

JOB PROGRESS REPORT

FEDERAL AID IN WILDLIFE RESTORATION

UNGULATE ECOLOGY AND POPULATION DYNAMICS

IN WASHINGTON

December 2001

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OBJECTIVE

To determine habitat use, habitat quality, population dynamics, reproductive performance, seasonal movements of select ungulate populations in Washington State.

APPROACH

Conduct field studies of select ungulate populations using radio-telemetry techniques, assessments of habitat quality, trends, population dynamics, and reproductive performance, and describe landscape features and associations within ungulate population boundaries.

Job 1. Conduct studies of mule deer population dynamics in eastern Washington.

Mule deer populations are generally assumed to be regulated by one of three potential mechanisms: density dependence, density independence, or inverse density dependence. The major objective of Study 1 is to determine which mechanism or mechanisms regulate mule deer numbers across the variety of habitats found in eastern Washington. To achieve this objective, the following hypotheses need to be tested to identify which regulatory mechanism is at work:

Primary hypothesis: Mule deer populations in eastern Washington are not regulated by density independent mechanisms (e.g., population regulation is density dependent with changes in fecundity, survival/mortality rates, body mass, age at first birth, birth interval, and dispersal contingent upon available forage).

Alternate hypothesis: Regulation of mule deer populations is density independent (e.g., not nutritionally driven or density dependent).

Alternate hypothesis: Mule deer populations are regulated by inverse density dependence (compensatory mortality patterns).

In order to complete hypotheses testing and ascertain the appropriate population regulatory mechanism for each population, information on a number of population variables is required. These variables include current measurement of reproduction and recruitment (fetal rates, fawn survival, birth interval, age at first birth), adult survival, dispersal (emigration and immigration), and habitat resources (forage quality, availability, and preferences). A number of tasks and subobjectives have been designed to guide collection of information necessary for hypothesis testing. These tasks and related progress in data collection for the last year are listed and discussed in the following section.

Task 1.1. Capture and instrument mule deer with very high frequency (VHF) and global positioning system (GPS) radio collars. Mule deer (adult females and juveniles) will be captured and marked with radio collars at select sites across eastern Washington.

A total of 74 adult female mule deer were successfully captured and instrumented with radio collars during late February and early March 2001. Twenty-six deer were captured in Chelan County (10 in Swakane Canyon, 10 above the town of Entiat, and 5 near Navarre Coulee), bringing the total number of deer wearing radio-collars to 41 in the Chelan study area. Twenty-five additional deer were marked in the southeast corner of the Colville Indian Reservation; thirty-eight deer now carry radio-collars on the south Colville study area, counting the recent captures. Twenty-three mule deer does were radio-marked within the shrub-steppe habitats of Lincoln, Whitman, and Adams Counties (One on Swanson Lakes WMA, nine at Coffee Pot Lake, five at Lakeview Ranch, and eight on the Escure Ranch-Revere WMA complex).

An additional 52 adult female mule deer were successfully captured and instrumented with radio collars in late March and early April 2001 as part of the on-going Cooperative Mule Deer Project, bringing the total number of deer radio marked during spring 2001 to 126. Twenty-one deer were captured on the Tonasket Ranger District in NE Okanogan County, six northeast of Omak Lake in SE Okanogan County on the Colville Reservation, seventeen more near Vulcan Mountain in northern Ferry County, and eight near Flagstaff Mountain on the Kettle River Ranger District in Stevens County.

When added to the 38 mule deer does captured during March 2000 (14 on the Colville Reservation study area and 20 in Chelan County), the number of deer captured and radio-marked since field studies began in February 2001 now totals 164.

Task 1.2. Measure reproductive parameters (fetal rates, fawn survival, birth interval, age at first birth) of select mule deer populations across eastern Washington. Reproductive parameter values will be determined from various sources. Fetal rates will be measured by ultrasound from re-captures of radio-marked and newly captured does. Fawn survival rates will be estimated from observations of fawns at the side of radio-marked does of known fetal rates, survival rate calculations from radio-marked fawns, and/or comparisons of mean fetal rates and results of winter and spring age and sex composition surveys (fawn:doe ratios). Birth interval and age at first birth will be measured from biannual capture of radio-marked does and captured fawns and monitoring of radio-marked female yearlings and adults, respectively.

Only pregnancy and fetal rates were estimated during the reporting period. Observed pregnancy and fetal rates, based upon sonogram examination, were 0.83 and 1.44 respectively (N=82).

Task 1.3. Measure dispersal of yearling and adult mule deer. Estimates of annual dispersal and emigration rates will be assessed from observations and comparisons of seasonal movements and home range estimations of radio-marked deer.

No formal assessments were performed during the reporting period.

Task 1.4. Determine adult survival rates. Estimates of adult survival rates will be calculated from observations of radio-marked adult does.

Observed survival rate of adult female mule deer for the entire study area was estimated to be 0.87 (N=141). Survival rates were similar between core study areas. Estimated survival rates observed on the South Colville were 0.87 (n=38); North Colville were 0.87 (n=45); Chelan were 0.91 (n=35); and the shrub-steppe study area were 0.83 (n=23).

Task 1.5. Measure age and sex composition and densities. Estimates of densities, age and sex composition on winter use areas will be determined from aerial surveys of randomly selected quadrats.

Surveys were only flown in the Chelan County portion of the study area. Results of helicopter surveys in Chelan County showed composition ratios of 78 fawns and 24 bucks per 100 does (N=1,088). Winter deer densities have not been estimated.

Task 1.6. Measure body mass indices. Body mass indices will be calculated using weight, girth, and body condition measurements.

An example of the relationship between heart girth measurements and body condition scores (in this case rump scores) from mule deer in Chelan County is shown in Figure 1. Four groupings of rump scores (1.75, 2.00, 2.24, and 2.5) become apparent regardless of heart girth; further analysis including age, pregnancy status and number of fetuses is needed before an explanation could be offered regarding these groupings. It is interesting to note that the animal with the highest rump condition score (2.5) and presumably in the best physical condition was determined to not be pregnant.

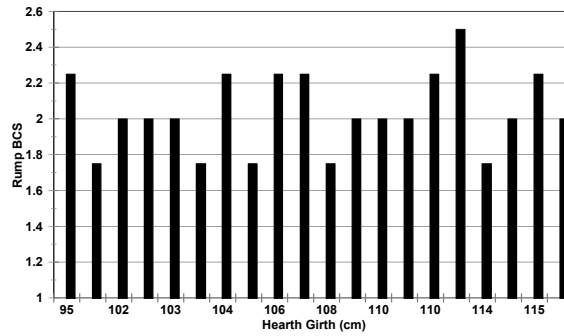


Figure 1. A comparison of spring rump condition scores with heart girth measurements from mule deer does in north central Washington in 2000.

Task 1.7. Measure seasonal forage preferences. Fecal samples will be collected seasonally from within monthly home ranges of GPS radio-marked does and sent to Washington State University's Habitat Lab (WSUHL) for analysis.

Fecal samples have been collected from all major study areas and sent to WSUHL for preliminary analysis. However, intensive collections will not begin until deer are marked with GPS radio collars.

Task 1.8. Determine seasonal forage availability and quality. GIS analysis of vegetative cover classes occurring within monthly or seasonal home ranges of GPS radio-marked and field measurements of species occurrence by percent will be performed. Major forage species will be clipped seasonally and analyzed by WSUHL to determine levels of digestible energy and crude protein.

GIS data layers of vegetative cover classes have been collated for use in producing cover maps of seasonal home ranges of individual radio marked deer. However, no ground truth of cover maps, field measurements of plant species occurrence, or clipping has occurred as yet and will not until deer are marked with GPS radio collars.

Task 1.9. Analyze data and test hypotheses.

This task will not be addressed until field data collection is completed.

Task 1.10. Compose final reports and manuscripts for peer reviewed publications.

This task will not be addressed until field data collection is completed.

Job 2. Conduct radio telemetry studies of mule deer habitat use.

There is a need to describe the landscape currently and historically used by mule deer across eastern Washington and document changes to the landscape, both natural and anthropogenic, that have affected the landscape and potentially mule deer numbers. The approach will be to map current landscape characteristics using geographic information system (GIS) technology. A historic perspective will be gained by reviewing records of existing conditions, study plots, and exclosures/enclosures. Some historic LANDSAT data are available which would document landscape changes over the last 30 years. Models using current vegetative conditions and work back in time may provide a view of landscape conditions up to 100 years ago and less.

Current habitat use patterns will be determined from observations of movements by radio marked deer. Both univariate and multivariate analysis of deer locations, nutritional indices, deer densities, and associated landscape characteristics (vegetation, topography, hydrology, anthropogenic features) will furnish inputs for development of habitat use and carrying capacity models. These models will be the basis for exploring current and historic habitat suitability and potential.

Task 2.1. Develop GIS maps and data layers.

To date, multiple GIS data layers have been acquired from a variety of sources including WDFW files, USFS, Washington State Department of Natural Resources (WDNR), United States Fish and Wildlife Service (USFWS), CCT, and BLM. These data layers include current and historic vegetation cover maps, hydrologic and topographic features, transportation, urban/suburban development, and other anthropogenic manifestations. GIS data are being re-projected into standard datum and projections for use by all cooperators.

Task 2.2. Evaluate GPS radio collar accuracy under varying canopy coverage. Tests will be conducted to measure time required to obtain location fix, accuracy of fixes, and fix obtainability under varying canopy coverage, slope, aspect, and ski views. A model will be developed to treat location result data so as to minimize bias in habitat use measurements.

A study plan to evaluate GPS radio collar accuracy has been developed (See Appendix B) and preliminary field testing conducted. Final evaluations will be completed and reported in the next progress report.

Task 2.3. Measure habitat use at varying spacial levels. Using GIS technology, deer locations will be correlated with attribute information using univariate and multivariate analysis to determine habitat preferences and use patterns at varying levels of spacial scale (individual, home range, herd, subpopulation, community, and landscape).

Winter Range Assessment

Protocols were developed for sampling vegetation on select winter and summer use areas. For sampling purposes, the winter range was stratified into the following categories:

- High elevation winter range (2500 to 4000 feet)
- Low elevation winter range (< 2500 feet)
- North aspect (271 – 45 degrees)
- East (46 – 135 degrees)
- West (136 – 225 degrees)
- South (226 – 270 degrees)

Using digital elevation model (DEM) data, sample polygons were created using a computer geographic information system (GIS) based on the above stratifications. Total area and coordinates (UTM) at the center were determined for each polygon. Polygons within a given stratification category were summed to calculate the total area. Percentages were determined by dividing the total areas for each stratification category by the total sample. This percentage was applied to the sampling distribution to maintain proportionality. In each stratified category, sites to be sampled were selected randomly.

An intended sampling strategy was to select sampling locations within areas disturbed by fire including the 1988 Dinkleman Burn and 1994 burn areas. However, this was not specifically achieved due to difficulties with the production of the GIS map. Due to the number of wildfires early in the season U.S. Forest Service (USFS) personnel within the GIS were unable to complete the map necessary for this project within a reasonable time frame. Other USFS personnel were created the GIS map and the two fires were omitted. The up-shot was that the burned areas were included due to the random sampling design.

A line-intercept method was used to gather the following information:

- Cover of herbaceous vegetation
- Cover of shrubs
- Cover of Trees

Cover categories were created to species level for trees, woody shrubs, and know species of herbaceous plants highly used by mule deer during winter as documented in Burrell (1977). Other herbaceous material and grasses were lumped together into two respective categories. Soil, rock and detritus were placed in the category labeled “other”.

Cover Sampling Methods

1. Random polygon UTM coordinates were generated within GIS mapped and proportionally selected as compared to the availability, and navigated to using GPS (accuracy approximately 10 – 15 meters).
2. A 50 meter transect began at the UTM coordinate and was ran along a randomly (generated from a 0 – 360 random number table) selected azimuth.
3. Every two-meter section within the 50 meter transect was evaluated for coverage of each species category. Coverage was determined by the amount of a specific species crossing the tape within that section.
4. All categories summed to at least 100 percent total coverage of the two-meter section with many sections being well beyond 100 percent due to multi-layered canopies.
5. All data was stored in a specific category and lumped into more general categories depending on the analysis purposes.

Shrubs Productivity

Current productivity of bitterbrush was evaluated by measuring the current season growth on unbrowsed leaders, number of leaders per shrub, and the overall dimensions of the shrub. Plants were selected by using the first two plants located on the 50 meter transect. If one or no plants were found on a transect then transects were rotated clockwise around the axis of the UTM coordinate and the first two bitterbrush plants within this radius were included in the sample. If only one plant was located within the site then only one was recorded and noted.

Shrub Productivity Method

1. Plants crown cover was measured in two directions and multiplied to determine the area of the crown cover.
2. Leader counts were taken in quadrants of the plant. The plant was sectioned into North, South, East and West quadrants and all leaders were counted within each quadrant.
3. Leaders were clipped, five from each quadrant, and placed in a plastic zip lock bag. All 20 leaders were placed in the same zip lock bag. Some plants did not have five leader in each quadrant, therefore whatever was in the quadrant was sampled.
4. Bags were marked with the site and plant number for later data collection.
5. Leaders were measured to compare and add to previous data collected by Chelan County PUD.
6. Leaders were then placed in an oven at 55-60 degrees Celsius for 5 days, then weighed and replaced back in the oven for 2 more days and reweighed to determine a dry weight mass.

Productivity of Herbaceous Vegetation (done following cover estimates)

1. At 25 meter and 50 meter points along the transect a 1 meter square was placed to the left of the transect.
2. All above ground herbaceous vegetation was clipped and placed within a bag that was marked with the site number, date, and meter location.
3. In the lab, bags were placed in the oven at 55 – 60 degrees Celsius for 5 days, then weighed and replaced back in the oven for 2 more days and reweighed to determine a dry weight mass.

A total of 57 sites were surveyed for vegetation species and percent frequency across the winter use areas, and 48 bitterbrush plants were sampled for productivity.

Summer Range Vegetation Assessments

Coordinates of marked deer locations provided the sample sites for vegetation assessment of summer use areas. At each site, percent canopy cover was estimated and over-story plant species were identified. Similarly, under-story plant species and percent frequency were noted. Photo records were taken of each site.

Thirty-six sites within the summer use area were investigated to determine species composition and percent cover.

GIS and Home Ranges

Literature was reviewed for methods to create a GIS cover of topographic position to use to objectively describe and quantify this aspect of habitat use for future habitat modeling efforts. A cover of relative slope position has been created using a digital elevation model that quantifies topography on a scale of 0 (drainages) to 100 (ridgeline). Refinements are being made to this cover and when completed it will be used to create a topographic position cover that identifies ridges, flats, upper-mid-lower slopes, and valleys or drainages. Attempts have been made to create solar insolation covers using Solar Analyst (Helios Environmental Modeling Institute, LLC) for describing habitat use and for habitat modeling, but were terminated early due to extremely long processing time. Alternative methods for creating solar insolation covers will be pursued.

Minimum convex polygons (Table 1), distances between successive locations, and time between locations for select radio marked deer were calculated in ArcView (Environmental Systems Research Institute, Redlands, CA) for relocations between April and August 2001 using the Home Range Extension. Distance and time between locations were standardized to distance per week to determine average, minimum, and maximums for each month (Table 2). Long movement coupled with relatively localized areas of concentrated activity suggests that several of the deer captured may be migratory by definition that they may have discrete winter and summer ranges.

Table 1. Home range estimates using minimum convex polygon (MCP) area for mule deer in north central Washington, April-August 2001.

Id_No	Frequency	Number Of Observations		Mcp Acres	Mcp Hectares
		Used			
CL01	150.1990	12.0000		504	204
CL02	149.8290	13.0000		1254	508
CL03	148.7810	10.0000		4933	1996
CL04	149.2800	10.0000		517	209
CL05	149.9510	9.0000		1637	663
CM01	148.6900	11.0000		3036	1228
CM02	148.2600	11.0000		3460	1400
CM03	149.6400	12.0000		2777	1124
CM04	149.9830	13.0000		481	195
CM05	150.3700	13.0000		2614	1058
CY01	151.4000	13.0000		7842	3174
CY03	150.5190	14.0000		20259	8199
CY06	149.7310	6.0000		42230	17090
CY07	150.6400	5.0000		8420	3407

Id No	Frequency	Number Of Observations		Mcp Acres	Mcp Hectares
		Used			
CY08	149.9710	11.0000		5398	2184
CY10	150.0420	12.0000		4475	1811
MR01	149.6300	11.0000		14368	5815
OM01	148.3800	6.0000		47	19
OM02	148.3300	6.0000		781	316
OM03	148.4000	6.0000		787	319
OM04	148.1400	6.0000		607	246
OM05	150.3000	6.0000		3081	1247
OM06	149.8920	6.0000		1509	611
Total		222.0000		131017	53023
Average		9.7		5696.4	2305.3

Table 2. Average distance moved per week for each month, April-August, by radio marked mule deer in north central Washington

	April 2001	May 2001	June 2001	July 2001	August 2001
Average	4.87	3.04	5.59	2.93	3.35
Minimum	0.13	0.03	0.10	0.15	0.18
Maximum	22.10	31.24	33.49	20.46	17.40

Task 2.4. Assess potential interspecific competition with sympatric ungulates. Using GIS technology, an analysis of interspecific competition between sympatric ungulates to determine potential impacts to mule deer numbers and reproductive performance. Potential impacts will be assessed by comparing range over-lap, relative densities, available forage estimates, and nutritional requirements between mule deer and sympatric ungulates. Density estimates and nutritional requirements of sympatric ungulates will be acquired from existing literature and WDFW file data.

No work was performed under Task 2.4 during this reporting period.

Task 2.5. Assess historic landscape conditions and mule deer densities. Historic landscape conditions will be described by reviewing records of existing conditions, study plots, and exclosures/enclosures as well as analyzing historic LANDSAT data. Models that use current vegetative conditions and work back in time may provide a view of landscape conditions up to 100 years ago and less. Similarly, historic information of mule deer densities will be acquired from agency (WDFW and USFS) records and other sources as available. Newly developed nutritional carrying capacity models will also be employed to estimate mule deer densities using descriptions of landscape conditions derived from modeling.

Data base development of historic information on mule deer numbers and landscape conditions was initiated during this reporting period. No analysis has been performed.

Task 2.6. Develop predictive models for habitat use, suitability, and nutritional carrying capacity. Using results from Task 2.3, predictive models will be developed for use in present and future development and management of mule deer habitats.

This task will not be addressed until field data collection is completed.

Job 3. Conduct studies of physical condition of mule deer in eastern Washington.

Mule Deer Nutrition, Body Condition, and Reproduction

Laboratory studies will be conducted at WSU under the direction of Dr. L. Shipley and Dr. C. Robbins using captive mule deer in feeding trial experiments. Lab experiments will address the effects of digestible energy intake and body fat composition on lactation, fawn growth, and estrus. Experimental data will be used to develop quantitative body condition and reproductive indices for mule deer that may be applied in the field to assess body condition on live, free-ranging mule deer.

Task 3.1.1. Obtain mule deer for lab studies. Free-ranging mule deer fawns will be obtained from several sources: a) captures targeted from neonate mule deer, b) orphaned fawns held by state licensed wildlife rehab facilitates, and c) off-spring from other study animals.

A total of 10 neonate mule deer were turned over to wildlife rehab facilitates and are now being hand raised for future use in lab studies at WSU. One adult mule deer buck is also being held for these studies.

Participating Personnel

The following personnel contributed significantly to The Cooperative Mule Deer Study during the reporting period:

W. Myers, WDFW	J. Priest, CCT	S. Zender, WDFW
J. Agee, UW	P. Fielder, CCPUD	D. Base, WDFW
K. Raedeke, UW	T. West, CCPUD	T. McCall, WDFW
R. Wielgus, WSU	S. Kreiter, CCPUD	S. Luttich, USFS
L. Shipley, WSU	W. Moore, CWU	G. Paulsen, BLM
C. Robbins, WSU	A. Gibson, UW	T. Moore, WVSD
C. Kallstrom, UI	B. Hall, WDFW	B. McCall, INWC/BHF
T. Jafari, CCT	W. Emmel, INWC	

Job 4. Conduct moose telemetry studies and translocation from urban/suburban areas.

Six moose were (four cows and two calves) captured within urban/suburban areas in and around Spokane and translocated to remote areas northern Spokane County, southern Pend Oreille County, or southern Ferry County. One cow-calf pair which that were translocated to northern Spokane County moved back into a suburban area north of Spokane. This pair was re-captured and translocated a second time to southern Pend Oreille County; they then returned to an area near where they were originally captured in the Spokane Valley and have remained in that area but have not become a nuisance to area residents. Regular monitoring of twenty radio-marked moose to measure movements and habitat use continued during the reporting period.

Job 5. Conduct evaluations of ungulate survey techniques.

No activities were conducted under Job 5.

Job 6. Conduct evaluations of DNA techniques to determine genetic signatures and abundance of local ungulate populations.

WDFW Final Report provided under separate enclosure

Job 7. Conduct manuscript composition of peer reviewed publications, technical bulletins, progress/completion reports, and symposia presentations.

The following two manuscripts (Appendix A and B) were written in 2001 as part of the mule deer ecology study documented in Jobs 1-3 above. These manuscripts contain preliminary information and should not be cited without permission of the authors.

Appendix A. The Cooperative Mule Deer Project Study Plan:

A Multi-Agency Approach to Determine Population Regulation and Habitat Use Patterns by Mule Deer in Eastern Washington.

Written by Woodrow. L. Myers.

Problem Statement

Management of mule deer populations in much of the mountainous, foothill and shrub steppe regions of north central (NC) and northeast (NE) Washington State has been complicated due to changes in population density. Although some of these changes likely relate to current and long term trends in habitat capacity for mule deer, population harvesting is still the largest direct mortality factor acting on population demographics. Population management in Washington generally follows a density dependent model, where hunting mortality is assumed to be compensatory to other mortality factors (e.g., as hunting harvest increases, natural mortality declines). This model, developed primarily from white-tailed deer population dynamics, allows hunters to harvest both the annual production of the population and a portion of the annual mortality normally expressed in other areas (e.g., disease, predation, etc) in the harvest; the result is a sustainable annual harvest larger than that based on annual production alone. In Washington and other areas, however, mule deer harvests have historically not been sustainable; similar regulations tend to result in very different population responses (i.e., under-harvest vs. over-harvest). The general trend has been a declining mule deer harvest and resource, resulting in more stringent harvest regulations, buck harvest strategies of questionable value, and dissatisfaction of the general and hunting public over the state of the resource.

How well mule deer populations actually fit the density dependent model is questionable. As a general rule, populations which are compressed (either by man made or natural barriers, or by their own numbers distributed functionally uniformly across the landscape) exhibit strong density dependent regulation and, therefore, have the capacity for compensatory mortality. Alternatively, populations which regulate by dispersal (usually populations associated with more patchy habitat distribution across the landscape) tend to show much weaker density dependence, and thus a much lower potential for any mortality factor to be compensatory, since mortality rates are closer to minimal chronic levels.

Studies assessing mule deer regulatory dynamics are rare. In Colorado, Bartman et al. (1992) found mortality in mule deer to be density dependent and thus potentially compensatory. These studies were done in contiguous high quality habitat and with a confined (compressed) population, characteristics which favor the expression of density dependence. In contrast, Wood et al. (1989) found hunting mortality to be additive in mule deer in the foothills of eastern Montana. This population was characterized by patches of high quality habitat dispersed in a landscape of lower quality habitat; mule deer apparently regulated through dispersal amongst the patches. Based on this limited evidence, regulation in mule deer populations appears to be tied to the characteristics of the habitat at the landscape level. Patchy habitat may favor a regulatory mechanism based on weak density dependence and dispersal, while contiguous uniform quality habitat results in compression by deer distribution and strong density dependence. Since strong density dependence is a prerequisite for hunting mortality to be compensatory, the nature of regulation in NC and NE mule deer populations is key to proper harvest management.

Complicating population management is the role of habitat in mule deer dynamics. Both population management and habitat quality can affect deer numbers in a proximate sense. However, the ultimate determinant of deer numbers across a landscape is habitat quantity (Mautz 1978, Guthery 1997). Anecdotal evidence suggests that mule deer numbers were once substantially greater in eastern Washington than at present. Although the current intensity of human harvest is likely much greater than in the early and mid 1900's, landscape level habitat features have also changed dramatically. Thus, the ultimate ability of the landscape to support mule deer may have changed irrespective of harvest intensity. Currently, no long-term habitat assessment exists in Washington for mule deer. Since both the hunting and nonhunting public often desire a return to "the good old days" of large healthy populations, it is necessary to contrast past levels of mule deer habitat with current, to determine whether the landscape has the capability of supporting greater numbers of deer than currently seen.

The interaction of direct mortality (which is primarily human caused), habitat quality, and habitat quantity ultimately will determine mule deer habitat capacity and realized population size and harvest. If the overall landscape quantity of mule deer habitat has significantly declined over the past century, mule deer numbers will never again reach historic levels, barring the development of new habitat. Within the quantity of habitat present, population demographics will be dictated by recruitment, mortality, and habitat distribution. If current mule deer habitat at the landscape level consists of a mosaic of high quality patches interspersed in a low quality matrix, mule deer likely regulate through dispersal, density dependence is minimized, and hunting mortality is only weakly compensatory or additive. The harvestable surplus of the population consists solely of annual production, since mortality levels are near the minimum. Since annual production is the most vulnerable population segment, annual sustainable yields can vary significantly dependent upon survival of the annual production. Mortality of the annual cohort tends to be partitioned into heavy early (summer) density independent mortality (disease, drought, accidents, predation) and comparatively minor late (winter) density dependent mortality; harvestable surplus is thus critically dependent upon those

individuals who survive the chronic summer mortality period. These individuals face a variety of potential mortality factors during their first winter, primarily density dependent affects which can be minimized by maximizing per capita resource availability (e.g., habitat quality). However, infrequent but critical density independent affects such as severe winters can result in the loss of the entire cohort. In this situation, harvesting becomes entirely additive and populations will decline even in the face of very limited harvests. Thus, it is critical that a model of harvestable surplus include a sensitive weather and habitat quality index.

In the alternative sustained yield model, if current mule deer habitat is fairly homogenous across the landscape, the population will be compressed by its own numbers and regulation will be strongly density dependent. Since strong density dependence implies increased survival as density declines, mortality factors are compensatory and deer mortality normally allocated to factors other than harvesting can be "captured" in the harvest. The harvestable surplus thus consists of both the annual production and mortality that can be captured from other causes. Since the harvestable surplus includes other contributions beyond the annual production, it is less sensitive to vagaries in the annual production and may be lower than an additive level even in the loss of an entire annual cohort. Under this scenario, deer populations are more stable, more responsive to harvest management, less influenced by other mortality and weather affects, and produce much higher annual sustainable yields. In reality, mule deer dynamics in Washington state likely rest somewhere between the two extremes in sustained yield models described above. It is the level of density dependence exhibited by the population, as influenced by the landscape level habitat patterns and relative quality, that determine the extent of density dependence and thus the level of the sustainable harvest.

Very little information is available on the dynamics of mule deer, and no information on regulatory mechanisms or landscape level habitat relationships is available in Washington. Currently, population management of mule deer is very imprecise due to this lack of knowledge. As a consequence, mule deer numbers are low and harvest opportunity is severely restricted throughout much of Washington. The interaction of regulatory mechanisms and landscape level habitat characteristics is critical to develop a sustainable yield harvest model for mule deer in Washington. The major project goal is to document the nature of these interactions and consolidated them into a management tool if mule deer populations are to be properly managed for long term health, stability, and sustained yield in Washington. Given that, the objectives of this project can be divided into three major areas: 1) Determine the nature of mule deer population dynamics and regulation; 2) Measure landscape level habitat use characteristics; and 3) Assess the influences of nutrition and body condition upon reproduction. Ultimately, development of a mule deer harvest management model which incorporates population regulation mechanisms, habitat quality, and nutritional carrying capacity is the expect result.

A project covering such a broad level of study and geographic area requires the involvement and cooperation of a number of individuals, agencies, and institutions. Field and laboratory work will be conducted by scientists, biologists, and students from the Washington Department of Fish and Wildlife (WDFW), Colville Confederated Tribes (CCT), Chelan County Public Utility District (CCPUD), University of Washington (UW), Washington State University (WSU), Central Washington University (CWU), University of Idaho (UI), the United States Forest Service (the Colville, Okanogan, and Wenatchee National Forests) and Bureau of Land Management (BLM) with assistance from high school and middle school students and teachers from school districts across eastern Washington and volunteers from the Inland Northwest Wildlife Council (INWCV). Funding is being provided by the WDFW, CCT, CCPUD, WSU, INWC, the Bonneville Power Administration (BPA), Colville National Forest (CNF), Okanogan National Forest (ONF), Wenatchee National Forest (WNF), and the West Valley School District (EVSD).

Part 1. Mule Deer Population Regulation

It is generally assumed that deer populations are regulated by one of three potential mechanisms: density dependence, density independence, or inverse density dependence. It is a major objective of this project to determine which mechanism or mechanisms regulate mule deer numbers across the variety of habitats found in eastern Washington. To achieve this objective, the following hypotheses will be tested:

Primary hypothesis: Mule deer populations in eastern Washington are not regulated by density independent mechanisms (e.g., population regulation is density dependent with changes in fecundity, survival/mortality rates, body mass, age at first birth, birth interval, and dispersal contingent upon available forage).

Alternate hypothesis: Regulation of mule deer populations is density independent (e.g., not nutritionally driven or density dependent).

Alternate hypothesis: Mule deer populations are regulated by inverse density dependence (depensatory mortality patterns).

Predictions

As forage resources increase or density decreases, the following responses in measured parameters from lab studies, within populations, and among populations would be expected:

Parameter	H₀ (DD)	H₁ (DI)	H₂ (IDD)
Fetal Rates	<i>Increase</i>	<i>No Change</i>	Decrease
Fawn Survival Rates	<i>Increase</i>	<i>No Change</i>	<i>Decrease</i>
Body Mass Index	<i>Increase</i>	<i>No Change</i>	<i>Decrease</i>
Birth Interval	<i>Decrease</i>	<i>No Change</i>	<i>Decrease</i>
Age at First Birth	<i>Decrease</i>	<i>No Change</i>	<i>Decrease</i>
Dispersal Rates	<i>Decrease</i>	<i>No Change</i>	<i>Increase</i>
Adult Survival Rates	<i>Increase</i>	<i>No Change</i>	<i>Decrease</i>

Definitions:

Compensatory mortality and reproduction:

As harvest rates increase, natural mortality rates decrease.

As harvest rates increase, reproductive success increases (e.g., fetal rates, fawn survival rates, and body mass increases while birth interval and age at first birth decreases).

Additive mortality and reproduction:

As harvest rates increase, natural mortality and reproductive parameters remain unchanged and unrelated.

Depensatory mortality and reproduction:

As harvest rates increase, natural mortality increases and reproductive parameters decrease.

Field Methods for Reproduction Parameters

Fetal (Maternity) Rates: Measured by ultrasound from newly captured does and re-captures of radio-marked does.

Fawn Survival Rates: Measured from observations of fawns at the side of radio-marked does of know fetal rates, survival rate calculations from radio-marked fawns, and/or comparisons of mean fetal rates and results of winter and spring age and sex composition surveys (fawn:doe ratios).

Body Mass Index: Weights of re-captured radio-marked and newly captured does, manual body condition scores, and biannual ultrasound measurements of subcutaneous fat deposits and muscle catabolation.

Birth Interval: Measured from biannual capture of radio-marked does.

Age at First Birth: Captured fawns and monitoring of radio-marked female yearlings and adults.

Dispersal: Measured from movements and home range estimations of radio-marked fawns and yearlings.

Adult Survival Rates: Estimated from observations of radio-marked adult does.

Field Methods for Diet and Nutritional Analysis

Study animals: Diet and nutritional analysis will be limited to study of adult does wearing GPS radio collars.

Physical Condition: Biannual ultrasound measurements of subcutaneous fat deposits and body condition scores.

Seasonal Forage Preferences: Fecal samples collected seasonally from within monthly or seasonal home ranges of radio-marked does.

Seasonal Forage Availability: GIS analysis of vegetative cover classes occurring within monthly or seasonal home ranges of radio-marked does and field measurements of species occurrence by percent.

Seasonal Forage Quality: Major forage species will be clipped seasonally and analyzed to determine levels of digestible energy and crude protein.

Statistical Analysis

An analysis of covariance (ANCOVA) and repeated measures ANCOVA will be performed to assess the relationships between the following covariates, assuming area effects between populations. A repeated measures ANCOVA will be applied to measure the relationship between these covariates within populations.

Harvest rates – independent variable
Densities – independent variable
Mortality rates – dependent variable
Reproductive parameters – dependent variable

If no area effect is detected, a regression analysis will be performed.

Population Regulation Study Tasks

Objective: Determine population regulation mechanisms used by mule deer in eastern Washington.

Task 1.1. Capture and instrument mule deer with very high frequency (VHF) and global positioning system (GPS) radio collars. Mule deer (adult females and juveniles) will be captured and marked with radio collars at select sites across eastern Washington. Task to be completed by WDFW, CCT, CCPUD, CNF, ONF, WNF, BLM, and INWCV.

Task 1.2. Measure reproductive parameters (fetal rates, fawn survival, birth interval, age at first birth) of select mule deer populations across eastern Washington. Reproductive parameter values will be determined from various sources. Fetal rates will be measured by ultrasound from re-captures of radio-marked and newly captured does. Fawn survival rates will be estimated from observations of fawns at the side of radio-marked does of known fetal rates, survival rate calculations from radio-marked fawns, and/or comparisons of mean fetal rates and results of winter and spring age and sex composition surveys (fawn:doe ratios). Birth interval and age at first birth will be measured from biannual capture of radio-marked does and captured fawns and monitoring of radio-marked female yearlings and adults, respectively. Task to be completed by WDFW.

Task 1.3. Measure dispersal of yearling and adult mule deer. Estimates of annual dispersal and emigration rates will be assessed from observations and comparisons of seasonal movements and home range estimations of radio-marked deer. Task to be completed by WDFW.

Task 1.4. Determine adult survival rates. Estimates of adult survival rates will be calculated from observations of radio-marked adult does. Task to be completed by WDFW.

Task 1.5. Measure age and sex composition and densities. Estimates of densities, age and sex composition on winter use areas will be determined from aerial surveys of randomly selected quadrats. Task to be completed by WDFW.

Task 1.6. Measure body mass indices. Body mass indices will be calculated using weight, girth, and body condition measurements. Task to be completed by WDFW.

Task 1.7. Measure seasonal forage preferences. Fecal samples will be collected seasonally from within monthly home ranges of GPS radio-marked does and sent to Washington State University's Habitat Lab (WSUHL) for analysis. Task to be completed by WDFW, WSUHL, CNF, ONF, WNF, BLM, WVSD, and other School Districts.

Task 1.8 Determine seasonal forage availability and quality. GIS analysis of vegetative cover classes occurring within monthly or seasonal home ranges of GPS radio-marked and field measurements of species occurrence by percent does will be performed. Major forage species will be clipped seasonally and analyzed by WSUHL to determine levels of digestible energy and crude protein. Task to be completed by WDFW, WSUHL, CNF, ONF, WNF, BLM, WVSD, and other School Districts.

Task 1.9. Analyze data and test hypotheses. Task to be completed by WDFW and WSU.

Task 1.10. Compose final reports and manuscripts for peer reviewed publications. Task to be completed by WDFW and WSU.

Part 2. Landscape Level Habitat Use Characteristics

There is a need to describe the landscape currently and historically used by mule deer across eastern Washington and document changes to the landscape, both natural and anthropogenic, that have affected the landscape and potentially mule deer numbers. The approach will be to map current landscape characteristics using geographic information system (GIS) technology. A historic perspective will be gained by reviewing records of existing conditions, study plots, and exclosures/enclosures. Some historic LANDSAT data are available which would document landscape changes over the last 30 years. Models using current vegetative conditions and work back in time may provide a view of landscape conditions up to 100 years ago and less.

Current habitat use patterns will be determined from observations of movements by radio marked deer. Both univariate and multivariate analysis of deer locations, nutritional indices, deer densities, and associated landscape characteristics (vegetation, topography, hydrology, anthropogenic features) will furnish inputs for development of habitat use and carrying capacity models. These models will be the basis for exploring current and historic habitat suitability and potential.

Task 2.1. Develop GIS maps and data layers. GIS data layers will be created from current and historic vegetation cover maps, hydrologic and topographic features, transportation, urban/suburban development, and other anthropogenic manifestations. Tasks will be completed by WDFW, CNF, ONF, WNF, CCPUD, BLM, and WWSA.

Task 2.2. Evaluate GPS radio collar accuracy under varying canopy coverage. Tests will be conducted to measure time required to obtain location fix, accuracy of fixes, and fix obtainability under varying canopy coverage, slope, aspect, and ski views. A model will be developed to treat location result data so as to minimize bias in habitat use measurements. Task will be completed by WDFW, ONF, and UI.

Task 2.3. Measure habitat use at varying spatial levels. Using GIS technology, deer locations will be correlated with attribute information using univariate and multivariate analysis to determine habitat preferences and use patterns at varying levels of spatial scale (individual, home range, herd, subpopulation, community, and landscape). Task will be completed by WDFW.

Task 2.4. Assess potential interspecific competition with sympatric ungulates. Using GIS technology, an analysis of interspecific competition between sympatric ungulates to determine potential impacts to mule deer numbers and reproductive performance. Potential impacts will be assessed by comparing range over-lap, relative densities, available forage estimates, and nutritional requirements between mule deer and sympatric ungulates. Density estimates and nutritional requirements of sympatric ungulates will be acquired from existing literature and WDFW file data. Task will be completed by WDFW, CNF, ONF, WNF.

Task 2.5. Assess historic landscape conditions and mule deer densities. Historic landscape conditions will be described by reviewing records of existing conditions, study plots, and exclosures/enclosures as well as analyzing historic LANDSAT data. Models that use current vegetative conditions and work back in time may provide a view of landscape conditions up to 100 years ago and less. Similarly, historic information of mule deer densities will be acquired from agency (WDFW and USFS) records and other sources as available. Newly developed nutritional carrying capacity models will also be employed to estimate mule deer densities using descriptions of landscape conditions derived from modeling. Task will be completed by WDFW, CNF, ONF, WNF.

Task 2.6. Develop predictive models for habitat use, suitability, and nutritional carrying capacity. Using results from Task 2.3, predictive models will be developed for use in present and future development and management of mule deer habitats. Task will be completed by WDFW and UI.

Part 3. Mule Deer Nutrition, Body Condition, and Reproduction

Laboratory studies will to be conducted at WSU under the direction of Dr. L. Shipley and Dr. C. Robbins using captive mule deer in feeding trial experiments. Lab experiments will address the effects of digestible energy intake and body fat composition on lactation, fawn growth, and estrus. Experimental data will be used to develop quantitative body condition and reproductive indices for mule deer that may be applied in the field to assess body condition on live, free-ranging mule deer.

Task 3.1.1. Obtain mule deer for lab studies. Free-ranging mule deer fawns will be obtained from several sources: a) captures targeted from neonate mule deer, b) orphaned fawns held by state licensed wildlife rehab facilitates, and c) off-spring from other study animals. Task to be completed by WDFW, WSU, INWCV, CNF, ONF, and WNF.

Task 3.1.2. Develop experimental diets that mimic the range of nutrition available to free-ranging mule deer for use in feeding trials. Three pellet diets will be developed to simulate high, medium, and low digestible energy (DE) content of summer and fall mule deer range forage within the Columbia Plateau in Northeastern Washington. The high-quality diet will be designed so as not to limit performance by fawns and does based on predictions from the livestock literature. The lowest-quality diet will mimic the lowest level of nutrition encountered by mule deer in the study area during summer and fall. The medium level will reflect the minimum required by a lactating mule deer. To design these diets, fecal samples collected from free-ranging mule deer in the study area during early summer, late summer, and fall in Year 1 will be analyzed to determine seasonal diet composition. Microhistological analyses of feces will be conducted at the Wildlife Habitat Lab at Washington State University. To determine the forage quality of dietary components, forage samples will be collected and analyzed, by season, for crude protein content (Kjeldahl analysis), fiber composition (Neutral Detergent Fiber analysis), and in vitro digestibility. Samples will be analyzed at the Wildlife Habitat Lab. Based on similar studies with elk in the Blue Mountains in Oregon, these diets will most likely span the range of 2.3 – 3 kcal/g digestible energy. Study pellet diets will be developed at

the Feed Mill at WSU. During Year 2, actual in vivo digestibility will be determined by conducting a 5 day complete balance digestion trial for each diet using 5 captive female mule deer. Before the trial, animals will be gradually introduced to the diet over 2 weeks, and experience a 5 day pretrial in the digestion crates. During the trial, food offered and remaining will be weighed and corrected for dry matter. Feces and urine will be collected. Food, feces, and urine will be analyzed for energy (bomb calorimetry) and protein (Kjeldahl analysis) at the Wildlife Habitat Lab. Digestible energy digestibility will be calculated. Task to be completed by WSU.

Task 3.1.3. Conduct summer-fall feeding trials with lactating females and fawns. We will acquire 50 fawns (at least 45 females and 5 males) during Year 1 of the project by directly capturing them on the study site and by collecting orphans routinely acquired by wildlife rehabilitators and agencies in the area. These fawns will be hand-reared and trained to experimental protocol. These animals will be bred during their second fall. In Year 3, we will select 30 doe/fawn pairs to participate in the feeding trials. Doe/fawn pairs will be randomly assigned a feeding treatment (10 each for high, medium, or low DE intake based on the diets created in Task 1). All pairs will be fed on the high DE diet from January through June. Starting in late June (or after all fawns are born), animals in the high-DE group will be fed at the original level. Animals in the medium and low-DE treatments will be gradually reduced to their low DE intake diets, reaching a low in October. Treatments will continue through November. Each doe and fawn will be weighed weekly, and body condition assessed bi-monthly using the DEXA unit at WSU Veterinary Teaching Hospital, Bioelectric Impedance Analysis, ultrasound, various condition index scoring systems, and serum metabolites. Daily intake will be monitored for all animals. Starting in mid-October, fecal samples will be collected weekly, and from November-December they will be collected daily, and analyzed for fecal progesterone, an indicator of estrus using radio-immunoassay (Monfort et al. 1993) at the Center for Reproductive Biology, Hormone Assay Core at WSU. Trials will continue through November, and will be repeated in Year 4 of the study with 2-year-old females with fawns. Body condition, doe/fawn weights, lactation duration, and estrus rates and times will be compared among 3 nutritional treatments using analysis of variance and analysis of covariance. Body fat requirements for estrus to occur in lactating females will be calculated. In elk, a body fat content of 6% is required for lactating females to show estrus the following fall. We expect a similar result for mule deer does. All protocols will be first approved by WSU's Institutional Animal Care and Use Committee. Task to be completed by WSU.

Task 3.1.4. Disseminate information gathered from experiments. Findings will be synthesized and submitted to a peer-reviewed scientific journal in Year 4 and made available to all resource management agencies, tribes, universities, and private citizens through web based electronic mail. Presentations on findings will be made during years 3-5. Task to be completed by WSU.

Task 3.2.1. Examine the correlation between common condition indices that may be used on live mule deer with direct measurement of total body fat. During Year 4, the body fat composition of each animal on the 3 feeding treatments above will be assessed bi-monthly from June through November using 5 noninvasive (or mildly invasive) methods – Bioelectric Impedance Analysis, ultrasound, DEXA unit, serum metabolites, and condition scores. At the end of November, 5 animals in each treatment group representing the greatest range of body condition will be returned to the high quality diet for 7 days. They will then be euthanized, shaved, and ground in the whole body grinder at Colorado State University to determine total body fat. Fat content of the carcass will be determined using petroleum ether extract in a Soxhlet apparatus (Association of Agricultural Chemists 1984) at the Wildlife Habitat Lab at WSU. Body condition estimates from the 5 noninvasive measurements will be correlated with total body fat measurements. Cost, portability, and strength of correlation will be used to develop recommendations for Washington Department of Fish and Wildlife for obtaining estimates of body fat composition in live, free-ranging mule deer. All protocols will be first approved by WSU's Institutional Animal Care and Use Committee (IACUC). Task to be completed by WSU.

Task 3.2.2. Develop protocol for using ultrasound to determine pregnancy in mule deer. Monthly from November through February, we will examine all does exposed to reproductive males using ultrasound to develop methods for assessing pregnancy in mule deer. We will collect feces and take blood samples to confirm pregnancy in these animals. Task to be completed by WSU.

Task 3.2.3. Develop techniques to be used by deer managers and biologists to assess physical condition of mule deer while in the field. Task to be completed by WDFW and WSU.

Inter-agency Team

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Appendix B. GPS Collar Performance Testing

Written by Corey Kallstrom and Woodrow L. Myers

INTRODUCTION

Global Positioning System (GPS) telemetry collars enable researchers to locate animals more often than conventional collars, in remote or rugged terrain, inclement weather, and during any time period (Rodgers and others 1996; Rumble and Lindzey 1997; Gamo and others 2000) and can provide a more fine-grained picture of animal movements or migration routes (Lindzey and others 2001). Relocations can be biased if animals are not relocated randomly or if they can't be located because of their activity or the habitat they occupy (Gamo and others 2000). The success of relocations is determined by satellite visibility that may be affected by animal activity, topography, and vegetative characteristics (Rempel and others 1995; Moen and others 1996; Rumble and Lindzey 1997; Gamo and others 2000; D'Eon and others 2001). Reductions in observation rate as a result of reduced satellite visibility in a habitat could result in underestimates of its use with concomitant over estimates of use in habitats with higher observation rates. Reductions in satellite visibility may also result in an increased proportion of less accurate 2-dimensional locations (Rempel and others 1995; D'Eon and others 2001).

A few studies have examined for effects of animal activity in the form of behavior or collar orientation (Moen and others 1996; Edenius 1997; Dussault and others 1999; Bowman and others 2000; Rumble and others 2001), and topography in the form of slope, aspect, topographic position, visible horizon, or available sky (Bennett and others 1997; Rumble and Lindzey 1997; Dussault and others 1999; Gamo and others 2000; D'Eon and others 2001). Topographic position descriptors have been used such as canyon, mesa top (Bennett and others 1997), mountain top, valley (Dussault and others 1999), as well as ground measurements of the angle of visible horizon (Rumble and Lindzey 1997; Gamo and others 2000). D'Eon et al. (2001) calculated the "available sky" using GIS to analyze the visibility of a "sky matrix" of points above the land surface represented by a DEM. Most commonly, a combination of vegetation characteristics such as crown closure or canopy cover, crown composition, basal area, tree density, stand density index, average tree height, average tree diameter, DBH x tree density, distance to nearest tree, stand age, shrub density, horizontal cover, and distance to first live branch have been assessed for their effects, or as indicators of stand qualities for their effect on GPS collar performance (Rempel and others 1995; Moen and others 1996; Rempel and Rodgers 1997; Bennett and others 1997; Edenius 1997; Rumble and Lindzey 1997; Dussault and others 1999; Bowman and others 2000; Gamo and others 2000; D'Eon and others 2001).

Studies examining behavior in the form of collar movement have not demonstrated an effect on collar performance (Edenius 1997; Bowman and others 2000; Rumble and others 2001), but have demonstrated decreased observation rates for behaviors such as standing (Dussault and others 1999) or animals lying down (Moen and others 1996; Rumble and others 2001). Canopy closure was examined in all studies and most

commonly affected GPS collar performance (Rempel et al. 1995; Moen et al. 1996; Rempel and Rodgers 1997; Rumble and Lindzey 1997; D'Eon 2001). Other measures vegetation characteristics as potential indicators overhead vegetation which could interfere with satellite visibility and have been found to have some effect on collar performance include; crown composition, basal area, average tree height, average tree diameter or basal diameter, and tree density. Terrain has also been described as having an effect of GPS collar performance in study areas with some relief (Rumble and Lindzey 1997; Dussault and others 1999; Gamo and others 2000; D'Eon and others 2001).

Objectives are to quantitatively assess observation rate bias and location error of GPS collars in various environmental conditions representative of the study area so that assessments of habitat use can be qualitatively and/or quantitatively evaluated or corrected. In a review of the literature, only one study (Johnson and others 1998) was identified, which developed a correction model for observation bias. Other authors have suggested using a 'sightability model' approach (Rumble and Lindzey 1997; Dussault and others 1999; Gamo and others 2000; D'Eon and others 2001) for correcting observation bias, but no studies documenting such correction methods could be found. Garton et al. (2001) list steps (from Johnson et al. 1998) for identifying and correcting biased observation rates:

1. Radio transmitters are placed throughout the study area in a random or stratified random manner, such that locations of transmitters span the spatial and environmental conditions that are representative of the area.
2. Locations are attempted, using the same sampling scheme that is planned for locating radio-marked animals; that is, locations are attempted with the same type of sampling approach as that planned for sampling radio-marked animals in the study area.
3. Observation rates are mapped and evaluated with the use of statistical models, such as regression or kriging approaches (Rumble and Lindzey 1997; Johnson and others 1998).
4. Performance of models to predict bias in observation rates are tested and validated in a spatially explicit manner.
5. Validated models are used to correct the bias for each pixel or polygon in which an animal location occurs.

METHODS

Stands or areas to place collars will be selected by randomly selecting points in areas stratified by canopy closure, cover type, and “available sky”. Okanogan and Wenatchee National Forest Geographic Information System (GIS) covers of canopy closure (1%-19%, 20%-39%, 40%-59%, 60-100%) and cover types generated from Landsat Thematic Mapper images will be used. The cover type data will be grouped into 6 forest types and classifications not placed in these categories will be classified as no data. To assess the potential effects of terrain on the line of site visibility between GPS collars and satellites, a cover of “available sky” (AS) was generated. Available sky values were calculated using ArcInfo Grid module (Environmental Systems Research Institute, Redlands, CA) and a 30 meter digital elevation model from the Okanogan and Wenatchee National Forests GIS library. The visibility of each 30 meter pixel from an infinite point in space for a systematic sample of the sky for various elevations and azimuths was performed using the “SHADOW” option of the “HILLSHADE” command. The resulting grids have a value of 1 if visible and 0 if not visible for each unique elevation and azimuth combination. The sky was sampled between elevations of 10° and 50° at 5° increments and between 0° and 359° azimuths at 10° increments. Starting azimuths alternated between 0° and 5° for each elevation increment. The resulting covers are added and the totals are divided by 324 to provide a percentage index of AS.

ArcView (ESRI) will be used to randomly generate 10,000 points within selected watersheds representative of the study area. Points will be randomly numbered and attributed with canopy closure and AS index. A point from each combination of canopy closure, cover type, and available sky will be selected within 250 meters of a road. If a selected point is inaccessible, the next sequentially numbered point with the same characteristics can be chosen.

Specific locations of collars on the ground will be chosen by selecting a stand in the immediate vicinity of the random point which meets its criteria. Collars will be placed in conditions representative of the study area. Tripods will be used to suspend the collars in a fixed vertical position 1 meter above the ground to simulate a standing deer. Topographic and vegetation variables measured at collar locations will include: angle of visible horizon (8 directions), slope, aspect, and crown closure, crown composition, stems per plot (fixed radius), basal area (variable radius), average tree height, and average tree diameter. Collars will be programmed to attempt a location every 30 minutes and will be retrieved after 24 hours. Collars record date, time, horizontal position, elevation, PDOP, and activity. Sampling will be replicated at two times of the year following the same procedure and in the same locations. True location of collars will be determined by recording the location of collars using a handheld GPS directly above collar locations and code phase processing which has an accuracy of 12 meters. Options for collar placement: specified distance from a tree, estimated center of a stand, and relative center of a group of trees.

New Classifications	Cover Type Classifications
Deciduous (could be grouped with larch)	deciduous, conifer/deciduous mixed
Dry Forest Types	Douglas-fir, ponderosa pine, ponderosa pine/Douglas-fir, dry mixed forest
Moist Forest Types (not sure this is too common in the study area)	Douglas-fir/grand fir, moist mixed forest, mountain hemlock, Pacific silver fir
Cool Forest Types	Englemann spruce, subalpine fir, subalpine forest mix, whitebark pine
Lodgepole forests (could be grouped with cool forest types)	lodgepole pine
Larch forests	western larch, lodgepole pine/western larch
No Data	Background, Agriculture, Burned Areas, Herbaceous, Rock, Shrub, Snow, Urban, Water

3 – 4 canopy closure classes
3 - 6 forest types
3 available sky classes
3 control sites of available sky with no canopy closure, open sky
30 – 75 collar locations

ANALYSES

Data analyses will follow protocols described by D'Eon et al. 2001, Dussault et al. 1999, or Gamo et al. 1999.

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