IDAHO DEPARTMENT OF FISH AND GAME

Ed Schriever, Director

Project F16AF00908
Amendment 5

Final Performance Report

Statewide Wildlife Research

July 1, 2016 to June 30, 2019

Prepared by:

Mark Hurley
Wildlife Research and Data Manager
&
Shane Roberts
Principal Wildlife Research Biologist

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FEDERAL AID IN WILDLIFE RESTORATION
ANNUAL PERFORMANCE REPORT

State: Idaho

Grant number: F16AF00908 Amendment 5

Grant name: Statewide Wildlife Research

Report Period: July 1, 2018 through June 30, 2019

Report due date: September 28, 2019

Geographic Location Statewide

If the work in this grant was part of a larger undertaking with other components and funding, present a brief overview of the larger activity and the role of this project.
N/A

Describe how objectives were met:
See individual project reports contained herein.

Discuss differences between work anticipated in grant proposal and grant agreement, and that actually carried out with WSFR grant funds; include differences between expected and actual costs
N/A

List any publications or in-house reports resulting from this work.
See "Peer-reviewed Publications from Grant Research" section.

SFY19 F16AF00908 Statewide Wildlife Research Final Report

Need

The Idaho Department of Fish and Game (IDFG) and the Idaho Fish and Game Commission (Commission) are mandated by State Law to preserve, protect, perpetuate, and manage all wildlife in Idaho. The state's big game mammals, upland game birds and other species are of great social and economic value, and the state holds a public trust responsibility to manage these species in a manner that will preserve, protect, and perpetuate them as natural resources owned jointly by the citizens of Idaho into perpetuity.

Fulfilling Idaho's public trust responsibility to Idaho citizens requires knowledge about each species and its relationship to its environment. To obtain this critical information, Idaho maintains a staff of highly trained professional wildlife research biologists, assisted on occasion by graduate students, to obtain needed information. The following objectives have been outlined as research needs by IDFG and this project will help both the IDFG and the Commission acquire the necessary biological information needed to carry out their mission.

Purpose

The purpose of this grant is to conduct research throughout Idaho that will inform and improve management of wildlife species, allowing IDFG and the Commission to fulfill their primary mission.

Measurable Objective(s)

Objective 1 – Conduct 1 Mule Deer study by 30 June, 2019.
Objective 2 – Conduct 1 White-tailed Deer study by 30 June, 2019
Objective 3 – Conduct 1 Elk study by 30 June, 2019
Objective 4 – Conduct 1 Bighorn Sheep study by 30 June, 2019
Objective 5 – Conduct 1 Moose study by 30 June, 2019
Objective 6 – Conduct 1 Mountain Goat study by 30 June, 2019
Objective 7 – Conduct 1 Gray Wolf study by 30 June, 2019
Objective 8 – Conduct 1 Mountain Lion study by 30 June, 2019
Objective 9 – Conduct 1 Greater Sage-grouse study by 30 June, 2019
Objective 10 – Conduct 1 Columbian Sharp-tailed Grouse study by 30 June, 2019.

Expected Results and Benefits

This grant will benefit the wildlife resources of Idaho by providing IDFG staff with science-based, quantitative data to ensure sound and responsible management of the associated wildlife species on a statewide basis. This grant will also provide benefit to Idaho’s hunters by enhancing management of Idaho’s game species populations which should result in increased hunting opportunities and increased hunter satisfaction. Additionally, enhanced management of Idaho’s wildlife populations should also result in increased sightings and satisfaction by those who enjoy wildlife-viewing. This grant will also benefit local economies since hunters and wildlife-viewers are willing to travel considerable distances to enjoy their respective recreational pursuits.

Objective 1 – Conduct 1 Mule Deer study by 30 June, 2019.

Approach

We plan to continue the multi-faceted, statewide research project that seeks to model mule deer demographics, seasonal ranges, migration corridors, and connectivity in relation to nutritional quality; develop new methods to estimate mule deer demographic rates, abundance, and composition; and understand mule deer buck vulnerability under different hunting season structures and in different habitats.

Data analysis and model development will be based on information from mule deer radio-collared from 2003-2018 as part of the statewide mule deer monitoring program. Helicopter drive-nets (Beasom et al. 1980) were generally used to capture deer but occasionally a netgun fired from a helicopter (Barrett et al. 1982) or clover traps (Clover 1954) were also used. Deer were physically restrained and blindfolded during processing with an average handling time of < 6 minutes.

Demographics Modeling - For climate covariates, we used remotely sensed and modeled measures of summer plant productivity (NDVI) and winter snow conditions (MODIS snow and SNODAS) that represent seasonal changes in plant phenology and deer energy expenditure. Vegetation type variables previous developed using SHRUBMAP (USGS 2005, Forest and Rangeland Ecosystem Science Center, Snake River Field Station, Boise, ID), will be transfer-transformed into the Land-Fire vegetation database (LF, http://www.landfire.gov/vegetation.php). The minimum mapping unit contained within LF is 30m^2, and LF existing vegetation type databases are routinely updated at 2-3 year intervals providing benefits in temporal resolution that can be critical in fire-disturbed landscapes. We reclassified the image into 18 vegetation classes with importance to mule deer ecology. These vegetation classes included; aspen woodland, riparian, other deciduous woodland, juniper woodland, mahogany woodland, coniferous forest, deciduous shrub land, mesic sagebrush shrub land, xeric sagebrush shrub land, wet meadow, mesic grassland, xeric grassland (includes Conservation Reserve Program lands), invasive grassland, agriculture, recent burn, developed, open water, and unavailable.

We will include habitat quality to increase the predictive ability of survival models where weather conditions alone are inadequate as covariates. We will determine forage quality at 2 scales, first the individual level and then the population management unit (DAU). We will use previously collared deer data to estimate kernel density home range size and shape in each of the 3 represented ecotypes and then apply these home range polygons to a random sample, stratified by ecotype, of ‘global positioning system’ (GPS) and ‘very high frequency’ (VHF) collared adult females. Availability and quality of forage will move up through spatial resolution from the very fine scale individual plant to estimation of annual variation with freely available remote sensed imagery.

Estimating Habitat Quality - We will map detailed forage species within fawn rearing ranges in the aspen, shrub/steppe and conifer ecotypes of eastern Idaho. The plant sampling methods for this work include a detailed estimation of availability within an adult female fawn rearing home range. Five to 12 composition and ground cover plots will be completed using 100m point intercept transects in adult females home ranges each year. The sample size will be dependent on the variability of vegetation covertypes within the home range. These samples will form the lowest level of the plant species modeling of the higher hierarchical levels. Previously, we sampled plant composition within home ranges of adult females with GPS collars distributed across the ecotypes, resulting in a total of 77 home ranges sampled with a total of 378 100 m point intercept and 378 100 m line intercept transects completed for the study in previous years. We also compiled vegetation occurrence data from the vegetation plots above and multiple sources from other projects within IDFG and Federal agencies. Each dataset had different data collection protocols, but from the protocols, we determined the type of data collection used (i.e., line point intercept or percent cover) and the specific location of each recorded plant species. Line point intercept and percent cover datasets were also aggregated and converted into two point files within a geodatabase that can matched with attributed polygon segments for modeling. These vegetation plots will be used to model vegetation understory for the fine scale vegetation models.

Fresh mule deer fecal samples from the focal collared animals were collected for microhistological analysis to determine forage species use by the adult female. These samples have been sent to the lab for analyses. Individual plant species frequently selected by deer will be collected during plot sampling and analyzed for digestible energy (DE), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and total percent dry matter digestibility %(DMD); with nutrition adjusted for secondary compounds (Freeland and Janzen 1974, Hanley et al. 1992, Villalba et al. 2002, Baraza et al. 2005). A portable chemical spectroscopy machine may be used to provide complementary forage analysis of cellulose, crude protein and oil composition of collected forage subsamples (https://www.bruker.com/products/infrared-near-infrared-and-raman-spectroscopy/ft-nir/mpa/overview.html). Adult female home ranges will be ranked in nutritional quality by the digestibility, energy, and protein content of the plants used versus available plants.

To scale up to the remote sensing level, we will produce a fine scale model/map of forage quality. Using the fine-scale vegetation plot data, a forage composition and ground cover model will be constructed using both: 1) 1-meter resolution satellite imagery, and 2) high resolution imagery acquired by an unmanned aerial vehicle (UAV) equipped with a multi-spectral camera used to validate the first model.

We used National Agriculture Imagery Program (NAIP) imagery as a base layer for the fine scale vegetation maps. We have changed the approach from individual home ranges to a fine scale vegetation map of the entire state divided by Bailey's ecoregions. We have segmented 3 of the 5 ecoregions into 1-meter resolution stands with similar dominant over story species and canopy cover using eCognition, a machine learning software (Trimble Inc., Westminster, CO). We used this object-oriented image analysis to segment each NAIP image into polygons based on spectral values of red, green, blue, and near infrared (NIR) from the image. Object-oriented analyses identify natural boundaries and patches in the landscape and create relatively homogeneous landcover polygons. Multiresolution segmentation identifies image objects of 1 pixel and then merges them with neighbors based on homogeneity criteria, such as spectral and shape. The homogeneity of color is determined from the standard deviation of the spectral colors, whereas the homogeneity of shape is determined by the deviation of a compact shape (eCognition Developer 9.2 User Guide 2016). We have merged available vegetation plot databases including IDFG, Bureau of Land Management (BLM), and United States Forest Service (USFS) data sources as described above. Understory of segmented stands will be modeled with associated species, soils data, slope position, and climatic variables. We have extracted spatial covariates from a finalized modeling covariate list. We will use regression in the final step to predict the probability of plant presence and density from the spatial covariates.

One of the primary covariates for understory plant modeling is the overstory canopy cover of both trees and shrubs. We will calculate a canopy coverage estimate from the 1-meter resolution imagery for both shrub and tree species within each polygon (vegetation stand) as described above. LANDFIRE databases were also classified into vegetation forage classes of agriculture, aspen woodland, deciduous shrubland, developed, dry evergreen forest, invasive grassland, juniper woodland, mahogany woodland, mesic grassland, mesic sagebrush shrubland, open water, other deciduous woodland, riparian, unavailable, wet evergreen forest, wet meadow, xeric grassland, and xeric sagebrush shrubland. These combined classifications will be used to develop a final canopy cover percentage by species, an integral covariate in the understory modeling of species distribution and cover percentage.

Similarly, we will create very fine-scale resolution maps (< 5cm) to validate the statewide maps and specifically the adult female home ranges. The multi-spectral camera sensor has matching spectral bands used by the National Aeronautics and Space Administration (NASA) and European Space Agency's (ESA) space based satellite systems and has been developed for precision agriculture (LandSAT, OLI, MODIS, VIIRS, and Sentinel, http://www.micasense.com/red-edge.html). An abbreviated sampling scheme (focused on most selected plants) to capture plant composition will be used to ground truth the forage quality map within randomly selected adult female home ranges. One final scaling is required to move the forage quality map to freely available remote sensing imagery. We will perform a supervised classification of the combined images using the previously produced forage model as the training image.

Estimating Phenological Variation in Nutrition - Phenology will be determined at approximately 2 week intervals [16-day Moderate Resolution Imaging Spectroradiometer (MODIS)] for representative community types at the 2 extreme elevation gradients in which these species communities occur (July through August). Because we require fine spatial resolution, MODIS data will be used to calculate the Enhanced Vegetation Index (NDVI and EVI). Plots will consist of randomly selected home ranges stratified by elevation, community type, and aspect. We will document the growth cycle of plants within each MODIS window with plant samples collected for nutritional analyses. To accomplish this, 47 phenology plots were initiated in May and June, 2012 in all 3 of the major ecotypes in southern Idaho and revisited 157 times in 2012 and 139 in 2013 during mid to late summer. The plots were placed within mule deer summer range in homogeneous vegetation types large enough to contain a single MODIS pixel to facilitate linking vegetation phenology to the MODIS value for that area. Plant cameras were deployed at 70% of transects in 2012 as another intermediate step to link RGB levels of the photograph to the MODIS spectral signature. In 2013, we concentrated the cameras on the flat open sites (4-6 cameras/site) to maximize the likelihood of a season long stream of daily photos. Placement of cameras in 2014 replicated the design of 2013, but these cameras remained in place until 30 August, 2015. We then placed 30 cameras in April, 2016. We collected plant samples for nutritional analysis and each phenological stage of maturity and location. Point intercept and line transects were also conducted in each of the vegetation types contained within a home range to inform high-resolution vegetation map. Plants frequently used by mule deer were collected and analyzed for quality change to link EVI data to plant phenology stage and resulting availability. The primary function of interest will be the rate of quality decline from growth initiation to desiccation. The final product of this work will include a vegetation composition and quality map of mule deer summer/fall range that can be adjusted annually for quality using EVI derived data from MODIS.

Survival Modeling - We will use discrete-time known fates modeling to determine covariate effects on fawn survival and to develop models that can be used to successfully predict fawn survival 16 December to 1 June. We divided winter into 24 seven day periods to estimate survival. We used Bayesian hierarchical models to estimate survival, including covariates at the appropriate spatial and temporal resolution for each level: individual, capture site, DAU, and ecotype scales. Survival models developed for primary ecotypes in Idaho were validated against survival estimates of individual DAUs to determine the model that best predicted fawn specific to that DAU. Adult models will be produced with similar methods of the fawn models. Survival models will be validated with a procedure similar to K-fold cross validation used in the habitat modeling literature (Hastie et al. 2001, Boyce et al. 2002, Frair et al. 2007).

Completed DAU survival models will be incorporated into a population model based on survival, fawn ratios, harvest, and 4-year interval population surveys. Integrated population models were constructed with an R base, incorporating an interface for data entry and predictive modeling scenarios. These Bayesian state-space models allow for the combination of several metrics (i.e. survival, fawn ratios, population estimates) with inherently varying data quality. Data quality, importance to population estimation, and cost effectiveness will be evaluated with respect to estimate bias and variance of the predicted population size and trend. This analysis will provide a measure of minimum cost tools and gain in precision as additional funds are expended on each monitoring technique. The final product will include a detailed manual including instructions for spatial data acquisition and model usage.

Integrated Population Models - We will continue to refine mule deer fawn and adult doe survival models and the web-based integrated population model we've developed for mule deer population estimation in southern Idaho. Survival models will incorporate weather and habitat quality variables. To accommodate ever-changing habitat quality, we must be able to measure it repeatedly and efficiently. Therefore, the development of a fine-scale vegetation model/map and methods to estimate mule deer body condition (i.e., portable ultrasound measurements of rump fat) will be crucial to this effort. Integrated population models have been constructed that include an interface for data entry and predictive modeling scenarios. These Bayesian state-space models allow for the combination of several metrics (i.e. survival, fawn ratios, population estimates) with inherently varying data quality. Data quality, importance to population estimation, and cost effectiveness will be evaluated with respect to estimate bias and variance of the predicted population size and trend. This analysis will provide a measure of minimum cost tools and gain in precision as additional funds are expended on each monitoring technique. The online interface will be improved to incorporate fawn and adult survival models and other data acquisition and analysis interfaces (e.g., harvest data, sightability models, etc.). The final product will include a detailed manual including instructions for data acquisition and model usage.

Alternative Monitoring Methods - We will test and evaluate alternative methods to monitor mule deer. At a minimum, this evaluation will include estimates of composition ratios (male:female:young) and abundance from remote cameras. These techniques will be evaluated during scheduled aerial surveys for comparison. This evaluation will also include the continued development of additional methods involving remote cameras to estimate abundance and occupancy from unmarked animals and the further development of model-based aerial survey methodology that would allow us to utilize habitat and geographic variables to accurately estimate deer and elk abundance with aerial survey flight time. We will also evaluate new technologies for monitoring wildlife movements and survival, including solar-powered GPS transmitters in an eartag attachment package.

Seasonal Range and Migration Modeling - We have developed modeling techniques that use machine learning to estimate mule deer summer and winter ranges, and transitional habitats for mule deer across areas were we have location data. These seasonal range and transition habitat maps have been 'updated' using location data 'streams' provided by current GPS collaring efforts. Migration habitat will be estimated for mule deer and we are developing methods that estimate prioritized migration routes by mule deer elk numbers occurring in the vicinity. Further work in the coming year will include analysis of population spatial structure, updating covariates with more accurate information, and further scenario prediction (for example bad winter vs good winter, infrastructure development assessment). This work is complementing other studies on ungulate movement patterns for wildlife vehicle collisions, interstate ungulate range and movement (ID and adjacent areas of neighboring WY and MT), and regional ungulate range assessment. It will also be used to refine Idaho's big game management units/zones to more accurately reflect biological populations.

Habitat Change and Connectivity Modeling – We are evaluating the effects of habitat change on survival and landscape connectivity. Subprojects include: 1) evaluation of population level effects of deer-vehicle collisions and the effectiveness of mitigation efforts, 2) evaluation of landscape connectivity for multiple species and potential barriers to movement, and 3) evaluation of large-scale agricultural landscape habitat changes (i.e., CRP vs ag vs native) and how populations are influenced. These questions will be addressed using existing deer population demographics and movement data (e.g., radio and GPS collar data) and fine-scale spatial data (e.g., fine-scale vegetation map) and analyses. We will look for opportunities to collaborate with other state agencies and conservation organizations to incorporate additional data and broaden the applicability of the results and products. This research will help us better predict impacts of development (urban, roads, habitat modification), increasing the reliability of our information when we consult with other agencies and private landowners.

Buck Vulnerability - We will predict the effects of hunting season structure and habitat security on male mule deer survival. Because one season type or structure will not produce the same mortality results in Game Management Units (GMU) of different hunter access and security cover, we will alternate through tests of season type and habitat security while maintaining adequate control GMUs. This project will utilize the ongoing statewide vegetation model/map project to provide vegetation security cover estimates. We will capture, collar, and monitor movements and cause-specific mortality of male mule deer of various ages in GMUs throughout southern Idaho that represent varying levels of human access, hunting season structure, and vegetation composition. Male mule deer will be captured during statewide capture efforts for mule deer survival monitoring, using the same capture techniques described above. Males will be monitored with eartag transmitters, GPS collars, or a combination of both to allow monitoring of all age classes. A blood sample, body measurements, and ultrasound estimation of fat accumulation will be taken from each captured male for relation to habitat characteristics and survival rates. The research will provide managers with objective estimates of the effects of changing hunting season structure or habitat security, with the goal of maintaining hunter opportunity.

Geographic Location

Project activities in FY19 will primarily be model and software development and assisting management biologists with mule deer capture, collaring, and monitoring in Adams, Washington, Payette, Gem, Boise, Elmore, Valley, Custer, Lemhi, Clark, Butte, Blaine, Camas, Gooding, Lincoln, Twin Falls, Cassia, Power, Oneida, Bannock, Bingham, Bonneville, Caribou, Franklin, and Bear Lake counties. Capture of male mule deer will occur during, and in the same locations as, female and fawn mule deer capture for the statewide monitoring project with the exception of the addition of Owyhee County for male captures in the summer months. The alternate monitoring methods will include additional areas that are scheduled for aerial survey population and/or survival estimates identified within the Project Statement for the Statewide Wildlife Surveys and Inventories grant.

Principal Investigator(s)

Mark Hurley (IDFG Wildlife Research and Data Manager)	208-287-2891
Jon Horne (IDFG Senior Wildlife Research Biologist)	208-799-5010
Scott Bergen (IDFG Senior Wildlife Research Biologist)	208-232-4703
Erin Roche (IDFG Biometrician)	208-334-2920
Paul Atwood (IDFG Senior Wildlife Research Biologist)	208-390-8607

Timeline

- Capture of male mule deer – summer and winter months.
- Monitoring survival of male mule deer – yearlong.
- Fine scale vegetation modeling - summer months.
- UAS multi-spectral camera image collection – summer months.
- Integrated population and survival modeling – yearlong.
- Alternative monitoring methods - summer and winter months.
- Habitat change, season range, and connectivity modeling – yearlong.

List of Partners

University of Montana
University of Idaho
U.S. Forest Service
U.S. Geologic Survey
Bureau of Land Management

Results

Modeling Overstory Vegetation Structure - We reclassified the LandFire existing vegetation type (EVT) databases into 18 forage vegetation classes with importance to mule deer ecology, including: aspen woodland, riparian, other deciduous woodland, juniper woodland, mahogany woodland, coniferous forest, deciduous shrub land, mesic sagebrush shrub land, xeric sagebrush shrub land, wet meadow, mesic grassland, xeric grassland (includes Conservation Reserve Program lands), invasive grassland, agriculture, recent burn, developed, open water, and unavailable (Figure 1). Since LandFire's EVT databases are available on a biannual basis at best, EVT databases were reclassified for 2001, 2008, 2012, 2014, and 2016. This will be used to determine overstory species for the fine-scale vegetation map.

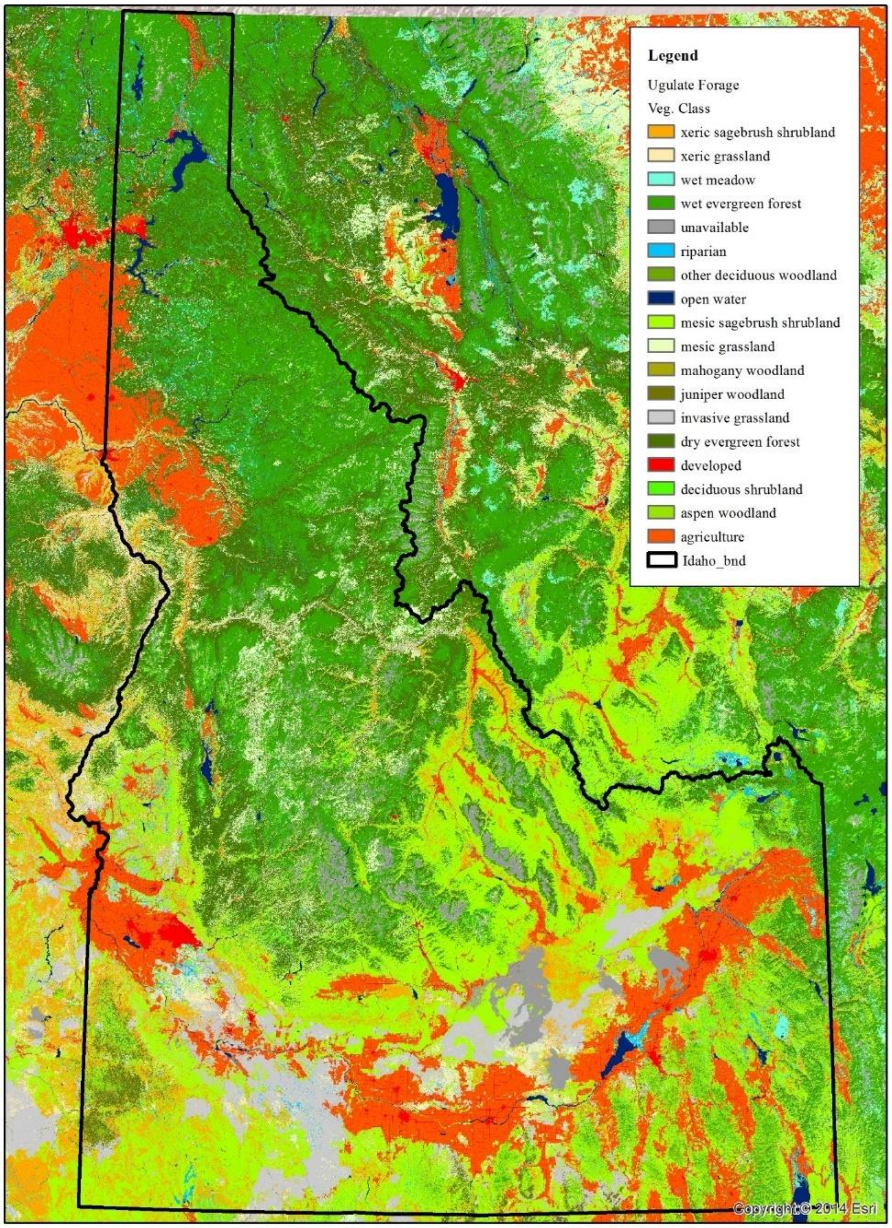


Figure 1. Ungulate forage map of Idaho and adjacent lands based on reclassification of 2014 LandFire existing vegetation type classification.

Fine-scale structural components - We created a 1m resolution vegetation structure map of the state of Idaho by classifying 2014 National Agriculture Imagery Program (*NAIP*) aerial imagery into the structural classes of open water, shadow, bare ground, mesic grass, xeric grass, mesic shrub, xeric shrub, conifer canopy, deciduous canopy, agriculture, and developed. To do so we added a NDVI band of information to the red, green, blue, and near infrared bands (NDVI =((red – near infrared)/ (red + near infrared)) * 10000) for the purposes of distinguishing deciduous canopy from mesic shrub canopies on the assumption that deciduous canopies would have a higher NDVI. Using maximum likelihood supervised classification methods, we initially classified each 1:100,000 scale quadrangle of NAIP imagery into a higher number of consistently identifiable classes than occur in the final product.

This allowed for classes with a high degree of classification accuracy to be separated from other, similar classes that had lower accuracies (e.g., juniper canopy that would subsequently become part of the conifer canopy class). This classification was then combined with LandFire's EVT and existing vegetation cover (EVC) classified databases to help guide the finer-scale classification into the most appropriate structural vegetation class. LandFire databases were used to identify the open water, agriculture, and developed classes. Seventy four 1:100,000 scale USGS quadrangles were classified and then mosaicked to create a uniform 1m resolution fine scale vegetation structure. The fine scale vegetation structure classifications were then used to estimate the polygons structural vegetation composition and these attributes were appended to the attributes of the image segmented polygons (Figure 2).

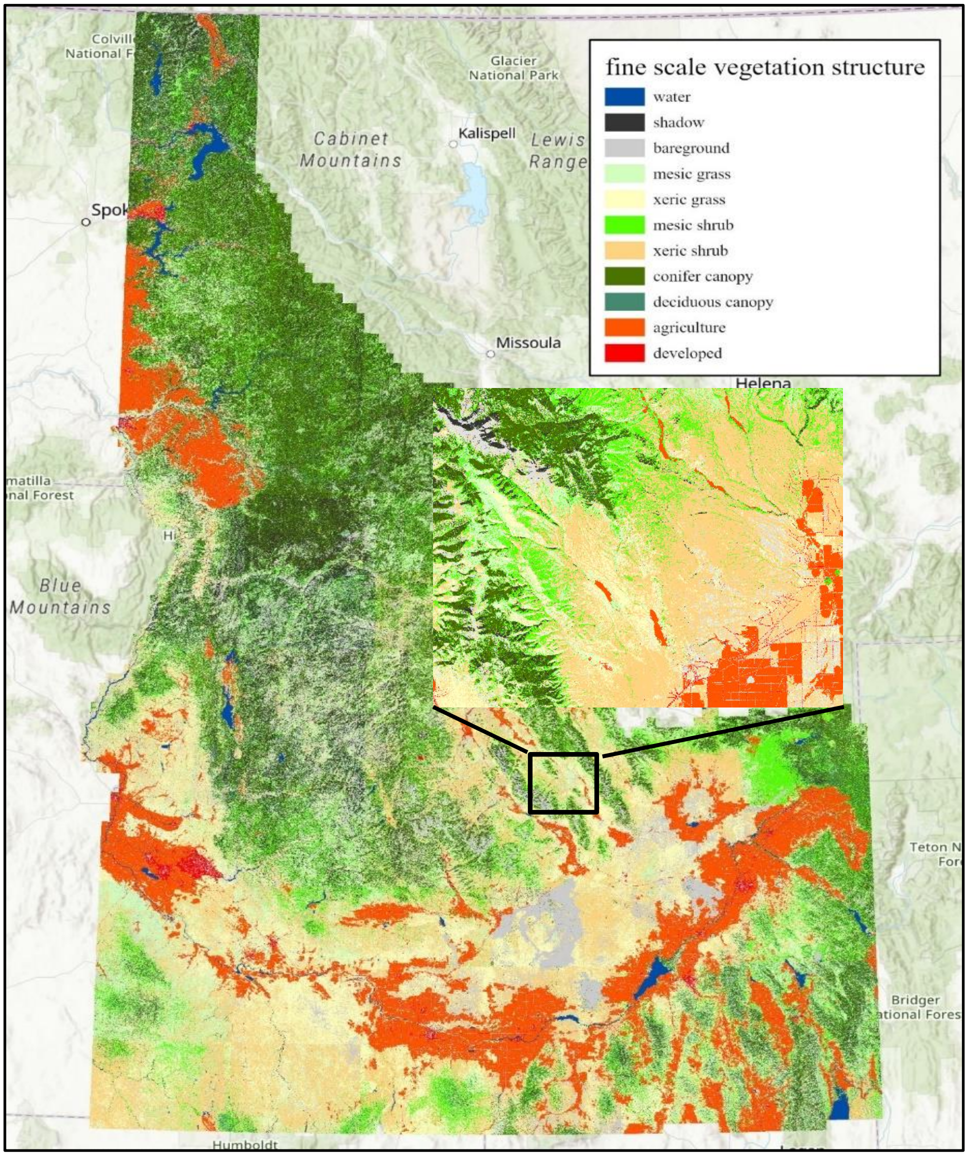


Figure 2. Fine-scale vegetation structure map of Idaho based upon maximum likelihood classification of 2014 NAIP imagery.

We also used a small unmanned aerial system (sUAS) to collect aerial imagery at 47 sites with a Mecasense multi-spectral camera (https://www. micasense.com/rededge-mx) to validate the classifications in the fine scale vegetation structure map of Idaho. In this process, we selected polygons that resulted from the segmentation process, each of which had a composition of structural classes calculated from the fine scale vegetation structure map. We used the sUAS to survey each area for comparison and processed images using Pix4D software. This image processing software stitches together several hundred images to produce an image composite of the survey area at an approximate 7cm resolution. Pix4D also has the capacity to calculate NDVI (and other vegetation indices), digital surface models (DSM; 3D estimations of structure in the imagery), and digital terrain models (DTM; digital models of the underlying topography). These accessory products have proven to be powerful tools in the classification of vegetation structure and composition for the survey sites (Figure 3). For example, NDVI yields information on the vegetation status (mesic vs. xeric, conifer vs. deciduous) because each of these classes has distinct reflectance characteristics. Further, a simple calculation between DSM and DTM yields an estimate of vegetation height, which can be used to distinguish deciduous tree canopies from lower shrubbery. Using vegetation height, NDVI, and natural color image composites, survey sites can be classified visually or via classification algorithms into the appropriate fine scale vegetation structure classes.

Figure 3. Small unmanned aerial system (sUAS) derived image mosaic of a female mule deer forage vegetation plot in the Whitehawk basin of Idaho. This image composite of several hundred individual sUAS images has a resolution of slightly larger than 7.4 cm.

Predicting plant presence. We had sufficient data (e.g. at least 3 ecognition polygons in our training and test data sets) to train plant presence models for 294 of the 593 identified species of importance for deer and elk forage or sage-grouse. We tested 11 Artificial Intelligence based model structures on each individual species to determine the best predictive model. All machine learning models were implemented and tuned using package caret in R (ver. 3.5.3) and are fully described here https://rdrr.io/cran/caret/man/models.html. Based on area under the curve (AUC) values, the Random Forest formulation appeared to train the best predictive models in 163 of the species, followed by XGBOOST in 41 species (Table 1). The composite models were the poorest performers with just 1 best species model each. We were able to attain AUC values of >= 0.8 for 86% of the trained species models (Figure 4).

Table 1. Model structure resulting in the best performing models for predicting presence for each plant species as determined by AUC statistic.

Best Model	**Number of Species**
RF	163
XGBOOST	41
GLMNET	27
GBM	26
GLMNET_class	18
GLM	10
RF,XGBOOST	4
GBM,RF	2
GBM,RF,XGBOOST	1
GLMNET,GLMNET_class	1
GLMNET,RF,XGBOOST	1

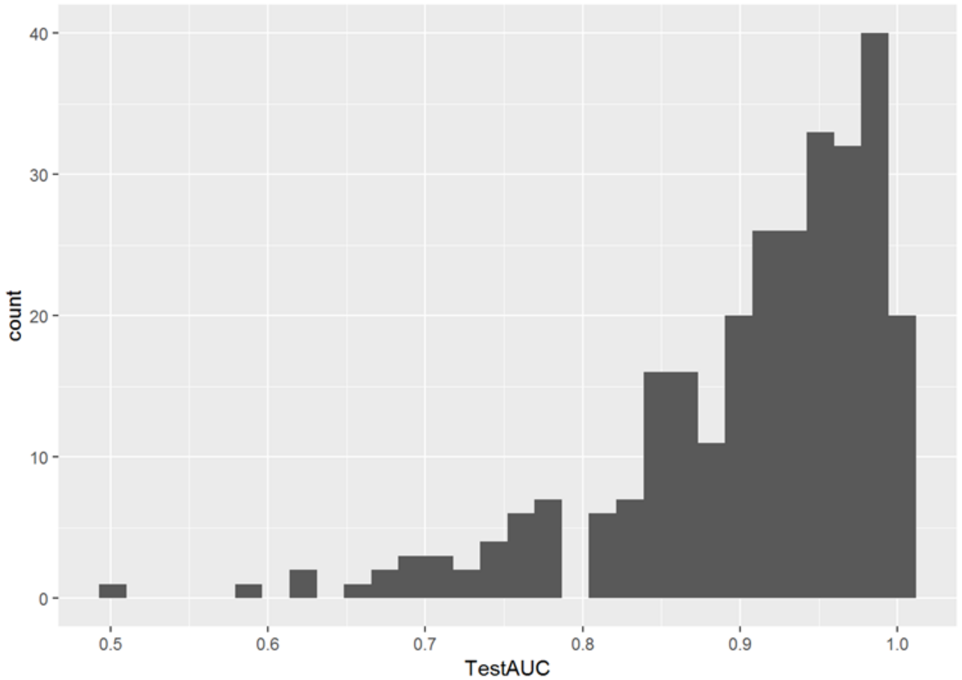


Figure 4. Validation of models using the AUC statistic to evaluate predictive performance of models predicting presence of plant species in an ecognition polygon (vegetation stand).

AI models converged on an unbiased estimate of presence often with very few plants observed in polygons (Figure 5). We have also developed genera and subspecies models that perform similar to the species models.

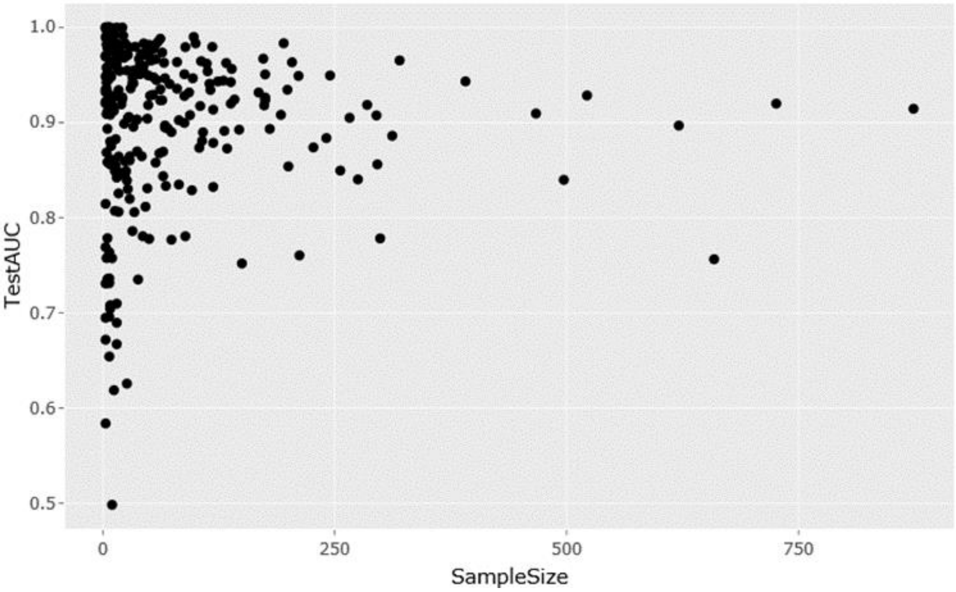


Figure 5. Relationship between predictive performance (TestAUC) and number of samples within vegetation plots.

Predicting plant abundance - We had sufficient data (e.g. at least 3 ecognition polygons in our training and test data sets) to train plant abundance models for 127 of the genera of the 182 identified genera of importance for deer and elk forage or sage-grouse. We tested 10 Artificial Intelligence based model structures on each individual species to determine the best predictive model. Based on root mean squared error (RMSE) values, the Random Forest formulation appeared to train the best predictive models in 86 of the species, follow by RPART in 14 species. GBM.RPART and XGBOOST were the poorest performers with just 1 best species model each (Table 2). Overall the species abundance models did not perform as well as the species presence models with R-squared values of >= 0.2 for 20% of the trained genera models (Figure 6).

Table 2. Model structure resulting in the best performing models for predicting presence for each plant genera as determined by root mean squared error (RMSE) values.

Best Model	Number of Genera
RF	86
RPART	14
GBM	7
TREEBAG	5
GLM	4
BAGEARTH	3
LM	3
RPART2	3
GBM,RPART	1
XGBOOST	1

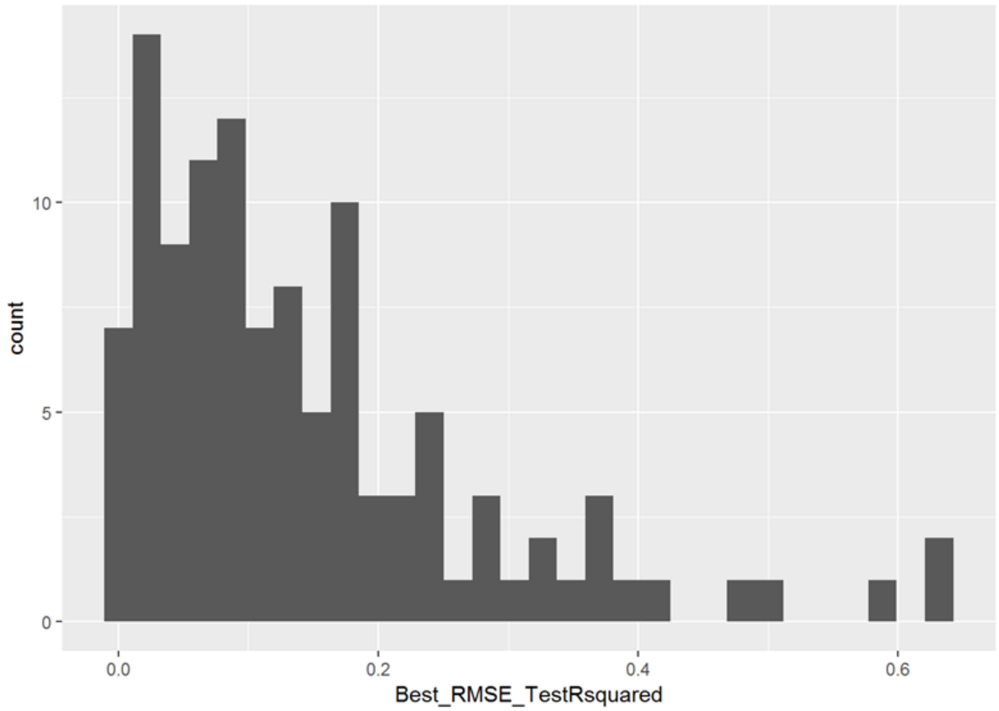


Figure 6. Validation of models using the AUC statistic to evaluate predictive performance of models predicting abundance of plant species in an ecognition polygon (vegetation stand).

RSME of AI models for plant abundance increased as the number of plants sampled in polygons increased (Figure 7). This suggests inadequate sample size for many of the species abundance models. We have also developed species and subspecies models, but performance of these models was lower than the Genera model presented here.

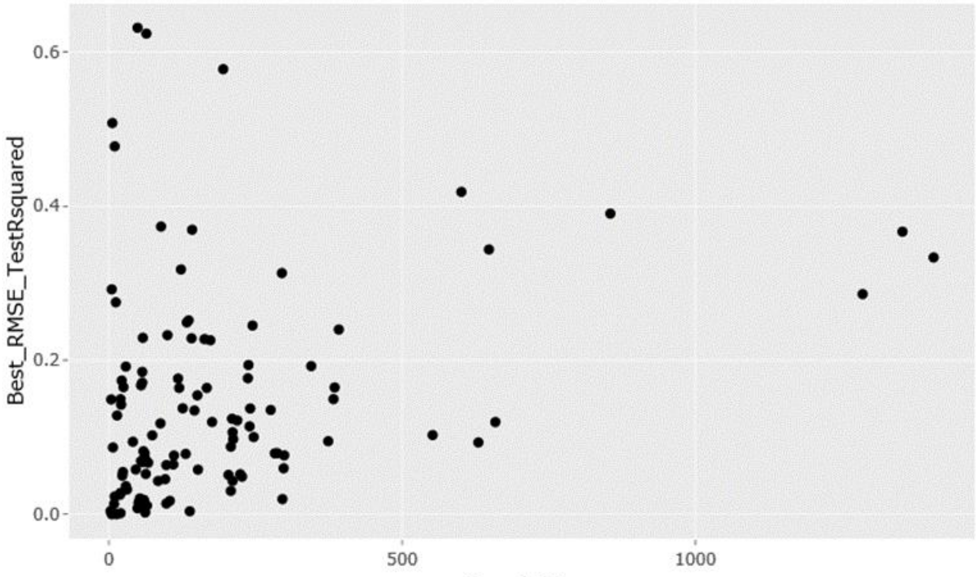


Figure 7. Relationship between predictive performance (TestAUC) and number of samples within vegetation plots.

Estimating Habitat Quality – As a proof of concept for estimating habitat quality, we composited the point intercept plant transects completed in each adult female home range. The number of transects completed was dependent on the variability of vegetation cover types within the home range (range = 3 to 12). We assigned digestible energy (IVDMD) and crude protein (CP) values at the mature plant stage from the nutritional analyses for the plant species selected by deer that were identified by the microhistological analyses. The plant sampling methods provided an estimation and ranking of forage quality availability within 77 adult female fawn rearing home range. The adult female home ranges were then averaged within mule deer DAUs to match the scale of demographic parameters estimated for each DAU from captured mule deer fawn in the winter. We tested the influence of IVDMD, CP, and plant diversity (number of unique species in a plot) on fawn weight in December, fawn/100 adult females in December, and overwinter survival.

Digestible plant diversity declined as the date of plot completion was later in the summer (Figure 8). This result was expected because annual and early growing plant will have desiccated by late July or August.

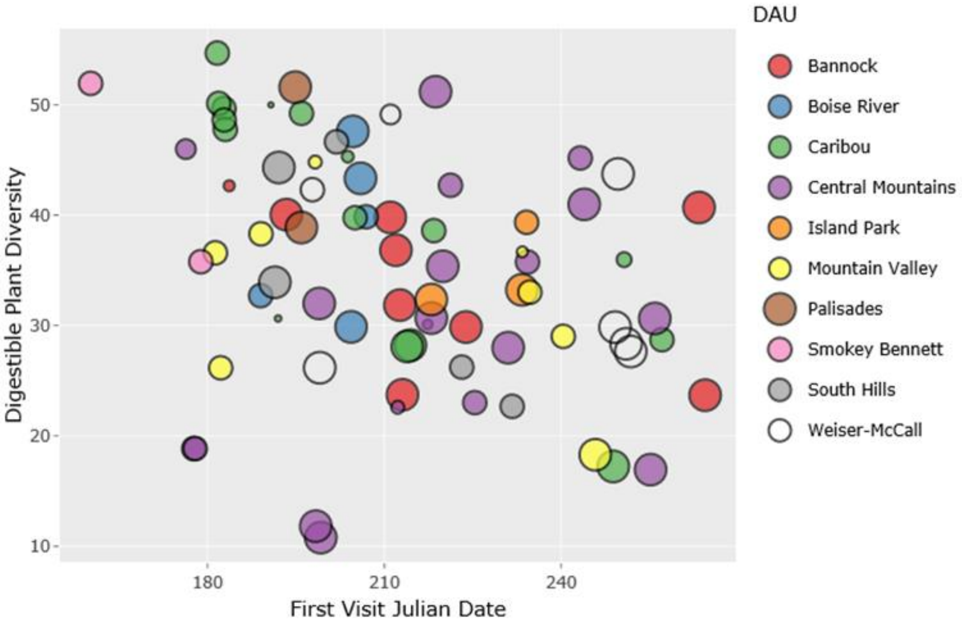


Figure 8. Relationship between number of species present (Digestible Plant Diversity) and the date of the vegetation transect visit. Point size is inversely proportional to number of days between first and last visit.

Female fawn weights in December (2012-2014) were larger in mule deer populations where plant digestible energy (IVDMD) was higher. Average fawn weight showed a positive trend to IVDMD in vegetation plots within fawn rearing home ranges of adult females (Figure 9; $F_{1,8}$ = 1.73, p = 0.22, R^2 = 0.18).

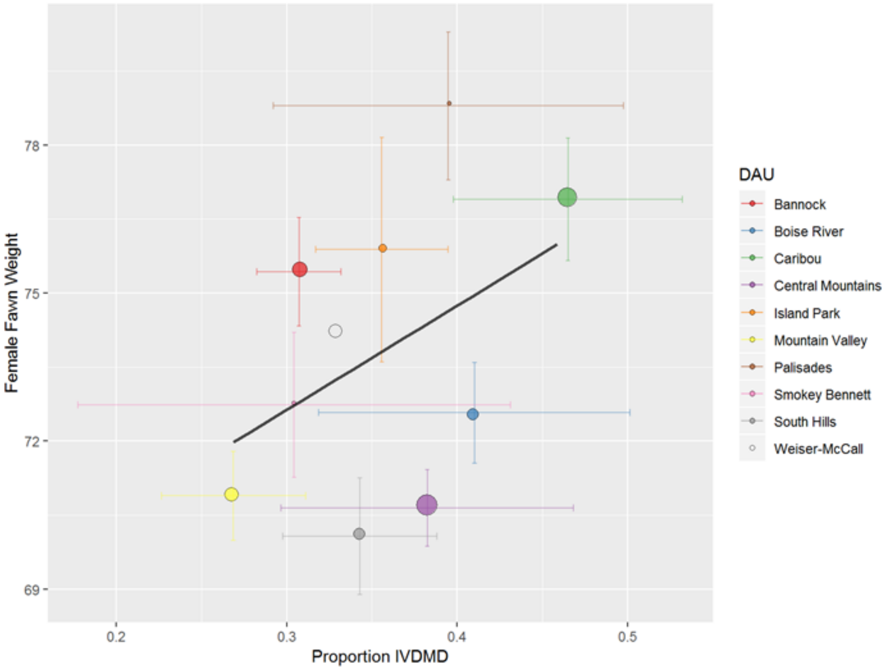


Figure 9. Correlation between mean weight (lbs) of fawns captured in December and early January (2012 - 2014) and digestibly energy (IVDMD) of adult female home ranges within a mule deer PMU.

Female fawn weights in December (2012-2014) were larger in mule deer populations where plant diversity was higher. Average fawn weight was positively related to number of plant species in vegetation plots within fawn rearing home ranges of adult females (Figure 10; $F_{1,8} = 4.05$, $p = 0.079$, $R^2 = 0.34$). Although, all nutritional quality measures were related to fawn weight, no discernable relationship was evident with overwinter survival. Fawn / 100 adult females was only influenced by plant diversity (Figure 11; $F_{1,8} = 3.32$, $p = 0.11$, $R^2 = 0.29$).

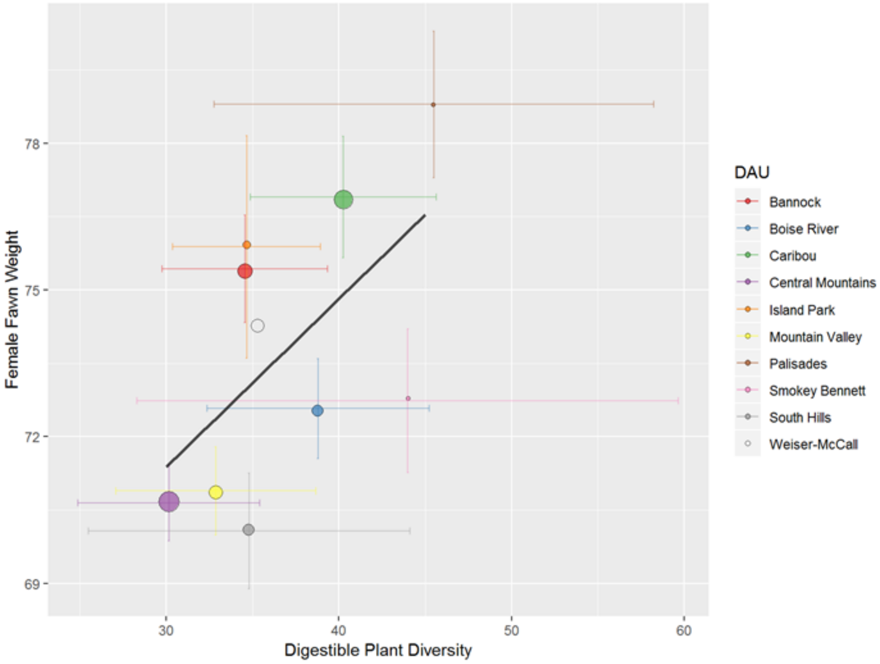


Figure 10. Correlation between mean weight (lbs.) of fawns captured in December (2012 - 2014) and plant diversity (number of selected forage plants) of adult female home ranges within a mule deer population management unit.

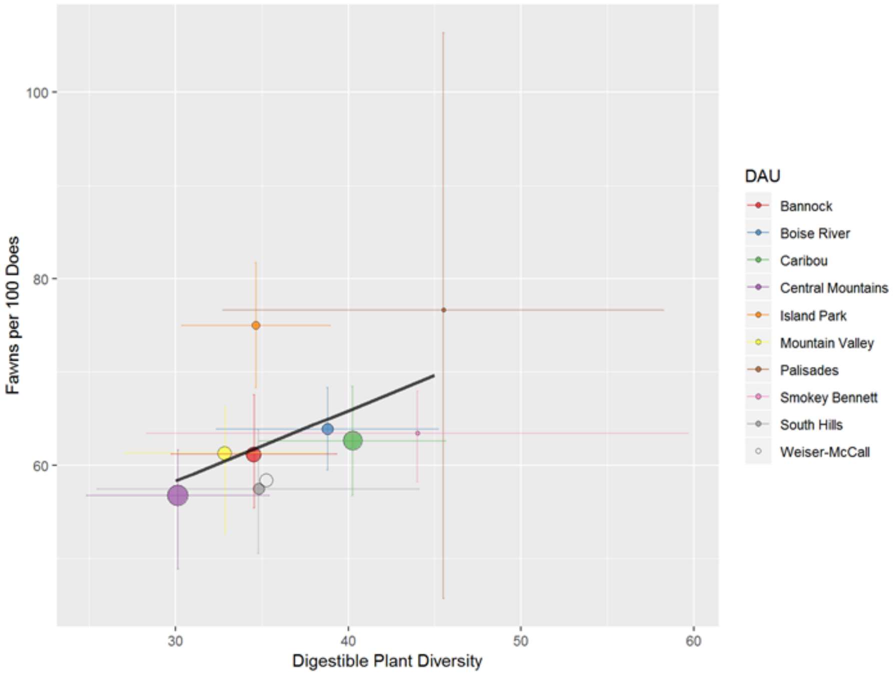


Figure 11. Correlation between ratio of fawns to 100 adult females in December (2012 - 2014) and plant diversity (number of selected forage plants) of adult female home ranges within a mule deer PMU.

Estimating Phenological Variation in Nutrition - The results of our site-level comparisons show that in the Idaho study area the ExG and GCC camera index values were highly correlated to MODIS NDVI (Pearson correlations of 0.80 to 0.95, respectively), while the VIgreen camera index had the lowest correlation to MODIS NDVI. Averaging data from multiple cameras per site smoothed the digital camera derived phenology indices and improved its correlation with MODIS NDVI. The 16-day mean DN values for camera indices were not significantly different (α = 0.95) from using the daily camera value for the corresponding MODIS NDVI date, and did not consistently improve or decrease the correlation results across sites. Thus, the following results were based on averaging the daily camera data into 16-day MODIS periods.

The high correlation between camera and MODIS NDVI at Idaho rangeland sites suggest that the camera indices are capturing the same vegetation green up signals as MODIS NDVI. The uniform results reflect the site selection of rangeland ideally suited for correlation with satellite observations. Start of season dates estimated from MODIS NDVI were earlier than the digital camera indices estimates in all but two sites. The exceptions were a mixed canopy and forested site respectively, where the camera indices were not significantly correlated to MODIS NDVI. The estimated day of maximum greenness (MAX) correlated well between NDVI and the camera indices. The differences in the frequency of observations between the camera indices (daily) and NDVI (16-day) should be considered when interpreting these results. Overall, the camera indices had consistently shorter estimates of the amount of time from start to maximum growing season than MODIS NDVI (Figure 12).

The results of our site-level comparisons show that in the Idaho study area the ExG and GCC camera index values were highly correlated to MODIS NDVI (Pearson correlations of 0.80 to 0.95, respectively), while the VIgreen camera index had the lowest correlation to MODIS NDVI (Figure 12). Averaging data from multiple cameras per site smoothed the digital camera derived phenology indices and improved its correlation with MODIS NDVI (Figure 13). The 16-day mean DN values for camera indices were not significantly different (α = 0.95) from using the daily camera value for the corresponding MODIS NDVI date, and did not consistently improve or decrease the correlation results across sites. Thus, the following results were based on averaging the daily camera data into 16-day MODIS periods.

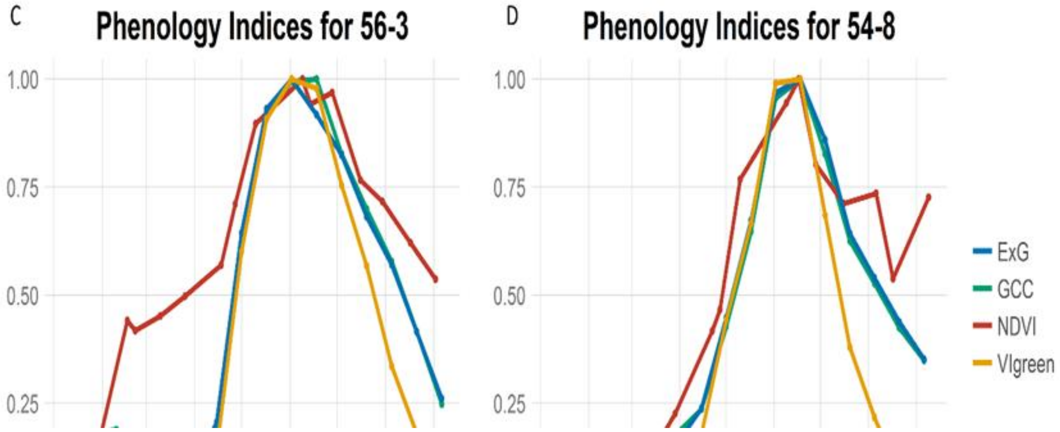


Figure 12. Comparison of camera derived 16-day averaged indices values from a network of digital cameras to MODIS NDVI values. The y-axis is a normalized scale from indices' minimum to maximum values, while the x-axis is the temporal period of observations. Camera indices values are assigned to the midpoint of the 16-day period while MODIS NDVI values are assigned to the day of observation.

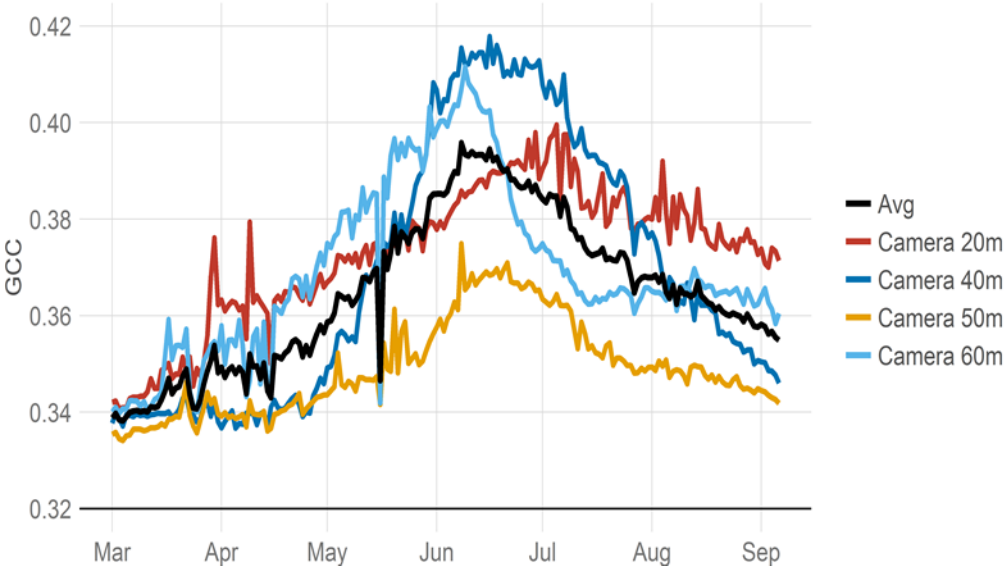


Figure 13. The daily GCC values from the four individual cameras and their average at rangeland site 54-8 in the Idaho study area.

Survival Modeling and Integrated Population Models. We assisted management staff with the capture and collaring of 248 mule deer (207 6-month old fawns, 41 adult females) during winter 2018-2019 for statewide population monitoring efforts.

Charles Henderson completed his dissertation this year with the goal of improving efficiency in data collection and analysis efforts by management agencies funded through this grant. His dissertation, "Optimizing the use of wildlife monitoring resources. Doctoral dissertation, University of Montana, Missoula, MT" is summarized below with a copy attached to this report.

Accurate knowledge regarding trends in the abundance of wildlife populations provides a foundation for the understanding of wildlife ecology and effective wildlife management. Abundance estimates enable managers and researchers to track the status of wildlife populations, supply information on which to base wildlife management decisions, and provide a metric to assess the outcome of specific management actions (Terletzky and Koons 2016). Consequently, accurate estimates of abundance provide essential knowledge for managing wildlife populations effectively. However, the amount of resources available for monitoring wildlife populations is limited and often fluctuates in response to changes in annual budgets (Chadés et al. 2008). Therefore, agencies responsible for the management of wildlife populations would benefit from knowing the most efficient manner in which to allocate their limited monitoring resources. In order to determine the most efficient manner for allocating monitoring resources, we began several converging lines of research to gather information regarding how and where to use monitoring resources most effectively. The information resulting from these lines of research are then combined to produce a set of data collection scenarios, which simultaneously maintain or increase the accuracy of abundance estimates while reducing the cost of monitoring. The resulting data collection scenarios provide a set of potential options to management agencies to decide from when allocating monitoring resources when monitoring resource availability and management needs change periodically.

The first element in the converging research lines is an assessment of the impacts of using different radio collar technologies on the estimate of survival. This assessment provides information regarding the how inherent differences in the function of GPS and VHF radio collar technologies impact the estimation of a vital rate crucial to the estimation of wildlife abundance. The second element of the converging lines of research develops a multinomial likelihood to account for classification error present in most surveys of wildlife populations. This development will allow managers and researcher to deal explicitly with the presence of classification error within a modeling framework and eliminate the common assumption that this type of error can be ignored or is too small to make a difference in the estimation of abundance. The third line of research explores and quantifies the impact of data with varying levels of quality on the estimation of abundance using integrated population models (IPM). The quantification of the behavior of data types of different relative qualities within the IPM provides information suggesting which data types contribute the most to the estimation of abundance and should inform decisions regarding the allocation of wildlife monitoring resources for data collection. The final research thread brings elements of the previous lines of research together to determine the optimal data collections scenarios for collecting data for estimating the abundance of wildlife populations. This research line develops a new metric for describing the relationship between the costs of gathering different data types and the expected gains in information about abundance from varying amounts and types of data.

Chapter 1 provides an analysis of the potential differences between survival data collected via GPS and VHF radio collars to directly assess the quality of one data type used within the IPM. Survival data is expected to have a large influence on the estimate of abundance and therefore any biases related to how this information is collected should be quantified. Our initial analysis focused on the estimates of survival for female adults. We expect the survival of this age and sex class to have the least amount of variability due to the evolutionary canalization of this vital rate (Gaillard and Yoccoz 2003), therefore if we analyze individuals that overlap both temporally and spatially, differences in the estimate of survival of this age and sex class are likely to be related to the technology used to collect survival information about them. Analysis of these two survival data gathering technologies can serve to improve the quality of data used in the IPM for this highly influential data source.

Ratio data provides information on potential or realized population growth and is an important component for models that estimate the abundance of populations. However, there are potential problems with ratio data that have been recognized for decades (Caughley 1974, McCullough 1994). One potential problem with ratio data is the presence of classification errors, assigning an individual to the wrong age or sex class. Misclassification can result in inaccurate age and sex ratios, which then influence the accuracy of abundance estimates generated using these ratios. Due to the potential for problems caused by inaccurate ratio data, it is important to address the presence of classification error in wildlife surveys to eliminate one potential source of error that can lead to poor quality ratio data. Chapter 2 provides a method using a multinomial classification likelihood to account for this type of error when estimating age and sex ratios.

Chapter 3 explores the ways in which IPMs incorporate data of different relative qualities and the influence that different quality data has on estimates of abundance are of interest when determining which data types to collect and how much of each data type is necessary for accurate estimates of abundance. By testing the performance of the IPM, by measuring the bias and precision of abundance estimates generated by the model, while changing the bias and precision of the data used by the model we can assess the influence that data of different relative qualities have on final estimate of abundance. Using this methodology we can also track the weights given to each data type within the IPM and follow how these weights change as the quality of the data changes. Tracking weights is one way to determine whether the IPM is performing in a manner consistent with expectations, poorer quality data should receive less weight within the model than higher quality data. This is important information to quantify because it provides further evidence that integrated models are capable of accommodating different quality data types within the hierarchical model structure. More importantly, tracking weights also provides information that can be used to prioritize which data types are most important to the accurate estimate of abundance and suggests that the quality of certain data types can be changed without influencing the accuracy of abundance estimates. This analysis provides information regarding both the quality and quantity need for different data types to generate accurate estimates of abundance.

In Chapter 4 we quantify how the amount of information gained, in the form of the precision of the abundance estimate, is related to the cost of gathering different quantities and qualities of various data types. We accomplish this by combining the methods and results from previous analyses and by developing a new metric, the information gain (IG) ratio, which quantifies the relationship between data collections costs and abundance estimate precision. The IG ratio is then used to determine sets of data collection scenarios which optimally allocation available monitoring resources. The results of this analysis provide information for wildlife management agencies to efficiently use the limited and changing amounts of monitoring resources available to them and provides a defensible method for making decisions regarding the use of public resources.

Alternative Monitoring Methods – Camera based estimation of abundance and productivity is reported in the final report for Project F15AF00001 Amendment 3, titled "Evaluation of Camera-Based Occupancy Modeling for Estimating Ungulate Abundance" and dated September 2019. During this reporting period we designed 3 multi-species (elk, white-tailed deer, and mule deer) population surveys using remote cameras. Research personnel developed resource selection models to design the sampling scheme and used simulation and previous data to estimate needed sample sizes. We developed a very rigorous camera deployment protocol and supervised the placement and retrieval of cameras. During November 2018, management personnel deployed 427 remote cameras in portions of GMUs 6 (148 cameras) and 15 (130 cameras) and the Caribou Population Management Unit (PMU; GMUs 66, 69, 72, and 76; 149 cameras) to estimate ungulate abundance during winter 2018-2019. These cameras took over 8 million photos at 10-minute intervals throughout the winter. Cameras were retrieved in spring 2019 and we are currently in the process of categorizing and classifying the pictures. As of the writing of this report, approximately 66% of all the cameras have been processed and categorized (Caribou PMU 100% processed, GMU 6 47% processed, GMU 15 59% processed). Once picture processing is complete, we will use models developed by Moeller et al. (2017) to estimate the abundance of mule deer in GMUs 6 and the Caribou PMU. GMU 15 is assumed to have very mule deer density and the picture results to date support that assumption. Therefore, there likely won't be enough mule deer detections in GMU 15 to estimate abundance.

Seasonal Range and Migration Modeling – Since 2003, IDFG has deployed GPS collars on thousands of mule deer throughout the state of Idaho. During the early deployment years, GPS collars were set to collect location data on or near 4-hour intervals. From 2015 on, we transitioned to GPS collars that only collected 1-2 locations per day in an effort to extend collar battery life to monitor individual animals longer and decrease collar costs which allowed us to collar/monitor higher percentages of populations. That change in the GPS location collection schedule had implications for existing methodologies that we could use to estimate seasonal movement corridors and stopover zones. For example, Brownian bridge movement modeling (BBMM) techniques are less precise with less frequent locations because greater time increments increase the motion variance to estimate the utilization distribution from known GPS locations (Horne et al. 2007). As a technical guide, BBMM require a location interval of less than 7.5 hr. to construct utilized distribution probability surfaces to be useful for estimating these areas with precision needed for management purposes. Therefore, we focused on exploring and developing new techniques that would allow for more precise estimation of movement corridors from GPS locations that were collected >7.5 hrs. apart.

We start by describing the spatial life history strategy of GPS-collared mule deer using net – squared displacement (NSD, Bunnefeld et al 2011). This methodology characterizes the type of migration that is expressed by an individual's annual movement as seasonally migratory, mixed migratory, residential, nomadic, or dispersal. If an individual has seasonal or mixed migratory behaviors, individual locations are then classified as winter range, spring migration, summer range, and fall migration classes. Other metrics including migration start and end dates, distances, and rate of movement are collected and used to describe the seasonal movement patterns and characteristics of winter herds across the state of Idaho.

To describe the spring and fall migration corridors of collared mule deer, we evaluated 2 newer methods that have been developed for situations where GPS location schedules are greater than every 7.5hr. Continuous time movement models (CTMM; Fleming et al. 2015, Fleming et al. 2016) have been developed to interpolate utilized distributions of movement paths. To evaluate CTMMs, we sub-sampled GPS collar data to a 12-hr schedule, estimated the CTMM utilization distribution, and compared those results to a BBMM calculated from 2-hr GPS locations. We also examined the use of a technique called forced motion variance (FMV), which uses a population level estimate of motion variance to calculate a 2-hr BBMM utilization distribution. Our initial evaluations determined that CTMM provided a more accurate estimation of mule deer movement corridors than FMV or 12-hr BBMM estimations. However, FMV techniques were more precise and accurate in determining stopover locations. We are in the process of developing statistical software which will identify whether CTMM or FMV is best for each individual; estimate the resulting movement corridors (CTMM) and stopovers (FMV); and then incorporate those results with traditional BBMM estimates to produce population level estimates of migration corridors, stopover locations, and use levels.

In the past, IDFG used machine learning techniques (Maxent; Phillips et al. 2006, Phillips et al. 2017) to model seasonal ranges (i.e., winter, summer, and transition ranges) of mule deer across the state. We are in the process of updating our mule deer seasonal range models to include advances in resource selection function modeling, multi-temporal covariates for temporally variable covariates (vegetation condition, weather, snow condition), and location data collected since 2016.

Habitat Change and Connectivity Modeling- IDFG has evaluated the effects of deer-vehicle collisions statewide for mule deer, elk, pronghorn and other managed species which has resulted in the identification of 5 management priority areas recognized by the U.S. Department of Interior's Secretarial Order 3362. These 5 areas are recognized as having high WVC rates due to collisions occurring along ungulate seasonal migration corridors and/or winter seasonal ranges. We are utilizing existing GPS collar data and data from newly-collared animals in these locations to evaluate landscape connectivity and potential barriers to movement for multiple species, including mule deer.

Idaho Department of Fish & Game has also begun to evaluate the effects of large-scale agricultural landscape habitat changes (i.e., CRP vs agricultural vs native) on wildlife populations. We have conducted preliminary analyses of mule deer movement characteristics throughout the regions as part of statewide NSD analyses (Bunnefeld et al. 2011). We are in the process of estimating and updating movement statistics associated with mule deer inhabiting specific winter ranges. Preliminary results suggest there is a correlation between the distance an individual migrates and the amount of the surrounding landscape covered in agriculture or developed areas. There also appears to be a correlation between the amount of the landscape in agriculture or developed classes and the propensity of mule deer to use agricultural and developed lands for late summer range. We will continue to use existing and new data to examine how landscape composition and structure affect the spatial life history strategies of mule deer.

As part of the fine scale vegetation structure analysis and the Columbia sharp-tail grouse objective (Objective 10), we have also conducted sUAS surveys of CRP lands that support sharp-tailed grouse leks and mule deer. Thirty-two leks locations were surveyed (@ 20 acres) to produce highly accurate image composites which were then compared to data from ground vegetation surveys. We developed sUAS survey techniques and image post-processing methodologies.

Buck Vulnerability - We collared/tagged male mule and white-tailed deer in an effort to predict the effects of hunting season structure and habitat security on male mule deer survival. Because one season type or structure will not produce the same mortality results in GMUs with different hunter access and security cover, we are alternating through tests of season type and habitat security, while maintaining adequate control GMUs. This project is utilizing the ongoing statewide vegetation modeling efforts to provide vegetation security cover estimates. IDFG deployed 17 solar powered/GPS ear tags on male fawns and 2 yearling males in addition to GPS collars designed to drop off after one year. Additionally, IDFG deployed 39 expandable GPS collars on mule deer bucks (≥ 2.5 years of age) in GMUs 22, 32, 39, 40, and 41 and 5 expandable GPS transmitters on adult white-tail deer bucks in GMU 10A (Figure 14). Blood samples and body measurements were collected on captured deer. We will monitor these, and additional collared male deer in future years, for survival and movements related to habitat and human activity until death or collar failure. This research will provide managers with objective estimates of the effects of changing hunting season structure or habitat security, with the goal of maintaining hunter opportunity. To date, we have documented 4 mortalities on collared adult male mule deer and 2 mortalities on collared adult male white-tailed deer.

Objective 2 – Conduct 1 White-tailed Deer study by 30 June, 2019

Approach

We plan to continue white-tailed deer research which seeks to estimate abundance and demographics using remote cameras and monitoring of GPS-marked (collars and/or eartags) deer of various sexes and age classes. We will utilize information from white-tailed deer radio-collared in 2018-2019 to 1) continue to develop methods involving remote cameras to estimate abundance and occupancy of unmarked animals, 2) document survival and cause-specific mortality of various sex/ages classes of white-tailed deer, 3) measure seasonal movements and habitat selection of white-tailed deer, and 4) investigate interactions between white-tailed deer, other ungulates, and their predators. In the coming year, we will evaluate alternative methods for abundance estimation and develop a sampling design for extrapolating results to a desired study area. We will design and assist with implementation of composition and abundance estimates of white-tailed deer in coordination with the statewide surveys and inventory projects. We will also mark and monitor adult males, adult females, and neonatal fawns of both sexes to examine survival, cause-specific mortality, seasonal movements and habitat selection, and inform the use of non-invasive techniques to monitor their populations.

Geographic Location

We may utilize pictures from remote cameras across the State to assess white-tailed deer abundance, but the primary focal areas for the assessment of white-tailed deer abundance and monitoring of survival and movements will be in the north Idaho counties of Boundary, Bonner, Kootenai, Shoshone, Clearwater, and Idaho (GMUs 1, 4, 6, 7, 10A, 15).

Principal Investigator(s)

Mark Hurley (IDFG Wildlife Research and Data Manager)	208-287-2891
Shane Roberts (Principal Wildlife Research Biologist)	208-287-2722
Jon Horne (IDFG Senior Wildlife Research Biologist)	208-799-5010

Timeline

- Develop sampling design for deployment of remote cameras – summer months
- Deploy remote cameras - summer months.
- Evaluate alternative methods for analyzing camera-trap data – year long
- Capture and GPS-mark adult female and male deer – winter months
- Capture and mark neonatal fawns – spring months
- Monitor marked deer survival, movements, and habitat selection – year long

Results

During this reporting period we designed 3 multi-species (elk, white-tailed deer, and mule deer) population surveys using remote cameras. Research personnel developed resource selection models to design the sampling scheme and used simulation and previous data to estimate needed sample size. We developed a very rigorous camera deployment protocol and supervised the placement and retrieval of cameras. During November 2018, management personnel deployed 427 remote cameras in portions of GMUs 6 (148 cameras) and 15 (130 cameras) and the Caribou Population Management Unit (PMU; GMUs 66, 69, 72, and 76; 149 cameras) to estimate ungulate abundance during winter 2018-2019. These cameras took over 8 million photos at 10-minute intervals throughout the winter. Cameras were retrieved in spring 2019 and we are currently in the process of categorizing and classifying the pictures. As of the writing of this report, approximately 66% of all the cameras have been processed and categorized (Caribou PMU 100% processed, GMU 6 47% processed, GMU 15 59% processed) and the processed pictures contained a total of 7,446 white-tailed deer (1 in Caribou, 931 in GMU 6, and 6,514 in GMU 15) in 5,997 pictures. Once picture processing is complete, we will use models developed by Moeller et al. (2017) to estimate the abundance of white-tailed deer in GMUs 6 and 15. Caribou PMU is assumed to have very low white-tailed deer density and the picture results to date support that assumption. Therefore, there likely won’t be enough white-tailed deer detections in Caribou PMU to estimate abundance.

In winter 2018-2019, we used box/clover traps to capture adult and 6-month old fawn white-tailed deer in GMUs 10A and 15 (Table 3). We successfully collared 88 deer, 49 of which were adult female deer that received a vaginal implant transmitter (VIT) to aid in the capture and collaring of neonatal fawns. In May-June of 2019, we used VIT signals combined with grid searches around does suspected of giving birth to capture and collar 36 neonatal fawns (13 in GMU 10A, 23 in GMU 15). Fawns were fitted with expandable collars that communicated with their doe’s GPS collar to transmit their status. Neonatal fawn survival through August 2019, across both areas combined, was 47% with black bear, mountain lion, and coyote/dog predation as the major determined sources of mortality. We will continued to monitor these deer year-round to document survival, seasonal movements, and habitat selection and utilize those results to help inform and refine camera-based population and survival estimation efforts.

Table 3. Status of white-tailed deer collared in GMUs 10A and 15, Idaho, 2019.

	GMU 10A				GMU 15			
Status	**Neonate Fawn**	**6-month Fawn**	**Adult Female**	**Adult Male**	**Neonate Fawn**	**6-month Fawn**	**Adult Female**	**Adult Male**
Number Collared	13	2	21	12	23	13	35	5
Collar Failure						1		
Alive	5 (38%)	2 (100%)	18 (86%)	10 (83%)	12 (52%)	9 (75%)	29 (83%)	3 (60%)
Mortality Causes								
Accident	1				1			
Automobile							1	1
Black Bear Predation	2				5			
Coyote Predation			2		1		1	
Coyote/Dog Predation					1			
Mountain Lion Predation	1		1		1	1	2	
Malnutrition				1		1	1	
Wolf Predation							1	
Unknown Predation								1
Unknown Not Predation						1		
Unknown	4			1	2			

Objective 3 – Conduct 1 Elk study by 30 June, 2019

Approach

We plan to continue the multi-faceted, statewide research project to model elk population dynamics, seasonal ranges, migration routes, and connectivity; better understand relationships between elk populations and predation; and develop new techniques to estimate demographic rates and abundance.

Modeled Effects of Predator Harvest on Ungulate Survival - We are utilizing all of the historic ungulate and predator population monitoring data in the State, new data collected during statewide elk and mule deer population monitoring, and data acquired from collaborating States and the scientific literature, to evaluate the effect of removing predators on prey populations, other predator populations, and the cascading effects on their prey populations. This modeling-only effort will estimate how the harvest of various predators (wolf, bear, or lion) will impact growth of ungulate populations. Models developed during this project will then be tested and refined as new ungulate and predator population data are acquired.

Elk Population Modeling - The following integrated population model (IPM) development will be based on information collected primarily from elk radio-collared as part of the statewide elk monitoring program. We will assist management with helicopter net gunning, aerial or ground darting, or clover trap elk captures. Elk will be physically restrained or chemically-immobilized and blindfolded during processing with an average handling time of <15 minutes. During processing, we will collect age, body measurements, blood samples, and fecal samples. We will estimate elk survival and cause-specific mortality across the range of major habitat types and productivity levels in Idaho by maintaining a sample of over 800 GPS-collared adult female and 6-month old male and female elk statewide. Collared elk will be allocated across the State based on habitat type/productivity and elk abundance. In addition to survival, we will measure elk pregnancy through blood collection and nutritional condition with rump fat measurements taken with a portable ultrasound unit. All of this information will be used to inform a web-based elk IPM similar to the one developed for mule deer.

We will continue to develop methods involving remote cameras to estimate abundance and occupancy from unmarked animals, including elk. In the coming year, we will evaluate alternative methods for abundance estimation and develop a sampling design for extrapolating results to a desired study area. We will also continue to develop and evaluate an approach for extrapolating aerial surveys using model-based inference. The model will estimate elk populations in adjoining, non-surveyed areas with habitat and weather covariates, thereby reducing the helicopter hours needed to complete the survey. We will test the efficacy of this less intensive approach with existing data from completed sightability surveys.

Predicting Elk Pregnancy - Pregnancy is an essential, but not easily obtained at the population scale, vital rate for modeling elk populations within the IPM framework. If we were able to accurately estimate pregnancy rates without collecting hundreds of blood samples each year it would dramatically improve our efficiency. Therefore, we are evaluating methods of estimating pregnancy from remote (e.g., NDVI from satellite) or non-invasive (e.g., fecal) methods. We have collected vegetation biomass, forage quality, and fecal samples from elk within the Diamond Creek and Sawtooth elk zones, areas with different pregnancy rates and nutritional landscapes. We have also worked with the Clearwater Basin Collaborative to obtain vegetation biomass and quality data for modeling the nutritional landscape in the South Fork Clearwater River drainage. We successfully evaluated the pregnancy status of over 200 individual adult cow elk to relate to nutrition and landscape metrics. We are using the FRESH deer model to develop integrated habitat quality measurements at each of our vegetation sampling units. The FRESH model output will then be used as the response variable in subsequent regression models that will incorporate a suite of predictor variables (e.g., topographical characteristics and remotely-sensed values of vegetation greenness [NDVI]).

Seasonal Range and Migration Modeling - We have developed modeling techniques that use machine learning to estimate elk summer and winter ranges, and transitional habitats for elk across areas were we have location data. These seasonal range and transition habitat maps have been ‘updated’ using location data ‘streams’ provided by current GPS collaring efforts. Migration habitat has been estimated for elk and we are developing methods that estimate prioritized migration routes by elk numbers occurring in the vicinity. Further work in the coming year will include analysis of population spatial structure, updating covariates with more accurate information, and further scenario prediction (for example bad winter vs good winter, infrastructure development assessment). This work is complementing other studies on ungulate movement patterns for wildlife vehicle collisions, interstate ungulate range and movement (ID and adjacent areas of neighboring WY and MT), and regional ungulate range assessment. It will also be used to refine Idaho’s big game management units/zones to more accurately reflect biological populations.

Geographic Location

Elk survival and population modeling work will occur in Boundary, Bonner, Shoshone, Kootenai, Clearwater, Idaho, Valley, Adams, Washington, Boise, Elmore, Custer, Camas, Blaine, Gooding, Lincoln, Butte, Lemhi, Clark, Bonneville, Bingham, Caribou, and Bear Lake counties.

Principal Investigator(s)

Jon Horne (IDFG Senior Wildlife Research Biologist)	208-799-5010
Scott Bergen (IDFG Senior Wildlife Research Biologist)	208-232-4703
Shane Roberts (IDFG Principal Wildlife Research Biologist)	208-525-7290
Mark Hurley (IDFG Research and Data Manager)	208-287-2891

Timeline

- Capture and collaring of adult elk - winter months.
- Mortality monitoring - periodically as mortality events occur throughout the year.
- Fecal sample collection - regular intervals during summer and winter months.
- Blood sample collection and analysis - following capture activities in winter months.
- Develop sampling design for deployment of remote cameras – summer months
- Deploy remote cameras - summer months.
- Evaluate alternative methods for analyzing camera-trap data – year long

List of Partners

University of Montana
University of Idaho
U.S. Forest Service
U.S. Geologic Survey

Results

Modeled Effects of Predator Harvest on Ungulate Survival - We collaborated with the University of Montana to bring on a Ph.D. student in fall of 2017 to work on this project. The student completed an approved dissertation proposal in November 2018. The overall objective is to build multi-predator, multi-prey population models (MPPMs) for IDFG to explore various management strategies and optimize management across the large mammal predator-prey community. The Ph.D. project is split into 6 chapters.

Chapters 1 and 2 address internal ecological processes (e.g., density dependence) that drive ungulate and carnivore population dynamics. This is essential to determine so that population dynamics in MPPMs are built sufficiently. The goal of Chapter 1 is to determine if animal population dynamics, including ungulates and carnivores, are capable of complex, nonlinear dynamics. By analyzing >700 time-series of animal population dynamics, we determined that most animals, including 60% of ungulates and 40% of carnivores, were capable of nonlinear dynamics. This indicates the need to build nonlinear, phase-space reconstructions to model these animal dynamics. Currently, this publication is in revision at *Nature Ecology & Evolution*. The aim of Chapter 2 is to explore how environmental stochasticity and density-dependence affect ungulate population dynamics. We've found that fast life-history species (i.e., r-selected) are more resistant to low densities and extinction due to environmental stochasticity. In contrast, slow life-history species like ungulates are prone to extinction due to environmental stochasticity (Figure 14). However, ungulate species like white-tailed deer may be able to buffer the effects of environmental stochasticity due to their demography such as reproductive potential (high likelihood of twinning) and relatively linear density-dependence. Currently, we are building alternative nonlinear density-dependent population models that account for a realistic relationship between density and population growth rate.

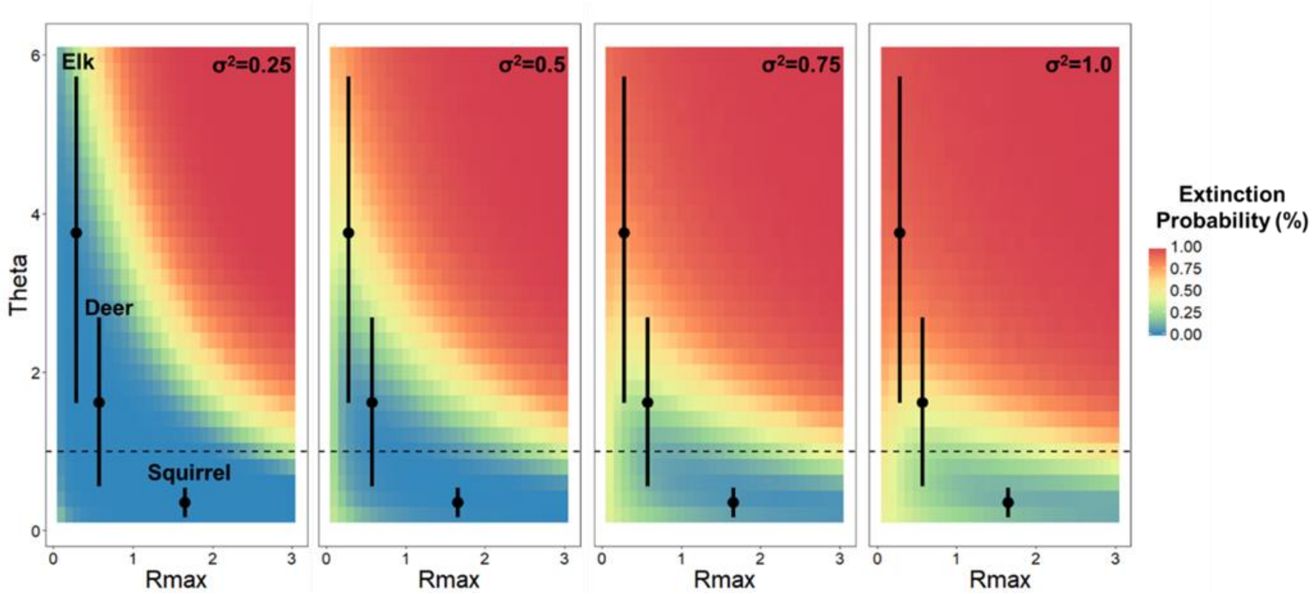


Figure 14. Probability of local extinction due to varying environmental stochasticity as a function of intrinsic rate of growth (rmax) and nonlinear density dependence (θ). This was carried out with 5,000 simulations of the theta-logistic model (Eq. 1) at a constant carrying capacity of 5. The dashed line indicates the parameter space in which life-history strategies switch between r-selected ($\theta < 1$) and K-selected ($\theta > 1$). Vertical lines for elk, white-tailed deer ("deer"), and arctic ground squirrels ("squirrel") represent the mean (black dot) and 95% CI for θ.

Chapters 3 and 4 address single-predator, single-prey population models to determine broadly if large carnivores affect their ungulate prey. Chapter 3 addresses whether stochastic predation can cause predator-pit dynamics, where two alternative stable states exist and prey are held at a low density equilibrium by predation and cannot pass the threshold needed to attain a high density equilibrium. We found that stochastic predation can generate predator pits (Figure 15), but in poor habitat quality environments (low carrying capacity), predator pits do not occur and only low-density equilibria or extinction happens. This suggests two potential management scenarios of prey populations under stochastic predation given our simulations. If habitat is poor, then only one low-density stable state is possible. In this scenario, one cannot use predator control to increase prey populations, then let the predator populations regrow and expect prey to stay at high densities, as a predator pit is not occurring and there are no alternative stable states. To have both high densities of predators and prey, improving the habitat is essential to move the population to a predator pit scenario. If habitat is productive or is improved from the previous scenario (i.e., high carrying capacity), then a predator pit could occur and prey populations might be held at a low density equilibrium (Figure 2e). In this scenario, predator control might allow prey to grow to a high density equilibrium, then letting predator populations regrow should achieve both predator and prey populations at high densities. Currently, we are finishing editing Ch. 3 for submission to *The American Naturalist*. The aim of Chapter 4 is to conduct a metaanalysis of predator control experiments to determine if they are effective in increasing ungulate populations for managers. We are currently in the process of collecting data and building meta-analytical models. We intend for this manuscript to be submitted to either the *Journal of Wildlife Management* or *Journal of Animal Ecology*.

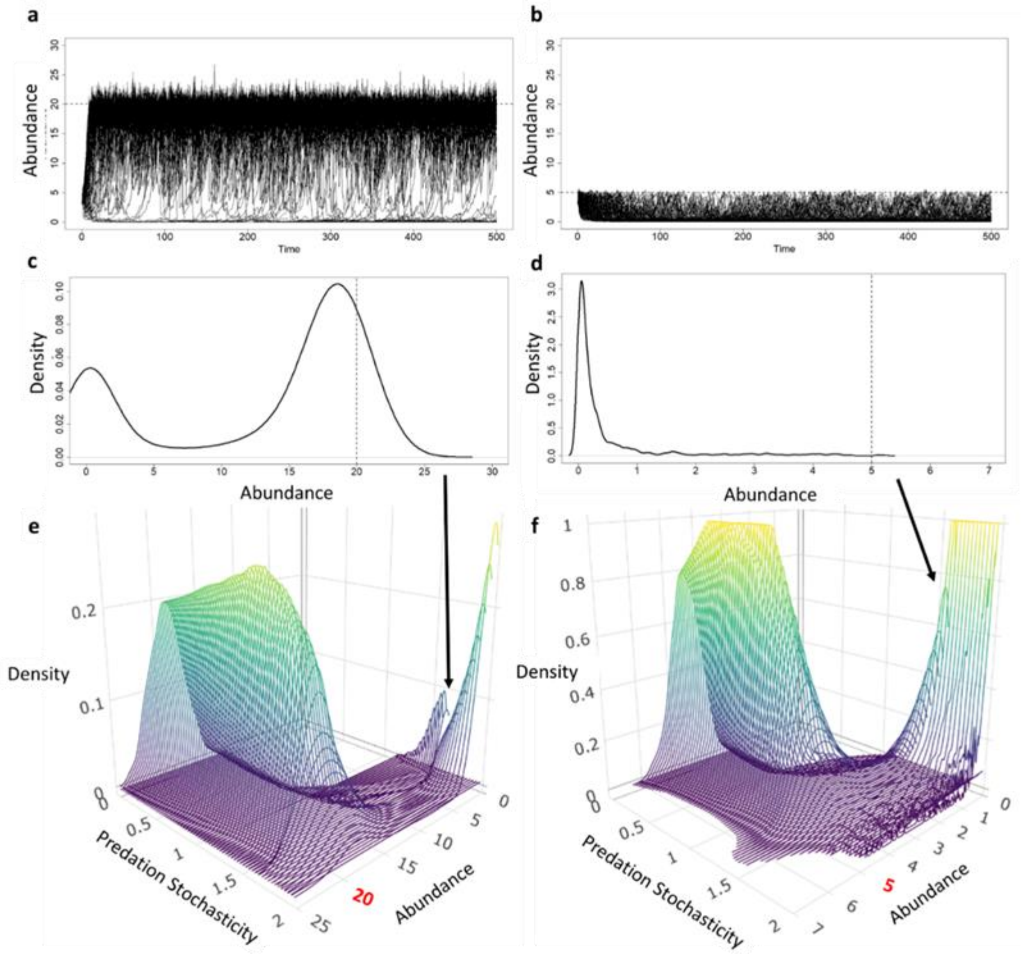


Figure 15. Population growth under predation stochasticity with high (K = 20) and low carrying capacity (K = 5). a and b represent 1,000 simulations of population growth (Eq. 8) with high predation stochasticity (τ2 = 1.75) under high (a) and low (b) carrying capacity. c and d show density plots of the stationary distribution of abundances a and b at t = 500. Dashed lines represent carrying capacity. e and f show the change in the distribution of abundances at t = 500 across varying levels of predation stochasticity (τ2). Bold arrows indicate the relative position of the distribution in c and d in the density plots e and f. Red numbers in the “abundance” axis indicate carrying capacity.

Lastly, the aims of Chapters 5 and 6 are to build MPPMs to investigate how predation and competition regulate large mammal assemblages, and how IDFG should optimize ungulate management given these assemblages. Chapter 5 addresses how predation drives the population dynamics of wolves and their prey, across a wide variety of ecosystems. This will quantify the shape and nature of wolf-multiprey models and help inform the final IDFG MPPM. We are currently collecting data for this project. Finally, Chapter 6 is the MPPM for IDGF, which is to determine how harvest of predators/prey in large mammal assemblages across Idaho affects population management. We began this chapter by building deterministic MPPMs, but given uncertainty in parameterization, observation error, and the known effects of stochasticity (from Chapters 2 and 3), we are exploring the use of multi-species integrated population models. With these results, we will be able to determine how harvest of one species affects the other species in the system, and if harvest strategies of multiple species should be considered together.

Elk Population Modeling - We assisted management staff with the capture and collaring of 218 elk (186 6-month old calves, 32 adult females) during winter 2018-2019 for statewide population monitoring efforts. Those elk were added to 628 elk that were already being monitored across the State for a statewide total of 846 elk monitored during 2019. We are using survival estimates from these elk combined with data from elk collared in previous years, sightability and composition estimates from aerial surveys, and annual harvest estimates to feed an integrated population model (IPM) to produce annual estimates of abundance, survival, and composition for Idaho's primary elk zones.

Our online software platform for analyzing elk data is fully functional and contains many enhancements curated over the last year. Since inception, our team has made more than 322 updates to the system, accounting for more than 500,000 changes to the code base. The past year's work alone tallied 147 updates. Updates not accounted for in that tally include upgrading backend servers, reduced dependencies on external software and generalized workflows that will better accommodate future feature requests and model complexities.

Functionally, the platform allows users to quickly estimate survival from telemetry data, abundance and ratios from aerial surveys and run population models. Survival analyses can take multiple forms depending on the needs of the user. Users can now subset data to certain ages, sexes and years while allowing estimates to vary temporally and/or spatially. Users may also choose to estimate the probability of death by certain causes using novel multi-state models or simply focus on survival as the response variable using more traditional known-fate methods. Data collected on elk populations via aerial survey can be entered directly into the web interface, which streamlines the process of data handling and time to analysis while maintaining a higher standard of data quality. Through a few mouse clicks, users can now estimate abundance and ratios describing the composition of the herd. Harvest, survival, abundance and other estimates all stream seamlessly into population models, which allow users to interact with projections of future elk populations based on hypothetical harvest prescriptions. The last year has ushered in numerous enhancements that increased the capability of the platform and provide novel insights for decision makers.

The interface has also been updated to make model inputs more transparent to users. Each tab now has numerous graphs, maps and tables that provide multiple perspectives of each input data stream. Upon loading data, a series of checks have been implemented that immediately provide users feedback on the state of the data by flagging errors and generally summarizing the integrity of data. Users interacting with the survival tool set can even que data for an individual animal and view side-by-side comparisons that highlight the steps taken to prepare data for analysis. Another noteworthy addition is the reporting workflow, which will produce reports on the fly. Report templates were created that meet the needs of different reporting cycles and promise real-time feedback, enhanced accessibility to data, and standardized workflows.

During November 2018, management personnel deployed 427 remote cameras in portions of GMUs 6 (148 cameras) and 15 (130 cameras) and the Caribou Population Management Unit (PMU; GMUs 66, 69, 72, and 76; 149 cameras) to estimate ungulate abundance during winter 2018-2019. Cameras placed in GMUs 6 and 15 were stratified and placed based on the results of an elk resource selection function model predicting winter elk habitat selection. These cameras took over 8 million photos at 10-minute intervals throughout the winter. Cameras were retrieved in spring 2019 and we are currently in the process of categorizing and classifying the pictures. As of the writing of this report, approximately 66% of all the cameras have been processed and categorized (Caribou PMU 100% processed, GMU 6 47% processed, GMU 15 59% processed) and the processed pictures contained a total of 6,134 elk (5,398 in Caribou, 592 in GMU 6, and 144 in GMU 15) in 2,536 pictures. Once picture processing is complete, we will use models developed by Moeller et al. (2017) to estimate the abundance of elk in each study area.

Predicting Elk Pregnancy - We evaluated methods for estimating pregnancy from remote (e.g. EVI from satellite) or non-invasive (e.g., fecal) methods across seven elk zones in Idaho (Figure 16).

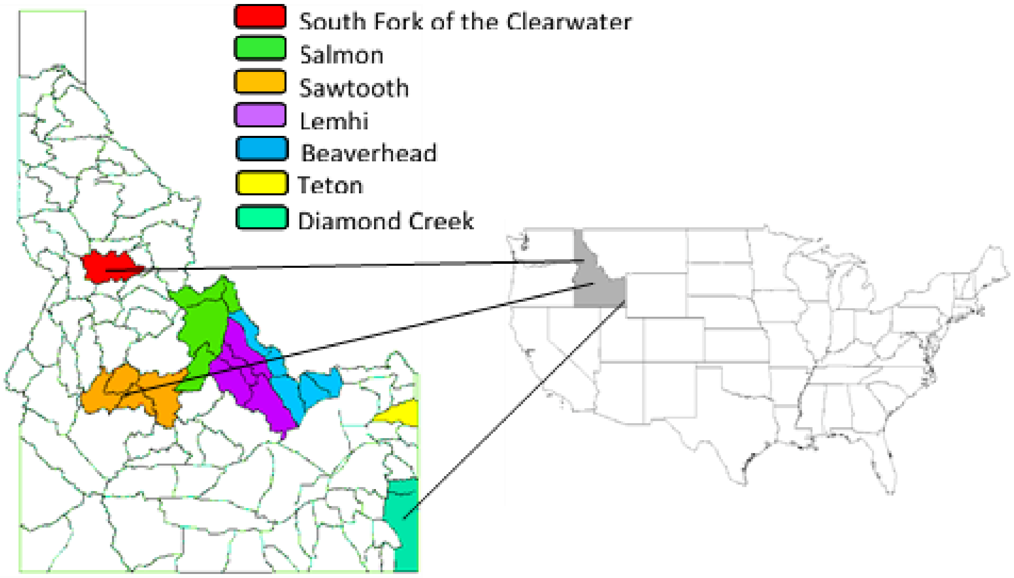


Figure 16. Study area locations in Idaho, USA. Intensive vegetation sampling was conducted in the South Fork of the Clearwater River drainage and the Sawtooth and Diamond Creek elk zones.

We collected vegetation biomass, forage quality, and fecal samples from elk within the Diamond Creek and Sawtooth elk zones, which spanned a gradient of pregnancy rates (Table 4) and nutritional landscapes. We worked with the Clearwater Basin Collaborative to obtain vegetation biomass and quality data for modeling the nutritional landscape in the South Fork Clearwater River drainage. We developed a series of linked dynamic models for predicting a) spatiotemporal variation in the nutritional landscapes available to elk in 7 distinct populations in Idaho and b) inter-annual variation in pregnancy rates of those populations as a function of the overall quality and abundance of forage resources available to them and/or how they used those resources (Figure 17). We used the FRESH deer model to develop integrated habitat quality measurements at each of our vegetation sampling units. The FRESH model output was then used as the response variable in subsequent regression models (Table 5) that incorporated a suite of predictor variables (e.g., topographical characteristics and remotely-sensed values of vegetation greenness [EVI]). These nutritional landscape models were then applied to elk locations (representing habitat use) and random locations (representing available habitat) in each of the 3 primary study areas, as well as 4 additional areas with adequate collar and pregnancy data (Beaverhead, Salmon, Teton, and Lemhi elk zones). High-quality foraging habitat was most abundant during summer in the Teton and Diamond Creek elk zones and was least abundant in the Beaverhead and Sawtooth elk zones (Figure 18). This trend was similar during the fall, with the Teton and South Fork of the Clearwater elk zones supporting the most high-quality habitat, and the Beaverhead and Sawtooth zones supporting the least high-quality habitat. Differing patterns of habitat use were observed among the 4 elk populations for which we had simultaneous GPS-collar and pregnancy data. Elk in the Diamond Creek and Sawtooth zones appeared to utilize the nutritional landscape sub-optimally, particularly during summer, whereas elk in the South Fork of the Clearwater used high-quality foraging habitat in greater proportion than it was available (Figure 19).

Table 4. Pregnancy rates of elk (*Cervus canadensis*) in each of seven elk management zones in Idaho, USA, estimated from blood samples, fecal samples, or both between 2013 and 2018.

Zone	Year	Pregnancy rate	Sample size (blood)	Sample size (fecal)
Diamond Creek	2015-16	1.00	n = 24	
	2016-17	0.84	n = 26	n = 30
	2017-18	1.00	n = 20	
Sawtooth	2014-15	0.86	n = 21	
	2015-16	0.67	n = 12	
	2016-17	0.68	n = 2	n = 25
	2017-18	0.75	n = 11	n = 19
South Fork	2013-14	0.53	n = 17	
	2014-15	0.80	n = 15	
	2015-16	0.73	n = 11	
	2016-17	0.75	n = 0	n = 28
	2017-18	0.66	n = 0	n = 32
Beaverhead	2014-15	0.87	n = 23	
	2015-16	0.93	n = 14	
	2016-17	0.89	n = 4	n = 43
	2017-18	0.85	n = 13	
Salmon	2014-15	0.93	n = 15	
	2017-18	0.82	n = 28	
Lemhi	2017-18	0.93	n = 27	
Teton	2017-18	0.90	n = 21	
Statewide Average	**2014 -18**	**0.88**	**n = 598**	**n = 177**

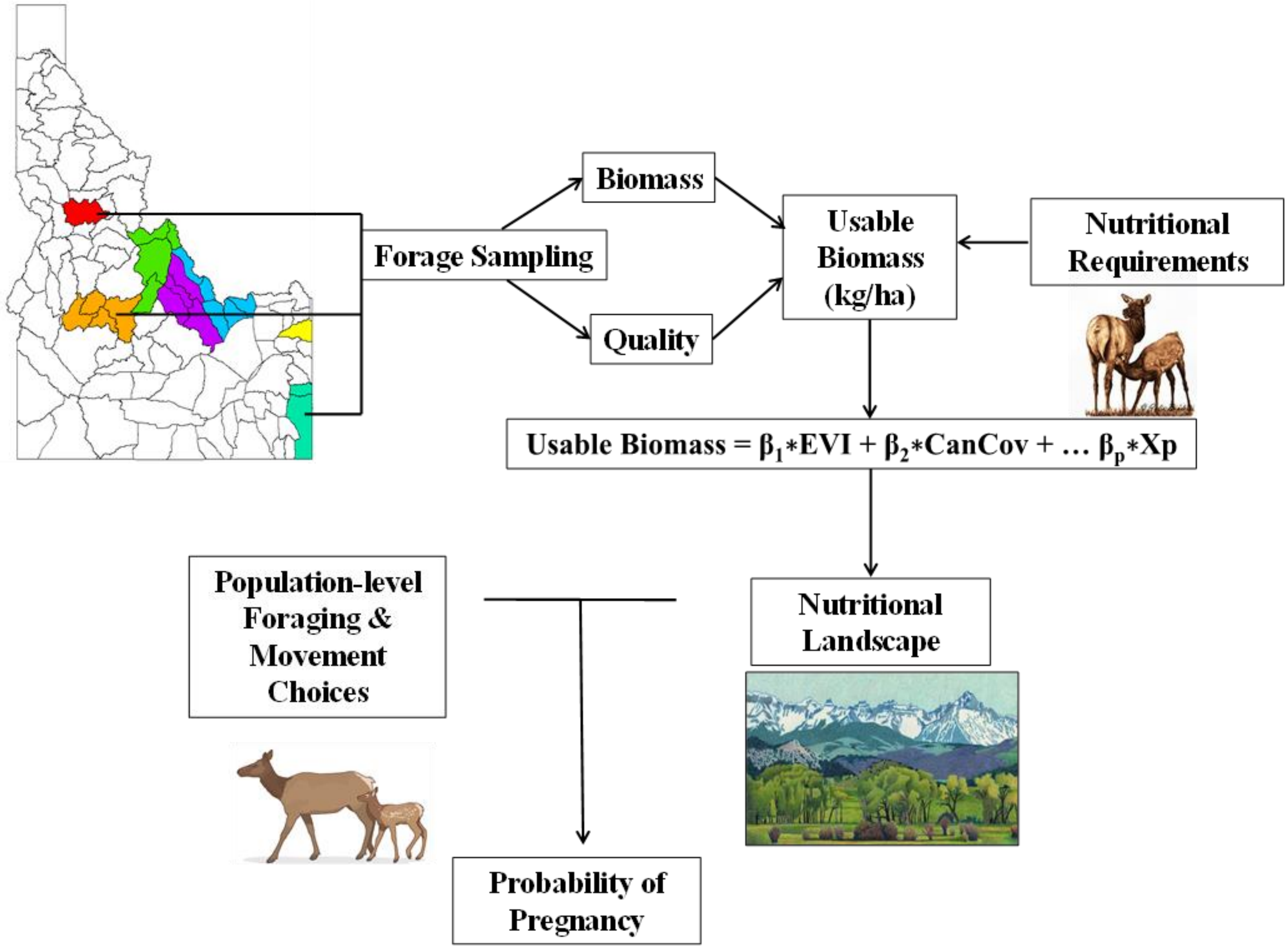


Figure 17. Conceptual model illustrating our approach to relating pregnancy rates of elk (*Cervus canadensis*) to spatiotemporal variation in the nutritional landscape and how that landscape is used by elk. We first combined detailed data on biomass and quality of forage plants consumed by elk with data on nutritional requirements for supporting lactation to estimate “usable” forage biomass at each sampled location. We then used regression models to explain spatiotemporal variation in usable biomass as a function of key environmental covariates, and used the resulting models to map the nutritional landscape available to elk in each population-year included in our study. Finally, we related metrics of the nutritional landscape and how it was used by elk to pregnancy rates in a second regression analysis.

Table 5. Top models (based on adjusted R^2) for predicting spatial variation in usable forage biomass in the Diamond Creek (DC), Sawtooth (SAW), and South Fork of the Clearwater (FORK) elk management zones in Idaho, USA, during summer (June 1 – July 31) and fall (August 1 – September 15), 2016-2017. Predictor variables are defined as follows: 1) CanCov = percent canopy cover; 2) MnPrecip = average precipitation (mm) during the month in which forage sampling occurred; 3) AprilSWE = snow water equivalent in April (mm); 4) EVI = Enhanced Vegetation Index; 5) PVT = potential vegetation type; 6) SampleSWE = snow water equivalent (mm) during the month in which forage sampling occurred; 7) AvgTemp = average temperature (C°) during the month in which forage sampling occurred; 8) MeltDate = the first day snow levels equaled 0 cm and snow remained absent for the remainder of the sampling season; 9) PrevMnPrecip = average precipitation (mm) during the month prior to forage sampling; 10) Elevation = elevation (m); and 11) Slope = slope (degrees).

Zone_Season	Nutritional model	Adjusted R^2
DC_Summer	Usable Biomass = CanCov + AprilSWE + Elevation + MnPrecip + EVI + PVT	0.44
DC_Fall	Usable Biomass = EVI^2 + PVT + EVI^2 : PVT	0.61
SAW_Summer	Usable Biomass = CanCov + Elevation + log(Slope) + PVT + SampleSWE	0.26
SAW_Fall	Usable Biomass = PVT + log(CanCov) + AprilSWE + EVI	0.56
FORK_Summer	Usable Biomass = CanCov + EVI + AvgTemp + MeltDate + Elevation	0.47
FORK_Fall	Usable Biomass = CanCov + EVI + log(PrevMnPrecip)	0.44

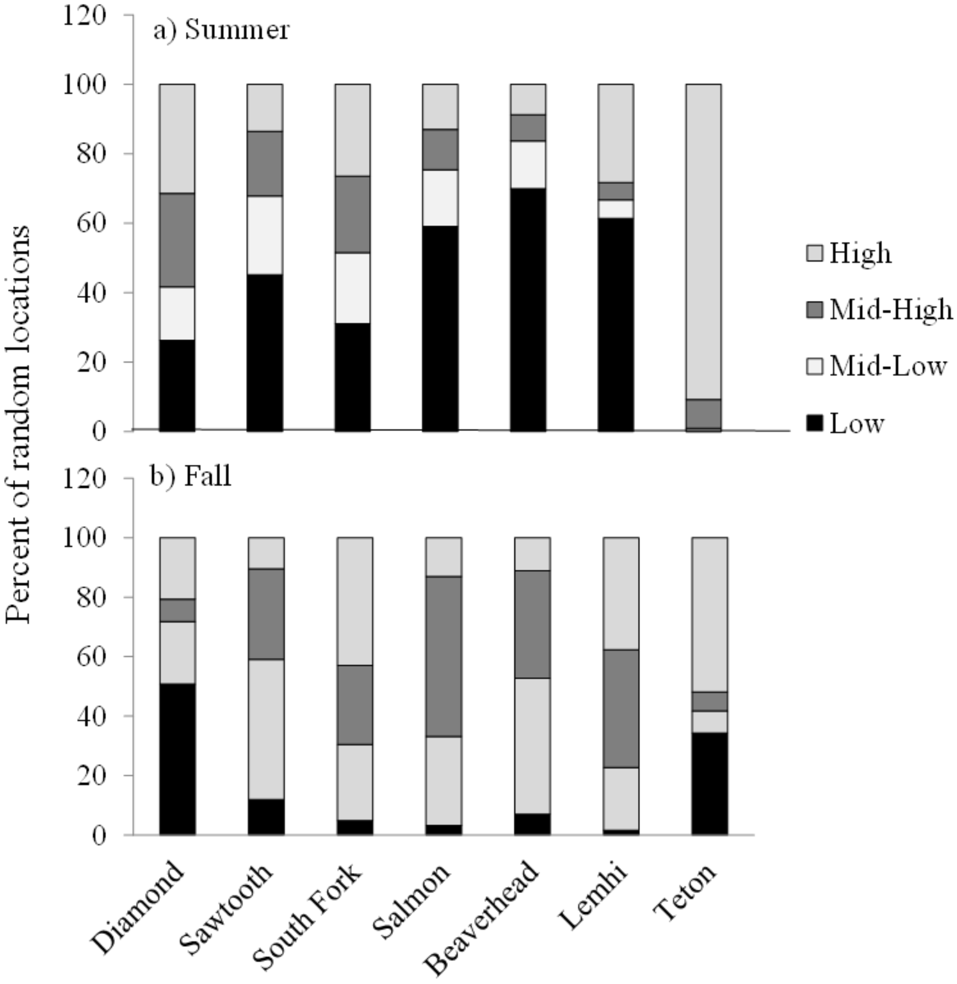


Figure 18. Percent of randomly sampled locations in each zone during summer (June 1 – July 31) and fall (August 1 – September 15) that fell into each of four quartiles of usable forage biomass (low = <245 kg/ha, mid-low = 245-423 kg/ha, mid-high = 423-705 kg/ha, and high = >705 kg/ha).

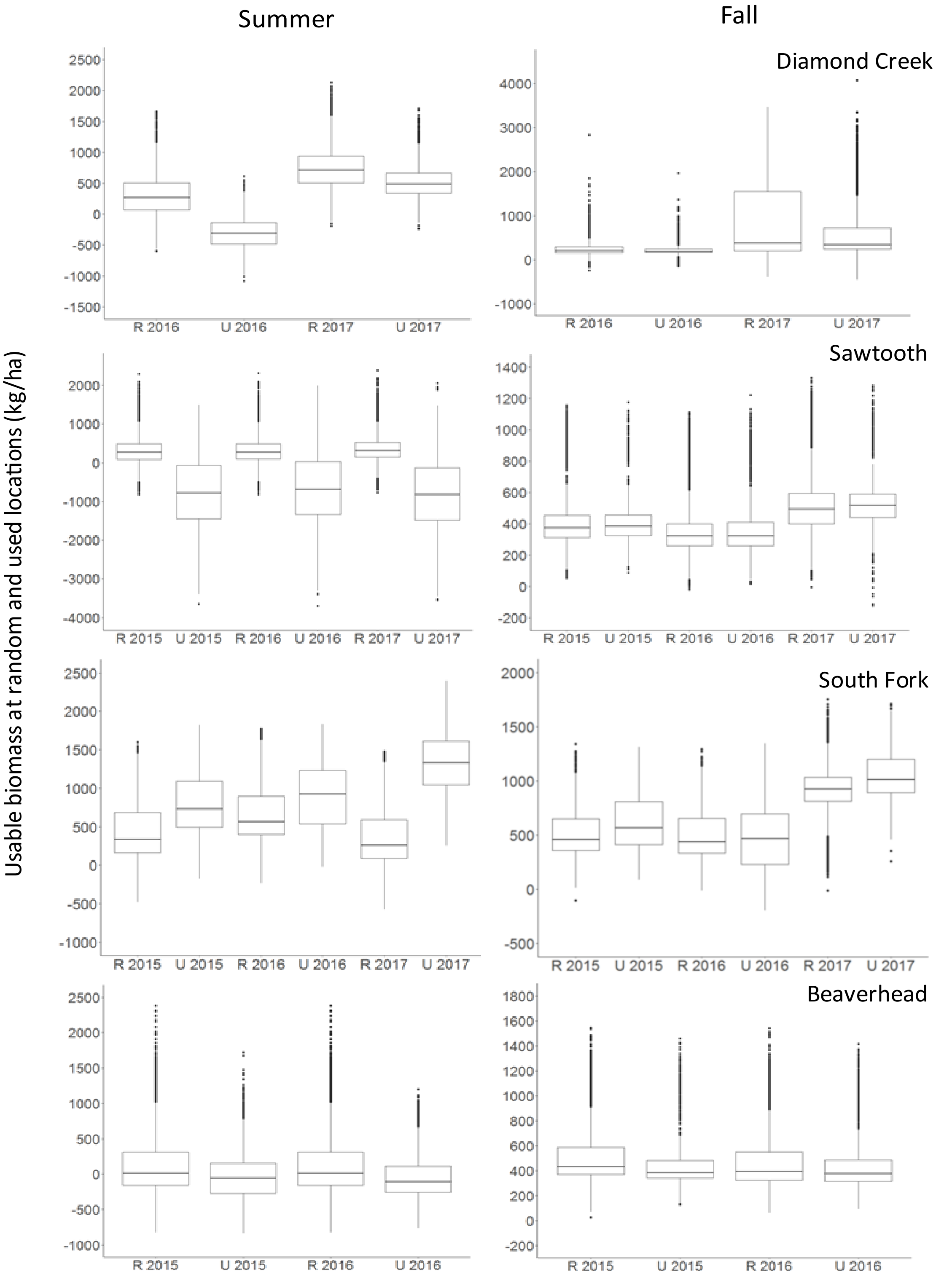


Figure 19. Boxplots of predicted usable biomass of forage at random locations (R; 1,000 locations per potential vegetation type) and locations used by elk (Cervus canadensis: U; derived from GPS-collar data)in each of four elk management zones in Idaho, USA for which we obtained GPS-collar data during summer (June 1 – July 31) and fall (August 1 – September 15).

Our top model for relating pregnancy rates of elk to the nutritional landscape explained 60% of the variation in pregnancy rates among 18 elk-population-years (Table 6). Our top model for relating pregnancy of elk to how they used the nutritional landscape explained 75% of the variation in pregnancy rates among 10 population-years. Variation in pregnancy rates was positively related to both the maximum value of usable forage biomass and the degree of heterogeneity in the nutritional landscape across elk management zones in Idaho (Figure 20). This supports our hypothesis that pregnancy is mediated by habitat quality, and provides additional empirical evidence of a fundamental link between the nutritional landscape in summer and fall and population performance of elk.

Table 6. Candidate models for explaining interannual variation in pregnancy rates of elk (*Cervus canadensis*) in seven elk-management zones in Idaho, USA (n = 10 population-years; see Table 1 for detailed data on sampling units) as a function of how elk used the nutritional landscape (a) and as a function of the nutritional landscape alone (b). Descriptive statistics used to represent the nutritional landscape included the mean, max, and coefficient of variation (CV) in usable forage biomass available to elk in each population-year during summer (June 1 – July 31) and fall (August 1 – September 15.

Model	**AICc**	**ΔAICc**	**w_i**	**Adjusted R^2**
[a]Pregnancy = Summer_CV + Fall_CV	76.23	0.00	0.57	0.75
[b]Pregnancy = Summer_max + Summer_CV + Fall_max	137.61	0.00	0.36	0.60

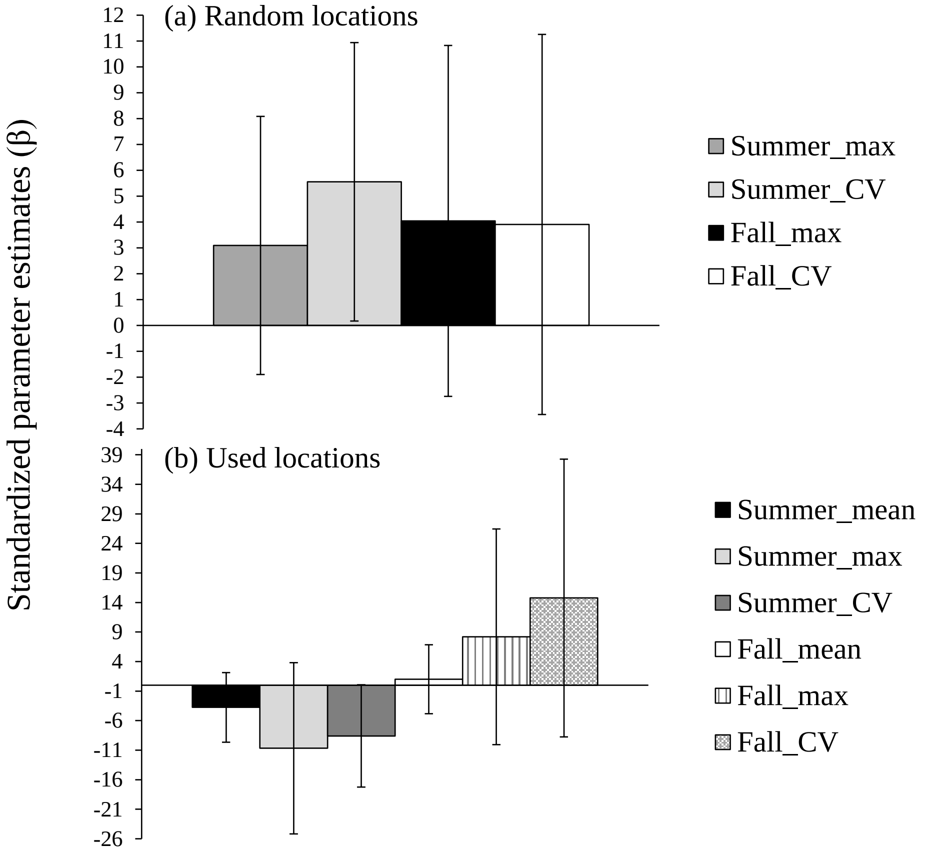


Figure 20. Model-averaged, standardized parameter estimates (with 90% confidence intervals) obtained from multiple regression models of elk (Cervus canadensis) pregnancy rates in Idaho, USA. Predictor variables were descriptive statistics (mean, max, and coefficient of variation) derived from model-predicted estimates of usable forage biomass at (a) random locations (n = 1,000 locations per PVT) that served as an index of the available nutritional landscape in each of seven elk management zones, and (b) locations used by elk in each management zone (determined from GPS-collared females).

Seasonal Range and Migration Modeling - IDFG has deployed GPS collars on thousands of elk throughout the state of Idaho since 2007. During the early deployment years, GPS collars were set to collect location data on or near 4-hour intervals. From 2015 on, we transitioned to GPS collars that only collected 1-2 locations per day in an effort to extend collar battery life to monitor individual animals longer and decrease collar costs which allowed us to collar/monitor higher percentages of populations. That change in the GPS location collection schedule had implications for existing methodologies that we could use to estimate seasonal movement corridors and stopover zones. For example, Brownian bridge movement modeling (BBMM) techniques are less precise with less frequent locations because greater time increments increase the motion variance to estimate the utilization distribution from known GPS locations (Horne et al. 2007). As a technical guide, BBMM require a location interval of less than 7.5 hr to construct utilized distribution probability surfaces to be useful for estimating these areas with precision needed for management purposes. Therefore, we focused on exploring and developing new techniques that would allow for more precise estimation of movement corridors from GPS locations that were collected >7.5 hrs. apart.

We start by describing the spatial life history strategy of GPS-collared elk using net – squared displacement (NSD, Bunnefeld et al 2011). This methodology characterizes the type of migration that is expressed by an individual's annual movement as seasonally migratory, mixed migratory, residential, nomadic, or dispersal. If an individual has seasonal or mixed migratory behaviors, individual locations are then classified as winter range, spring migration, summer range, and fall migration classes. Other metrics including migration start and end dates, distances, and rate of movement are collected and used to describe the seasonal movement patterns and characteristics of winter herds across the state of Idaho.

To describe the spring and fall migration corridors of collared elk, we evaluated 2 newer methods that have been developed for situations where GPS location schedules are greater than every 7.5hr. Continuous time movement models (CTMM; Fleming et al. 2015, Fleming et al. 2016) have been developed to interpolate utilized distributions of movement paths. To evaluate CTMMs, we sub-sampled GPS collar data to a 12-hr schedule, estimated the CTMM utilization distribution, and compared those results to a BBMM calculated from 12-hr GPS locations. We also examined the use of a technique called forced motion variance (FMV), which uses a population level estimate of motion variance to calculate a 2-hr BBMM utilization distribution. Our initial evaluations determined that CTMM provided a more accurate estimation of mule deer movement corridors than FMV or 12-hr BBMM estimations. However, FMV techniques were more precise and accurate in determining stopover locations. We are in the process of developing statistical software which will identify whether CTMM or FMV is best for each individual; estimate the resulting movement corridors (CTMM) and stopovers (FMV); and then incorporate those results with traditional BBMM estimates to produce population level estimates of migration corridors, stopover locations, and use levels.

In the past, IDFG used machine learning techniques (Maxent; Phillips et al. 2006, Phillips et al. 2017) to model seasonal ranges (i.e., winter, summer, and transition ranges) of elk across the state. We are in the process of updating our elk seasonal range models to include advances in resource selection function modeling, multi-temporal covariates for temporally variable covariates (vegetation condition, weather, snow condition), and location data collected since 2016.

Objective 4 – Conduct 1 Bighorn Sheep study by 30 June, 2019

Approach

We plan to continue the multi-faceted, statewide research project that seeks to better understand bighorn sheep disease ecology, population estimation methods, and the relationships between habitat, nutrition, movements, and demographics.

Disease Ecology - We will capture, test, and individually mark approximately 50 bighorn sheep in 4 Hells Canyon populations using corral traps, ground darting, and helicopter netgunning. Capture is being conducted to monitor health and shedding status of *Mycoplasma ovipneumoniae* (*M. ovi*) to investigate the role of chronically infected bighorn ewes in causing pneumonia epizootics in lambs and to mark individuals for evaluating alternative methods for population estimation.

We will monitor approximately 300 marked sheep (previously- and newly-collared) from the ground and from the air to estimate survival, cause-specific mortality, productivity, and population size and trend. This work is ongoing and complementary to laboratory and captive animal investigations. These data are also used for spatial assessment of risk of transfer of pathogenic organisms from domestic to wild sheep.

We plan to use multi-locus sequence typing to characterize strains of the bacterium *M. ovi* within and between bighorn sheep populations, We will assess the utility of using quantitative polymerase chain reaction (qPCR) and other diagnostic tests on swabs, blood, or serum that may correlate to health and carriage. Key cooperators include Washington State University (WSU) and US Geological Survey Rocky Mountain Research Center (USGS). Biological samples (e.g. ear swabs, nasal pharyngeal swabs, fecal, blood) are collected from bighorn sheep found dead, captured during radio-collaring efforts, and captured specifically to monitor disease status. Repeated sampling of individuals is ongoing to document changes (if any) in infection status through time.

Controlled experiments on captive animals will test field hypotheses and observations about causes of pneumonia in bighorn sheep. These include hypotheses regarding pathogen transmission among bighorn sheep. Understanding the causes and epidemiology of disease in bighorn sheep is critical for developing successful management solutions and many of these questions can only be reliably investigated, at least initially, in a controlled setting. Key cooperator is WSU. A second ongoing experiment is designed to test the role of chronic shedders in maintaining disease. Lamb survival will be compared in shedders and non-shedders penned separately and commingled. Captive bighorn sheep are maintained at WSU and South Dakota State University under their Animal Care & Use Committee permits.

Population Estimation Methods - We will continue to evaluate alternative methods to monitor bighorn sheep population sizes. We will conduct ground-based surveys including capture/recapture population estimates of previously collared individuals. When complete, we envision a multi-faceted approach to monitoring bighorn sheep that incorporates variables such as diverse topography and habitat, widely varying population density, and ground access, among others. This framework will produce various data products depending on statistical, logistical, and species natural history constraints.

Habitat, Nutrition, Movements, and Demographics - We will utilize collared bighorn sheep, vegetation surveys, and remotely-sensed data to examine the relationships between bighorn sheep nutrition, movements, population performance, and habitat quality. We will use helicopter net-gunning capture to attempt to maintain a GPS-collared sample of approximately 30 bighorn sheep (ewes and rams of various age classes, ≥1.5 years of age) in the Owyhee River, East Fork Salmon, and Lost River Range study areas of southern Idaho (initial captures occurred in winters of 2017 and 2018). We will also utilize sheep collared in Hells Canyon as part of disease research. During capture we will sample sheep for disease exposure; estimate body condition through fat and musculo-skeletal measurements taken with a portable ultrasound unit, weight, and palpation-based condition scoring; collect fecal samples for diet analysis; and draw blood for DNA analysis and pregnancy testing. We will utilize pregnancy results from capture and fixed-wing aerial and ground observations during the lambing season to document lambing. We will then use GPS locations and at least monthly aerial (fixed-wing visual observations or infrared imagery) or ground observations of bighorn sheep lambs to monitor movements and early lamb survival (birth through September).

We will use line-intercept sampling to estimate canopy cover, the disc pasture method to estimate plant biomass (Dorgeloh 2002), and establish plots to repeatedly-measure plant phenology throughout the growing season to quantify forage availability at random sites within habitat types occupied by bighorn sheep during the lambing and early lamb-rearing seasons (spring-summer). Line-intercept transects won't have any lasting markers post-measurement but we will mark the start, end, and frame corner points at phenology plots with metal or wooden stakes (<12 inches long) so we can effectively measure phenology on the exact same plants repeatedly. Stakes will be removed after the last phenology plot reading of the study. There will be 4-12 phenology plots at each study site, with the final number depending on the major canopy cover types and elevation gradients we need to sample to effectively characterize plant phenology for the entire lamb rearing season. The number of line-intercept transects will ultimately depend on the number of different vegetation types at each study site and the variation in species-specific canopy cover between transects within the same vegetation types (i.e., we will use this variation to determine the needed sample size and potentially even split or combine vegetation types based on this variation) but will likely exceed 25 per study site. Line-intercept transects and phenology plot measurements won't result in any significant disturbance to vegetation.

During mule deer research in Idaho, we have amassed a large library of the forage quality of many plants (particularly forbs and grasses) in various phenological stages across southern Idaho, but there may be some plant species that occur on these bighorn sheep study areas which we have not yet tested. For present grass and forb species or phenological stages for which we don't have forage quality estimates, we will use clipping to collect >¼ gallon of plant material for subsequent forage analysis. Plants will be clipped near, but not in, phenology plots and line-intercept transects. We will not clip any plants that are protected under the Endangered Species Act or that have a special management status from the appropriate land management agency (e.g., U.S. Forest Service sensitive species). The exact number of species and phenological stages we'll need to clip will not be known until they are encountered, but will likely exceed 30 at each study site. We will not clip multiple species from the exact same point (i.e., creating bare ground) and will spread clippings throughout the landscape. We will obtain appropriate permission to clip vegetation on special status federal lands (e.g., Owyhee wilderness). Vegetation sampling will result in measures of species-specific canopy cover, biomass, and forage quality along with site-specific plant phenology that can be related to remotely-sensed measures of vegetation growth, with the ultimate goal of measuring bighorn sheep forage quality from remotely-sensed data (e.g., NDVI) alone.

We will conduct aerial and ground surveys to estimate bighorn sheep population abundance, population structure (ram:ewe:lamb ratios), and ram age structure. The final analysis will investigate relationships between lamb and adult survival, sheep movements, landscape forage quality, population structure, and body condition. We will look for opportunities to collaborate with researchers in neighboring States investigating related aspects of bighorn sheep nutrition and disease status.

Geographic Location

The field portions of this project will take place in study areas across the State encompassing portions of Adams, Butte, Clark, Custer, Idaho, Lemhi, Nez Perce, and Owyhee counties. Study areas include Hells Canyon of the Snake River in Idaho, Oregon, and Washington and the Owyhee River, East Fork Salmon River, and Lost River Range of Idaho. The laboratory portion is primarily at Washington State University. Captive animal experiments are conducted at Washington State University and South Dakota State University. The population monitoring methods will be conducted in Hells Canyon and the East Fork Salmon River study areas but may also be conducted at locations throughout the State that are scheduled for aerial surveys and/or survival estimates identified within the Project Statement for the Statewide Wildlife Surveys and Inventories Grant.

Principal Investigator(s)

Frances Cassirer (IDFG Senior Wildlife Research Biologist) 208-799-5010

Timeline

- Capture and collaring of bighorn sheep – summer, fall, and winter months.
- Aerial and ground monitoring of radio-collared bighorn sheep – year-round.
- Lamb survival monitoring - birth to weaning, spring, summer, fall.
- Mortality investigation - periodically as mortality events occur throughout the year.
- Swab and blood sample collection and analysis - following capture activities summer, fall, winter months.
- Vegetation monitoring Spring - fall

List of Partners

Washington Department of Fish and Wildlife
Oregon Department of Fish and Wildlife
University of Idaho
Bureau of Land Management
U.S. Forest Service
Washington State University
U.S. Geologic Survey
South Dakota State University
Idaho Chapter Wild Sheep Foundation
Washington Chapter Wild Sheep Foundation
Oregon Foundation for North American Wild Sheep

Results

Disease Ecology - We captured 80 bighorn sheep to radio-collar, document body condition, and determine disease status August 2018 – April 2019 (Table 7). We used ultrasound and palpation to document body condition and submitted serum and blood samples for trace element analysis at the University of Idaho Analytical Sciences Laboratory. We also collected samples to test for exposure to and carriage of the respiratory pathogen *Mycoplasma ovipneumoniae* (Movi, Table 8), and other bacteria, parasites and respiratory viruses. Movi infection was detected in a single Hells Canyon population – Lostine, Oregon. No exposure to Movi was detected in Hells Canyon GMU 13, or in any sheep tested in the Washington portion of Hells Canyon (Asotin, Black Butte, Tucannon). We monitored approximately 400 marked bighorn sheep July 2018 – June 2019 including 159 in 4 focal populations (Table 9). Annual adult survival ranged from 0.87 – 0.98, summer lamb survival ranged from 0.60 – 0.80 and December lamb:ewe ratios were 0.64 in Hells Canyon and 0.50 in the East Fork Salmon River.

Table 7. Bighorn sheep captured in July 2018 – June 2019.

Population	Adult Males	Adult Females	Yearling Males	Yearling Females	Lambs	Total
Hells Canyon GMU 11	1	9	0	0	2	12
Hells Canyon GMU 13	1	5	1	1	2	10
Imnaha	1	8	1	1	4	15
Wenaha	4	6	0	1	2	13
Lostine	4	10	1	0	3	18
Asotin	0	6	2	0	0	8
Tucannon	0	1	0	0	0	1
Black Butte	0	1	0	0	0	1
East Fork Salmon River	0	2	0	0	0	2
Total	11	48	5	3	13	80

Table 8. Proportion of bighorn sheep sampled (n) that tested positive on nasal swabs for Movi shedding and proportion that tested positive for presence of serum antibodies to Movi in Idaho bighorn sheep populations August 2018 – April 2019.

Population	n	% Movi PCR positive (shedding)	% ELISA positive (exposed)
Hells Canyon GMU 11	12	0	17%
Hells Canyon GMU 13	10	0	0
East Fork Salmon River	2	0	NA
Imnaha	15	0	20%
Wenaha	13	0	8%
Lostine	18	44%	67%
Tucannon	1	0	0
Black Butte	1	0	0
Asotin	8	0	0
Total	80	8	18

Table 9. Survival and productivity of bighorn sheep in four Idaho populations, 2018 – 2019.

Population	No. marked females	No. marked males	Female survival	Male survival	Observed productivity 2018	Lamb summer survival	Lamb:ewe ratios at 6 – 9 months
Hells Canyon (GMU 11)	58	14	0.92	0.93	0.79	0.76	0.64
Owyhee River	9	0	0.80	NA	0.77	0.60	N/A
East Fork Salmon R.	23	0	0.91	N/A	0.87	0.70	0.50
Lost River Range	40	15	0.98	0.87	0.98	0.80	N/A

We conducted another year of a crossover experiment evaluating effect of chronic Movi carriers on bighorn lamb health and survival. In 2018, the experiment was conducted in two pens at Washington State University containing a carrier and one pen without carrier. All lambs in the carrier pen developed severe pneumonia and 4 of 5 lambs died. All lambs in the pen without the carrier remained healthy. Between 2015 and 2018 all 27 lambs born in 11 pens containing a carrier have developed pneumonia and 98% have died. None of 14 lambs born in 7 pens without a carrier have developed pneumonia and 98% have lived.

We also continued an experimental challenge of chronic Movi carriers with a suite of goat origin Movi multi-locus sequence types (MLST) to assess whether the less virulent but novel MLST might boost the immune response of chronic carriers, clearing the original Movi strain. So far the carriers have become infected with goat strains but do not appear to have cleared the original MLST (domestic sheep origin strain). This experiment was conducted at both Washington State University and South Dakota State University in 2018.

Population Estimation Methods – We conducted surveys along the East Fork Salmon River between Big Boulder Creek and Joe Jump Basin on December 11, 13, 19, and 21, 2017. We selected this time period because we thought it would be the most effective in this population. Sheep are concentrated at lower elevations in a relatively small wintering area that is accessible by road, and it is during the breeding season when rams and ewes are together. GPS locations of radio-collared sheep in December 2016 indicated all marked animals with functioning collars were in the survey area, however locations were available from only a single collared ram. We surveyed by glassing from observation points with binoculars and spotting scopes along the East Fork Salmon River Road and Herd and Road Creek roads and by hiking in to observation points north of the East Fork Salmon River Road up Cherry Gulch, Marco Creek and adjacent unnamed draws, and from the Lake Creek Road. We also included one incidental observation of a group of bighorn sheep recorded during a mule deer helicopter survey conducted December 12 in Joe Jump Basin. During this period there were 23 marked ewes known to be alive in the survey area. Twenty-two had functioning VHF collars and 10 of those were uploading GPS locations. None of 8 collars on rams were functioning so we didn't know how many were alive and in the study area. Therefore, we ran all analyses assuming that we observed all marked rams that were in the survey area (Table 10). This assumption yielded a conservative abundance estimate. For comparison, we also calculated estimated ram numbers assuming up to 8 marked rams were present.

We used pre-defined logit normal mark-resight models in Program Mark version 8.1 to estimate population and group abundance (White and Burnham 1999). The logit normal estimator assumes that marked animals have the same sightability as unmarked animals, population closure (demographic and geographic), sampling is without replacement (i.e., any individual is only observed once per survey), and the number of marked animals available for resighting is known (Cooch and White 2016).

Table 10. Marks potentially present in the East Fork Salmon River bighorn sheep population, December 2017.

	Ear Tagged and Collared
Ewes	23
Rams	3 – 8[a]
Lambs	0
Total	26 – 31

[a] Eight marked rams were potentially present but since none of the radiocollars were functioning we assumed post-hoc that 3 marks were available in the survey area for our analyses.

To generate recapture histories we combined the data from December 11th and 13th to represent the first encounter occasion and from Dec. 19th and 21st to represent the second encounter occasion. Any apparent repeats, the same group seen on multiple days or by multiple observers within an encounter session were removed. We also analyzed each of the 4 survey days as separate encounter occasions and ran the same analyses as for the combined 2-day encounter occasions.

We ran several analyses to estimate total population size and abundance by sex and age class. The first analysis included covariates for sex and excluded lamb sightings. Probability of resight (p) and individual heterogeneity (σ) were allowed to vary by group, time, and a group x time interaction. Population size was allowed to vary by group. Model averaging was then used to produce ewe and ram estimates. Because no lambs were marked, we assumed the same detection probability for lambs as for ewes, and derived the lamb estimate by calculating the difference between the ewe estimate and a combined ewe and lamb estimate in which capture probability and individual heterogeneity were allowed to vary by time and population size was held constant.

Between 4 and 7 ground surveyors observed 11 - 14 groups of bighorn sheep on 4 separate days for a total of 52 observations over 21 observer-days. One incidental observation was obtained during a mule deer helicopter survey. All observations were between Lake Creek and Joe Jump Basin and most sheep were observed between Cherry Gulch and Marco Creek (Figure 21). Each day there were a few duplicate observations of marked individuals by ground observers. A total of 47 of the 53 observations (89%) were considered non-replicates and used for the mark-resight analysis. Eighty unique individuals were observed December 11 – 13, and 90 unique individuals were observed December 19 – 21 (Table 11). Each of 23 marked ewes was observed and identified on 1 – 3 survey days (marked ewes were observed an average of 1.5 times over the 4 days) and 2 of 8 marked rams were observed on 2 – 4 survey days. One unidentified marked ram was distinguished as different from the identified marks by horn size classification. Between 6 and 17 marked animals were observed each day.

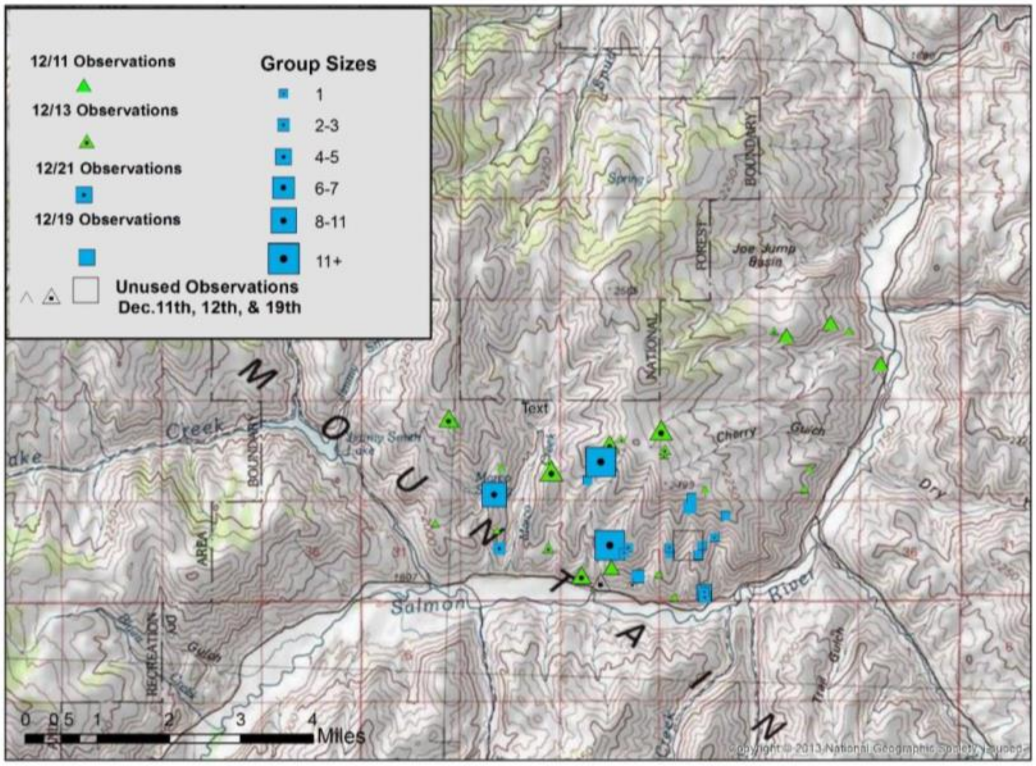


Figure 21. Locations and group sizes of bighorn sheep observed during population surveys along the East Fork Salmon River, December 2017.

Table 11. Summary of unique bighorn sheep observations in the East Fork Salmon River population, December 2017 used for 2 encounter occasion mark-resight analysis.

Class	**12/11/17**	**12/12/17 (helicopter)**	**12/13/17**	**Combined survey 1**	**12/19/17**	**12/21/17**	**Combined survey 2**
Ewes	8	3	25	36	12	28	40
Yearling Ewes	1	0	2	3	3	3	6
Lambs	5	1	8	14	2	13	15
Cl I ram	0	0	2	2	1	1	1
Cl II ram	0	0	3	3	1	2	3
Cl III ram	12	0	7	19	7	11	18
Cl IIIB ram	0	0	0	0	1	0	1
Cl IV ram	1	0	2	3	2	3	5
Total	27	4	49	80	29	62	90

Population estimates did not differ significantly between analyses that grouped observations into 2 encounter periods and analysis of each of the 4 survey days separately, but confidence intervals were smaller for the 2 encounter estimate due to the much higher resight probability (Tables 12 and 13). Although we made the conservative estimate that there were only 3 marked rams in the survey area, we also calculated ram estimates using the two occasion model for scenarios with 4 – 8 marked rams. Ram estimates ranged from 41 for 4 marked rams to 92 for 8 marked rams. Confidence intervals increased from +/- 61% for 4 marked rams to +/- 91% for 8 marked rams.

Table 12. Population (N) estimates (95% confidence intervals) East Fork Salmon River bighorn sheep December 2017 using 2 encounter occasions.

		Resight Probability	
	N	**11th-13th**	**19th-21st**
Ewes	49 (43 – 55)	0.71	0.78
Lambs	19 (16 – 21)		
Rams	32 (20 – 43)	0.67	0.76
Total	102 (89 – 115)		

Table 13. Population (N) estimates (95% confidence intervals) of the East Fork Salmon River, ID bighorn sheep herd using 4 encounter occasions.

		Resight Probability			
	N	**11th**	**13th**	**19th**	**21st**
Ewes	49 (25 – 56)	0.23	0.49	0.45	0.55
Lambs	16 (14 – 20)				
Rams	26 (16 – 35)	0.24	0.47	0.49	0.58
Total	90 (73 – 108)				

We found December ground-based mark-resight surveys to be a feasible technique for estimating bighorn sheep population size and composition in the East Fork Salmon River. These surveys were superior to previous helicopter surveys of unmarked animals because detection probability was known and generally high (from ~ 43% on a single survey to ~95% over 4 surveys) allowing precise estimates of abundance. Success of the mark-resight surveys was due to the concentration of bighorn sheep in an area that was accessible for ground observation and to the high proportion of animals, especially ewes, that were marked (~ 46% females marked, ~ 8 – 25% of males marked).

We also conducted ground-based mark-resight surveys in Hells Canyon GMU 11 (Redbird) for the first time in December 2018. We observed 93% of marked males and 73% of marked females during the 2 surveys. This method looks like it will work well in this population and may be especially good for estimating ram numbers when conducted in December. We also conducted another year of mark-resight estimates in the East Fork Salmon River population. Analyses are ongoing with these data and a summary report of ground based mark-resight surveys conducted for bighorn sheep will be completed in late 2019.

Habitat, Nutrition, Movements, and Demographics - In the summer of 2018 we measured 42 vegetation plots for nutritional quality and biomass of vegetation available to bighorn sheep and conducted 43 monthly phenology plots in the Owyhee, East Fork Salmon, and Lost River Ranges to track the availability and succession of plant species. From May – July 2019 we measured a total of 52 habitat plots in the East Fork Salmon and Lost River Range. We measured a total of over 100 vegetation plots on the project during FY18. We conducted lamb-at heel surveys to determine recruitment through September in concert with management in GMUs in each of the above study areas and summer lamb survival ranged from 60% in Owyhee to 80% in Lost River Range (Table 3). We're conducting the final season of lamb survival estimation and vegetation sampling in 2019 with a final project report expected in 2020. A poster titled "Effects of dam body condition on lamb survival of bighorn sheep in Idaho" was presented at the Idaho Chapter of the Wildlife Society Meetings in Boise, ID.

Objective 5 – Conduct 1 Moose study by 30 June, 2019

Approach

This work is part of a multi-state effort to understand moose declines throughout the lower 48 states. Throughout Idaho, moose (*Alces alces*) exist at low density, and are difficult yet important to monitor. Compared with aerial surveys, spatially balanced arrays of remote camera traps offer a relatively safe and cost-effective means to monitor moose in Idaho. This year, we are using newly developed methods using remote camera traps to estimate abundance of moose using a survival-modeling framework (space-to-event and time-to-event models) and the trapping rate of cameras (Moeller 2017). We are currently using and expanding these methods to estimate moose abundance using trail cameras during winter in northern and southeastern Idaho. We will compare abundance estimates from trail cameras in southeastern Idaho with a recent aerial survey of moose in the study area to assess advantages and disadvantages between the methods. We also seek to develop software to automatically sort photos with versus those without animal detections. Results from this work will help guide future monitoring efforts of ungulate populations that exist at low density using remote trail cameras in lieu of aerial surveys.

Geographic Location

Estimation of moose abundance will occur in Caribou and Clearwater counties.

Principal Investigator(s)

Mark Hurley (IDFG Research and Data Manager)	208-287-2891
Brendan Oates (Wildlife Management Institute Research Biologist)	307-343-3895

Timeline

- Model and software development for estimating moose abundance – year around
- Camera deployment – fall months
- Camera retrieval – spring months
- Analyses – summer months

List of Partners

Montana Fish Wildlife & Parks
Wyoming Game and Fish Department
Washington Department of Fish and Wildlife
Oregon Department of Fish and Wildlife

Results

In March 2018, when moose were concentrated on winter range, we deployed 45 trail cameras in an approximately 207 km^2 study area of GMU 76. Cameras were programmed to take photos using both motion-trigger and 2-minute time-lapse. During the same timeframe, we captured and fitted adult female moose in (n = 8) with GPS collars to better understand movement rates and habitat selection. Unfortunately, the low camera density combined with very low movement rates of moose that winter in GMU 76, likely due to extreme snow loads, resulted in a very low number of moose detections on cameras, preventing a valid estimate of moose abundance from cameras.

During November 2018, management personnel deployed 427 remote cameras in portions of GMUs 6 (148 cameras) and 15 (130 cameras) and the Caribou Population Management Unit (GMUs 66, 69, 72, and 76; 149 cameras) to estimate ungulate abundance during winter 2018-19. These cameras took over 8 million photos at 10-minute intervals throughout the winter. Cameras were retrieved in spring 2019 and we are currently in the process of categorizing and classifying the pictures. As of the writing of this report, approximately 66% of all the cameras have been processed and categorized (Caribou PMU 100% processed, GMU 6 47% processed, GMU 15 59% processed) and the processed pictures contained a total of 141 moose (77 in Caribou, 59 in GMU 6, and 5 in GMU 15) in 103 pictures. Once picture processing is complete, we will use models developed by Moeller et al. (2017) to estimate the abundance of moose in GMU 6 and the Caribou PMU. An abundance estimate may not be possible in GMU 15 due to the low number of camera detections, which coincides with manager perceptions on a very low moose population in that GMU.

Objective 6 – Conduct 1 Mountain Goat study by 30 June, 2019

Approach

We will test 3methods for improved occupancy and abundance estimates of rocky mountain goats. The low densities exhibited by, elusive behaviors, and remote habitat that mountain goats occupy are shared qualities of many rare species. These characteristics make mountain goats a good fit for this study in which we will determine the efficacy of camera trapping techniques, single-observer, and double-observer methods for estimating abundance of low-density or rare species.

We will place remotely triggered cameras and conduct line-transect surveys in select random locations across one or more study areas from July 1 – August 31. The study area will be overlaid with a 500 x 500 meter grid to delineate contiguous sampling units. A random sample of 30 cells will be selected from this grid to determine survey sampling units. Technicians will place one camera per cell that will remain untouched throughout the study period. Each camera will be positioned in order to optimize capturing photos of animals passing in front of the view shed either on game trails or facing open areas/cliff bands. Cameras will be mounted to trees >8 inches in diameter at a height >8 feet and angled toward the cliff, meadow, or trail we desire to capture. Technicians will also record camera site characteristics, including UTM coordinates, habitat type, and percent canopy cover. All cameras will remain untouched by technicians until collection in mid-September. Every camera will be set up on a motion-triggered setting to capture animals moving in front of the immediate camera detection zone. Additionally, cameras will be set up on time-lapse setting which will take photos at a regular interval (every 30 min) during daylight hours. This time-lapse setting will allow for mountain goat groups to be captured in images beyond the immediate 30 meter detection zone of the camera (Moeller 2017). Each time a mountain goat is captured in a photo will be considered an individual event. Therefore, the more events that occur in different cells, the more space mountain goats occupy and the higher density of mountain goats, and vice versa. From each photo containing images of mountain goat groups, we will estimate individual mountain goat group sizes and sex and age ratios.

For the independent double observer (IDO) and single observer (SO) line-transect abundance estimates, we will survey 20-30 of the randomly selected cells throughout July and August. The number of cells surveyed will be determined based on the ability to conduct a minimum of 3 repeat surveys of each cell. For IDO and SO methods, technicians will travel set routes through sample cells and survey each cell for a select amount of time. Within the survey cell, each line-transect will have specific vantage points that fall within a 100 meter buffer – to maximize view shed visibility- on either side of each line transect. The vantage points will be locations where upon technicians will spend a set amount of time (no more than one hour) surveying for mountain goats. The number of cells surveyed, locations of the specific line transects, vantage points, and time at each vantage point is subject to change as we test these methods in the field and determine appropriate protocol.

Each technician will have a map of the area he or she is travelling through and mark on the map where each mountain goat group (≥1 individual) was observed that falls within the survey cell. Technicians will also make note of mountain goat group activity (e.g., feeding, resting, traveling, or other), young:adult ratio, and estimate sex ratios. These travel routes (primarily along trails, drainage bottoms, and ridgelines) will be designed to accommodate 2-3 day backpacking trips and cover sample grid cells in all accessible regions of the study areas during the summer season. Observers will survey cells with the aid of binoculars and spotting scopes to determine if each sampling unit is occupied by a mountain goat group. For IDO, two observers will survey the same cell independently and offset by a time of 5-10 minutes from the start of each transect, respectively. This offset is to situate the observers such that neither will be influenced.

Upon repeated visits, technicians will also collect mountain goat genetic information through scat collection found in each camera's view shed. From photos captured on remote cameras and ground observations within each cell, technicians will record mountain goat group sizes, sex ratios, and young:adult ratios. Genetic information gathered will assist with determining sex and age ratios of mountain goats captured in images in addition to providing the potential to contribute to abundance estimates through a mark-recapture framework.

For remotely-triggered camera trap abundance estimates, we will use a newly developed space-to-event (STE) model that uses spatial trapping rates to estimate animal abundance (Moeller 2017). The observed space-to-event models the number of random plots (or cells in this case) sampled before the species of interest is captured. For IDO we will use a single species multinomial N-mixture model to estimate abundance of mountain goats. We will also conduct an aerial helicopter survey, using established IDFG aerial survey protocols, to provide an abundance estimate (currently used methodology) for comparison with the new methods.

Geographic Location

Ground surveys, camera stations, and aerial surveys will be conducted in the Snake River Range of eastern Idaho in Bonneville and Teton counties. Additional study areas may include the Pioneer Mountains in Blaine and Custer counties, the Sawtooth Mountains in Blaine and Camas counties, or the Lolo area of Clearwater County.

Principal Investigator(s)

Frances Cassirer (IDFG Senior Wildlife Research Biologist)	208-799-5010

Timeline

- Deploy remote cameras - summer months
- Conduct single- and double-observer ground surveys - summer months
- Retrieve remote cameras – fall months
- Data summarization, analysis, and graduate student coursework – fall-spring months

List of Partners

University of Montana
U.S. Forest Service

Results

In July and August 2018, we conducted single and double observer surveys of 35, 500 x 500 m cells in the study area. We surveyed each cell at least twice for a total of 73 surveys of the 35 cells (Figure 22). These cells covered about 5% of the study area and mountain goats were observed on two occasions in one of the cells. Four goats were observed on the first survey of the cell and 9 goats were observed during the third survey. Fourteen remote cameras were installed in 5 survey cells for 11 days and took 17,052 photos on a combination motion sensitive/15 minute time lapse setting between the hours of 0530 and 2130. Goats were photographed in 2 cells: one camera captured 6 photos of mountain goats and one photo of mountain goats was taken by the other camera. All photos were captured on the time-lapse setting. A minimum count of 121 goats was obtained during helicopter surveys on August 20th and 21st. We searched unsuccessfully for mountain goat scat in the vicinity of the camera traps to obtain genetic data and will drop this effort.

Camera data were used to work through space-to-event modeling in preparation for the second year of the study. Survey data were analyzed with an independent double-observer abundance model. In summer 2019, to increase detections, we'll survey at least 15 more cells and deploy cameras in at least 35 cells. Also, we will utilize assistance from regional IDFG personnel to complete a blanket survey of all the cells over a 10 day period.

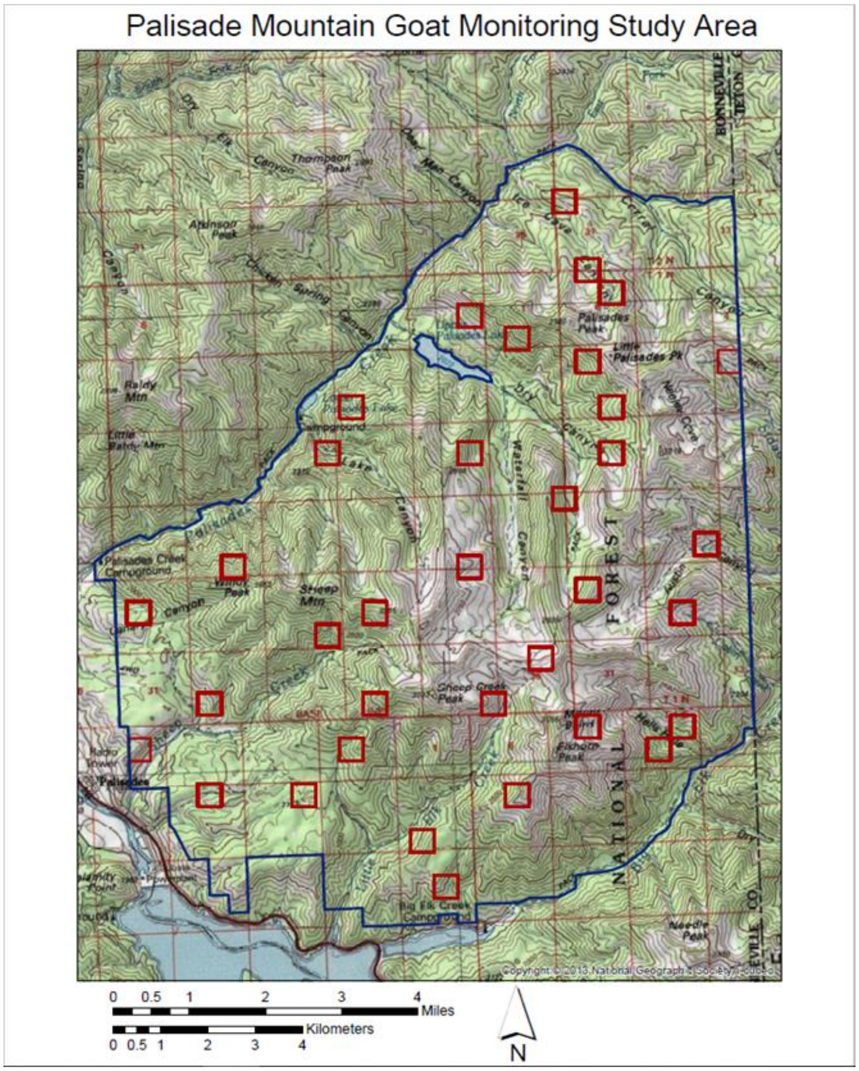


Figure 22. Location of 35 randomly distributed cells surveyed for mountain goats in the Palisades Mountains in July and August 2018.

Objective 7 – Conduct 1 Gray Wolf study by 30 June, 2019

Approach

We plan to continue the multi-faceted, statewide research project that seeks to estimate statewide wolf abundance and distribution using occupancy modeling; examine relationships between wolf harvest, pack dynamics, territory sizes, and recruitment; and better understand the influence of wolf predation in the multi-predator/multi-prey systems in Idaho.

Estimating Wolf Abundance and Distribution – We plan to implement a web-based survey that is sent electronically to all big game hunters in Idaho to document their wolf observations. Such an effort would allow for greater accuracy and precision in resulting patch occupancy model estimates. A web page can be established for big game hunters for which no email address is available.

We will continue to survey historic and highly suitable rendezvous sites throughout the State. We will conduct howl and sign surveys at predicted rendezvous sites and record all wolf sign observed in the sites as well as any incidental sign encountered. When an active rendezvous site is found we will collect fecal samples from all pup and adult scats present. Scat samples will be sent to the University of Idaho's Conservation Genetics Lab for DNA genotyping. A major benefit of this approach is that, even when pups go undetected, genotypes from scat samples can still provide information about pack size as well as data useful for populating an overarching patch occupancy model. Lastly, fecal DNA can be coupled with genotypes of harvested wolves to estimate harvest levels, survival, and recruitment. This rendezvous site monitoring is a proven estimator of wolf presence and will be used to test the effectiveness of developing camera-based methods.

During summer, we will deploy camera stations at historic and predicted rendezvous sites throughout Idaho. We placed a 686 km^2 grid (26.2 km x 26.2 km) over the state and allocated 1 camera for each grid cell. We did not include several GMUs in southern Idaho that did not have strong management interest and have not been occupied by wolves since reintroduction in 1995. Grid cell size was chosen by estimating a wolf pack's territory size from satellite collared individuals in Idaho. This grid yielded 212 static camera stations with >90% power to detect a 20% statewide population change. We will also test the potential for estimating wolf abundance solely from cameras by deploying 1 camera/50 km^2 in GMUs 4, 28, 33-35. We will compare estimates from camera stations to an independent estimate of abundance derived from rendezvous site surveys and subsequent genetic analyses. We will then compare estimates from rarefied camera station data (e.g., 1 camera/100 km^2; 1 camera/200 km^2, etc.) to an independent estimate of abundance and determine the most efficient camera station density for estimating wolf abundance. Cameras will be installed on existing vegetation (preferable large trees). When existing vegetation is not sufficient for camera mounting a t-post or fence post will be used. Any post installed for camera monitoring will be removed at the end of the study.

We will use wolf detection data from hunter surveys, rendezvous site surveys, camera stations, and radio-collared wolves (collared as part of management survey and monitoring efforts, not research) to populate a patch occupancy model that will estimate statewide wolf abundance and distribution. Currently the number of packs estimated from the model is multiplied by average pack size. Such an approach may lead to spurious population estimates if pack sizes are highly skewed and if small packs are more difficult to detect and accurately count. Incorporating pack size as a probability distribution that can incorporate all of the variation around pack size, rather than simply using an average, may be a good method to obtain more accurate abundance estimates. Furthermore, if management-led, radio-collar monitoring indicates there has been a change in average territory size or other patterns of space use the model can be appropriately adjusted to incorporate such new information. Lastly, we currently define an area as "occupied" if >2 wolves are detected. Simulations may show that different definitions of detection (e.g., >4 wolves) yield more accurate population estimates. Additionally, we propose to combine data from two concurrent study areas in southwest Alberta and southeast British Columbia to create a meta-patch occupancy model that can be used to explore how adjacent management entities actions might affect wolf occupancy in Idaho and Montana.

Montana Fish, Wildlife, and Parks (MTFWP) has an ongoing study exploring the influences of territory and pack size on patch occupancy estimates. Further, they aim to expand a monitoring framework that uses patch occupancy and adaptive management to test hypotheses about the effects of harvest on gray wolf populations. Specifically, they plan to 1) improve estimation of recruitment, 2) improve and maintain calibration of abundance estimates generated through patch occupancy modeling, and 3) develop a framework for dynamic, adaptive harvest management based on achievement of objectives 1 and 2. The goals of this study will require empirical data for testing and our study will collect such data.

Harvest, Recruitment, and Pack and Territory Size - We will continue to collect tissue samples and genotype every harvested wolf. Matching genotypes of harvested wolves to those detected during rendezvous site surveys permits estimation of harvest level, survival, and recruitment in the focal study areas. The Department and MTCWRU have genetically sampled packs in GMUs 28 and 33-35 each year since 2008 and the resulting data are allowing us to answer timely questions about how harvest affects pack composition, size, and recruitment. Coupling data from our proposed focal study areas with simultaneous satellite-collar work provides an ideal opportunity to explore relationships between harvest and pack size and recruitment. Additionally, such highly detailed genetic and spatial use data can allow us to explore potential links between breeder turnover events and fluctuations in territory size and subsequent occupancy rates.

Harvest Effect on Predator/Prey Relationships - Our rendezvous site surveys in focal study areas can provide highly-detailed data for packs of management interest. As part of another project, numerous radio-collared wolves and elk are available in the focal study areas. By having large numbers of both predator and prey we hope to learn more about the influence of wolves on elk abundance and also how human harvest of both wolves and elk might affect those relationships. Stenglein et al. (2011) found rendezvous site surveys and the resulting genotypes yielded more accurate pack counts than radio-telemetry. Rendezvous site information will be a critical piece for understanding the effect of harvest on wolves and, in turn, the potential effects of variable wolf densities on elk.

Geographic Location

Big game hunter surveys and camera stations will be deployed in all Idaho GMUs but rendezvous site surveys will be conducted in GMUs 4, 24, 25, 28, 33, 34, and 35 (Counties: Shoshone, Lemhi, Boise, and Valley).

Principal Investigator(s)

Shane Roberts (Principal Wildlife Research Biologist)	208-287-2722
Dave Ausband (Idaho Cooperative Fish & Wildlife Research Unit)	208-885-1172

Timeline

- Survey big game hunters for wolf sightings - spring months.
- Deploy cameras and conduct rendezvous site surveys - summer months.
- Retrieve cameras – fall months.
- Categorize camera images, conduct genetic analyses, and occupancy analyses – fall/winter months.

List of Partners

University of Montana
University of Idaho

Results

We surveyed 302 predicted rendezvous sites and collected 774 genetic samples from July 2018-June 2019. We used genetic data from rendezvous site surveys to generate an independent measure of abundance for comparison with abundance estimates derived simultaneously from camera stations (Tables 14 & 15). Further, DNA collected during rendezvous site surveys, as well as tissue samples collected from harvested wolves, allows us to estimate harvest rates for wolves in focal study areas.

Table 14. Total number of estimated gray wolf litters (i.e. putative sibling groups) in harvest by year, treatment type, and run number.

Treatment	Year	Run 1	Run 2	Run 3	Run 4	Run 5
Known allele freqs, 18 loci	2014	52	52	52	52	52
	2015	63	63	63	63	63
Unknown allele freqs, 18 loci	2014	53	53	53	53	53
	2015	64	64	64	63	64
Known allele freqs, 10 loci	2014	46	46	47	47	47
	2015	55	55	55	55	55

Table 15. Mean frequency of putative gray wolf litters by group size across cohorts and treatment types.

Treatment	Year	Number of pups							
		One	Two	Three	Four	Five	Six	Seven	Eight
Known allele freqs, 18 loci	2014	14	21	8	6	2	0	1	0
	2015	18	20	9	9	4	1	1	1
Unknown allele freqs, 18 loci	2014	16.2	19.8	8	5.8	2.2	0	1	0
	2015	20.2	17.4	9.8	10.4	3	1	1	1
Known allele freqs, 10 loci	2014	6.2	22.4	9	4	4	0	1	0
	2015	10	13	15	10	4	1	1	1

We deployed cameras in >205 cells across Idaho during 2016-2018 (Figure 23, Table 16). Each year, some cameras had data either wholly or partially censored due to theft, fire, animal damage, or user error. The percent of cameras with data either wholly or partially censored was approximately 10-18% annually. Theft was minimal (<1% of cameras deployed each year). The number of images of wolves increased each year. Changes in the number of wolf detections between 2016 and 2017 are likely due to changes in our deployment protocol that attempted to extend the detection zone length. Additionally, IDFG personnel became more familiar with the protocol and cameras used. The number of wolf images is not necessarily a reflection of poor or excellent results, however, because a single camera deployed near an active wolf rendezvous site can yield many wolf images. For example, 2018 yielded the highest number of wolf photos, but 63% of images captured were from just 15 cameras.

Table 16. Number of cameras deployed for occupancy modeling, censored, and resulting images of adult and pup wolves in Idaho, 2016-2018. Censored = stolen, malfunctioned, misdirected by animals or public, user error during programming or deployment.

	2016	2017	2018
No. cameras deployed	207	207	209
No. cameras censored	18	23	38
No. of wolf images	549	1,233	2,576
No. cameras with ≥1 adult wolf	70	82	76
No. cameras with ≥1 wolf pup	4	24	18

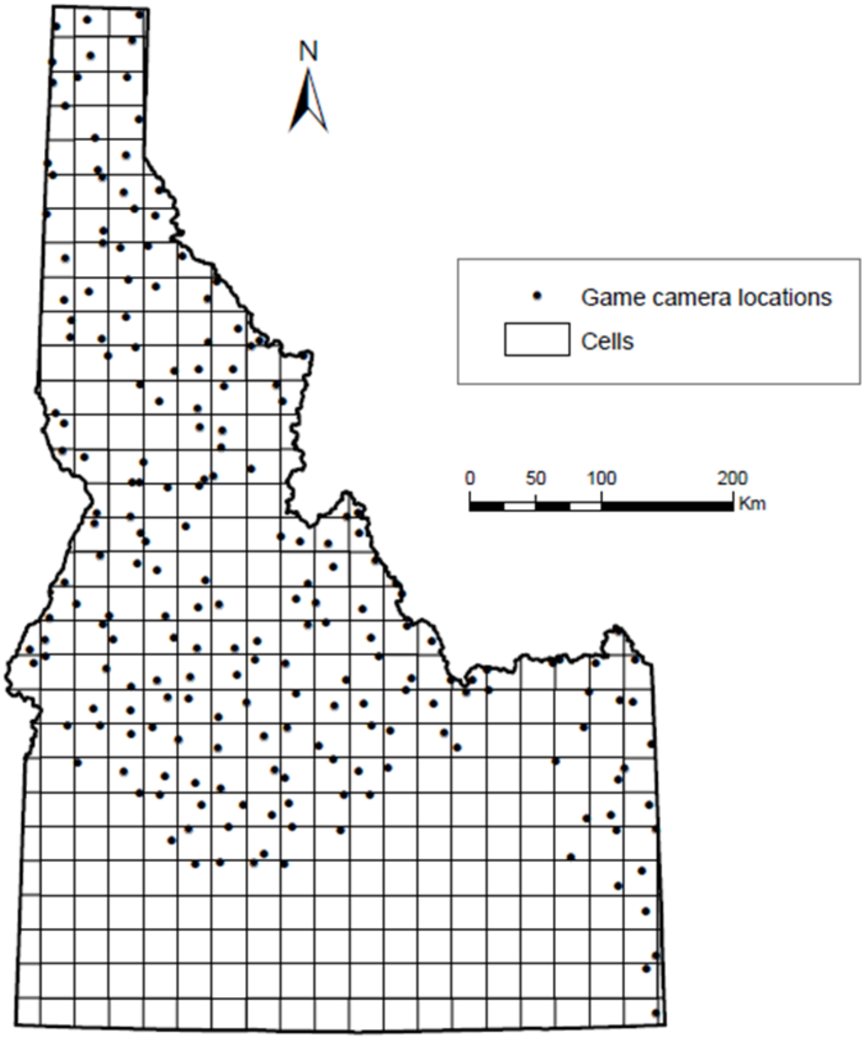


Figure 23. Location of cameras used for wolf occupancy modeling in Idaho, 2016-2019.

In 2016, there were >1.3 million images from the wolf camera survey effort in Idaho. A technician averaged 3,750 images/hour when categorizing what species, if any, was in each image. In 2016, the most supported model (Table 17) for predicting wolf occupancy using images from cameras included livestock density and the amount of predicted rendezvous site habitat in each cell. An equally supported model, and one that was similar to top models in subsequent years, included livestock density (β = -0.53, SE = 0.14), and the proportion of neighboring cells that were occupied by wolves (β = 0.05, SE = 0.04). The probability of detection was most affected by the amount of predicted rendezvous site habitat in the cell (β = -0.23, SE = 0.03). This model's overdispersion factor, ($\hat{c}$), = 2.8. Estimated occupancy for 222 cells in Idaho was 0.40, SE = 0.05, whereas "naïve" occupancy (i.e., not accounting for detection probability) was 0.34.

Table 17. Candidate models used to estimate wolf occupancy from images of wolves at camera traps, Idaho, summer 2016. Overdispersion estimate (ĉ) from global model = 3.0 and qAIC was used for model selection. Models are listed from lowest to highest qAIC value.

Model	qAIC	ΔqAIC	qAICw_i	K	-2LL
Occupancy (livestock dens.), Detection (predicted RS habitat)	267.9	0.0	0.25	3	789.9
Occupancy (livestock dens.), Detection (predicted RS habitat, dist. to trail)	268.8	0.9	0.16	4	786.7
Occupancy (livestock dens., prop. neigh. occupied), Detection (predicted RS habitat)	269.4	1.5	0.12	4	788.4
Null (intercept only)	270.1	2.2	0.08	3	796.5
Occupancy (livestock dens., prop. neigh. occupied), Detection (predicted RS habitat, dist. to trail)	270.3	2.4	0.08	5	785.0
Occupancy (livestock dens., slope), Detection (predicted RS habitat, dist. to trail)	270.8	2.9	0.06	5	786.6
Occupancy (livestock dens.), Detection (distance to trail)	271.0	3.1	0.05	3	799.3
Occupancy (slope), Detection (predicted RS habitat)	272.0	4.1	0.03	3	802.1
Occupancy (livestock dens., prop. neighb. occupied), Detection (dist. to trail)	272.4	4.5	0.03	4	797.6
Occupancy (constant), Detection (predicted RS habitat)	272.6	4.7	0.02	3	804.1
Occupancy (livestock dens., slope), Detection (distance to trail)	273.0		0.02	4	799.2
Occupancy (forest cover, slope, forest cover*slope), Detection (predicted RS habitat)	273.0	5.1	0.02	5	793.2
Occupancy (elevation), Detection (predicted RS habitat)	273.3	5.4	0.02	3	806.2
Occupancy (elk dens.), Detection (predicted RS habitat)	273.3	5.4	0.02	3	806.3
Occupancy (slope, slope^2), Detection (predicted RS habitat)	274.0	6.1	0.01	4	802.1
Occupancy (prop. neighb. occupied), Detection (predicted RS habitat)	274.5	6.6	0.01	3	809.8
Occupancy (forest cover), Detection (predicted RS habitat)	274.7	6.8	0.01	3	810.5
Occupancy (elevation, elevation^2), Detection (predicted RS habitat)	274.8	6.9	0.01	4	804.8
Occupancy (constant), Detection (dist. to trail)	276.0	8.1	0.00	3	814.2
Occupancy (livestock dens., management region), Detection (predicted RS habitat)	278.9	11.0	0.00	9	786.9
Global (all covariates)	294.0	26.1	0.00	19	772.0

In 2017, the most supported model for predicting wolf occupancy using images from cameras (Table 18) contained livestock density (β = -0.83, SE = 0.17), and the proportion of neighboring cells that were occupied by wolves (β = 0.16, SE = 0.04). The probability of detection was most affected by the amount of predicted rendezvous site habitat in the cell (β = -0.17, SE = 0.03). This model's overdispersion factor, ($\hat{c}$), = 5.5. Estimated occupancy for 222 cells in Idaho was 0.44, SE = 0.04, whereas "naïve" occupancy was 0.40. Several other models with similar or smaller number of covariates were equally supported (within 2.0 qAIC) but we used the top model to generate occupancy estimates and consistency among years.

Table 18. Candidate models used to estimate wolf occupancy from images of wolves at camera traps, Idaho, summer 2017. Overdispersion estimate ($\hat{c}$) from global model = 7.1 and qAIC was used for model selection. Models are listed from lowest to highest qAIC value.

Model	qAIC	ΔqAIC	qAICw_i	K	-2LL
Occupancy (livestock dens., prop. neighb. occupied), Detection (predicted RS habitat)	129.0	0.0	0.18	4	856.5
Occupancy (livestock dens.), Detection (predicted RS habitat)	129.3	0.4	0.15	3	873.2
Occupancy (livestock dens., prop. neighb. occupied), Detection (detection zone length)	129.4	0.4	0.14	4	859.7
Occupancy (livestock dens., prop. neighb. occupied, forest cover), Detection (predicted RS habitat)	130.5	1.6	0.08	5	853.3
Occupancy (livestock dens., prop. neighb. occupied), Detection (predicted RS habitat, detection zone length)	130.8	1.8	0.07	5	855.3
Occupancy (livestock dens., prop. neighb. occupied, slope), Detection (predicted RS habitat)	130.9	1.9	0.07	5	855.8
Occupancy (livestock dens., prop. neighb. occupied, elevation), Detection (predicted RS habitat)	130.9	1.9	0.07	5	856.1
Occupancy (slope), Detection (predicted RS habitat)	132.7	3.8	0.03	3	897.3
Occupancy (constant), Detection (predicted RS habitat)	133.0	4.0	0.02	3	898.8
Occupancy (elevation), Detection (predicted RS habitat)	133.0	4.0	0.02	3	899.0
Null (intercept only)	133.1	4.2	0.02	3	900.1
Occupancy (forest cover), Detection (predicted RS habitat)	133.2	4.2	0.02	3	900.2
Occupancy (prop. neigh. occupied), Detection (predicted RS habitat)	133.2	4.2	0.02	3	900.4
Occupancy (elk), Detection (predicted RS habitat)	133.2	4.3	0.02	3	900.8
Occupancy (constant), Detection (detection zone length)	133.4	4.4	0.02	3	902.1
Occupancy (livestock dens., prop. neighb. occupied, elevation, forest cover, forest cover*elevation), Detection (predicted RS habitat)	133.6	4.6	0.02	7	846.7
Occupancy (slope, slope^2), Detection (detection length)	134.6	5.7	0.01	4	896.6
Occupancy (elevation, elevation^2), Detection (detection length)	135.0	6.0	0.01	4	899.0
Occupancy (livestock dens., elevation, forest cover, forest cover*elevation, slope, forest cover*slope), Detection (predicted RS habitat)	136.0	7.0	0.01	8	849.6
Global (all covariates)	143.3	14.4	0.00	12	844.8

In 2018, the most supported model for predicting wolf occupancy using images from cameras (Table 19) again contained livestock density (β = -0.78, SE = 0.18) and proportion of neighboring cells occupied by wolves (β = 0.19, SE = 0.05). The probability of detection was most affected by the amount of predicted rendezvous site habitat in the cell (β = -0.24, SE = 0.03). This model's overdispersion factor, ($\hat{c}$), = 4.0. Estimated occupancy for 222 cells in Idaho was 0.45, SE = 0.05, whereas "naïve" occupancy was 0.39. Several additional covariates and model forms were evaluated in exploratory analyses but were found not to be influential (Table 20).

Table 19. Candidate models used to estimate wolf occupancy from images of wolves at camera traps, Idaho, summer 2016. Overdispersion estimate (ĉ) from global model = 3.0 and qAIC was used for model selection. Models are listed from lowest to highest qAIC value.

Model	qAIC	ΔqAIC	qAICw_i	K	-2LL
Occupancy (livestock density, prop. neighbors occupied), Detection (predicted RS habitat)	216.3	0.0	0.28	4	816.7
Occupancy (livestock density, prop. neighbors occupied, elevation), Detection (predicted RS habitat)	218.2	1.9	0.11	5	816.3
Occupancy (livestock density, prop. neighbors occupied, slope), Detection (predicted RS habitat)	218.3	2.0	0.10	5	816.5
Occupancy (livestock density, prop. neighbors occupied, forest cover), Detection (predicted RS habitat)	218.3	2.0	0.10	5	816.5
Occupancy (livestock density, prop. neighbors occupied), Detection (predicted RS habitat, detection zone length)	218.3	2.0	0.10	5	816.7
Occupancy (livestock density), Detection (predicted RS habitat)	218.9	2.6	0.08	3	834.6
Occupancy (livestock density, slope), Detection (predicted RS habitat)	219.1	2.7	0.07	4	827.3
Occupancy (livestock density, prop. neighbors occupied, slope, forest cover), Detection (predicted RS habitat)	220.2	3.9	0.04	6	816.2
Occupancy (livestock density, prop. neighbors occupied, slope, elevation), Detection (predicted RS habitat)	220.2	3.9	0.04	6	816.3
Occupancy (livestock density, prop. neighbors occupied, forest cover, elevation, forest cover*elevation), Detection (predicted RS habitat)	222.1	5.7	0.02	7	815.7
Occupancy (livestock density, prop. neighbors occupied, slope, elevation, slope*elevation), Detection (predicted RS habitat)	222.2	5.9	0.01	7	816.3
Occupancy (prop. neighb. occupied), Detection (predicted RS habitat)	223.0	6.7	0.01	3	850.6
Occupancy (forest cover, elevation, forest cover*elevation), Detection (predicted RS habitat)	223.5	7.2	0.01	5	837.0
Occupancy (forest cover), Detection (predicted RS habitat)	223.7	7.3	0.01	3	853.3
Occupancy (slope), Detection (predicted RS habitat)	223.8	7.4	0.01	3	853.7
Occupancy (elevation), Detection (predicted RS habitat)	223.9	7.5	0.01	3	854.1
Occupancy (constant), Detection (predicted RS habitat)	223.9	7.5	0.01	3	854.1
Occupancy (elk dens.), Detection (predicted RS habitat)	224.2	7.9	0.01	3	855.3
Null (intercept only)	226.1	9.7	0.00	3	862.7
Occupancy (constant), Detection (detection zone length)	227.8	11.5	0.00	3	869.5
Global (all covariates)	230.0	13.7	0.00	11	815.4

Table 20. Covariates used in exploratory analyses estimating wolf occupancy in Idaho, summers 2016-2018.

Covariate	Modeled on occupancy or detection?
IDFG management region	occupancy
Road density	detection
Proportion of cell in Idaho	occupancy and detection
Number of humans	occupancy and detection
Elk harvest*forest cover	occupancy
Elk harvest*slope	occupancy
Deer harvest	occupancy
Deer + Elk harvest	occupancy
W.t. deer harvest	occupancy
W.t. deer + Elk harvest	occupancy
Ungulate harvest*forest cover	occupancy
Ungulate harvest*elevation	occupancy
Ungulate harvest*slope	occupancy

Wolf population trend can be measured using occupancy over time and estimates by IDFG management region did not appear to change significantly over the course of our study (Table 21). The number of packs in Idaho can be estimated from an occupancy model if one assumes grid cell size is equal to average wolf pack territory size (Table 22). The number of packs estimated in Idaho during 2016-2018 was not significantly different from the number reported in 2009 when harvest began (i.e., 95% CI's overlap the 2009 count; Figure 24).

Table 21. Estimated wolf occupancy from a model using images of wolves captured at camera traps in Idaho, summers 2016-2018.

IDFG Region	2016 Occupancy (95% CI)	2017 Occupancy (95% CI)	2018 Occupancy (95% CI)
1	0.50 (0.41 – 0.60)	0.63 (0.53 – 0.71)	0.68 (0.56 – 0.78)
2	0.47 (0.39 – 0.55)	0.55 (0.46 – 0.63)	0.53 (0.45 – 0.60)
3 McCall	0.44 (0.36 – 0.53)	0.50 (0.42 – 0.59)	0.50 (0.42 – 0.58)
3 Nampa	0.33 (0.25 – 0.46)	0.37 (0.29 – 0.45)	0.40 (0.31 – 0.50)
4	0.29 (0.21 – 0.40)	0.23 (0.16 – 0.32)	0.28 (0.20 – 0.38)
5	0.13 (0.06 – 0.28)	0.06 (0.02 – 0.14)	0.07 (0.03 – 0.17)
6	0.29 (0.22 – 0.40)	0.28 (0.21 – 0.37)	0.27 (0.20 – 0.37)
7	0.41 (0.32 – 0.51)	0.43 (0.35 – 0.53)	0.48 (0.37 – 0.58)

Table 22. Number of wolf packs (95% CI) estimated from an occupancy model using images of wolves captured at camera traps in Idaho, summers 2016 - 2018. The number of estimated packs is the sum of the occupancy estimates for each cell sampled by an Idaho Department of Fish and Game (IDFG) region and assumes grid cell size equals wolf pack territory size.

IDFG Region	2016	2017	2018
1	16.7 (13.3 – 19.9)	20.7 (17.3 – 23.4)	22.5 (18.5 – 25.6)
2	22.8 (18.9 – 26.9)	26.9 (22.6 – 31.0)	25.8 (22.0 – 29.6)
3 McCall	9.3 (7.6 – 11.2)	10.5 (8.8 – 12.3)	10.5 (8.8 – 12.2)
3 Nampa	9.1 (6.7 – 12.3)	9.9 (7.9 – 12.2)	10.9 (8.5 – 13.6)
4	4.9 (3.5 - 6.8)	3.9 (2.8 – 5.5)	4.7 (3.4 – 6.5)
5	0.8 (0.4 – 1.7)	0.4 (0.2 – 0.9)	0.4 (0.2 – 1.0)
6	10.3 (7.6 – 14.0)	9.7 (7.3 – 13.1)	9.5 (7.0 – 13.1)
7	14.0 (10.9 – 17.2)	14.8 (11.9 – 17.9)	16.2 (12.7 – 19.6)
Idaho total	87.9 (69.0 – 109.9)	96.8 (78.7 – 116.2)	100.5 (81.1 – 121.2)

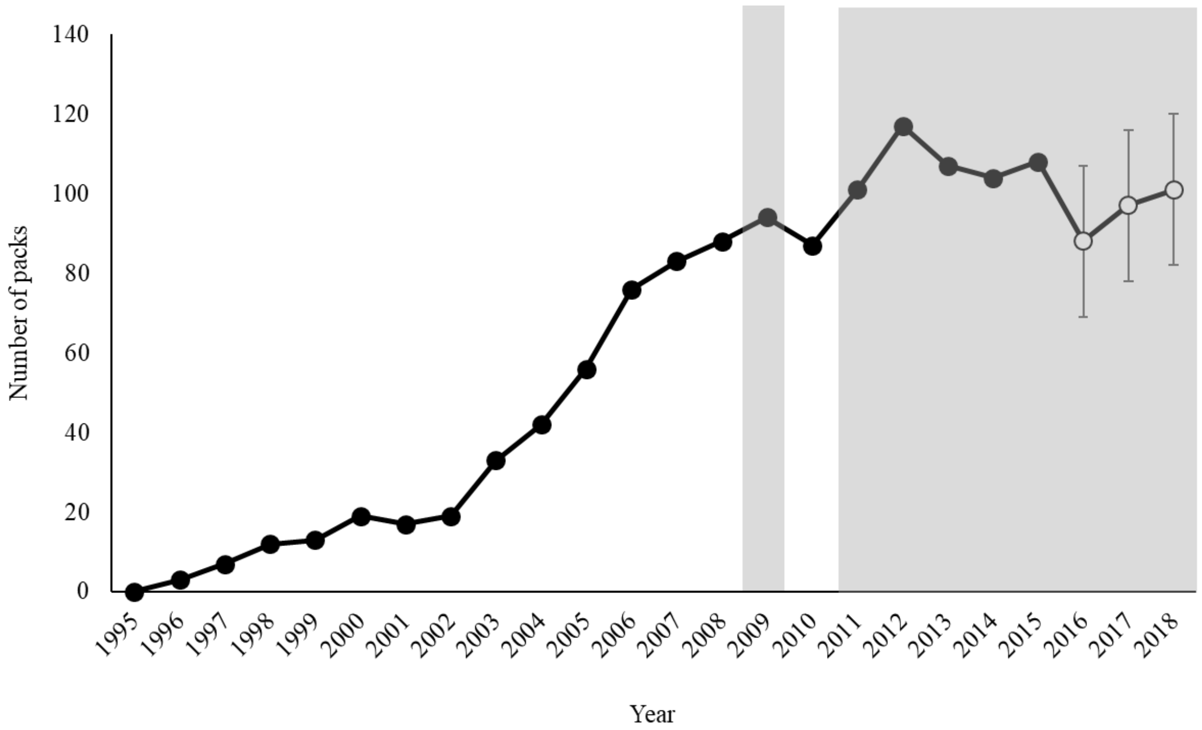


Figure 24. Number of wolf packs documented in Idaho, 1995-2018. Gray shading indicates years with harvest. Solid circles represent counts largely based on monitoring of radio-collared packs and open circles represent population estimates derived from camera surveys and an occupancy model. Error bars represent the 95% CI.

Additionally, we surveyed big game hunters for wolf sightings in spring 2018. Subsequent wolf observation data were used in a patch occupancy framework in an attempt to estimate wolf population trend statewide. Analyses indicated poor model performance using data from hunter surveys, thus we are assessing potential changes to our survey methodology and are also considering removing hunter survey data from our occupancy model. Images from cameras are also being used to test a method for estimating wolf density from cameras. Estimates of wolf density from cameras will be compared to estimates derived from DNA sampling during rendezvous site surveys (see above).

Objective 8 – Conduct 1 Mountain Lion study by 30 June, 2019

Approach

Our goal is to develop a framework for estimating mountain lion population trend and potentially abundance. During September in focal GMUs 33-35, 74, 75, and 77 we will move wolf camera stations to suitable habitat predicted by IDFG's mule deer and elk winter RSF model. We will affix cameras to existing vegetation where available or use t-posts or fence posts when vegetation is not suitable. Any post installed for camera deployment will be removed at the end of the study. Cameras will be active from 1 Oct – 30 April. Detections of cougars at camera stations will be used to estimate cougar abundance with spatial mark-resight models. Cougar detection data will be rarified so that we can compare models populated with detections of single cougars to extended models that include multiple states, including females with kittens as well as different time periods to assess closure. To provide a comparison and test of camera stations, we will tree cougars in winter using hounds and biopsy dart or chemically-immobilize them to obtain DNA samples and generate an independent measure of abundance. We will attempt to enlist local hound hunters to tree cougars and obtain samples by providing them with dart guns, sample kits, and reimbursement for expenses while sampling. We estimate up to 75 capture events per year of which we plan to radio collar at least 32 (16 males and 16 females) of those captured. The radio-collared animals will provide measures of space use for the spatial mark-resight models. We will also use backtracking of cougar tracks until hair or scat samples are located to attain DNA samples for mark-resight estimation.

Comparisons of camera station model results to the independent measure of abundance will provide a test of whether cameras are useful for such a purpose. If justified, further analyses using rarified camera data can provide insights for the most efficient sampling approach to estimate cougar abundance from camera stations. If cameras are reliable for detecting cougars and estimating cougar abundance we will expand the pilot study to include other GMUs that capture variability in predictive covariates of cougar occupancy across the state. Potential areas include GMUs in the northern Panhandle, Owyhees, and Middle Fork of the Salmon River. Data from such areas can be used to populate an occupancy model and generate statewide population estimates.

Geographic Location

Camera stations, captures, and backtracking will be conducted in Boise, Valley, Franklin, Bannock, Bear Lake, and Caribou counties.

Principal Investigator(s)

Shane Roberts (Principal Wildlife Research Biologist)	208-287-2722
Dave Ausband (Idaho Cooperative Fish & Wildlife Research Unit)	208-885-1172

Timeline

- Deploy cameras – fall months.
- Conduct genetic surveys for lions – winter months.
- Retrieve cameras – spring months.
- Categorize camera images – summer, fall months.

List of Partners

University of Montana
University of Idaho

Results

During 2017 and 2018, we deployed 143-147 cameras in suitable habitat predicted by IDFG's elk winter resource selection function model in focal study area GMUs 33-35, 75 and 77. One camera was placed in each 10 km^2 grid cell and was active from October 2 – April 30. Cameras yielded >400,000 images and an M.S. student at The University of Montana is analyzing these images. The student presented preliminary estimates of lion density from the cameras at the Idaho and Montana chapters of the wildlife society in March. The estimates ranged from 4 lions per 100 km^2 (GMUs 33-35; 2016/2017) to 11 lions per 100 km^2 (GMUs 33-35; 2017/2018). During the winters of 2017-2019, we also obtained 169 mountain lion DNA samples from biopsy darts of treed lions as well as scat and hair from backtracking lions in the focal study areas (GMUs 33-35, 75 and 77). DNA analyses are currently underway at the University of Idaho. Estimates of lion density derived from DNA marking and camera images will be compared to assess potential biases and identify possible areas for improvement with these new techniques.

The student successfully defended a research proposal in February 2018 and recently completed simulation work assessing how different movement rates, territoriality, and habitat selection of lions might affect population estimates derived from a time-to-event model that utilizes pictures from remote cameras. These results suggest time-to-event model results are robust to violations of the assumptions that movements are random (i.e., territorial movements or habitat preference could create violation) and the mountain lion population is closed (i.e., any changes in abundance during sampling could create violation) as long as cameras were placed randomly with respect to habitat (Table 23). However, the time-to-event model was sensitive to the estimated movement speed of lions, which incorrect assumptions of this rate creating significant bias in abundance estimates (Figure 25). A space-to-event model should be used if accurately estimating movement rates is not possible. The graduate student plans to defend his thesis in winter 2019-20.

Table 23. Summarized results from the walk simulations of mountain lion movements. Mean estimate is the mean of the reported abundance estimates from each iteration of the simulation, SD of estimates is the standard deviation of those means, Mean SD is the mean of the standard deviation from the posterior distributions, and Mean error is a measure of the distance from truth of the estimates.

Simulation	Mean Estimate	SD of Estimates	Mean SD	Mean Error
Control	15.244	1.953	1.480	-0.756
Speed = 0.5	9.198	2.156	1.225	-6.802
Speed = 2	28.359	2.285	2.166	12.359
Territoriality	15.349	2.092	1.487	-0.651
Open Population	15.437	2.027	1.490	-0.563
Habitat – Random – Base	16.391	2.629	1.530	0.391
Habitat – Random – GLM	12.620	2.966	2.485	-3.380
Habitat – Targeted – Base	26.370	3.349	1.953	10.370
Habitat – Targeted – GLM	10.181	5.024	3.803	-5.819

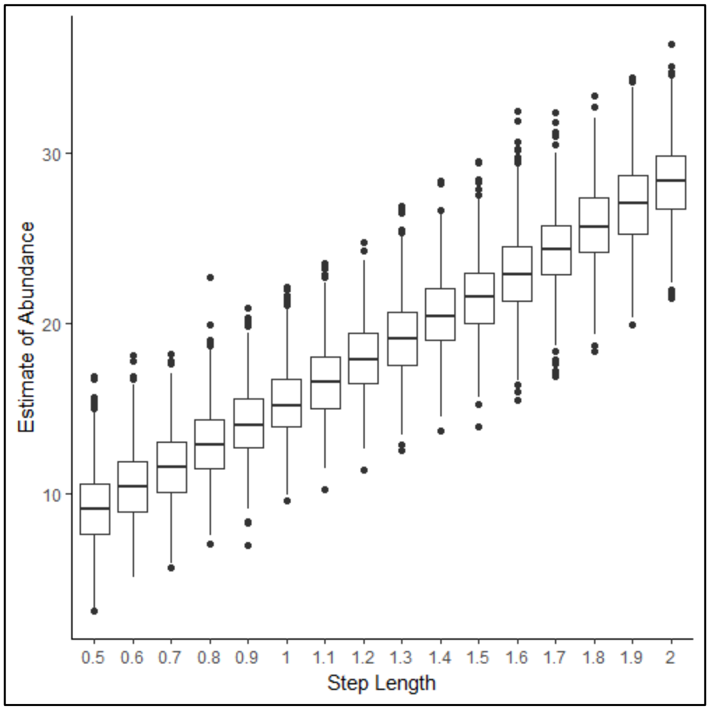


Figure 25. Box plots of mean mountain lion abundance estimate by step length (i.e., estimate of movement rate) from the speed simulations. Each step length was simulated 1000 times.

Objective 9 – Conduct 1 Greater Sage-grouse study by 30 June, 2019

Approach

We plan to continue the multi-faceted, statewide research project that seeks to understand the relationships between cattle grazing and sage-grouse demographics, how sage-grouse demographics and affected by high-elevation sagebrush habitats and their management, and the reasons for apparent decreases in sage-grouse abundance and distribution in the greater Curlew area of southeastern Idaho.

Effect of Livestock Grazing - This study will provide the first rigorous assessment of the effects of cattle grazing on sage-grouse populations. We are conducting experiments to assess the effects of cattle grazing at five study sites throughout southern Idaho (Sheep Creek, Browns Bench, Jim Sage, Big Butte, Pahsimeroi), but our results will be relevant to management decisions throughout the range of greater sage-grouse.

Our primary objectives for this portion of the sage-grouse research are to 1) document the effects of different levels of cattle grazing intensity on sage-grouse demographic and behavioral traits including: nesting propensity, nest initiation date, clutch size, daily nest survival, re-nesting rate, brood size, brood survival, post-fledging movements, natal recruitment, hen survival, inter-annual nest-site fidelity, and site occupancy; 2) document the effects of different levels of cattle grazing intensity on density and diversity of insects (species common in sage-grouse diets) within sage-grouse breeding habitat; and 3) document the effects of different levels of cattle grazing intensity on nest concealment, sagebrush canopy cover, density and diversity of grasses and forbs, and other vegetation features that contribute to sage-grouse habitat suitability.

We are employing a two-tiered approach (correlative and experimental) to meet our objectives. For the correlative approach, we are documenting the relationships between spatial foraging patterns of cattle and our suite of sage-grouse response variables. We then use the information on sage-grouse nest placement gained from the correlative portion of the study to identify areas where we will experimentally alter the extent of herbaceous offtake by cattle and assess the effects of these changes on our suite of response variables. We are comparing three experimental grazing treatments: 1) spring grazing every other year; 2) alternating spring and fall grazing each year, and 3) areas that are not grazed for four consecutive years. We are using water, salt, herding, topography, and fencing (existing and new temporary electric fencing) to alter grazing intensity in our treatment areas. We will also include the duration of spring cattle grazing as a covariate in the analysis to account for variation in duration of grazing among allotments which may influence the extent to which spring grazing affects sage-grouse populations.

In addition to sage-grouse demographic traits, we are also measuring the following sage-grouse habitat characteristics, both before and after treatment: sagebrush canopy cover and height, cover and height for other shrub species, cover, height, and diversity of grasses and forbs, frequency of herbaceous species, litter, bare ground, and insect abundance. We will compare habitat characteristics, both before and after grazing treatments are implemented, to values reported in peer-reviewed literature for other populations of sage-grouse.

Properly evaluating the effects of experimental changes in grazing on sage-grouse reproductive parameters is challenging for an animal where individuals move such great distances between breeding site (lek), nest site, and brooding-rearing site. Success of this project will continue to depend on: 1) a sufficient number of replicates (study sites); 2) a commitment to monitor response variables at each study site for numerous years before and after experimental manipulation of grazing intensity; and 3) collaboration among many individuals and organizations, including experts in sage-grouse ecology, GIS, rangeland management, botany, entomology, and plant/wildlife nutritional ecology.

Sage-grouse Ecology in High-elevation Sagebrush Habitats - Sage-grouse inhabiting mountain foothill, higher-elevation habitats (i.e., dominated by mountain big sagebrush and/or low sagebrush above 1,500 m elevation; hereafter high-elevation sagebrush) may or may not interact with their habitat similarly to sage-grouse inhabiting the more-studied, lower-elevation habitats of southern Idaho (i.e., dominated by Wyoming big sagebrush). In recent years there have been numerous, independent efforts to document location-specific sage-grouse movements and seasonal habitat use throughout high-elevation sagebrush habitats in eastern Idaho. In this portion of the sage-grouse project we are using survival, reproduction, location, and vegetation data from previously GPS- or VHF-marked sage-grouse to model the relationship between sage-grouse fitness and habitat in these unique landscapes. This modeling effort will provide useful information for habitat management and restoration efforts that will have population-level impacts. Analyses conducted at multiple spatial scales (i.e., traditional microsite habitat characteristics plus macrosite or landscape scale habitat evaluation) will facilitate application of research results within the landscape scale at which federal agencies manage habitats. Model results identifying the attributes of high-elevation sagebrush habitats where sage-grouse are successful at recruiting young and surviving will be compared to attributes of habitat at manipulated sites (e.g., burns of varying age) to evaluate the benefits or detriments of various management activities on sage-grouse production and persistence, thereby informing future management actions.

Our primary objectives with this portion of the research are to 1) model sage-grouse nest and brood site selection and success in relation to habitat variables across high-elevation sage-steppe habitats in eastern Idaho and 2) compare characteristics of these "successful" habitats identified in #1 to habitats manipulated with management prescriptions (e.g., prescribed fire of various age) to evaluate management action benefits and detriments to sage-grouse population dynamics. We will monitor sage-grouse marked with GPS or VHF transmitters during the springs of 2015-2019 to document nest initiation, nest success, brood success, survival, and seasonal movements. Sage-grouse are captured using rocket nets set up on lek sites or spotlighting and dip nets near lek sites prior to or during the lek season. We will also use BLM HAF-AIM vegetation sampling protocol to quantify vegetation composition and structure around nests and random sites throughout the study areas. We'll use these ground measurements, in combination with remotely-sensed vegetation classification and imagery products, in our analyses of demographics and to characterize the habitat composition in management polygons.

Demographics and Lek Distribution in the Curlew - The greater sage-grouse population within the greater Curlew area of Idaho has been declining during recent years, prompting IDFG to close sage-grouse hunting seasons in most of Oneida and Power counties. We're cooperating with BLM and U.S. Forest Service (USFS) to determine what factors are contributing to the decline and investigate why the population seems unable to rebound in years when other populations are increasing.

The specific objectives of this aspect of the project were to 1) conduct spring helicopter aerial surveys to determine the current distribution and status of occupied and historic sage-grouse leks in the greater Curlew area, 2) conduct habitat assessments using BLM HAF-AIM methods at sage-grouse use sites (nests) and at random locations throughout available shrub-steppe habitat in the greater Curlew area, and 3) maintain a sample of at least 30 adult sage-grouse (all female if possible) fitted with GPS transmitters (PTT) throughout the study area to assess adult survival, nest site selection, nest success, brood success, and seasonal movements.

Sage-grouse aerial surveys were conducted during spring of 2017 and sage-grouse were captured and marked with GPS or VHF transmitters in the springs of 2017 and 2018. We'll monitor nest initiation, nest success, brood success, survival, and seasonal movements of marked sage-grouse during FY19. We'll also measure vegetation at nest and random sites throughout the study area to facilitate nest site selection and nest success analyses incorporating vegetation composition and structure metrics.

Geographic Location

Study areas include the Shoshone Basin, Big Desert, Jim Sage Mountains, Sheep Creek, Pahsimeroi River Valley, Sand Creek desert, Lemhi River, Big and Little Lost Rivers, Birch Creek, Crooked Creek, Medicine Lodge, Rockland Valley, Arbon Valley, and the Black Pine area. Idaho counties include Twin Falls, Cassia, Minidoka, Owyhee, Oneida, Blaine, Power, Butte, Cassia, Custer, Clark, Fremont, and Lemhi counties.

Principal Investigator(s)

David Musil (IDFG Senior Wildlife Research Biologist)	208-324-4359
Shane Roberts (IDFG Principal Wildlife Research Biologist)	208-525-7290

Timeline

- Capture and collaring of female grouse for grazing study - spring months
- Lek and nest monitoring - spring months
- Vegetation and insect monitoring – spring-summer months
- Brood monitoring – summer months
- Grazing manipulation – spring-fall months
- Seasonal movement and adult survival monitoring (GPS marked birds) – year around
- Data summarization, analyses, and preliminary reporting – fall-winter months

List of Partners

University of Idaho
Bureau of Land Management
U.S. Forest Service
U.S. Geologic Survey Cooperative Fish and Wildlife Research Units
Idaho Office of Species Conservation
Western Association of Fish and Wildlife Agencies
Public Lands Council
Idaho Cattle Association
Idaho Cattle Foundation, Inc.
Great Basin Landscape Conservation Cooperative
Private Livestock Permittees

Results

Effect of Livestock Grazing – This long-term, landscape-scale project has been ongoing for 6 years and now encompasses 6 study areas. We have monitored the survival, habitat selection, and reproductive effort and success of 760 female greater sage-grouse to date (Table 24). Female survival during the breeding season has varied from 60% to 85% during 2014-2018. We have monitored the success of 571 nests during the study (Figure 26).

Table 24. Number of adult and yearling female greater sage-grouse captured by year across 6 study sites in southern Idaho for the grazing project. This table includes recaptures and excludes birds that had an unknown age at capture.

Age	2014	2015	2016	2017	2018	2019
Adult	52 (57%)	57 (53%)	82 (68%)	76 (58%)	90 (73%)	111 (59%)
Yearling	40 (43%)	51 (47%)	38 (32%)	55 (42%)	33 (27%)	77 (41%)
Total	92	108	120	131	123	188

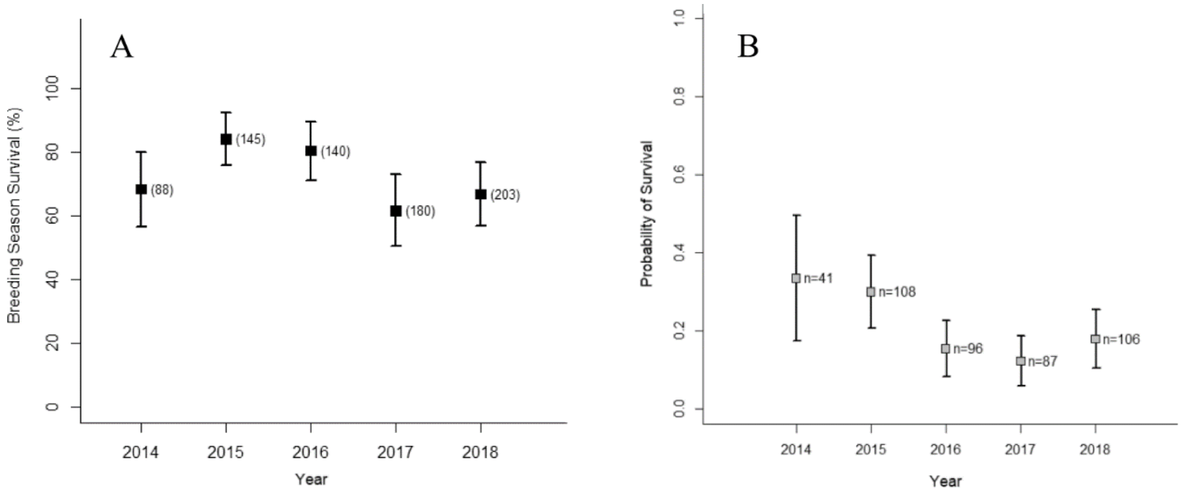


Figure 26. A) Survival estimates (± 95% C.I.) of female sage-grouse during the breeding season monitoring period (Mar – Jul) and B) annual probability of nest survival (± 95% C.I.) across 5 southern Idaho study areas, 2014-2018. n = the number of encounter histories that contributed to the estimate. An additional 133 nests were monitored in 2019 but survival has not yet been estimated.

Grazing schedules for treatment pastures within each study area follow a before-after treatment plan (Figure 27). The 2 years of pre-treatment monitoring allows us to determine where sage-grouse nests are most likely to be located and allows us to measure survival and reproductive parameters at the site under the current management conditions. The study areas is divided into 4 pastures and 4 years of treatments are implemented in each pasture; with alternate years of spring grazing for 2 pastures, no grazing at all for 1 pasture, and alternating spring/fall grazing for 1 pasture. At the conclusion of the 2019 season, 2 study areas (Jim Sage and Browns Bench) will reach the end of the 4 year treatment period, 2 study areas (Sheep Creek and Big Butte) will reach the end of 3 treatment years, Pahsimeroi Valley will finish the first year of the treatment period, and the Idaho National Laboratory (INL) site will complete the first year of monitoring. The INL site has not been grazed for decades, thus, it will serve as a comparison for long term grazing rest.

Treatment	Year 1	Year 2	Implement Grazing Treatments	Year 3	Year 4	Year 5	Year 6
Spring Odd Years	Current grazing	Current grazing		Spring Grazing	No Grazing	Spring Grazing	No Grazing
Spring Even Years	Current grazing	Current grazing		No Grazing	Spring Grazing	No Grazing	Spring Grazing
No Grazing	Current grazing	Current grazing		No Grazing	No Grazing	No Grazing	No Grazing
Spring and Fall	Current grazing	Current grazing		Spring Grazing	Fall Grazing	Spring Grazing	Fall Grazing

Figure 27. Monitoring and treatment schedule used to evaluate effects of cattle grazing on sage-grouse demographic traits and habitat features within 4 treatment pastures at each southern Idaho project study area.

We have deployed and maintained over 45 km of temporary electric fence (solar powered) to aid in utilization and livestock distribution and to allow permitees to continue their regular grazing schedules on portions of pastures not used by nesting sage-grouse. We use visual estimates of forage utilization and measurements of vegetation heights along transects to quantify forage utilization on each study pasture at the end of each growing season (Figures 28, 29, and 30). We also sample vegetation at nest sites and random plots within our experimental pastures. Analyses of those data are ongoing.

We also monitored insect abundance and frequency of occurrence at each study site. We have counted, identified, and measured 45,725 arthropods from 424 pitfall trap samples (average of 108 arthropods per pitfall sample). The sampled arthropods are comprised of 15 taxonomic Orders, but 89% of the biomass in the samples is from 3 Orders: Orthoptera (grasshoppers and crickets; 47%), Hymenoptera (ants and bees; 24%), and Coleoptera (beetles; 17%). These 3 Orders are also the most common arthropod Orders found in the diets of sage-grouse chicks. We detected 40 ant mounds (≥1 at 19 of 21 transects) at Big Butte, 27 ant mounds (≥1 at 11 of 18 transects) at Browns Bench, 8 ant mounds (≥1 at 6 of 30 transects) at Jim Sage, and 58 ant mounds (≥1 at 17 of 23 transects) at Sheep Creek. Analyses comparing insects between grazed and ungrazed pastures are upcoming.

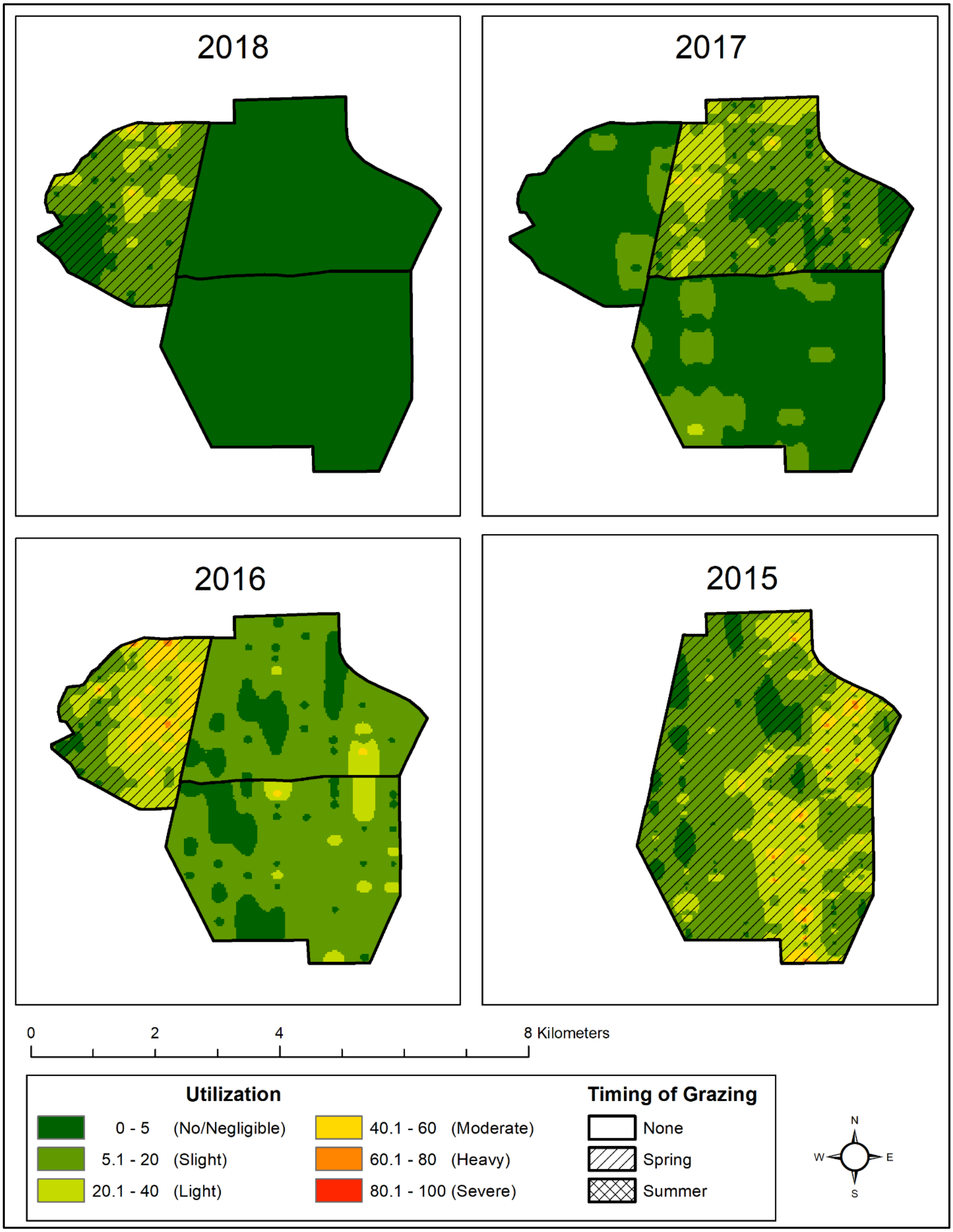


Figure 28. Map of livestock utilization at Jim Sage study area, Idaho, 2015-2018. Grazing treatment pastures were established in 2016 at this site, dividing the allotment into 3 treatment pastures.

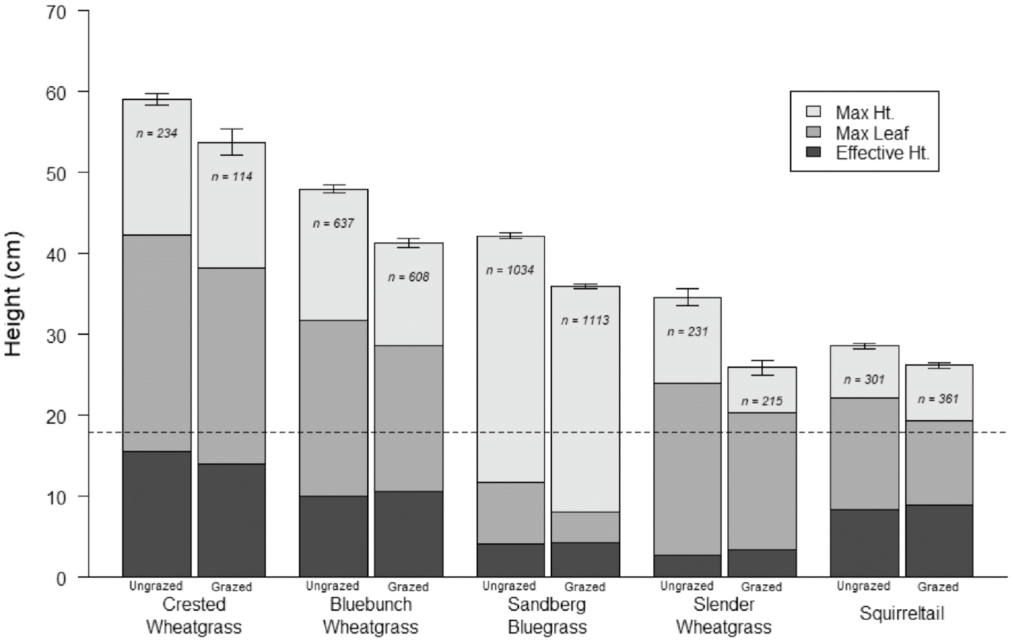


Figure 29. Mean values (± 1 SE for maximum droop height only) of 3 height measurements of the 5 most common species of perennial grasses collected at post-growing season (Jul-Aug) random plots at Big Butte, Idaho, 2018. Max Ht. = maximum droop height (using highest part of plant), Max Leaf = maximum droop height excluding the flowering stalk, and Effective Ht = effective height (modified visual obstruction for an individual plant). Sample sizes are denoted near the top of each bar. The dashed line represents 18 cm (7 in.), the grass height recommended in the sage-grouse habitat guidelines.

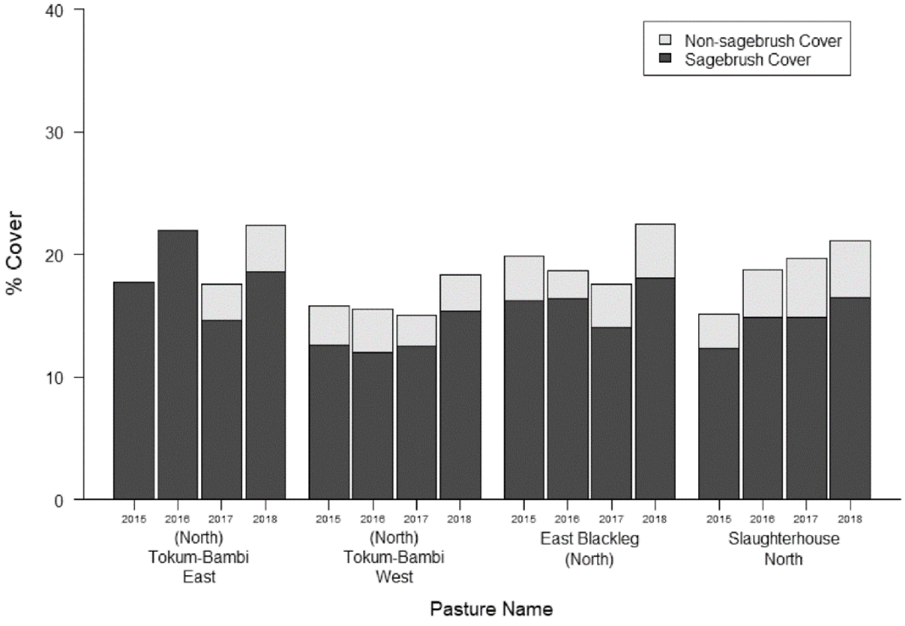
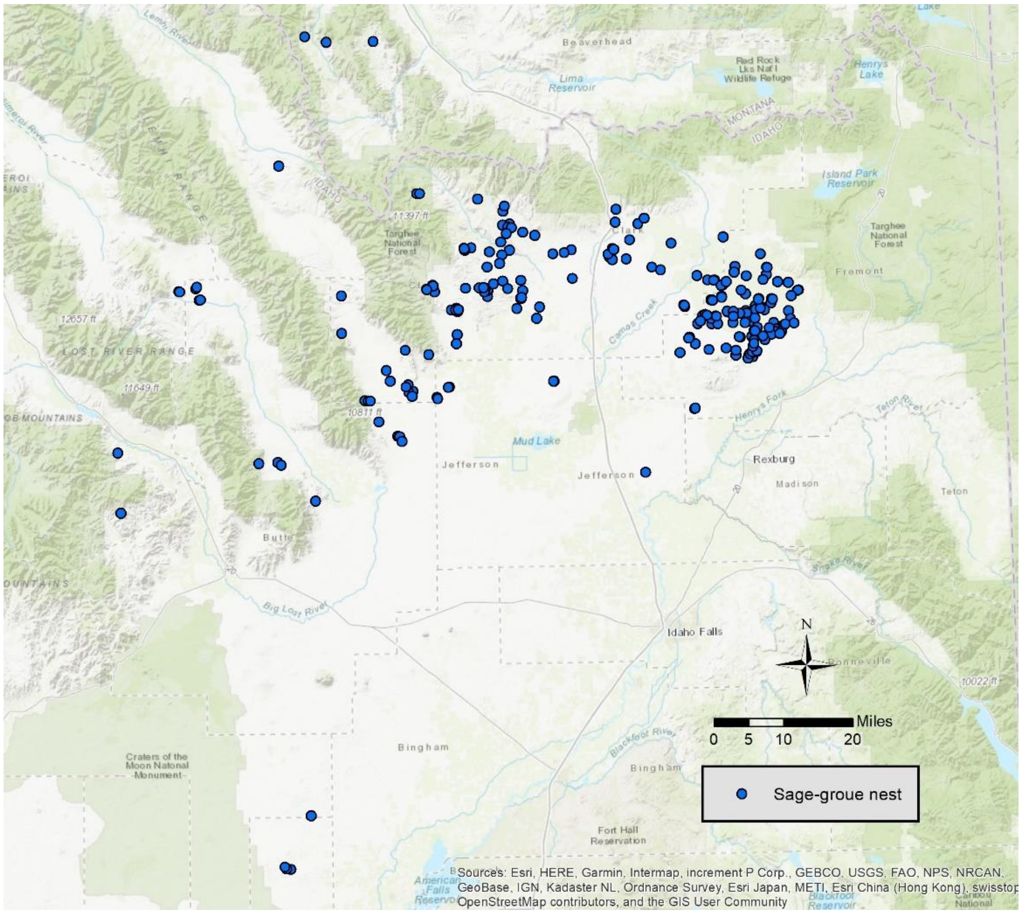


Figure 30. Shrub canopy cover of all brush species combined within each of 4 treatment pastures at Sheep Creek, Idaho, 2015-2018.

Sage-grouse Ecology in High-elevation Sagebrush Habitats – During 2015-2019, we monitored the success of 191 greater sage-grouse nests from PTT-marked females throughout the Upper Snake Region of eastern Idaho (Figure 31). We used BLM HAF-AIM vegetation sampling protocol to measure vegetation at these nests and at 338 random plots throughout predicted sage-grouse habitat within 18 km of leks marked females were captured from. The majority of vegetation transects were from the Sand Creek and Medicine Lodge areas of the Upper Snake Region.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstop OpenStreetMap contributors, and the GIS User Community

Figure 31. Location of sage-grouse nests monitored for habitat selection and success during 2015-2019 in the Upper Snake Region of eastern Idaho.

Sage-grouse tended to use areas for nesting that had greater canopy coverage of sagebrush and all shrubs combined than what was available at random (Table 25). They used areas with less perennial grass and shorter perennial forbs, but that is likely correlated with the areas having denser shrub cover. They also used areas with a high variety of forb species.

Table 25. Average vegetation measurements at greater sage-grouse nests and random plots among all high elevation study areas in eastern Idaho, 2015-2019

	Nests		Random	
Variable	Mean (SE)	n	Mean (SE)	n
Canopy Cover (%)				
Sagebrush	27.1 (0.8)	191	19.5 (0.8)	334
All shrubs	39.3 (1.1)	191	30.9 (1.0)	334
Non-sagebrush shrubs	12.2 (0.8)	191	11.5 (0.7)	334
Perennial grass	33.8 (1.3)	191	39.2 (1.1)	334
Perennial forb	16.4 (0.9)	191	16.9 (0.7)	334
Forb richness	9.4 (0.6)	184	6.8 (0.3)	323
Height (cm)				
Sagebrush	55.2 (1.3)	180	52.5 (1.3)	292
Non-sagebrush shrubs	45.4 (1.8)	162	45.2 (1.4)	260
Perennial grass	30.8 (0.7)	183	35.9 (0.6)	324
Perennial forb	16.5 (0.6)	177	19.7 (0.5)	304

These vegetation data are being used in conjunction with nest and brood success data to analyze the effects of high-elevation habitats on these sage-grouse vital rates. We have completed preliminary analyses of nest site selection and success with respect to shrub cover at the Sand Creek study area (east of Interstate 15; eastern group of nests in Figure 31) using resources selection function modeling for nest selection and logistic regression to evaluate vegetation effects on apparent nest success. Nesting sage-grouse at Sand Creek were approximately 4 times more likely to select a nest site with 50% total brush canopy cover as they were to select a nest site with 20% total brush canopy cover (Figure 32a). Similarly, they were about 2 times more likely to select a nest site with 40% sagebrush canopy cover as they were to select a site with 20% sagebrush canopy cover (Figure 32b). In these preliminary analyses, these difference in brush canopy cover for nest site selection did not translate to differences in brush effects on nest success, with successful and unsuccessful nests having similar total brush (successful nest total brush averaged 47%, unsuccessful nest total brush averaged 43%) and sagebrush canopy cover (successful nest sagebrush averaged 26%, unsuccessful nest sagebrush averaged 29%). These results suggest other factors were more impactful on nest success than brush cover. We will be evaluating the effects of other variables in future analyses (precipitation, temperature, other vegetation structure, etc) and it is possible those variables may be influential on nest success. We'll also be examining the effects of vegetation and environmental variables on brood success to evaluate overall reproductive success.

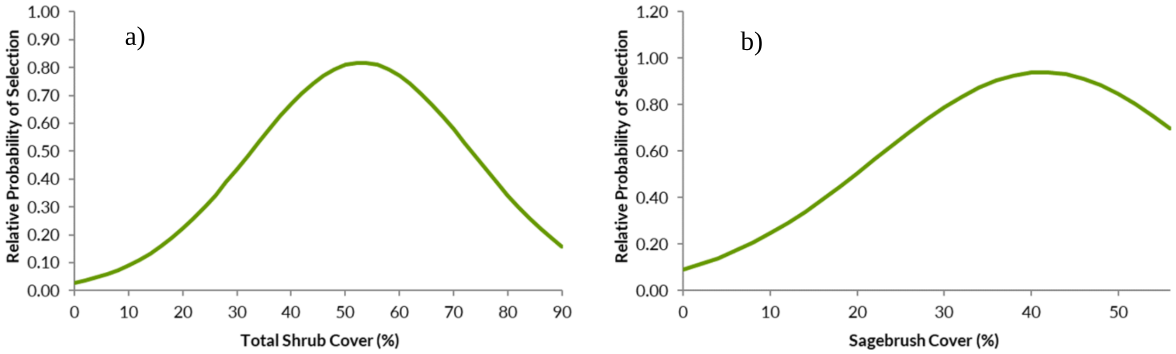


Figure 32. Effects plots of resource selection function results showing the relative probability of nest site selection across a range of values of a) total shrub canopy cover and b) sagebrush canopy cover on Sand Creek, Idaho, 2015-2019

We conducted a preliminary analysis evaluating the effects of management actions—specifically prescribed fire—on sage-grouse reproductive habitat by relating nest site selection to shrub characteristics of prescribed fires of various ages on Sand Creek. We used shrub structure data from HAF-AIM vegetation plots conducted throughout Sand Creek to characterize the prescribed fire boundaries they fell within (Figure 33). We then fit a quadratic regression line through the data relating fire age to total shrub (Figure 34) and sagebrush canopy cover to define the average relationship between these variables. We then graphed nest site selection results from resource selection function modeling for total shrub and sagebrush cover against this regression line describing the relationship between shrub canopy cover and fire age to examine how sage-grouse hen nest site selection related to prescribed fire age and shrub regeneration post-fire (Figure 35). Past research suggests brush canopy cover in Sand Creek's very productive mountain big sagebrush (*Artemisia tridentata vaseyana)* landscape can return to pre-fire conditions within about 18-20 years. The results of this analysis suggest sage-grouse were selecting nests with total brush and sagebrush canopy cover levels that, on average, would be found in stands that hadn't been burned in over 20 years, suggesting they were selecting areas that had returned to pre-burn shrub canopy cover conditions.

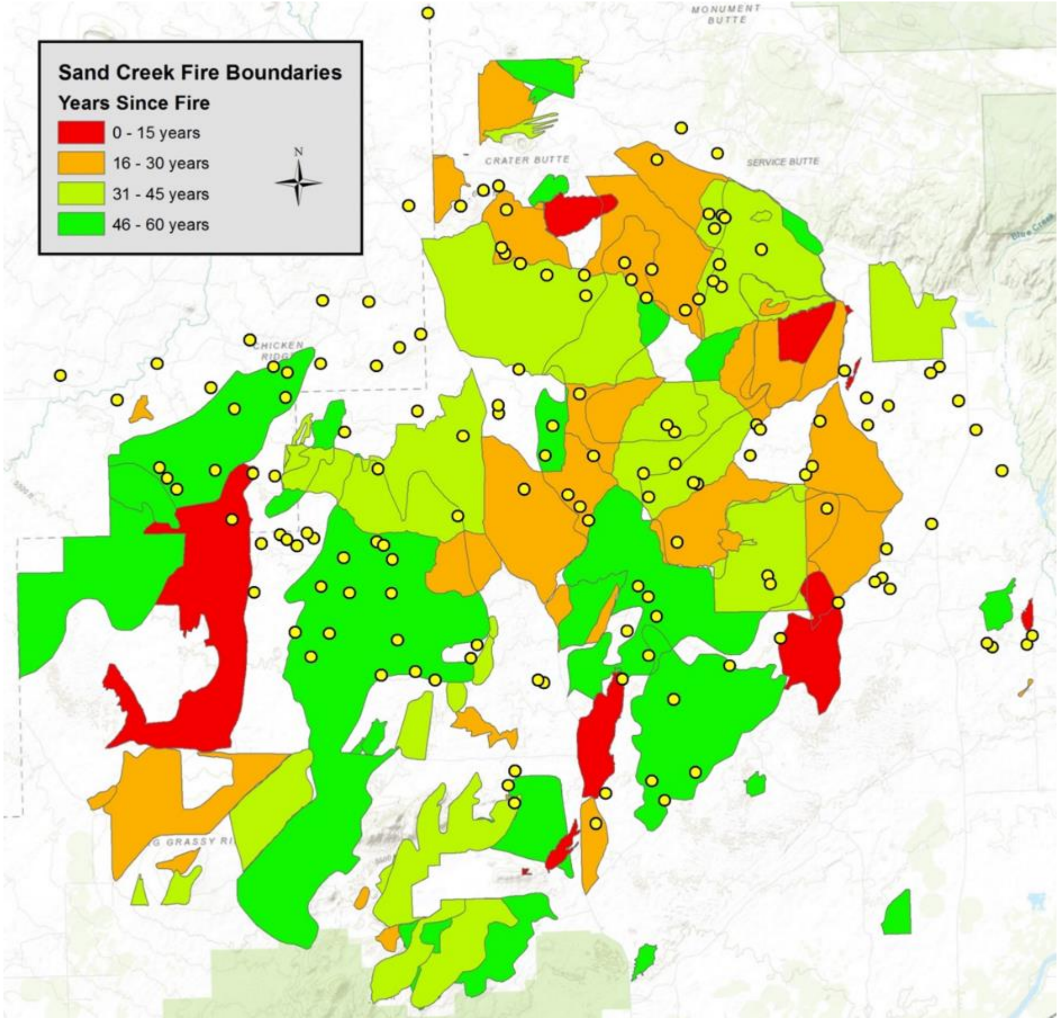


Figure 33. Age of prescribed fires and HAF-AIM vegetation plots (yellow circles) used to characterize shrub structure within fire boundaries on Sand Creek, Idaho

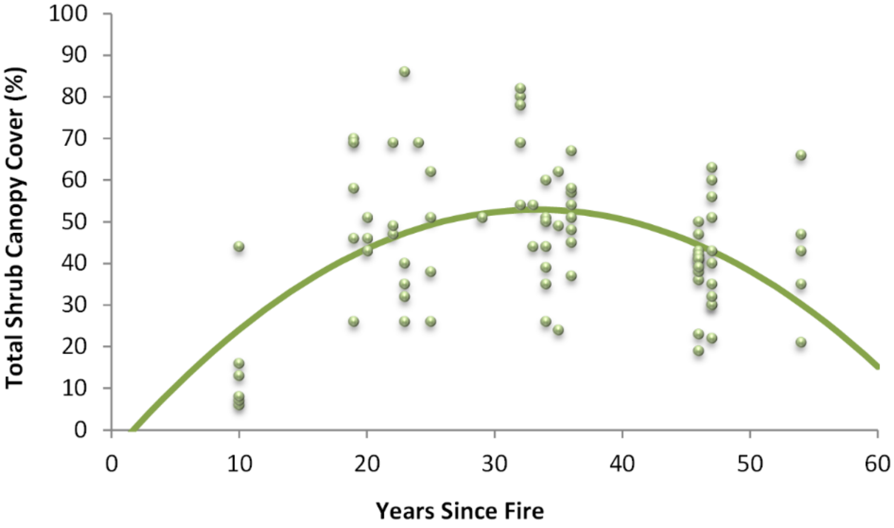


Figure 34. Best fit quadratic regression line describing average total shrub canopy cover across prescribed fires of various age, Sand Creek, Idaho.

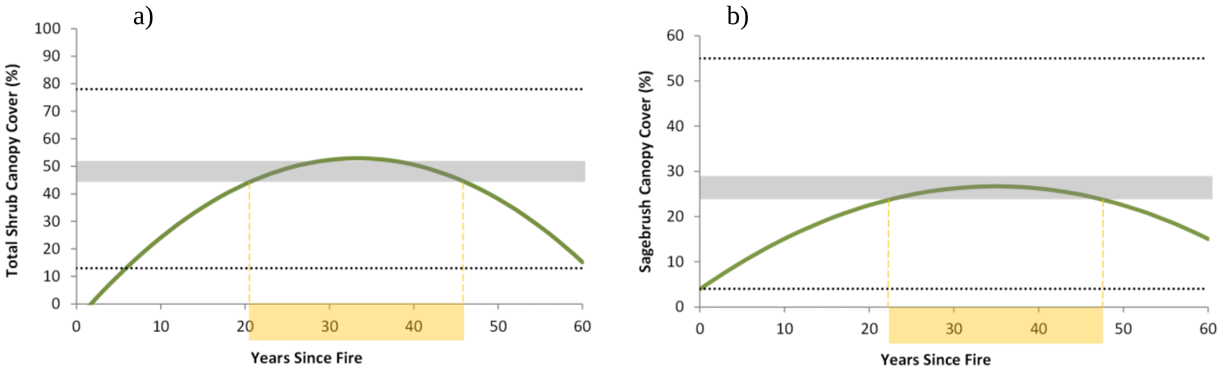
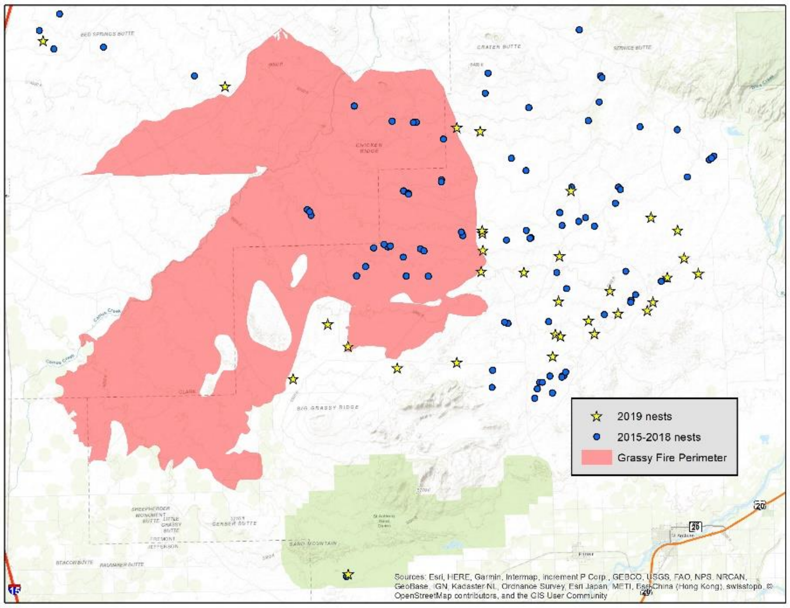


Figure 35. Intersection of results from sage-grouse nest site selection analysis and the relationship between a) total shrub and b) sagebrush canopy cover and years since the area was burned on Sand Creek, Idaho. Horizontal gray bar is 95% C.I. around preferred canopy cover of sage-grouse nests from resource selection function model, dotted horizontal lines are the range of canopy cover values for sage-grouse nests, green line is the best fit quadratic regression line relating canopy cover to years since fire, and the vertical orange dashed lines and orange panel on the x-axis depict the range of years since fire where sage-grouse nest selection preferences (horizontal gray bar) and shrub canopy cover on the landscape (green line) intersect.

In summer 2018, the Grassy Ridge wildfire burned approximately 99,000 acres of the Sand Creek study area (Figure 36), providing an opportunity to evaluate the short-term effects of large scale wildfire (i.e., much larger than prior prescribed fire plots we were investigating) on sage-grouse habitat selection and demographics. The data previously collected at the Sand Creek and Medicine Lodge study areas (directly west of Sand Creek on the west side of Interstate 15), provided an opportunity for us to design a before-after-control-impact study, with Sand Creek serving as the treatment area and Medicine Lodge serving as the control. During 2019, we monitored approximately 30 female sage-grouse in each of the study areas with PTT transmitters and measured vegetation at their nests and at random plots (Figures 37, 38, and 39). Sage-grouse were using nest sites with greater sagebrush and total shrub canopy cover. Some vegetation differences were inherent between the sites, with Sand Creek having more non-sagebrush cover and taller sagebrush and non-sagebrush than Medicine Lodge. Greater sage-grouse were using nest sites with shorter grass than was available at both sites, which may correlate to increased shrub cover. Sand Creek had more perennial forb cover than the control site as well as taller perennial forb height. Sage-grouse used nest sites with a greater variety of forb species at both Sand Creek and Medicine Lodge. We plan to collect an additional year of vegetation and sage-grouse demographic data and more in-depth analyses of vegetation effects on sage-grouse reproductive demographics (nest success, brood success) will be completed after data collection has concluded in 2020.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 36. Sage-grouse nests relative to the Grassy Ridge fire boundary, Sand Creek, Idaho

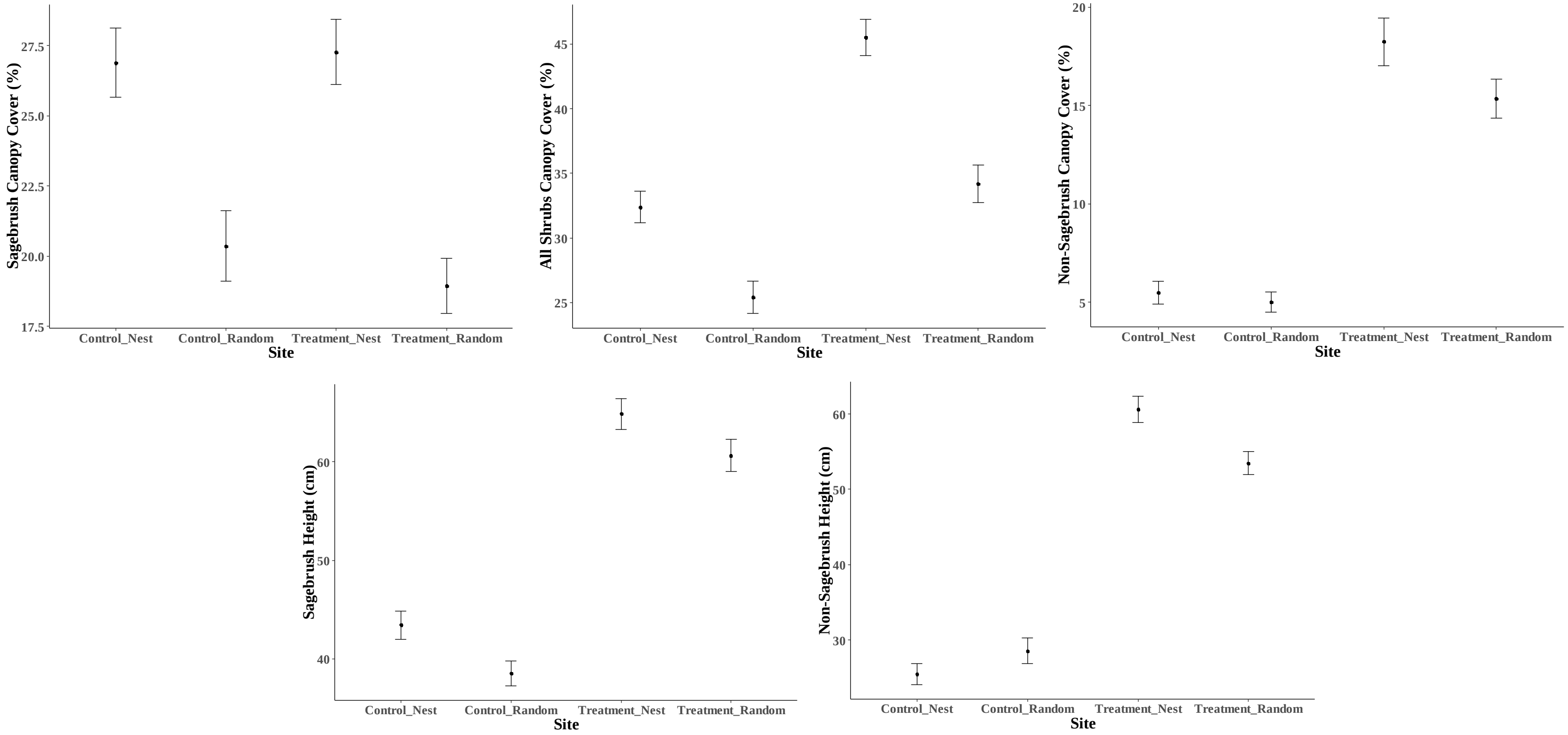


Figure 37. Sagebrush, all shrubs, and non-sagebrush canopy coverage and height at treatment and control sites for greater sage-grouse nests and random plots in eastern Idaho, 2015-2019. Means are bound by 1 SE.

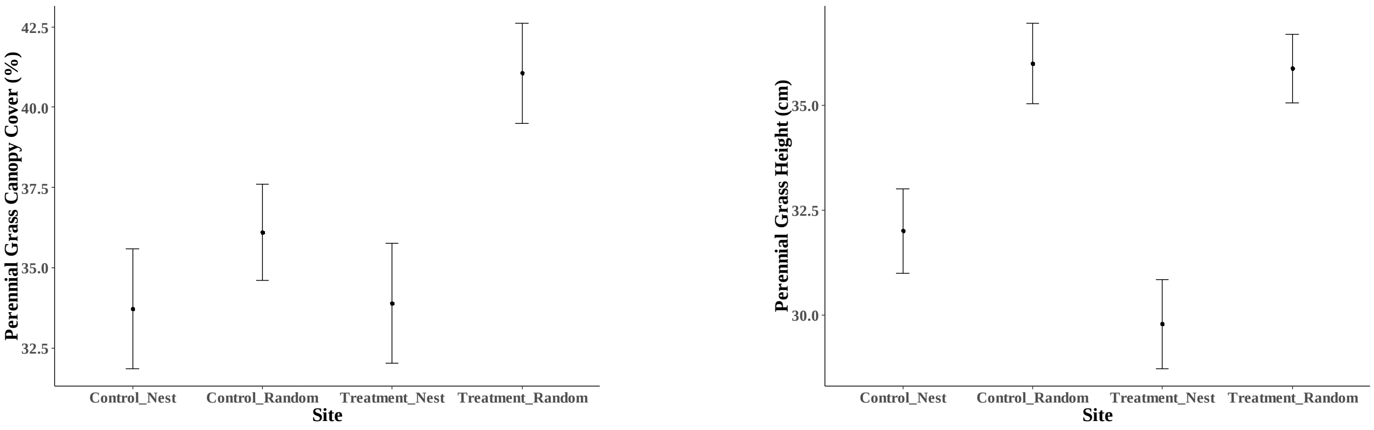


Figure 38. Perennial grass canopy coverage and height at treatment and control sites for greater sage-grouse nests and random plots in eastern Idaho, 2015-2019. Means are bound by 1 SE.

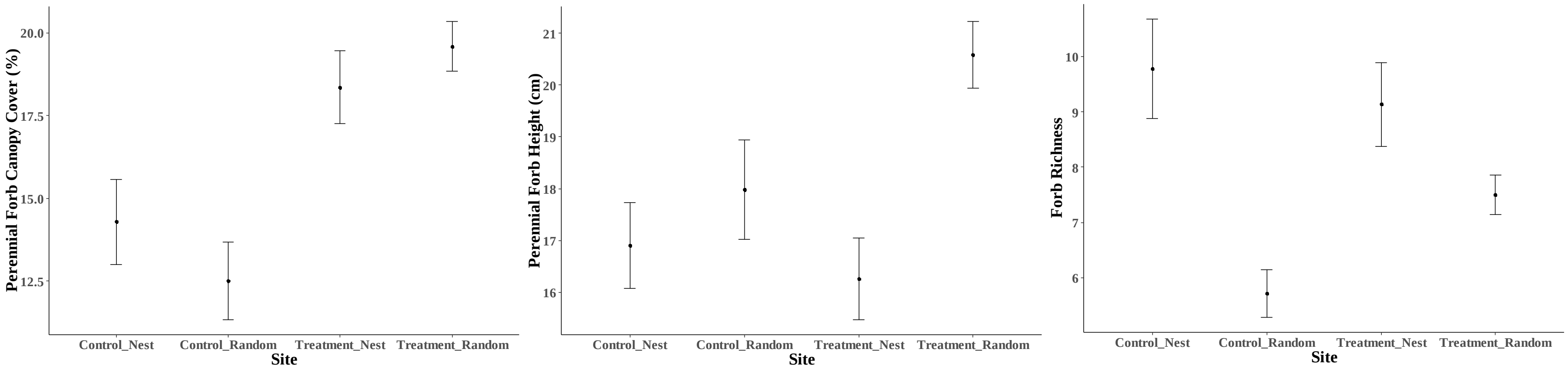


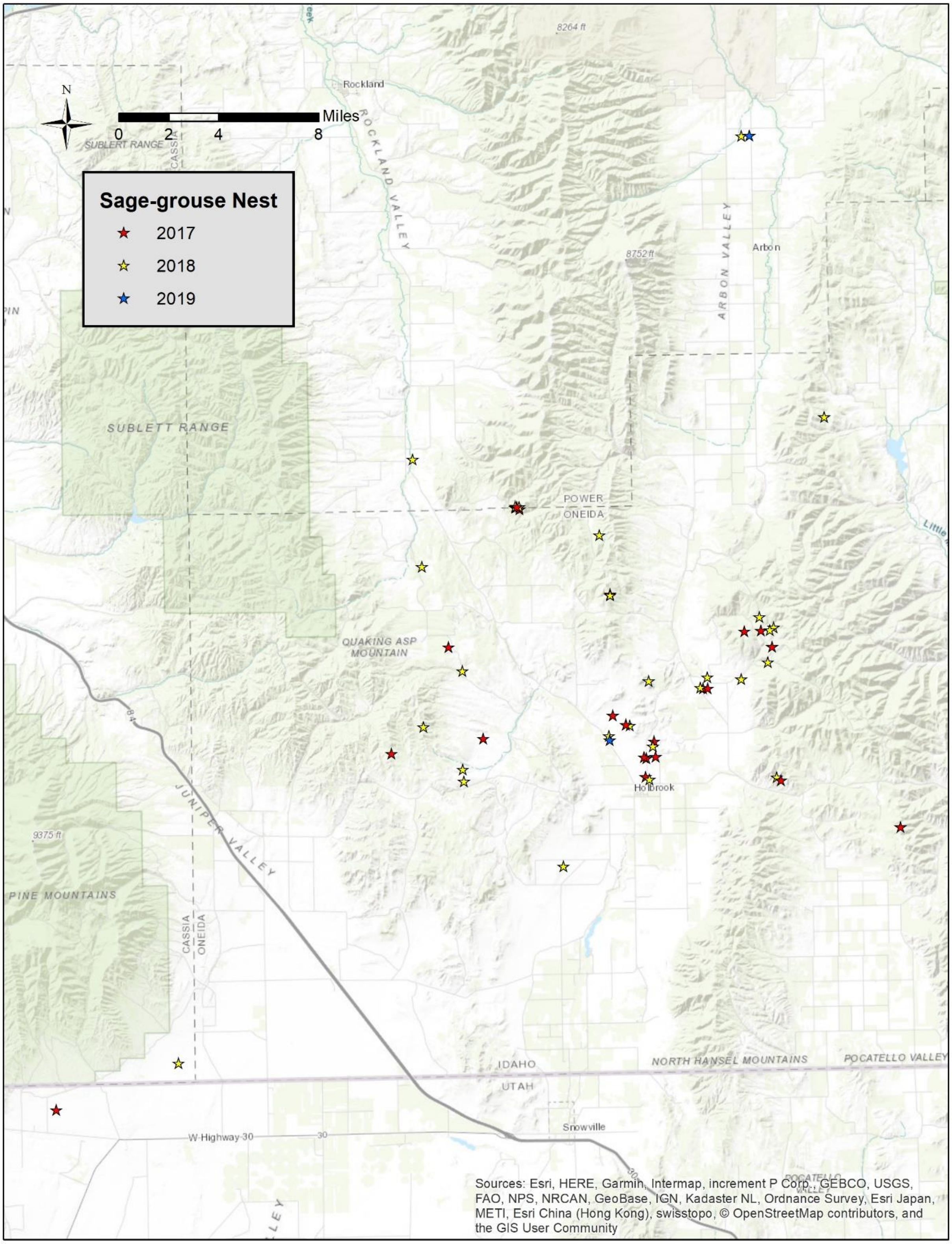
Figure 39. Perennial forbs canopy coverage, height, and species richness at treatment and control sites for greater sage-grouse nests and random plots in eastern Idaho, 2015-2019. Means are bound by 1 SE.

Demographics and Lek Distribution in the Curlew – We conducted aerial surveys of the greater Curlew landscape in 2017 to survey leks on unknown status and look for newly-formed leks. We surveyed 23 (40%) of the 58 known greater sage-grouse leks in the area. None of these leks were active from the air but 2 were active when observed during later ground surveys. No new leks were found with aerial surveys. Seven of 38 (18%) leks ground surveyed in 2017 had displaying males and averaged 16.1 ± 7.6 males/active lek (mean ± 95% CI). In 2018, 8 of 37 (22%) surveyed leks were active and averaged 9.9 ± 4.0 males/active lek. Lek attendance was similar to 2017 in 2019, with 11 of 45 (24%) leks surveyed having males attending and averaged 11.6 ± 5.7 males/active lek. For the 33 leks surveyed in both 2019 and 2017, 9 (27%) were active in 2019 and 7 (21%) in 2017. The number of males counted on active leks went from 113 males in 2017 to 119 males in 2019. Of 27 leks observed in both 1999 and 2019, 21 (78%) in 1999 and 5 (19%) in 2019, were active. The number of males counted on these same leks were 61% fewer in 2019 (88 males) than 20 years earlier in 1999 (228 males).

We captured greater sage-grouse (n = 57) and fitted them with necklace (VHF) or rump mounted transmitters (GPS PTT; Table 26). We monitored 53 nests over 3 years, with an overall apparent nest success of 60% (2017 - 50%, n = 24; 2018 - 67%, n = 27; 2019 - 100%, n = 2; Figure 40). We sampled vegetation at 27 nests and 17 random plots in 2018. Complete analyses examining the relationship between vegetation and sage-grouse reproductive demographics (nest success and brood success) will be completed in the coming year.

Table 26. Greater sage-grouse captured and radio marked with satellite (rump mounted PTT) and very high frequency (necklace VHF) transmitters in the Curlew Valley, Idaho, 2017-2018.

	2017		2018		
Sex/age	PTT	VHF	PTT	VHF	Total
Female					
Adult	20	7	8	11	46
Yearling	3		3	1	7
Subtotal	23	7	11	12	53
Male					
Adult	1		3		4
Grand Total	24	7	14	12	57



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 40. Sage-grouse nests monitored during 2017-2019 in the greater Curlew landscape of southeastern Idaho.

Objective 10 – Conduct 1 Columbian Sharp-tailed Grouse study by 30 June, 2019.

Approach

This project is part of a long term evaluation of how large-scale agricultural landscape habitat changes (i.e., CRP vs ag vs native) affect wildlife populations. In this study we will investigate the effects of agriculture landscape change (native shrub-steppe vs active agriculture vs CRP) on Columbian sharp-tailed grouse (CSTG) population performance (lek trends, recruitment from wing data, harvest data) and habitat quality metrics. We are cooperating with a remote-sensing team at Idaho State University that will use landscape classification and change detection of remotely-sensed imagery and unmanned aerial vehicle (UAV) surveys to quantify landscape change. We'll also conduct UAV surveys to investigate the utility of high-resolution hyperspectral and infrared sensors in describing vegetation composition and structure. We'll compare the UAV survey data to ground truth vegetation surveys to assess the techniques usefulness in describing vegetation composition and its potential to upscale to inform courser remotely-sensed products. The results of this project have the potential to provide a quicker means of assessing grassland habitat composition, and therefore habitat quality for wildlife, and improve our understanding of how landscape-scale habitat changes in the agriculture landscape affect wildlife populations.

We also plan to capture and GPS-mark sharp-tailed grouse in an eastern Idaho landscape where Columbian sharp-tailed grouse continue to inhabit relatively intact native shrub-steppe habitats that haven't been significantly altered by agriculture or CRP grasslands (i.e., the Sand Creek desert). We'll capture sharp-tailed grouse with established methods utilizing passive walk-in traps with drift fences on lek sites. Captured birds will be sexed, aged, weighed, and fitted with an aluminum leg band and rump-mounted PTT/GPS transmitter. Birds will be monitored year-round to document annual survival, nesting propensity, nest success, brood success, seasonal habitat selection, and seasonal movements. These data will help us understand how sharp-tailed grouse in this primarily-native habitat landscape select and interact with habitat, how they interact with areas that have been disturbed (e.g., burned areas), how those interactions may differ from birds inhabiting CRP/ag landscapes, and how those differences might help us understand impacts of future changes in the CRP program and large-scale fires.

Geographic Location

Study will be conducted in grassland habitats of Oneida, Power, and Bannock counties and the sage-steppe habitats of Fremont and Clark counties in southeast Idaho.

Principal Investigator(s)

Scott Bergen (IDFG Senior Wildlife Research Biologist)	208-232-4703
Shane Roberts (IDFG Principal Wildlife Research Biologist)	208-525-7290

Timeline

- Organization of historic lek, wing, and harvest data and collection of aerial photography and other remotely-sensed products – year around
- Lek surveys - spring months
- UAV vegetation surveys and ground truthing – summer months
- Analyses and graduate student coursework – fall-winter months
- Capture and GPS-marking of sharp-tailed grouse – spring months
- Monitoring of marked sharp-tailed grouse survival, movements, and habitat selection – year around

List of Partners

Idaho State University

Results

We partnered with Idaho State University to investigate how we could use sUAS technologies to accurately identify and quantify forb composition in CRP fields, which would help with rapid assessment of habitat quality for CSTG and other species relying on grassland forbs. We used a sUAS fitted with a natural color digital camera and a multi-band hyperspectral sensor to map vegetative characteristics (vegetative structure, density, and composition) of fields under CRP management. We used the occurrence of plant species within gridded 1-m plots in five CRP fields to measure the accuracy of sUAS measurements. The sUAS was flown at low altitude to produce image mosaics at a 2 cm resolution. Mosaicked hyperspectral images were then segmented and classified using object oriented classification algorithm's that are capable of classifying objects based on their reflectance spectra composition, adjacency to identified features (proximity), and position to landscape features (pattern analysis). Object oriented classification analysis with high spatial resolution data has been shown to have higher accuracies in identifying vegetation structures, since it can incorporate pattern recognition processes. Pattern recognition incorporates and digests, spectral information coming from parts of the entity being identified in smaller scale resolution pixel data (e.g. 2 cm). For example incorporating the data from the sunlit versus shaded sides of a shrub, as well as the shrub's shadow, to identify the shrub. The shrub is represented by possibly several thousand pixels with different reflectance spectra based on the plants physical structure and differences in reflected spectra across these different structures (barked branch vs. leaf cluster). We compared sUAS measurements to data collected from ground plots to calculate the percentage of correctly identified forbs, sage, dry grass, green grass, bare soil, and shrub-brush as metrics of sUAS classification accuracy (Table 27).

Table 27. Classification accuracies for different vegetation types across five CRP field site locations and the mean from object-based classification methods using hyperspectral image composites collected by sUAS.

Field	*Class*					
	Forb	Sage	DryGrass	GreenGrass	BareSoil	Brush
1	86.5%	86.5%	85.8%	84.0%	90.9%	83.3%
2	77.2%	75.4%	76.8%	79.6%	79.6%	76.1%
3	81.5%	80.7%	81.1%	81.1%	89.3%	80.7%
4	55.8%	64.2%	62.5%	72.3%	78.8%	66.1%
5	71.2%	70.1%	70.8%	77.3%	74.3%	75.1%
Mean	74.5%	75.4%	75.4%	78.9%	82.6%	76.3%

Further, by analyzing the hyperspectral components of the different types of vegetation classes, we can see that forb's generally have a higher reflectance in the red to near-infrared (i.e., 653-707 nm) than other 'dormant' vegetation classes, but not as high as green grass or trees (Figure 41). This suggests the red, red-edge, and near-infrared wavelength bands currently used by IDFG sUAS multispectral sensors have potential for identifying forb vegetation using sUAS image data.

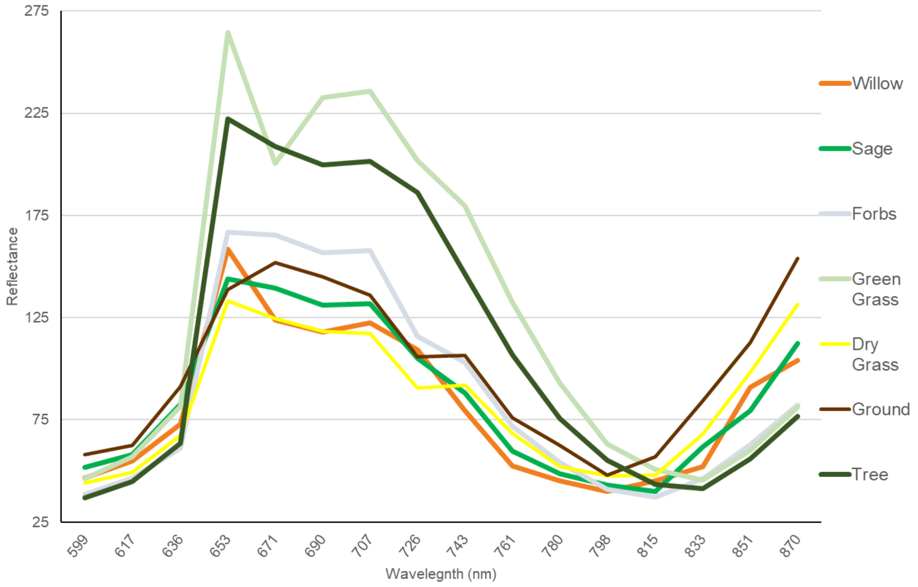


Figure 41. Comparison of wavelength reflectance curves of different vegetative groups across hyper-spectral imagery in the red to the middle infrared parts of the spectrum.

Lek Vegetation Surveys - We surveyed CSTG lek sites in southeast Idaho for the purposes of characterizing local vegetation structural composition. Columbia Sharp-tailed Grouse leks that were surveyed in 2018 where classified into groups based on their attendance numbers (zero, low = 1-10, medium = 11-20, and high = 21-30) and lek survey history (surveyed since 1988, surveyed since1998, and surveyed since 2008). Within each grouping, 4 random survey sites (3 primary, 1 alternate) were selected. The alternate was surveyed if a site was unavailable due access restrictions. There were no leks that had high attendance and had been surveyed since 1988 and only two sites with medium current lek attendance and surveyed since 1988. This resulted in a total of 31 lek sites which were surveyed for vegetation using a sUAS equipped with a multispectral camera (Figure 42). For each survey, a 150m radius around the recorded lek location where a sUAS collected multispectral image data, resulting in a survey area of approximately 20 acres. The sUAS were flown at a height of 300 feet above ground level which produced an image composite with a resolution of approximately 7cm. The resolution and image processing outputs allowed us to identify structural components of vegetation (i.e. bare-ground, grass, shrub, and trees; Figure 43).

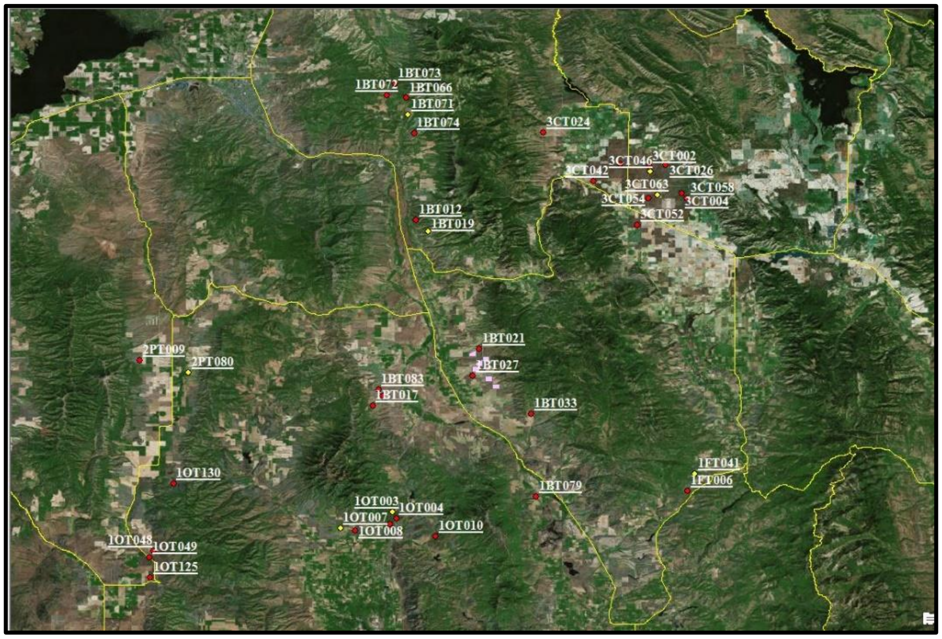


Figure 42. Columbian sharp-tailed grouse lek locations within the IDFG's Region 5 which were selected at random for vegetation surveys conducted from a sAUS using a multispectral camera. Sites in red are priority locations with yellow dots representing alternate sites for survey

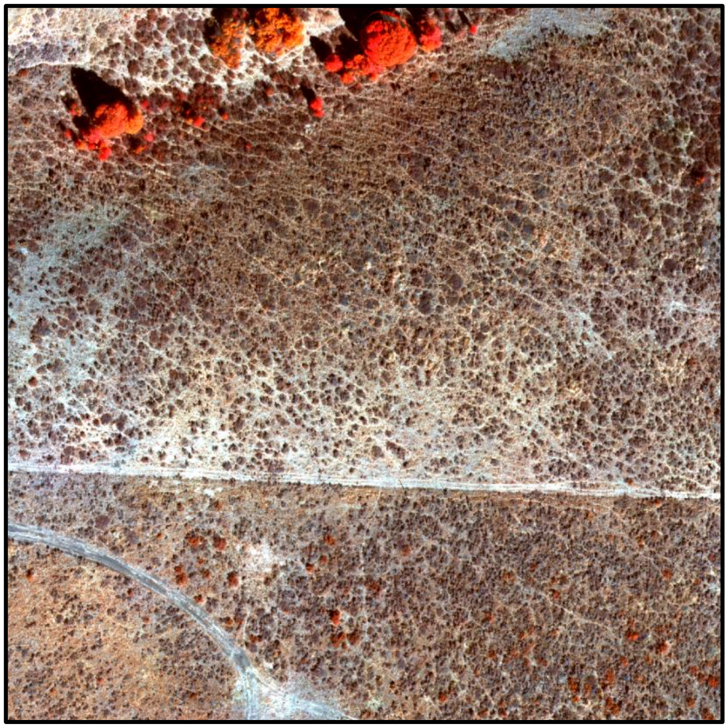


Figure 43. False-color image composite (B, G, NIR) of a native vegetation survey of a Columbian sharp-tailed grouse location in southeast Idaho. Photosynthetically active vegetation appear with a red hue.

Idaho Department of Fish & Game will continue to conduct CSTG lek vegetation surveys for an additional 30+ leks sites in the coming year. During the classification process, we will explore using the higher reflectance values of forbs in the red-edge to near infrared wavelengths to distinguish forbs from grasses. At a larger regional scale, we will classify satellite imagery from 1988 to present at 5-10 year increments to estimate the land-use transitions and composition that has occurred through time. Using local lek site vegetation characteristics and the historic satellite classification, we will then statistically test how these local and regional land-use components correlate with individual and spatially grouped CSTG lek attendance and population trajectories through time. Spatiotemporal statistical techniques such as empirical Bayesian regression prediction, emergent hot-spot, local outlier, and time-series clustering will be investigated and evaluated for data ‘mining’ these complex and spatially hierarchical patterns that may help explain CSTG lek attendance. In so doing, we hope to disentangle local lek site conditions from regional composition, so that site specific land management can be evaluated for its efficiency relative to CSTG population performance.

Sand Creek CSTG – As described above, we planned to capture, mark, and monitor CSTG at Sand Creek in eastern Idaho to examine how they interacted with native and disturbed habitats in that landscape. This work objective was not completed for the following reasons. In summer 2018, the Grassy Ridge fire burned approximately 99,000 acres of the Sand Creek desert. This fire created a large-scale disturbance on approximately 40% of the Sand Creek desert. Since our objective in monitoring CSTG in this landscape was to get a baseline understanding of how they interact with habitat features and how that interaction affected their demographic performance (e.g., nest success, brood success, survival), continuing with this evaluation immediately after a large-scale disturbance that could significantly affect their habitat selection and population demographics could have led to erroneous results. Additionally, that fire created an opportunity to expand the work being conducted on Greater sage-grouse in that area (see *Sage-grouse Ecology in High-elevation Sagebrush Habitats* section above) to better understand the effects of large-scale fires on sage-grouse ecology and population performance. Therefore, resources were dedicated to further sage-grouse capture and monitoring instead of new CSTG capture and monitoring efforts.

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Capital Outlay Purchases

2 Camp trailers

Name, title, phone number, and e-mail address of person compiling this report:

Mark Hurley
Wildlife Research and Data Manager
Mark.hurley@idfg.idaho.gov

Shane Roberts
Principal Wildlife Research Biologist
Shane.roberts@idfg.idaho.gov

Submitted by: IDAHO DEPARTMENT OF FISH AND GAME

Approved by:

Martha Wackenhut
Federal Aid Coordinator

Toby Boudreau, Chief
Bureau of Wildlife

FEDERAL AID IN WILDLIFE RESTORATION

The Federal Aid in Wildlife Restoration Program consists of funds from a 10% to 11% manufacturer's excise tax collected from the sale of handguns, sporting rifles, shotguns, ammunition, and archery equipment. The Federal Aid program then allots the funds back to states through a formula based on each state's geographic area and the number of paid hunting license holders in the state. The Idaho Department of Fish and Game uses the funds to help restore, conserve, manage, and enhance wild birds and mammals for the public benefit. These funds are also used to educate hunters to develop the skills, knowledge, and attitudes necessary to be responsible, ethical hunters. Seventy-five percent of the funds for this project are from Federal Aid. The other 25% comes from license-generated funds.