female capercaillie (according to the text on the stamp) chukar partridge appeared on the stamp. It is not only a disinformation but also a proof of lacking cooperation between artists and zoologists during the stamp design process.

Besides the Europa 2021 stamps, the Ukrainian Post issued in August 2021 a block of nice stamps with capercaillie, black grouse, hazel grouse and willow ptarmigan. Except these species chukar partridge, grey partridge, quail and pheasant are part of the block of eight stamps. The issue of nine stamps by five countries in a single year is a proof of conservation concerns aimed at grouse species in Europe.

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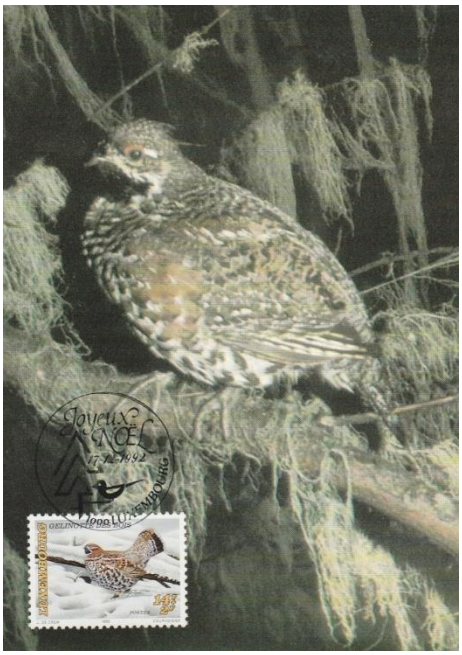
FÉDÉRATION DES SOCIÉTÉS PHILATÉLIQUES
LUXEMBOURG - 1992
Joyeux NOËL
17.12.1992
1000 LUXEMBOURG
Bëschhong - Gelinotte - Haselhuhn


Joyeux NOËL
17.12.1992
1000 LUXEMBOURG


MONGOLIA
60
Tetrastes bonasia
L. Burmandorj


БЕЛАРУСЬ
Belarus
Lagopus lagopus
Seasonal variations
www.belpost.by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UCCELLI DELLE ALPI
PERNICE BIANCA
ITALIA
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BELGIË-BELGIQUE
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V. TAGER 2008
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IN MEMORIAM

Arthur T. Bergerud, 1930–2019
David Mossop

One of our good colleagues has passed away. Arthur T. (Tom) Bergerud, born 11 November 1930, died 27 November 2019. Tom, among most circles was best known for his deep passion for the natural history and population demographics of caribou (read McLaren, Butler and Page: The Canadian Field-Naturalist. 2021). But for the community of grouse-files he was much more than that.

Starting in the 1950s he was drawn to the population gymnastics of willow ptarmigan (*Lagopus lagopus*) while he was employed as a provincial biologist in Newfoundland. He published 9 papers about grouse in his 13-year term there. Those early papers provided some of the foundational literature for decades of new grouse students: sexing and aging, census techniques, habitat use, and mortality issues among others. Beyond caribou and grouse, he was a consummate natural historian; in that era he also published papers on hares, moose, marten, and beaver.

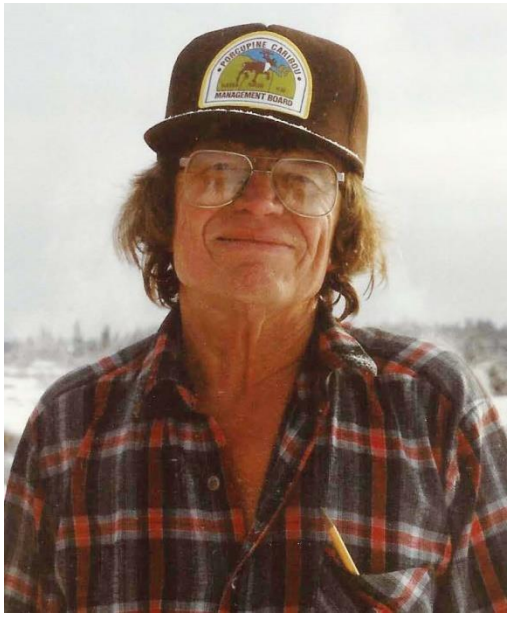

Photo provided by Heather Butler and published in "A tribute to Arthur T. Bergerud, 1930–2019" in The Canadian Field-Naturalist (135:68–77).

Years later during his stay at the University of British Columbia, during the late 1960s while pursuing his caribou-centered PhD, he was introduced to ideas championed by Denis Chitty about the possible genetic polymorphism-based explanation for population cycles in small mammals. Never one to shrink from new and controversial ideas, Tom saw something in these hypotheses that talked to him about what we were all seeing in grouse numbers -- in particular, those fascinating regular '10-year' cycles in abundance. This proved a sea-change. I met Tom at this time (1970) and heard about population-level differences in aggressive behavior of sooty grouse (blue grouse in those days). This set his considerable mind working on ways to devise experiments in the field to test whether these observations could somehow be harnessed to begin explaining grouse population dynamics.

Tom moved to land he purchased on Salt Spring Island and shortly afterward began instructing at the University of Victoria. It was from this base he began encouraging students to pursue ideas of genetic-level grouse population phenomena. His own last grouse work was to devise an ambitious experiment that involved capturing sooty grouse from three Vancouver Island populations that Mossop had shown to have different agonistic behavior, and to introduce them to presumably vacant habitat on three of the BC Gulf islands. This work showed that some behavioral differences between the introduced populations persisted (Bergerud and Hemus 1975). That, along with fascinating student results (Redfield 1972, Page 1984), convinced him to cast about for other authors (13 responded) in a grand collaborative effort to create a publication presumably synthesizing all these tantalizing findings into a general explanation for grouse population dynamics.

The jury is still out over whether he succeeded. That work published by the University of Minnesota by Bergerud and Gratson (1988 -- Adaptive Strategies and Population Ecology of Northern Grouse) provided a platform for the publication of valuable previously unpublished results of research on population behavior, breeding strategies, survival strategies, population fluctuations, and centrally how numbers of grouse seem to be controlled. His synthesis of all this work in his own words was 'great fun' and a great deal of speculation that will occupy grouse-minded field researchers for many decades.

We'll miss those well-into-the-night discussions-turned-debates among the firs and cedars of Salt Spring Island where way too much coffee was drunk and mysteries of grouse seemed to just grow thicker.

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