SEX-SPECIFIC HABITAT SELECTION OF ROUGH-LEGGED HAWKS (*BUTEO LAGOPUS*) WINTERING IN WESTERN NORTH AMERICA

By

Genevieve Christa Rozhon

A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Natural Resources: Wildlife

Committee Membership

Dr. Jeffrey Black, Committee Chair

Dr. William Bean, Committee Member

Dr. Matthew Johnson, Committee Member

Dr. Rick Zechman, Program Graduate Coordinator

July 2018

ABSTRACT

SEX-SPECIFIC HABITAT SELECTION OF ROUGH-LEGGED HAWKS (*BUTEO LAGOPUS*) WINTERING IN WESTERN NORTH AMERICA

Genevieve Christa Rozhon

The rough-legged hawk (*Buteo lagopus sanctijohannis*) is one of the most under-studied raptor species in North America. As a species that exhibits reversed sexual dimorphism, sex-specific habitat preferences may exist. To investigate rough-legged hawk sex-specific habitat selection preferences, we equipped 17 rough-legged hawks (n = eight females, nine males) with GPS backpacks on their wintering grounds (n = six study areas) during the winter months of 2014 and 2015 in five states in western North America. I analyzed rough-legged hawk habitat selection in relation to sex at four spatial scales: nocturnal roosting site, 50% core range, 95% winter range, and 200% ecoregion range. Habitat selection variables included land cover, patch size, terrain ruggedness, indicators of anthropogenic disturbance, and measures of interspecific competition. Species and sex-specific preferences existed at each spatial scale, suggesting that hawks balanced competition for roosting and foraging habitat against prey availability and anthropogenic sources of disturbance when selecting habitat. At each spatial scale, female hawks preferentially selected for high quality habitat, while male rough-legged hawks used high as well as lower quality habitat (qualified by the presence of perching structures, human disturbance, and prey catchability). I posit that reversed sexual

dimorphism in rough-legged hawks leads to social dominance of female hawks on their wintering grounds and that females may outcompete males for higher quality foraging habitat.

ACKNOWLEDGEMENTS

First and foremost, I thank my advisor, Professor Jeff Black, for accepting me as a master's student in raptor biology in a lab that was essentially focused on waterfowl at the time, for supporting and letting me have free-rein to pursue my research ideas, and for providing professional guidance at all stages of my graduate school experience. I'm grateful to Professor Tim Bean for his significant help with the statistical aspects of my modeling efforts, and Professor Matt Johnson for providing valuable guidance on habitat selection studies. I sincerely appreciate Jeff Kidd of Kidd Biological, Inc., for supporting my desire to study rough-legged hawks, providing all trapping equipment and GPS units, and generously giving professional guidance during all facets of the project. The trapping experience of Jeff Kidd and his associate, Scott Thomas, was critical in terms of obtaining study subjects for this project, since very few rough-legged hawks decided to show up in Humboldt County during my time here. My fellow graduate students in the Black Lab, particularly Liz Morata, provided moral and field support along my journey to obtain my master's degree, and I cannot thank them enough. I would also like to thank my pre-grad school raptor mentors at the Golden Gate Raptor Observatory (Buzz Hull and Allen Fish) and the California Raptor Center (Bret Stedman). Finally, I thank my family for fostering my love of wildlife from an early age and my partner, Greg Gray, for his infinite patience and support while I completed my research. I am forever indebted to you all. This work was supported by Kidd Biological, Inc. and a Wildlife Graduate Student Society Travel Grant.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Habitat selection theory predicts that birds will select the best available habitat to maximize their fitness (Sergio and Newton 2003, Sergio et al. 2007). In avian species that exhibit sexual dimorphism, where one sex is larger and potentially more socially dominant than the other, the dominant sex may exclude the subordinate sex from higher quality habitat (Summers et al. 1987, Desrochers 1989, Marra and Holmes 2001). Reversed sexual dimorphism (RSD), the phenomenon where females are larger than males, is common in several avian orders, particularly Falconiformes, Strigiformes, and Accipitriformes, or raptors (Storer 1966, Newton 1979, Mueller 1990). Over twenty theories have been posited to explain how RSD arose and is maintained in raptor species (Krüger 2005). These theories may be grouped into three non-exclusive general categories: role-differentiation hypotheses, behavioral hypotheses, and ecological hypotheses (Mueller 1990, Bildstein 1992, Krüger 2005). Role-differentiation hypotheses posit that there is a selective advantage for larger female raptors and smaller male raptors, due to increased efficiency in female incubation as well as male foraging and territorial defense (Reynolds 1972, Snyder and Wiley 1976, Lundberg 1986, Massemin et al 2000). Behavioral hypotheses theorize that larger females are better at nest defense, dominating males, and maintaining pair bonds than smaller females, and that smaller males are more agile and thus more successful at attracting females than larger males during aerial displays (Storer 1966, Amadon 1975, Jehl and Murray 1986, Hakkarainen et al. 1996). Ecological hypotheses suggest that sexual dimorphism in breeding pairs allows for niche partitioning and reduced competition for prey (Storer 1966, Newton 1979, Temeles 1985). If RSD arose to allow for niche partitioning in raptor breeding pairs (ecological hypothesis), female dominance to maintain pair bonds (behavioral hypothesis), or breeding season efficiency (role-differentiation hypothesis), it follows that sex-specific habitat selection may serve as a consequence of reversed sexual dimorphism. In the case of the rough-legged hawk (*Buteo lagopus sanctijohannis*), an arctic breeding raptor and latitudinal migrant that exhibits reversed sexual dimorphism, sex-specific differences in wintering habitat selection have not been thoroughly studied.

The rough-legged hawk exists as a common Holarctic species with a pan-boreal breeding range that includes the northern reaches of Alaska, Canada, Scandinavia, and Russia. The North American subspecies, *Buteo lagopus sanctijohannis*, breeds in arctic and subarctic Alaska and Canada, and winters in southern Canada and the United States, with approximately half their lives split between these areas (Cade 1955). *B. l. sanctijohannis* (hereafter rough-legged hawk) serves as one of the most historically abundant wintering raptors in North America (Bock and Lepthien 1976). While the majority of these individuals spend their non-breeding season on the Great Plains, a significant number winter in the intermountain west. In particular, the Great Basin region occasionally reports the highest Christmas Bird Count (CBC) total for this species and certain areas of Nevada and Utah are believed to hold the highest concentrations of wintering rough-legged hawks in the Western U.S. (Garrison 1993, Hinde 2011).

Previous research suggests that rough-legged hawks may have very specific habitat requirements including exposed tundra on their breeding grounds and structurally if not floristically similar open grassland and seasonal wetland habitat on their wintering grounds (Mindell 1983, Ritchie 1991, Littlefield et al. 1992, Wilson et al. 2010). Rough-legged hawks may require land with a minimal degree of human development and disturbance (Bildstein 1978, Holmes et al. 1993, Berry et al. 1998, Schmidt and Bock 2004). In addition, rough-legged hawks were positively associated with areas that had more Conservation Reserve Program (CRP) land on the east coast of the U.S. and with idle lands versus grazes lands on the west coast (Littlefield et al. 1992, Wilson et al. 2010).

As a species that exhibits reversed sexual dimorphism, rough-legged hawk habitat use may be related to sex. Sex-specific differences in wintering habitat selection have not been studied in this species with the exception of Kjellén (1994), Olson and Arsenault (2000), and Kasprzykowski and Cieśluk (2011), who described sex-specific wintering latitudes for rough-legged hawks. Female rough-legged hawks may be socially dominant and outcompete males for higher quality winter foraging habitat (Olson and Arsenault 2000, Olson 2006). Selection for particular wintering habitats may have significant consequences on breeding season success (Newton 1991, Norris et al. 2004). To further investigate sex-specific rough-legged hawk wintering habitat selection, I examined which landscape, anthropogenic disturbance, and inter- and intraspecific competition variables served as predictors of rough-legged hawk distribution by sex at the nocturnal roosting site, core range, winter range, and ecoregion scales in California, Nevada, Oregon, Idaho, and Montana.

METHODS

Study Areas

I selected possible study areas based on known, high density wintering raptor locations (Griffen 1983, Hinde 2011, eBird 2015). These study areas included locations in Plumas, Mono, Sierra, and Humboldt counties in California, and Churchill and Eureka counties in Nevada. In 2015, two of my study subjects from 2014 wintered in new regions, so I expanded my study areas to encompass Klamath County in Oregon, Lemhi County in Idaho, and Ravalli County in Montana. The habitat types in these counties included coastal prairies, riparian corridors, alkali playas, seasonal and permanent wetlands, high elevation desert scrubland, open space, agricultural land, and coniferous forest (USGS 1995, Humboldt County Planning Commission 2002, Eureka County Master Plan 2010, Mono County Local Agency Formation Commission 2010, USFWS 2010, Holladay Engineering Co. 2012, Osborn 2012, Big Hole Watershed Committee 2013). Minimum temperatures in the counties ranged from 6.8ºC to -13.0ºC (mean = -8.1ºC), while maximum temperatures ranged from 15.7 ºC to 33.4 ºC (mean = 28.8 ºC). Mean yearly precipitation was 47.2 centimeters and mean snowfall was 96.8 centimeters (Western Regional Climate Center 2013).

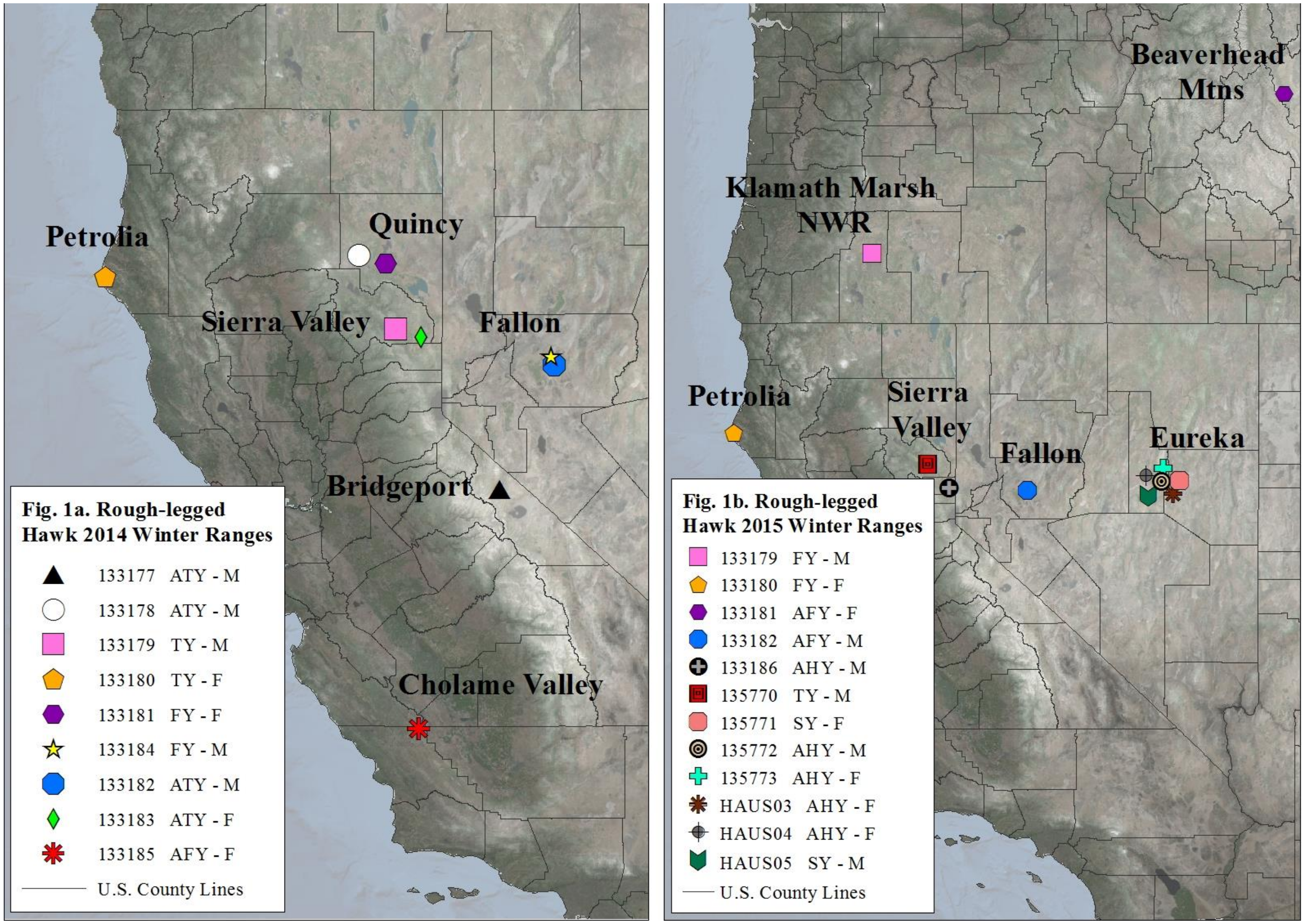

Figure 1. Rough-legged hawk 2014 and 2015 study areas in California and Nevada (n = 17 birds, eight females, nine males). Age is abbreviated as TY (third year), ATY (after third year), FY (fourth year), AFY (after fourth year). ESRI aerial imagery and county boundaries. U.S. Census 2013 State Cartographic Boundaries.

Field Methods

Raptor biologists, Jeff Kidd, Scott Thomas, and I selected 17 rough-legged hawks (eight females and nine males ranging in age from second year or first winter birds to after fourth year birds) for Solar Argos/GPS PTT or Ecotone GPS-GSM attachment in California and Nevada (Microwave Telemetry Inc., Columbia, MD, ECOTONE Telemetry, Sopot, Poland; IACUC 13/14. W.49-A, approved January 29, 2014). We captured rough-legged hawks on public and private lands with approval from various landowners. Trapping methods varied from road trapping, pre-set bal-chatri traps, or verbail pole traps (Berger and Mueller 1959, Bloom et al. 2007). If the raptor was ensnared by a trap, the bird was immediately retrieved and processed (banded).

We banded and color marked all rough-legged hawks in accordance with the North American Bander's Manual for Raptor Banding Techniques and the Golden Gate Raptor Observatory's bander manual (Hull and Bloom 2001, Golden Gate Raptor Observatory 2008). This included marking hawks with a USGS lock-on band and color band. Hawks were aged and sexed according to Cade (1955) and Clark and Bloom (2005). We collected morphometric measurements and down feather samples from each bird (Hull and Bloom 2001). We also attached a 22 gram (g) Argos/GPS PTT backpack or a 24 g ECOTONE GPS backpack to each study animal with a harness constructed from Teflon© ribbon (Snyder et al. 1989). The 22 g satellite transmitters or 24 g ECTONE GPS-GSM units did not exceed 3% of the bird's total mass (Phillips et al. 2003). After processing, we released each bird at its capture location. As of 2018, the project was ongoing with several of the initial transmitters in working order.

Data Cleaning and Processing Methods for GPS/Satellite Locations

I obtained GPS/satellite locations for the hawks at regular intervals of roughly one to two hours for the duration of the study period (winters of 2014 and 2015). Each set of data had different associated accuracies, with the GPS data being accurate to ±15 meters (ECOTONE) or ±18 meters (ARGOS/GPS PTT), and the satellite data (ARGOS/GPS PTT) having coded accuracies of 3 (<250m), 2 (<500m), 1 (<1500m), 0 (>1500m), A (unknown accuracy), B (unknown accuracy), and Z (unknown accuracy) (Argos 2015, Microwave Telemetry 2015). I choose to include only the GPS points in my analysis to minimize spatial error, although the small degree of uncertainty associated with the GPS accuracy levels could not be corrected for. I also eliminated GPS points reported closer than an hour apart in time to reduce spatial and temporal autocorrelation in the data and to ensure an approximate time to independence between points (Cushman and Huettmann 2010). In addition, I eliminated any GPS points that were linked to unit errors (e.g. clusters of points from the GPS reporting every few seconds). I only included nocturnal and diurnal points from birds on their wintering grounds (October through March) and not points obtained during migratory movements (which typically began in April) for analysis.

Fixed Kernel Winter Home Ranges

To ensure that the number of GPS locations per bird was enough to accurately model individual winter ranges (spatial scale 3 of analysis), I created range asymptote plots with a loop code in RStudio (Calenge 2006, Bivand 2015, R Version 3.1.1, www.r-project.org, accessed 28 Feb 2014). The looping code added 5 points at a time and calculated the winter range area for each addition of points (started with a minimum of 10 points for all hawks). When the linear model of winter range area (km^2) and number of GPS locations reached a slope of 0.00, I determined that I had an adequate number of GPS locations to model a hawk's winter range (Odum and Kuenzler 1955). The minimum number of GPS points for all hawks was 19, while the maximum was 1,470 (mean = 243, SD = 194). The mean number of points necessary to reach an asymptote for all hawks was 71 (min = 15, max = 160, SD = 39). Each winter range reached an asymptote.

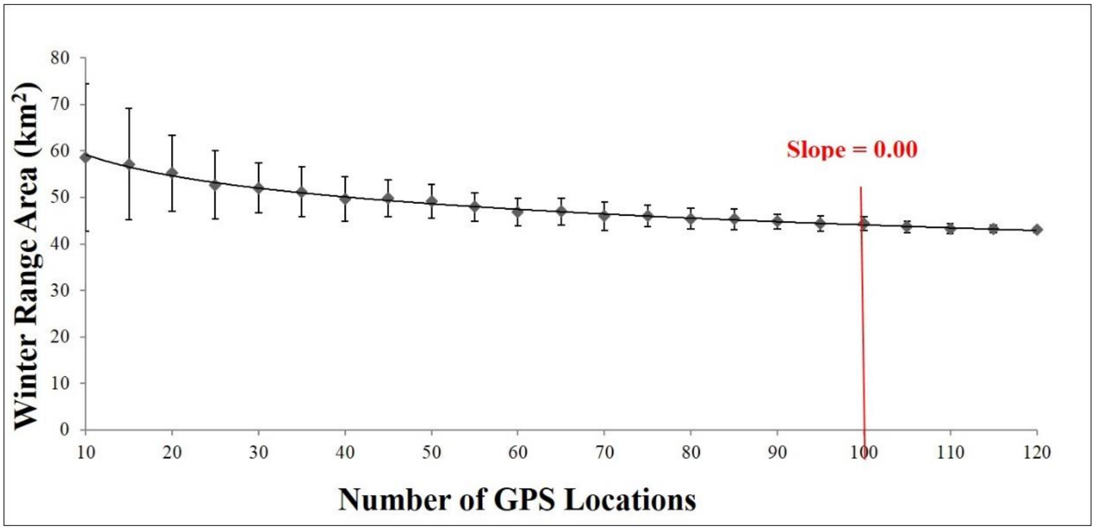

Figure 2. The number of GPS points necessary for the 95% fixed kernel winter range of rough-legged hawk 133182 to reach an asymptote (~100 points).

To quantify habitat use by rough-legged hawks at their winter ranges and core ranges, I created 50% and 95% fixed kernel ranges for each study animal with the adehabitatHR and maptools package in RStudio (see Appendices B and C for 50% core range and 95% winter range sizes). Kernels are non-parametric probability densities that serve to measure the area and intensity of use with species location data. I selected the reference band-width, h_{ref}, for modeling over the preferred least-squares cross validation (LSCV) method for selecting kernel bandwidth, since kernels failed to converge with the LSCV bandwidth method as well as plug-in bandwidths (Worton 1989, Worton 1995, Seaman and Powell 1996).

Geospatial Methods to Obtain Predictor Variables

I grouped all the GPS points for each bird into the following four spatial scales: nocturnal roost points (i.e., all points with time stamps at least two hours after sunset and two hours before sunrise in PST and MST), GPS points within the 50% kernel core range scale, GPS points within the 95% kernel winter range scale, and GPS points within the 200% ecoregion scale. The 200% range scale served as a buffered version of the 100% kernel range. This buffered area was twice the diameter of the 100% kernel's longest side (used to address selection at the ecoregion area around each range).

Modeling Variables

At each of these four spatial scales, I generated an equal number of random points for each GPS location with the "create random points" tool in ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA 2011). I then brought a series of predictor layers into ArcMap obtained from remote sensing, census, and citizen science databases. These predictors included land cover type, habitat patch size, terrain ruggedness, distance to roads (multiple types), distance to other rough-legged hawks, and distance to red-tailed hawks. Predictors were selected for modeling *a priori* based on previous literature concerning rough-legged hawk behavioral ecology (see Table 1). I extracted predictor values at each point with the Extract Multi Values to Points and Spatial Join tools in ArcMap. The random point layer with associated predictor values represented available locations to the species while the GPS locations represented species presences. An assumption was made that the predictor values at each GPS location were correct, based on the relative high accuracy of the GPS units. However, a small amount of GPS error (± 15 to ± 18 meters) cannot be discounted and may have introduced a small degree of uncertainty into the spatial models.

Table 1. Predictor and response variables for rough-legged hawk 2014 and 2015 wintering habitat selection modeling in five states in western North America (n = 17 hawks, eight females, nine males).

Name	Variable Name in Models	Source	Variable Type	Units	Spatial Resolution
Presence	Presence	GPS Data/ ArcMap	Response; Factor	binomial	±18 meters
Land Cover	VEGTYPE	NLCD 2011 Land cover	Predictor; Factor	none; categorical	30 meters
Patch Size	Area	NLCD 2011 Land cover	Predictor; Integer	acres	30 meters
Terrain Ruggedness	TRI_VALUE	National Elevation Database	Predictor; Categorical	none; categorical	30 meters
Dist. to Major Roads	DIST_PR_SD	TIGER 2015 roads geodatabase; primary and secondary roads	Predictor; Integer	kilometers	variable
Dist. to Local Roads	DIST_LOCAL	TIGER 2015 roads geodatabase	Predictor; Integer	kilometers	variable
Dist. to Private Roads	DIST_PRIVA	TIGER 2015 roads geodatabase	Predictor; Integer	kilometers	variable
Dist. to 4-Wheel Drive (4WD) Tracks	DIST_4WD	TIGER 2015 roads geodatabase	Predictor; Integer	kilometers	variable
Dist. to Red-tailed Hawks	DIST_RT	eBird, 2014-2015 data	Predictor; Integer	kilometers	variable
Dist. to Rough-legged Hawks	DIST_RL	eBird, 2014-2015 data	Predictor; Integer	kilometers	variable

Land Cover and Patch Size.

Land cover classifications and the variable Patch Size were obtained from the 2011 National Land Cover Database (NLCD), a 30-meter resolution land cover raster dataset created by the United States Geological Survey (USGS), U.S. Environmental Protection Agency (US EPA), U.S. Forest Service (USFS), and the National Oceanic and Atmospheric Administration (NOAA) for the contiguous United States. A land cover classification table is presented in Appendix A. I included the variables land cover and patch size in my models since these variables influenced rough-legged hawk habitat selection preferences in previous studies (Craig et al. 1986, Loman 1991, Littlefield et al. 1992, Wilson et al. 2010). Land cover and Patch Size were examined as separate variables as well as an interactive term (Land Cover*Patch Size). This allowed me to determine whether rough-legged hawks were selecting for land cover type and/or patch size, or whether a combination of the two variables was significant (e.g. only larger patches of grassland may be preferred by rough-legged hawks).

To minimize linear model over-fitting during habitat selection analysis, I merged certain land cover categories with few GPS locations in them into “super” categories. I eliminated other categories with even fewer GPS points from the linear modeling portion of the analysis. However, all categories were included in Chi-squared Goodness-of-Fit tests to capture habitat selection of certain habitat types in greater detail. Chi-squared tests tend to be robust even with smaller sample sizes (Byers et al. 1984).

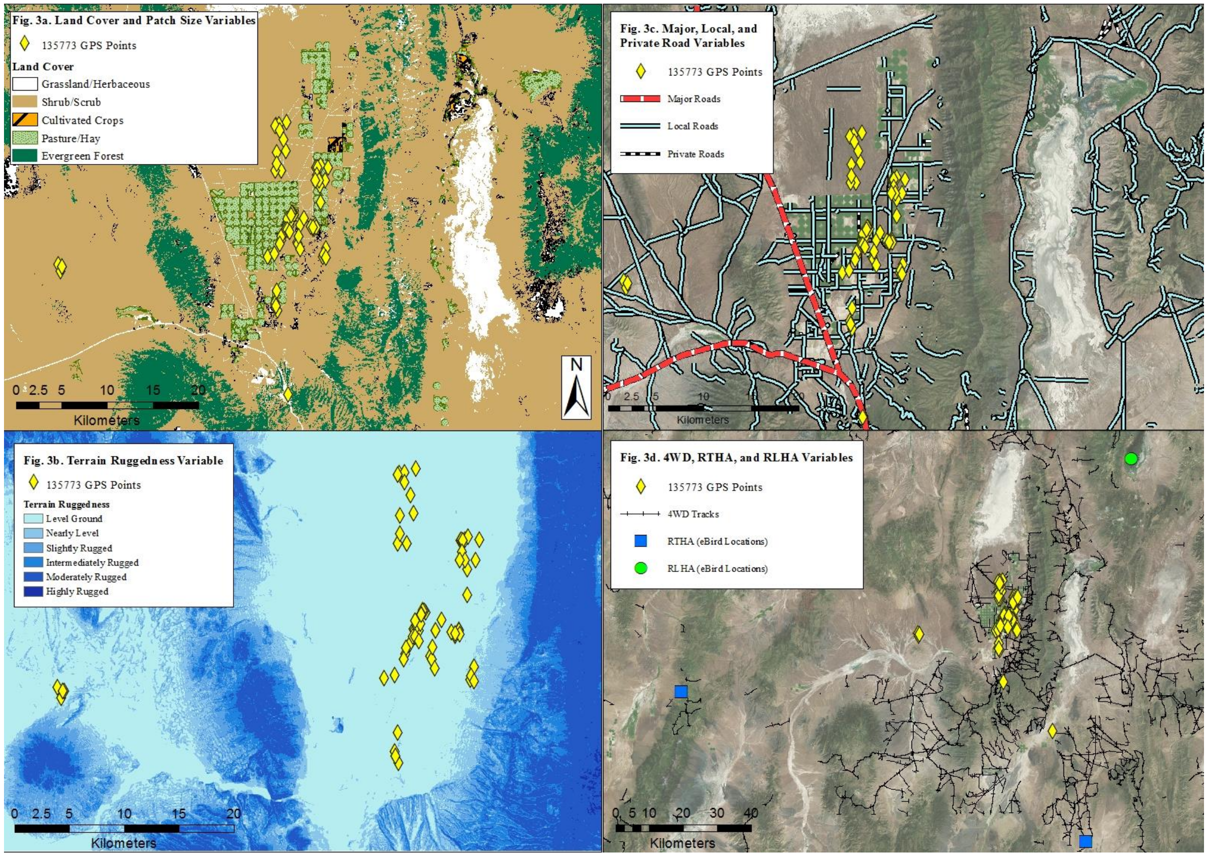

Figure 3. Modeling predictors Land cover, Patch Size (area of land cover not explicitly shown), Terrain Ruggedness, Distance to Major, Local, and Private Roads, Distance to 4WD Tracks, Distance to Red-tailed Hawks, and Distance to Rough-legged Hawks for rough-legged hawk 2014 and 2015 wintering habitat selection modeling in 5 states in western North America (n = 17 hawks, eight = females, nine = males). Shown here for rough-legged hawk 135773 (AHY Female) in Eureka, NV. NLCD 2011 land cover data. National Elevation Database elevation data. TIGER 2015 roads geodatabase data. ESRI aerial imagery. TIGER 2015 roads geodatabase data. eBird 2014 and 2015 data.

Terrain Ruggedness.

Terrain ruggedness was obtained from the 2014 National Elevation Database's 30-meter resolution DEM (Digital Elevation Model) raster dataset. The DEM was created by the U.S. Geological Survey (USGS) and EROS Data Center for the conterminous U.S.. I reclassified the DEM raster to have discrete values (scale of 1 to 6 representing progressively more rugged terrain; terrain ruggedness classification table in Appendix A) using the Riley reclassification technique for terrain ruggedness (Riley et al. 1999). This technique measures topographic heterogeneity by calculating change in elevation between a raster grid cell and its nearest neighbors (Riley et al. 1999). Terrain ruggedness had not been examined in the primary literature in relation to rough-legged hawk habitat selection, although evidence points to a general preference for relatively flat, open landscapes on their wintering grounds (Belknap 1966, Watson 1984, Littlefield et al. 1992, Olson 2006, Wilson et al. 2010). I chose to investigate this phenomenon further by including terrain ruggedness in my habitat selection models.

Distance to Roads.

Distance to various types of roads was derived in ArcMAP 10.1 from the U.S. Census Bureau TIGER (Topographically Integrated Geographic Encoding and Referencing) 2015 national roads geodatabase. Road types were included in habitat selection modeling as possible sources of disturbance as well as possible hawk perch or roosting locations. The four road variables I examined were primary/secondary highways (i.e. Major Roads; passed through open land such as scrubland/high elevation desert), local roads/city streets (i.e. Local Roads), Private Roads (roads associated with ranches, oil fields, farms, residences, etc.), and 4-Wheel Drive Tracks. In these models, Major and Local Roads represented access to perching structures (telephone poles and fences) as well as sources of vehicular disturbance. Private Roads represented sources of vehicular as well as pedestrian disturbance and residential areas. Four-wheel drive tracks represented land with minimal development (public land dominated by scrubland).

Distance to Red-tailed Hawks and Rough-legged Hawks

I obtained the distance to red-tailed hawks and distance to rough-legged hawks variables from the citizen science database, eBird (eBird 2015). Rough-legged hawks and red-tailed hawks exhibit a significant degree of niche overlap on their wintering grounds and rough-legged hawks are known to intraspecifically and interspecifically compete for resources (Schnell 1968, Bildstein 1978, Watson 1984, Olson 2006). I only used locations that overlapped temporally and spatially with my study subjects. These variables served as proxies for interspecific and intraspecific competition on the wintering grounds.

Sex-specific Generalized Linear Models

Initial modeling indicated sex-specific differences in rough-legged hawk habitat selection preferences. In addition, models failed to converge when including sex as a model variable. To address this, I built resource selection functions with binomial distribution GLMs (generalized linear models) for each sex with the logit link function to represent rough-legged hawk habitat selection at the nocturnal roost scale, 50% kernel core scale, 95% winter range scale, and 200% ecoregion scale (Boyce and McDonald 1999, McLoughlin et al. 2009, Zuur et al. 2009). I chose four spatial scales of selection to mirror Johnson's classic hierarchical habitat selection scales (Johnson 1980). Rough-legged hawk presence/absence served a binomial response variable, while my predictor variables were both continuous and categorical. I rescaled and normalized all continuous variables, ran correlation tests, and examined Variance Inflation Factors (VIFs) (Burnham and Anderson 2002). Ten to 20 models were developed at each spatial scale for both female and male hawks. Final models included only predictors without high VIFs and correlation coefficients below 0.4 (Zuur et al. 2007). I selected the best model at each spatial scale for each sex with Akaike's Information Criterion (AIC) in RStudio and ensured that the intercept and significant parameters of each top model had confidence intervals that did not overlap zero (Zurr et al. 2009). I also considered evidence ratios between the top model and each other candidate model to evaluate model uncertainty (Burnham and Anderson 2002).

Chi-squared Goodness-of-Fit Analysis

Preliminary modeling indicated that rough-legged hawk habitat selection preferences were heavily influenced by land cover and terrain ruggedness. Since GLM modeling with categorical variables in R does not allow for easy interpretation of results (first categorical variable dummy coded as reference value in results), I further examined the land cover and terrain ruggedness variables by conducting chi-squared tests for each sex at each spatial scale (roost, 50% core range, 95% winter range, and 200% ecoregion) (Neu et al. 1974, Howell and Chapman 1997). I used 95% Bonferroni confidence intervals to determine which land cover and terrain types rough-legged hawks selected and avoided (Byers et al. 1984). Land cover and terrain types with few GPS locations were either lumped into broader categories or eliminated from analysis.

RESULTS

Habitat Selection with Generalized Linear Models

Habitat Selection at Nocturnal Roost Scale

Table 2. Summary of top GLM habitat selection models for eight female and nine male rough-legged hawks explaining habitat selection at the nocturnal roosting site scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Variables	Trend (β Estimate)	
	Females	Males
Land Cover	Categorical	Categorical
Terrain Ruggedness	Categorical	Categorical
Patch Size	+	+
Distance to Major Roads	0	-
Distance to Local Roads	0	N/A
Distance to Private Roads	N/A	N/A
Distance to 4WD	0	-
Distance to Red-tailed Hawks	N/A	N/A
Distance to Rough-legged Hawks	N/A	

-: Selecting against variable
+: Selecting for variable
0: Variable confidence intervals overlap 0
N/A: Variable not present in top model

Table 3. Summary of Chi-squared Goodness of Fit Tests for eight female and nine male rough-legged hawks explaining categorical variable habitat selection at the nocturnal roosting site scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Categorical Variables	Females	Males
Evergreen Forest	-	0
Scrub	0	-
Grassland	0	+
Pasture	+	+
Herbaceous Wetlands	0	+
Level Ground	+	+
Nearly Level	+	-
Slightly Rugged	0	-
Intermediately Rugged	0	-
Moderately Rugged	-	-

-: Selecting against variable
+: Selecting for variable
0: Used as expected in relation to availability
N/A: Variable not present in top model

Female selection at the nocturnal roosting scale was best explained by six out of 10 habitat variables, including Land Cover, Patch Size, Terrain Ruggedness, Distance to Major Roads, Distance to Local Roads, and Distance to 4-Wheel Drive Tracks. The top model, Model 4, had a weight (w_i) of 0.74 (n = 152 GPS locations and 152 available locations, df = 7). Model 4, along with the second best model out of eight final candidate models, carried 100% of the cumulative model weights (Table 15, Appendix D includes all top models). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Female rough-legged hawks selected for pasture/hay and avoided evergreen forest at roosting sites. Grassland, mixed forest, and shrub/scrub were used as expected based on the availability of those habitat types (χ^2= 244.51, df = 4). Female hawks also selected for level and nearly level ground at roosting sites and avoided moderately rugged terrain. Slightly and intermediately rugged terrain was used as expected based on availability (χ^2 = 583.23, df = 4). In addition, female rough-legged hawks selected nocturnal roost sites in larger habitat patches that were further from major and local roads.

Male selection at the nocturnal roosting scale was best explained by four out of 10 habitat variables, including Land Cover*Area, Terrain Ruggedness, Distance to Major Roads, and Distance to 4-Wheel Drive Tracks. The top model, Model 12, had a weight (w_i) of 0.64 (n = 194 GPS locations and 194 available locations, df = 14). Model 12, along with the second best model out of 12 final models, carried 94% of the cumulative model weights (Table 18, Appendix D includes all models). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Male rough-legged hawks selected for larger patch sizes of herbaceous wetlands, grassland, and pasture/hay at roosting sites, and avoided smaller patches of shrub/scrub. Evergreen forest was used as expected based on the availability of that habitat type (χ^2= 9,859.90, df = 4). Male hawks also selected for level ground and avoided all more rugged terrain (χ^2 = 172.73, df = 4). In addition, male rough-legged hawks selected nocturnal roosting sites further major roads and 4-wheel drive tracks.

Habitat Selection at 50% Core Range Scale

Table 4. Summary of top GLM habitat selection models for eight female and nine male rough-legged hawks explaining habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Variables	Trend (β Estimate)	
	Females	Males
Land Cover	Categorical	Categorical
Terrain Ruggedness	N/A	Categorical
Patch Size	0	+
Distance to Major Roads	+	-
Distance to Local Roads	+	0
Distance to Private Roads	-	N/A
Distance to 4WD	-	N/A
Distance to Red-tailed Hawks	N/A	N/A
Distance to Rough-legged Hawks	N/A	N/A

-: Selecting against variable
+: Selecting for variable
0: Variable confidence intervals overlap 0
N/A: Variable not present in top model

Table 5. Summary of Chi-squared Goodness of Fit Tests for eight female and nine male rough-legged hawks explaining categorical variable habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Categorical Variables	Females	Males
Open Space	+	+
Developed Low Intensity	0	0
Evergreen Forest	-	0
Scrub	0	0
Grassland	-	0
Pasture	+	+
Cropland	0	-
Herbaceous Wetlands	+	0
Level Ground	N/A	+
Nearly Level	N/A	-
Slightly Rugged	N/A	-
Intermediately Rugged	N/A	-
Moderately Rugged	N/A	N/A

-: Selecting against variable
+: Selecting for variable
0: Used as expected in relation to availability
N/A: Variable not present in top model

Female selection at the 50% core range scale was best explained by six out of 10 habitat variables, including Land Cover, Patch Size, Distance to Major Roads, Distance to Local Roads, Distance to Private Roads, and Distance to 4-Wheel Drive Tracks. The top model, Model 2, had a weight (w_i) of 0.56 (n = 1,828 GPS locations and 1,828 available locations, df = 12). Model 2, along with the second best model out of nine final models, carried 90% of the cumulative model weights (Table 21, Appendix D includes all models). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Female rough-legged hawks selected for open space, herbaceous wetlands, and pasture at the 50% core range scale and avoided evergreen forest and grassland. Cropland, low-intensity developed land, and scrub/shrub were used as expected based on the availability of those habitat types (χ^2 = 2,649.47, df = 7). Within their core ranges, female rough-legged hawks also selected habitat closer to major and local roads and further from private roads and 4-wheel drive tracks.

Male selection at the 50% core range scale was best explained by five out of 10 habitat variables, including Land Cover, Patch Size, Terrain Ruggedness, Distance to Major Roads, and Distance to Local Roads. The top model, Model 3, had a weight (w_i) of 0.87 (n = 1,968 GPS locations and 1,968 available locations, df = 14). Model 3, along with the second best model out of seven final models, carried 91% of the cumulative model weights (Table 24, Appendix D includes all models). Male rough-legged hawks selected for open space and pasture/hay at the 50% core range scale and avoided cropland. Low and medium intensity developed land, herbaceous wetlands, evergreen forest, shrub/scrub, and grassland were used as expected based on the availability of those habitat types (χ^2= 164.95, df = 8). Male hawks also selected for level ground and avoided all more rugged terrain (χ^2 = 36.53, df = 4). Within their core ranges, male rough-legged hawks also selected habitat further from major and local roads.

<u>Habitat Selection at 95% Winter Range Scale</u>

Table 6. Summary of top GLM habitat selection models for eight female and nine male rough-legged hawks explaining habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Variables	Trend (β Estimate)	
	Females	Males
Land Cover	Categorical	Categorical
Terrain Ruggedness	Categorical	Categorical
Patch Size	+	-
Distance to Major Roads	+	N/A
Distance to Local Roads	N/A	N/A
Distance to Private Roads	-	0
Distance to 4WD	N/A	N/A
Distance to Red-tailed Hawks	-	N/A
Distance to Rough-legged Hawks	N/A	N/A

-: Selecting against variable
+: Selecting for variable
0: Variable confidence intervals overlap 0
N/A: Variable not present in top model

Table 7. Summary of Chi-squared Goodness of Fit Tests for eight female and nine male rough-legged hawks explaining categorical variable habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Categorical Variables	Females	Males
Open Space	+	+
Developed Low Intensity	0	+
Evergreen Forest	-	-
Scrub	-	-
Grassland	-	+
Pasture	+	+
Cropland	+	+
Herbaceous Wetlands	+	+
Level Ground	+	+
Nearly Level	0	-
Slightly Rugged	-	-
Intermediately Rugged	-	-
Moderately Rugged	-	-

-: Selecting against variable
+: Selecting for variable
0: Used as expected in relation to availability
N/A: Variable not present in top model

Female rough-legged hawk habitat selection at the 95% winter range scale was best explained by seven out of 10 habitat variables, including Land Cover, Patch Size, Terrain Ruggedness, Distance to Major Roads, Distance to Local Roads, Distance to Private Roads, and Distance to Red-tailed Hawks. Model 3, the top model out of eight final models, had a weight (w_i) of 0.50 (n = 2,467 GPS locations and 2,467 available locations, df = 17. The top two models carried 99% of the cumulative model weights (Table 27, Appendix D includes all models). Female rough-legged hawks selected for cropland, open space, herbaceous wetlands, and pasture/hay at the 95% winter range scale, and avoided barren land, evergreen forest, shrub/scrub, and grassland. Low intensity developed land, mixed forest, and woody wetlands were used as expected based on the availability of those habitat types (χ^2 = 4,841.77, df = 10). Female hawks also preferentially selected for level ground, used nearly level ground in relation to its availability, and avoided all more rugged terrain (χ^2= 2,733.43, df = 4). Within their winter ranges, female rough-legged hawks selected habitat closer to major roads, further from private roads, and further from red-tailed hawks.

Male rough-legged hawk habitat selection at the 95% winter range scale was best explained by four out of 10 habitat variables, including Land Cover, Patch Size, Terrain Ruggedness, and Distance to Private Roads. Model 15, the top model out of seven final models, had a weight (w_i) of 0.54 (n = 2,845 GPS locations and 2,845 available locations, df = 13). The top two models carried 100% of the cumulative model weights (Table 30, Appendix D includes all models). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Male rough-legged hawks selected for cropland, open space, low intensity developed areas, herbaceous wetlands, pasture/hay, and grassland at the 95% winter range scale, and avoided evergreen forest and shrub/scrub. Barren land and medium intensity developed lands were used as expected based on the availability of those habitat types (χ^2 = 2231.80, df = 9). Male hawks also selected for level ground and avoided all more rugged terrain (χ^2= 1,672.30, df = 4). Distance to Private Roads was not significant as the confidence intervals overlapped zero.

Habitat Selection at 200% Ecoregion Scale

Table 8. Summary of top GLM habitat selection models for eight female and nine male rough-legged hawks explaining habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Variables	Trend (β Estimate)	
	Females	Males
Land Cover	Categorical	Categorical
Terrain Ruggedness	Categorical	Categorical
Patch Size	N/A	N/A
Distance to Major Roads	+	-
Distance to Local Roads	N/A	N/A
Distance to Private Roads	-	N/A
Distance to 4WD	N/A	-
Distance to Red-tailed Hawks	+	+
Distance to Rough-legged Hawks	N/A	N/A

-: Selecting against variable
+: Selecting for variable
0: Variable confidence intervals overlap 0
N/A: Variable not present in top model

Table 9. Summary of Chi-squared Goodness of Fit Tests for eight female and nine male rough-legged hawks explaining categorical variable habitat selection at the core range scale in five states in western North America during the winters of 2014 and 2015.

Roosting Site Scale Significant Categorical Variables	Females	Males
Open Space	+	+
Developed Low Intensity	0	+
Evergreen Forest	-	-
Scrub	-	-
Grassland	0	+
Pasture	+	+
Cropland	0	+
Herbaceous Wetlands	+	+
Level Ground	+	+
Nearly Level	-	-
Slightly Rugged	-	-
Intermediately Rugged	-	-
Moderately Rugged	-	-

-: Selecting against variable
+: Selecting for variable
0: Used as expected in relation to availability
N/A: Variable not present in top model

Female rough-legged hawk habitat selection at the 200% ecoregion scale was best explained by five out of 10 habitat variables, including Land Cover, Terrain Ruggedness, Distance to Major Roads, Distance to Private Roads, and Distance to Red-tailed Hawks. Model 8, the top model out of 10 final models, had a weight (w_i) of 0.72 (n = 2,536 GPS locations and 2,536 available locations, df = 15). The top two models carried 100% of the cumulative model weights (Table 33, Appendix D includes all models; all other models had confidence intervals that overlapped 0). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Female rough-legged hawks selected for cropland, open space, herbaceous wetlands, and pasture/hay at the 200% ecoregion scale, and avoided barren land, evergreen forest, and shrub/scrub. Low intensity developed land, mixed forest, grassland, and woody wetlands were used as expected based on the availability of those habitat types (χ^2= 22,512.46, df = 10). Female hawks also preferentially selected for level ground and avoided all more rugged terrain (χ^2 = 4,002.46, df = 4). At the ecoregion scale, female rough-legged hawks selected habitat closer to major roads and closer to red-tailed hawks.

Male rough-legged hawk habitat selection at the 200% ecoregion scale was best explained by five out of 10 habitat variables, including Land Cover, Terrain Ruggedness, Distance to Major Roads, Distance to 4-Wheel Drive Tracks, and Distance to Red-tailed Hawks. Model 9, the top model out of nine final models, had a weight (w_i) of 0.53 (n = 2,980 GPS locations and 2,980 available locations, df = 14). The top two models carried 100% of the cumulative model weights (Table 36, Appendix D includes all models). The evidence ratio between the top two models was less than three, indicating model uncertainty and that both of the top two models may be good models at this spatial scale. Male rough-legged hawks selected for cropland, open space, low intensity development, herbaceous wetlands, pasture/hay, and grassland at the 200% ecoregion scale, and avoided barren land, evergreen forest, woody wetlands, and shrub/scrub. Medium intensity developed land was used as expected based on the availability of that habitat type (χ^2= 22,151.72, df = 10). Male hawks also preferentially selected for level ground and avoided all more rugged terrain (χ^2= 1,711.97, df = 4). At the ecoregion scale, male rough-legged hawks selected habitat further from major roads and 4-wheel drive tracks and closer to red-tailed hawks.

DISCUSSION

With high-accuracy GPS data, I quantified sex-specific habitat selection by 17 rough-legged hawks at four spatial scales, including the nocturnal roosting site, 50% core range, 95% winter range, and 200% ecoregion range. Modeling indicated sex-specific differences in rough-legged hawk habitat selection preferences in terms of land cover, anthropogenic sources of disturbance, and interspecific species competition at all spatial scales. Generalized linear modeling and chi-squared goodness-of-fit tests indicated that hawks selected habitat based on all the above-listed variables, balancing competition for high-quality roosting and foraging habitat against potential prey availability (via land cover type) and anthropogenic sources of disturbance.

Habitat quality is frequently evaluated in terms of factors such as density, reproductive success, survival, arrival times, and body condition (Prop and Black 1998, Franklin et al. 2000, Bock and Jones 2004, Norris et al. 2004). Since I studied rough-legged hawks during the wintering season, I was not able to quantitatively measure variables such as these that are associated with cross-seasonal effects. Instead, I considered factors such as higher winter prey base, ease of prey detectability (low canopy cover), structures (fences and telephone poles) for perch hunting, human development/disturbance, and landscape heterogeneity/homogeneity. These possible indicators of habitat quality were examined in relation to rough-legged hawk habitat selection modeling results.

Close examination of the model parameters allowed for description of the subtle preferences rough-legged hawks exhibited and/or cues they used when selecting habitat at multiple spatial scales. Rough-legged hawk sex-specific habitat selection on their wintering grounds may be related to reverse sexual dimorphism in the species. Specifically, each sex may inhabit different niches on their wintering grounds (related to differential prey selection). In contrast, larger female size may allow for female dominance over males on the wintering grounds and male exclusion from higher quality habitat.

Species-specific Habitat Selection

Data analysis revealed general rough-legged hawk habitat preferences at multiple spatial scales across the western U.S.. Specifically, rough-legged hawks generally selected for pasture/hay, open space, cultivated cropland, herbaceous wetlands, and level ground on their wintering grounds and avoided scrub, evergreen forest, rugged terrain, and 4-wheel drive tracks. The variable distance to other rough-legged hawks was not present in the top models for either sex at any spatial scale.

Land Cover.

A general preference for pasture/hay (specifically alfalfa, timothy, and mixed hay in many locations) and open space by both sexes was consistent with previous research findings by Craig et al. (1986) on rough-legged hawk habitat selection in Idaho, Wilkinson and Debban (1980) in California, and Fischer et al. (1984) in Utah. Pasture/hay (grazed or mowed vegetation with plentiful grain) has been documented as high quality foraging habitat for small mammals in the winter, and, in turn, for wintering raptors (Baker and Brooks 1981). Cultivated crops, open space, and herbaceous wetlands also likely served as higher quality habitat for rough-legged hawks at the scale of their winter range than evergreen forests or scrub for three reasons: higher winter prey base, easily detectable prey (low canopy cover), and structures (fences) for perch hunting (Baker and Brooks 1981, Parker et al. 1984, Preston 1990, Olson et al. 2017).

Terrain Ruggedness.

In general, both sexes preferred level ground and avoided rugged terrain. Terrain ruggedness at all spatial scales was likely linked to foraging habitat (pasture, grassland, and cropland), which was associated with more level terrain. In contrast, more rugged terrain was characterized by coniferous forest or barren ground associated with mountainous slopes around the study areas. By avoiding rugged terrain, rough-legged hawks avoided habitat less suitable for foraging.

Sex-specific Habitat Selection

Female and male rough-legged hawks also exhibited sex-specific habitat preferences at each spatial scale. Sex-specific habitat selection preferences were evident in almost all habitat variables including land cover, patch size, distance to roads, and distance to red-tailed hawks.

Land Cover.

Females avoided evergreen forests at their nocturnal roosting sites while males used evergreen forest in relation to its availability. Sex-specific differences in roost-site selection land cover preferences both support and contradict Olson's findings on rough-legged hawks in Montana. At his study site, females and males also exhibited different nocturnal roost site preferences. Males displayed a greater preference for roosting sites in the foothills than females, although both sexes used roosting sites in coniferous forest. In general, rough-legged hawks in my study preferred other habitat types such as pasture or herbaceous wetlands (Olson 2006). At this spatial scale, differences in roosting site selection were likely not related to sex-specific niche use, since male and female rough-legged hawks are known to roost communally (Olson 2006). Based on the roosting site land cover preferences in my study, rough-legged hawks may have selected roosting sites in relation to nearby foraging habitat. Female rough-legged hawks only selected for nocturnal roost sites in pasture, while males rough-legged hawks selected for roosting sites in pasture, grassland, herbaceous wetlands, and used evergreen forest in relation to its availability. At the nocturnal roost scale, females may outcompete males for the best roost sites and force them to use a greater variety of roosting sites, including ones in or adjacent to lower quality foraging habitat.

Sex-specific land cover preferences were also evident at the winter range scale. Female rough-legged hawks avoided grassland, while males selected for grassland. Female rough-legged hawks have been reported to be socially dominant over males on their wintering grounds (Olson 2006). This social dominance may allow females to outcompete males for higher quality habitat (i.e. pasture) on their wintering grounds and push them to forage in lower quality habitat such as grassland. Grassland may have served as lower quality foraging habitat than other land cover types such as pasture/hay due to greater canopy cover and therefore harder to detect prey (Baker and Brooks 1981, Preston 1990).

At the scale of the ecoregion, selection of land cover and patch size were likely related to rough-legged hawk preferences for open land with minimal vegetation cover and limited anthropogenic development on their wintering grounds (Littlefield et al. 1992, Berry et al. 1998, Schmidt and Bock 2005, Wilson et al. 2010).

Patch Size.

Rough-legged hawk preferences for bigger or smaller habitat patches varied by sex and spatial scale. Rough-legged hawks may have preferred to roost in larger habitat patches if the size of the patch buffered the roost site from disturbance (e.g, areas not bisected by roads). This supports findings by Olson (2006), who documented that rough-legged hawks chose roosts in large habitat patches upwards of 1,000 hectares (10 km^2) in size. In my study, male rough-legged hawks selected smaller habitat patches within their core ranges, which may have been related to foraging success. In Sweden, rough-legged hawks preferred to forage in smaller patches, where prey experienced higher raptor-related mortality (Loman 1991). A preference for larger patches, or different niche use, by female rough-legged hawks at the winter range scale may be related to the homogenous land cover type they selected with minimal anthropogenic development (Holmes et al. 1993, Berry et al. 1998). Conversely, male rough-legged hawks may be forced to use smaller habitat patches if females are outcompeting them for larger foraging areas on the landscape.

Distance to Roads.

Road variables were present in the top female rough-legged hawk habitat selection models at all spatial scales, with females generally selecting areas closer to major roads and local roads. In contrast, males avoided areas near major roads. Females may have selected for areas closer to major and local roads at the core and winter range scales since these roads were more likely to be bordered by telephone poles and fences (i.e., prime perching structures). In addition, socially dominant female rough-legged hawks have been documented bumping males from hunting perches during the winter (Olson 2006). Therefore male avoidance of major roads (with perches) may be related to male avoidance of socially dominant females. In contrast, female rough-legged hawk avoidance of private roads at the core range, winter range, and ecoregion scales could be linked to the fact that private roads in this landscape were usually associated with farms, houses, or residential areas, and therefore closer to areas of human disturbance. It is well documented in the primary literature that rough-legged hawks avoid areas of human development and are sensitive to disturbance from vehicular traffic (Holmes et al. 1993). Females may have also selected for areas closer to major since these roads typically ran through open scrubland with little development (i.e. limited anthropogenic disturbance). This open scrubland may have contained a suitable prey base specifically for larger foraging female rough-legged hawks (females selected scrub in relation to its availability at core range spatial scale) (Olson et al. 2017). Males may have avoided areas closer to major roads if those areas served as poorer foraging habitat due to less detectable or catchable prey (Baker and Brooks 1981, Preston 1990, Olson et al. 2017). Although sex-specific differences in prey selection and niche have not been examined for this species, females' larger body size may allow them to take larger prey than males, such as ground squirrels, which are common in scrub habitat (Watson 1984, Olson et al. 2017).

Distance to Red-tailed Hawks.

Rough-legged hawk selection preferences in relation to distance to red-tailed hawks varied by sex and spatial scale. At the nocturnal roost scale, distance to other red-tailed hawks may not have been significant because rough-legged hawks and other *Buteos*, such as red-tailed hawks and ferruginous hawks, roost communally during the winter (Hinde 2011). Females avoided areas closer to red-tailed hawks at the winter range scale while both sexes selected habitat closer to red-tailed hawks at the ecoregion scale. At the winter range scale, females may have selected habitat further from wintering red-tailed hawks due to interspecific competition, since rough-legged hawks and red-tailed hawks exhibit a significant degree of niche overlap on their wintering grounds (Schnell 1968). Female rough-legged hawks generally have larger wing chords and larger mean masses than males rough-legged hawks, although mass sizes may overlap between sexes (Cade 1955, Palmer 1988, Clark and Bloom 2016, Appendix G). The larger size of female rough-legged hawks compared to males may result in more competition with red-tailed hawks, who are generally as large if not larger than female rough-legged hawks, depending on the red-tailed hawk subspecies (Palmer 1988, Olson 2006, Clark and Bloom 2016, Tomalty et al. 2016). At the ecoregion scale, both sexes may have keyed in on the presence of red-tailed hawks to identify raptor "hot spots" when selecting wintering ranges (Hinde 2011).

CONCLUSION

The rough-legged hawk is experiencing population pressures year-round, with the effects of climate change altering habitat on their breeding grounds and agricultural development and urbanization contributing to habitat loss on their wintering grounds (Berry et al. 1998, Schmidt and Bock 2005, Beardsell et al. 2017). Data from the Audubon Christmas Bird Count (CBC) and Snake River Birds of Prey National Conservation Area (NCA) indicate that these environmental stressors may be causing a northern wintering range shift in the species or, alternatively, triggering population declines (Pandolfino and Wells 2009, Paprocki et al. 2014). This is particularly troubling since there are many gaps in our knowledge of rough-legged hawk behavioral ecology. It is critical to examine sex-specific differences in habitat selection to ensure that generalizations about rough-legged hawk habitat preferences do not negatively impact conservation strategies for this species.

In examining wintering habitat selection by rough-legged hawks at multiple spatial scales in five states in western North America, I determined which landscape variables, human development variables, and interspecific species cues predicted rough-legged hawk distribution by sex at four spatial scales. This research represented the first attempt to explain rough-legged hawk habitat selection at these landscape scales. In addition, this was the first study, to my knowledge, to describe sex-specific habitat use for this species. Possible reasons for sex-specific habitat selection included sex-specific niche use (related to prey) or social dominance. I posit that reversed sexual dimorphism in rough-legged hawks leads to social dominance of female hawks on their wintering grounds and that females may outcompete males for higher quality foraging habitat.

LITERATURE CITED

Amadon, D. 1975. Why are female birds of prey larger than males? Journal of Raptor Research 9:1-11.

Baker, J. A., and R. J. Brooks. 1981. Distribution patterns of raptors in relation to density of meadow voles. The Condor 83:42-47.

Beardsell, A., G. Gauthier, D. Fortier, J.-F. Therrien, and J. Bêty. 2017. Vulnerability to geomorphological hazards of an Arctic cliff-nesting raptor, the rough-legged hawk. Arctic Science 3:203–219.

Belknap, J. B. 1966. The rough-legged hawk in New York State. The Kingbird 16:133-136.

Berger, D. D., and H. C. Mueller. 1959. The bal-chatri: a trap for the birds of prey. Bird-Banding 30:18-26.

Berry, M. E., C. E. Bock, and S. L. Haire. 1998. Abundance of diurnal raptors on open space grasslands in an urbanized landscape. Condor 100:601–608.

Big Hole Watershed Committee. 2013. Big Hole River, Montana, watershed restoration plan, part II: middle & lower Big Hole watershed. Big Hole River watershed restoration plan.

Bildstein, K.L. 1978. Behavioral ecology of red-tailed hawks (*Buteo jamaicensis*), rough-legged hawks (*B. lagopus*), northern harriers (*Circus cyaneus*), american kestrels (*Falco sparverius*), and other raptorial birds wintering in south-central Ohio. Dissertation, Ohio State University, Columbus, USA.

Bildstein, K. L. 1992. Causes and consequences of reversed sexual size dimorphism in raptors: the head start hypothesis. Journal of Raptor Research 26:115-123.

Bloom, P. H., W. S. Clark, and J. W. Kidd. 2007. Capture techniques. Pages 193-219 *in* D. M. Bird and K. L. Bildstein, editors. Raptor research and management techniques. Hancock House Publishers, Madison, Wisconsin, USA.

Bock, C. E. and Z. F. Jones. 2004. Avian habitat evaluation: should counting birds count? Frontiers in Ecology and the Environment 2:403-410.

Bock, C. E., and L. W. Lepthien. 1976. Geographical ecology of the common species of

Buteo and *Parabuteo* wintering in North America. The Condor 78:554–557.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer, New York.

Byers, C. R., R. K. Steinhorst, and P. R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. The Journal of Wildlife Management 48:1050.

Cade, T. J. 1955. Variation of the common rough-legged hawk in North America. The Condor 57:313–346.

Clark, W. S., and P. H. Bloom. 2005. Basic II and basic III plumages of rough-legged hawks. Journal of Field Ornithology 76:83–89.

Clark, W. S., and P. H. Bloom. 2016. Plumages by sex of adult and basic III rough-legged hawks (*Buteo lagopus*). The Wilson Journal of Ornithology 128:867–873.

Craig, E. H., T. H. Craig, and L. R. Powers. 1986. Habitat use by wintering golden eagles and rough-legged hawks in southeastern Idaho. Journal of Raptor Research 20:69-71.

Cushman, S. A., and F. Huettmann, editors. 2010. Spatial Complexity, Informatics, and Wildlife Conservation. Springer Japan, Tokyo.

Desrochers, A. 1989. Sex, dominance, and microhabitat use in wintering black-capped chickadees: a field experiment. Ecology 70:636–645.

eBird: An online database of bird distribution and abundance [web application]. 2015. eBird homepage. <http://www.ebird.org>. Accessed on 12 Dec 2016.

Eureka County Master Plan. 2010. Eureka, NV, U.S.A.

Fischer, D. L., K. L. Ellis, and R. J. Meese. 1984. Winter habitat selection of diurnal raptors in central Utah. Journal of Raptor Research 18: 98-102.

Franklin, A. B., D. R. Anderson, R. J. Gutierrez, and K. P. Burnham. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70: 539-90.

Garrison, B. A. 1993. Distribution and trends in abundance of rough-legged hawks wintering in California. Journal of Field Ornithology 566–574.

Golden Gate Raptor Observatory. 2008. Bander's manual. Fourth edition. Golden Gate Raptor Observatory, Sausalito, California, USA.

Griffen, R. 1983. Behavioral and predatory energetics of a wintering rough-legged hawk. Thesis, Humboldt State University, Arcata, California, USA.

Hakkarainen, H., E. Huhta, K. Lahti, P. Lundvall, T. Mappes, P. Tolonen, and J. Wiehn. 1996. A test of male mating and hunting success in the kestrel: the advantages of smallness? Behavioral Ecology and Sociobiology 39:375-380.

Hinde, A. 2011. Wintering raptors of the great basin.

Holladay Engineering. 2012. Lemhi county transportation plan. Holladay Engineering, Payette, ID, USA.

Holmes, T. L., R. L. Knight, L. Stegall, and G. R. Craig. 1993. Responses of wintering grassland raptors to human disturbance. Wildlife Society Bulletin 21:461-468.

Howell, D. L., and B. R. Chapman. 1997. Home range and habitat use of red-shouldered hawks in Georgia. The Wilson Bulletin 131–144.

Hull, B., and P. Bloom. 2001. The North American banders' manual for raptor banding techniques. North American Banding Council, Point Reyes, California, USA.

Humboldt County Planning Commission. 2002. Humboldt County general plan, natural resources and hazards. Humboldt County, CA, U.S.A.

Jehl, J. R. and B. G. Murray Jr. 1986. The evolution of normal and reverse sexual size dimorphism in shorebirds and other birds. Current Ornithology 3:1-86.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Kasprzykowski, Z., and P. Cieśluk. 2011. Rough-legged buzzard *Buteo lagopus* wintering in central eastern Poland: population structure by age and sex, and the effect of weather conditions. Ornis Fennica 88:98-103.

Kjellén, N. 1994. Differences in age and sex ratio among migrating and wintering raptors in southern Sweden. The Auk 111: 274-284.

Krüger, O. 2005. The evolution of reversed sexual size dimorphism in hawks, falcons and owls: a comparative study. Evolutionary Ecology 19:467–486.

Littlefield, C. D., S. P. Thompson, and R. S. Johnstone. 1992. Rough-legged hawk habitat selection in relation to livestock grazing on Malheur National Wildlife Refuge, Oregon. Northwestern Naturalist 73:80-84.

Loman, J. 1991. Small mammal and raptor densities in habitat islands; area effects in a south Swedish agricultural landscape. Landscape Ecology 5:183–189.

Lundberg, A. 1986. Adaptive advantages of reversed sexual dimorphism in European owls. Ornis Scandinavica 17:133-140.

Marra, P. P. and R. T. Holmes. 2001. Consequences of dominance-mediated habitat segregation in american redstarts during the nonbreeding season. Auk 188:92-104.

Massemin, S., E. Korpimäki, and J. Wiehn. 2000. Reversed sexual dimorphism in raptors: evaluation of the hypothesis in kestrels breeding in a temporally changing environment. Oecologia 124:26-32.

McLoughlin, P. D., D. W. Morris, D. Fortin, D. E. Vander Wal, and A. L. Contasti 2010. Considering ecological dynamics in resource selection functions. Journal of Animal Ecology 79: 4-12.

Mindell, D. P. 1983. Nesting raptors in southwestern Alaksa: status, distribution, and aspects of biology. U.S. Bureau of Land Management Alaska Technical Report 8, Anchorage, A.K., USA.

Mono County Local Agency Formation Commission. 2010. Municipal service review and sphere of influence recommendation, Bridgeport Public Utility District, Mono County, California.

Mueller, H. C. 1990. The evolution of reversed sexual dimorphism in size in monogamous species of birds. Biological Reviews 65:553–585.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data. The Journal of Wildlife Management 38:541-545.

Newton, I. 1979. Population ecology of raptors. T. & A. D. Poyser Ltd., Berkhamsted.

Newton, I. 1991. Habitat variation and population regulation in sparrowhawks. Ibis 133:76-88.

Norris, D. R., P. P. Marra, T. K. Kyser, T. W. Sherry and L. M. Ratcliffe. 2004. Tropical winter habitat limits reproductive success on the temperate breeding grounds in a migratory bird. Proceedings: Biological Sciences 271:59–64.

Odum, E. P. and E. J. Kuenzler. 1955. Measurement of territory and home range size in birds. The Auk, 72:128-137.

Olson, C. V. 2006. Ecology and roosting behavior of rough-legged hawks (*Buteo lagopus*) wintering in the Mission Valley of northwestern Montana. Thesis, University of Montana, Missoula, Montana, U.S.A.

Olson, C. V., and D. P. Arsenault. 2000. Differential winter distribution of rough-legged hawks (*Buteo lagopus*) by sex in western North America. Journal of Raptor Research 34:157-166.

Olson, L. E., J. R. Squires, R. J. Oakleaf, Z. P. Wallace, and P. L. Kennedy. 2017. Predicting above-ground density and distribution of small mammal prey species at large spatial scales. PLOS ONE 12:e0177165.

Osborn, B. 2012. Plumas County existing vegetation map. Plumas County GIS.

Palmer, R. S. 1988. Diurnal raptors. Handbook of North American birds. New Haven, Connecticut, USA.

Pandolfino, E. R., and K. S. Wells. 2009. Changes in the winter distribution of the rough-legged hawk in North America. Western Birds 40:210-224.

Paprocki, N., J. A. Heath, and S. J. Novak. 2014. Regional distribution shifts help explain local changes in wintering raptor abundance: implications for interpreting population trends. PLoS ONE 9:e86814.

Parker, R. E. and E. G. Campbell. 1984. Habitat use by wintering birds of prey in southeastern Arizona. Western Birds 15:175-183.

Phillips, R. A., J. C. Xavier, and J. P. Croxall. 2003. Effects of satellite transmitters on albatrosses and petrels. The Auk 120:1082–1090.

Preston, C. R. 1990. Distribution of raptor foraging in relation to prey biomass and habitat structure. The Condor 92:107–112.

Prop J. and J. M. Black. 1998. Food intake, body reserves and reproductive success of barnacle geese *Branta leucopsis* staging in different habitats. Norsk Polarinst 200: 175-193.

Reynolds, R. T. 1972. Sexual dimorphism in accipiter hawks: a new hypothesis. The Condor 74:191-197.

Riley, S. J., S. D. DeGloria, and R. Elliott. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5:23-27.

Ritchie, R. J. 1991. Effects of oil development on providing nesting opportunities for gyrfalcons and rough-legged hawks in northern Alaska. The Condor 93:180–184.

Schmidt, E., and C. E. Bock. 2005. Habitat associations and population trends of two hawks in an urbanizing grassland region in Colorado. Landscape Ecology 20:469–478.

Schnell, G. D. 1968. Differential habitat utilization by wintering rough-legged and red-tailed hawks. The Condor 70:373–377.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

Sergio, F., J. Blas, M. G. Forero, J. A. Donázar, and F. Hiraldo. 2007. Sequential settlement and site dependence in a migratory raptor. Behavioral Ecology 18:811–821.

Sergio, F., and I. A. Newton. 2003. Occupancy as a measure of territory quality. Journal of Animal Ecology 72:857–865.

Snyder, N. F. R., S. R. Beissinger, M. R. Fuller. 1989. Solar radio-transmitters on snail kites in Florida. Journal of Field Ornithology 60:171-177.

Snyder, N. F., and J. W. Wiley. 1976. Sexual size dimorphism in hawks and owls of North America. Ornithological Society of North America. Ornithological monographs No. 20.

Storer, R. W. 1966. Sexual dimorphism and food habits in three North American accipiters. The Auk 83:423–436.

Summers, R. W., G. E. Westlake, and C. J. Feare. 2008. Differences in the ages, sexes and physical condition of starlings *Sturnus vulgaris* at the centre and periphery of roosts. Ibis 129:96–102.

Temeles, E. J. 1985. Sexual size dimorphism of bird-eating hawks: the effect of prey vulnerability. The American Naturalist 125:484-499.

Tomalty, K. M., A. C. Hull, A. M. Fish, C. W. Briggs, and J. M. Hull. 2016. Differential migration and phenology of adult red-tailed hawks in California. Journal of Raptor Research 50:45-53.

USFWS (U.S. Fish and Wildlife Service). 2010. Klamath Marsh National Wildlife Refuge final comprehensive conservation plan and environmental assessment. U.S Fish and Wildlife Service, Pacific Southwest Region.

USGS (U.S. Geological Survey). 1995. Irrigated croplands, estimated pumpage, and water-level changes in Diamond Valley, Eureka and Elko Counties, Nevada, through 1990. USGS Report 95-107.

USGS (U.S. Geological Survey). 2017. National Land Cover Database 2011 (NLCD2011) Product Legend. <https://www.mrlc.gov/nlcd11_leg.php>. Accessed on 12 Dec 2016.

Watson, J. W. 1984. Rough-legged Hawk winter ecology in southeastern Idaho. Thesis, Montana State University-Bozeman, College of Letters & Science, Bozeman, Montana, USA.

Western Regional Climate Center [web application]. 2013. <http://www.wrcc.dri.edu>. Accessed on 12 Dec 2016.

Wilkinson, G. S., and K. R. Debban. 1980. Habitat preferences of wintering diurnal raptors in the Sacramento valley. Western Birds 11:25-34.

Wilson, A., M. Brittingham, and G. Grove. 2010. Association of wintering raptors with Conservation Reserve Enhancement Program grasslands in Pennsylvania: Wintering raptors on conservation grasslands. Journal of Field Ornithology 81:361–372.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology, 70:164-168.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. The Journal of Wildlife management 59:794-800.

Zuur, A. F., editor. 2009. Mixed effects models and extensions in ecology with R. Statistics for biology and health, Springer, New York, New York, USA.

Zuur, A .F., E. N. Ieno, and G.M. Smith. 2007. Analyzing ecological data. Series: statistics for biology and health. Gail M., Krickeberg K., Samet JM, Tsiatis A., Wong W., editors. Springer-Verlag New York, NY, U.S.A.

APPENDIX A: LAND COVER AND TERRAIN RUGGEDNESS VARIABLES FOR MODELING ROUGH-LEGGED HAWK HABITAT SELECTION IN FIVE STATES IN WESTERN NORTH AMERICA DURING THE WINTERS OF 2014 AND 2015.

Table 10. National Land Cover Database 2011 habitat classification table. This table was obtained from the U.S. Geological Survey multi-resolution land cover consortium website and is presented here with minor edits (USGS 2017). Land cover used to model rough-legged hawk habitat selection in five states in western North America during the winters of 2014 and 2015.

Classification	Description
Developed (for GLMs, classes merged and represented as "VEGTYPE20" due to few GPS locations); all categories used in Chi-squared analysis since test allows for smaller sample sizes	
21	Developed, Open Space - large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity- areas with a mixture of constructed materials and vegetation. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. These areas most commonly include single-family housing units.
24	Developed High Intensity - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial.
Barren (category eliminated from GLMs due to a small sample size of GPS points); category used in Chi-squared analysis since test allows for smaller sample sizes	
31	Barren Land - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest (for GLMs, classes merged and represented as "VEGTYPE40" due to few GPS locations); all categories used in Chi-squared analysis since test allows for smaller sample sizes	
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Classification	Description
Herbaceous	
71	Grassland/Herbaceous - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Planted/Cultivated	
81	Pasture/Hay - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	Cultivated Crops - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Table 11. Terrain ruggedness categories obtained from Riley et al. 1999. In linear modeling, categories are presented as TRI_VALUE1 (Level), TRI_VALUE2 (Nearly Level), TRI_VALUE3 (Slightly Rugged), TRI_VALUE4 (Intermediately Rugged), TRI_VALUE5 (Moderately Rugged), and TRI_VALUE6 (Highly Rugged). Terrain ruggedness was used to model rough-legged hawk habitat selection in five states in western North America during the winters of 2014 and 2015.

Classification	Numerical Code for Modeling	Variation in Terrain (meters)
Level	1	0-80
Nearly Level	2	81-116
Slightly Rugged	3	117-161
Intermediately Rugged	4	162-239
Moderately Rugged	5	240-497
Highly Rugged	6	498-958

APPENDIX B: ROUGH-LEGGED HAWK WINTER RANGES AND SITE FIDELITY DURING THE WINTERS OF 2014 AND 2015 IN FIVE STATES IN WESTERN NORTH AMERICA

Methods

In order to obtain winter range size (95% fixed kernel) and core range (50% fixed kernel) size in square kilometers (km^2), I created 50% and 95% fixed kernel winter ranges for each study animal with the adehabitatHR and maptools package in RStudio. I imported these winter ranges into ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA 2011) and examined whether there was a significant difference (i.e. $P < 0.05$) in range sizes between ages, sexes, and years using Mann-Whitney U tests (Dytham 2011).

Results

50% Core and 95% Winter Ranges

Rough-legged hawks did not have differing 50% core range sizes between years (n = 24 ranges, U = 64, P = 0.67) or between sexes (n = 24 ranges, U = 94, P = 0.36). In addition, rough-legged hawk 95% winter range sizes did not differ between years (n = 24 ranges, U = 53, P = 0.29) or sexes (n = 24, U = 84, P = 0.65). However, at the 95% winter range scale, second year birds (SY, or juvenile birds) had significantly larger 95% winter ranges than after hatch year (AHY, or adult birds, n = 24 ranges, U = 3, P = 0.04). Many rough-legged hawk 95% winter ranges were multimodal (i.e. had multiple core use areas).

Table 12. Core range (50%) and winter range (95%) sizes (km^2) for rough-legged hawks wintering in five states in western North American during the winters of 2014 and 2015.

Age/Sex	50% Core Range Size (km^2)	95% Winter Range Size (km^2)
All Ages, All Sexes	54.50 ± 131.62	443.68 ± 752.50
All Ages, Males	15.04 ± 16.39	192.30 ± 308.35
All Ages, Females	93.97 ± 176.82	654.55 ± 935.06
SY Birds, All Sexes	80.38 ± 77.37	1648.78 ± 846.67*
AHY Birds, All Sexes	52.15 ± 136.24	333.04 ± 663.99

*significant at $P = 0.04$

Adult birds did not leave established ranges during the winter while juvenile birds tended to wander. The exception to this is, in 2014, two adult birds trapped in Quincy, CA moved north or south of their initial winter range after a major snow fall event (J. Kidd, pers. comm., 2014). Winter ranges sizes are presented for all study animals in Appendix C.

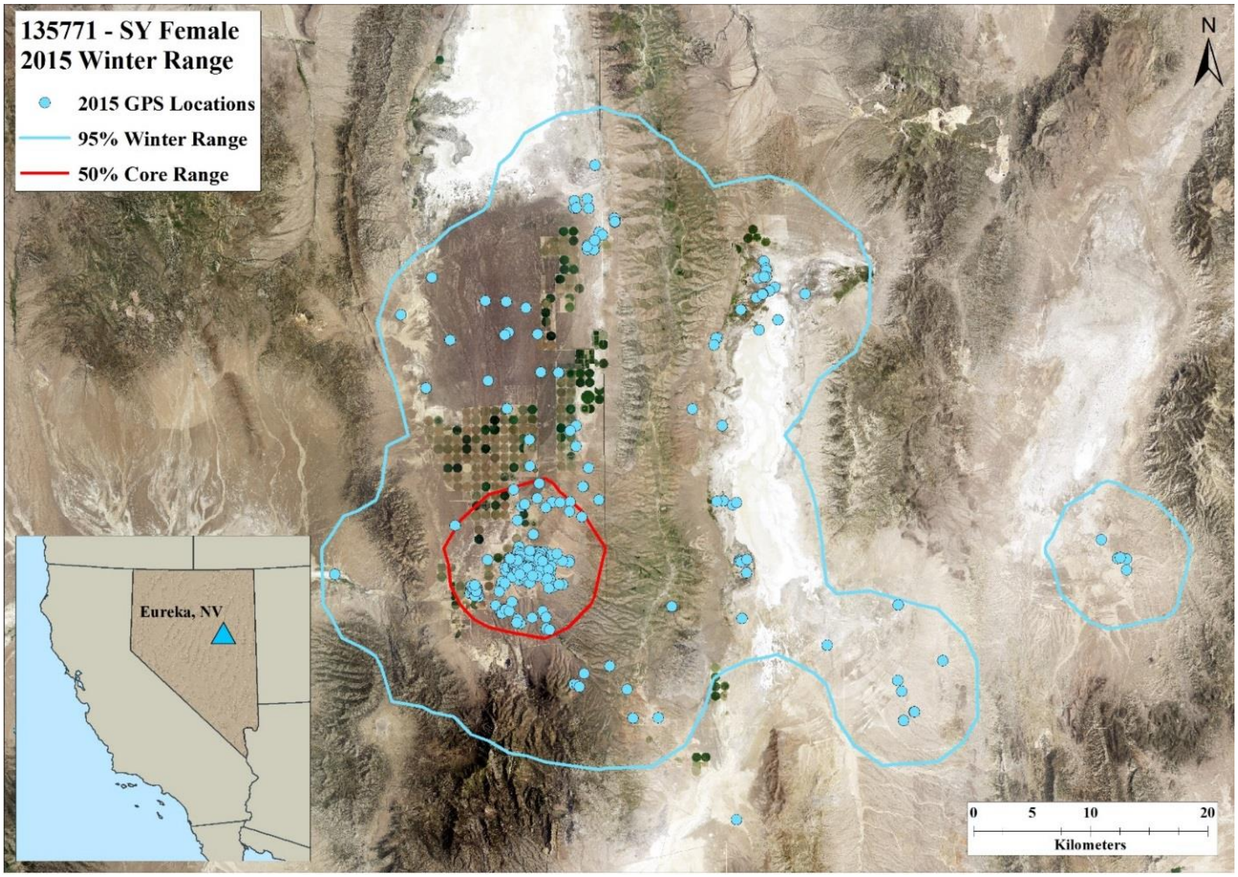

Figure 4. Rough-legged hawk 135771 (SY - Female) 2014 50% kernel core and 95% winter ranges in Eureka, Nevada. NAIP 2015imagery and U.S. Census 2013 State Cartographic Boundaries.

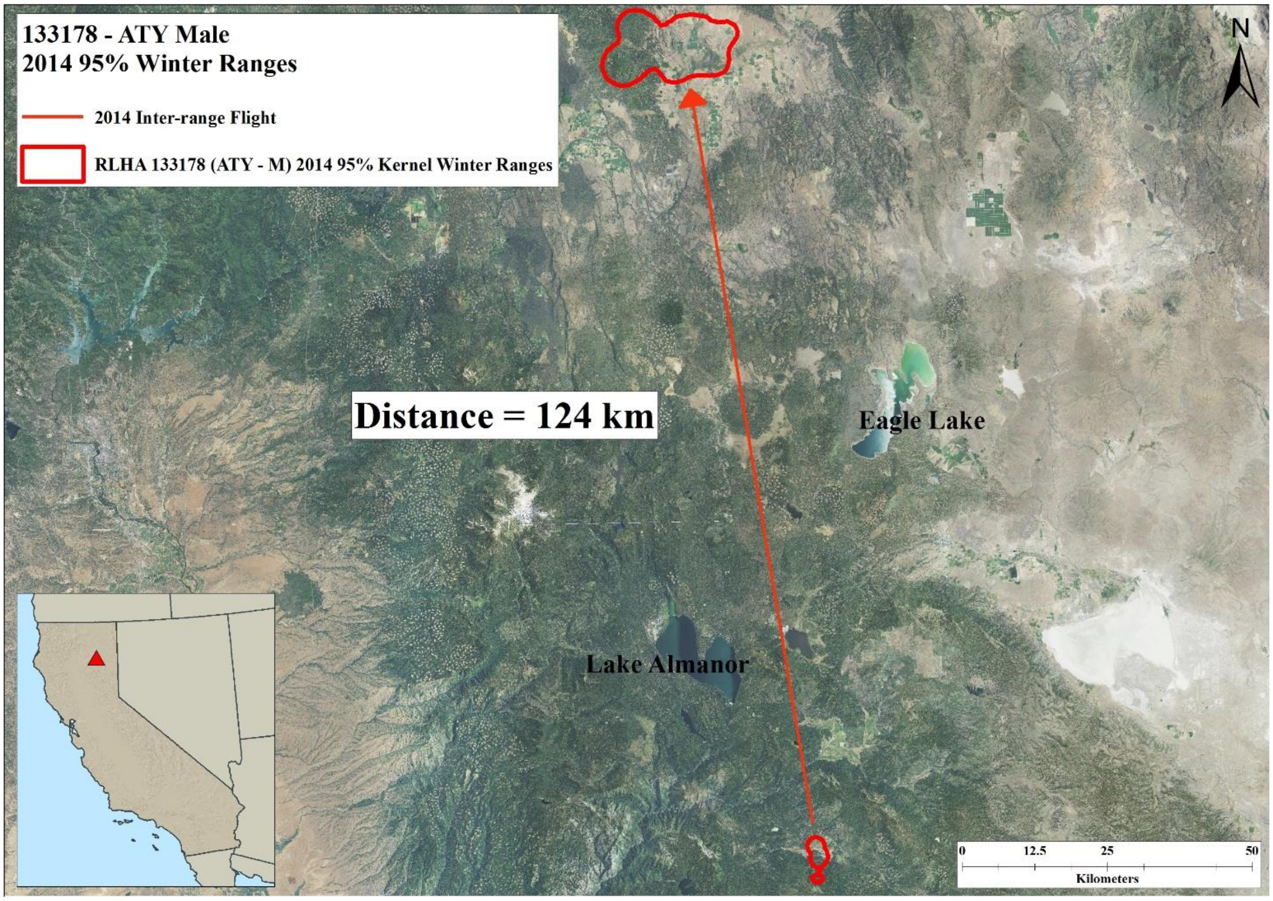

Figure 5. Rough-legged hawk 133178 (After Third Year, ATY - Male) 2014 winter ranges in northern California. This bird moved north from its initial winter range after a major snowfall even in early 2014. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

Rough-legged Hawk Shared Winter Range Habitat

Five out of nine hawks had overlapping 50% core ranges, and seven out of nine hawks had overlapping 95% kernel ranges in the winter of 2014 (sample size of n = 9 hawks in 2014) . In the winter of 2015, six out of twelve hawks have overlapping 50% core range areas, and eight out of twelve had overlapping 95% winter range areas (sample size of n = 12 hawks in 2015). At the 50% core range scale, female and male rough-legged hawks did not differ in the area of core range overlap (n = 17, U = 84, P =

0.39) or age classes (n = 17, *U* = 5.5, *P* = 0.07). In addition, at the 95% winter range scale, female and male rough-legged hawks did not differ in the area of winter range overlap (n = 17, *U* = 74.5, *P* = 0.8097). However, there was a difference in the area of range overlap between age classes. Juvenile birds shared larger areas of habitat within their 95% winter ranges with other rough-legged hawks than adult birds (n = 17, *U* = 1.5, *P* = 0.03).

Rough-legged hawk 50% core range areas overlapped with zero to four core areas of other study animals, while their 95% winter range areas overlapped with the winter ranges of zero to five other birds. Rough-legged hawks did not differ by age (n = 17, *U* = 7.5, *P* = 0.11) or sex (n = 17, *U* = 45, *P* = 0.42) in terms of the number of ranges that overlapped at the 50% core range scale. The area of overlap in the 50% winter range varied from 0.35 km^2 to 44.18 km^2 (mean = 8.55 km^2, standard deviation (*SD*) = 12.80 km^2), while the percentage of overlap ranged from 0.30% to 100.00% (mean = 33.98%, *SD* = 38.18%). Rough-legged hawks also did not differ in the number of ranges that overlapped at the 95% winter range scale by age (n = 17, *U* = 4, *P* = 0.06) or sex (n = 17, *U* = 74.5, *P* = 0.81). The area of overlap in 95% winter range varied from 1.47 km^2 to 1599.06 km^2 (mean = 334.45 km^2, *SD* = 449.61 km^2). The percentage of overlap at the 95% winter range scale ranged from 0.04% to 100.00% (mean = 44.07%, *SD* = 38.60%).

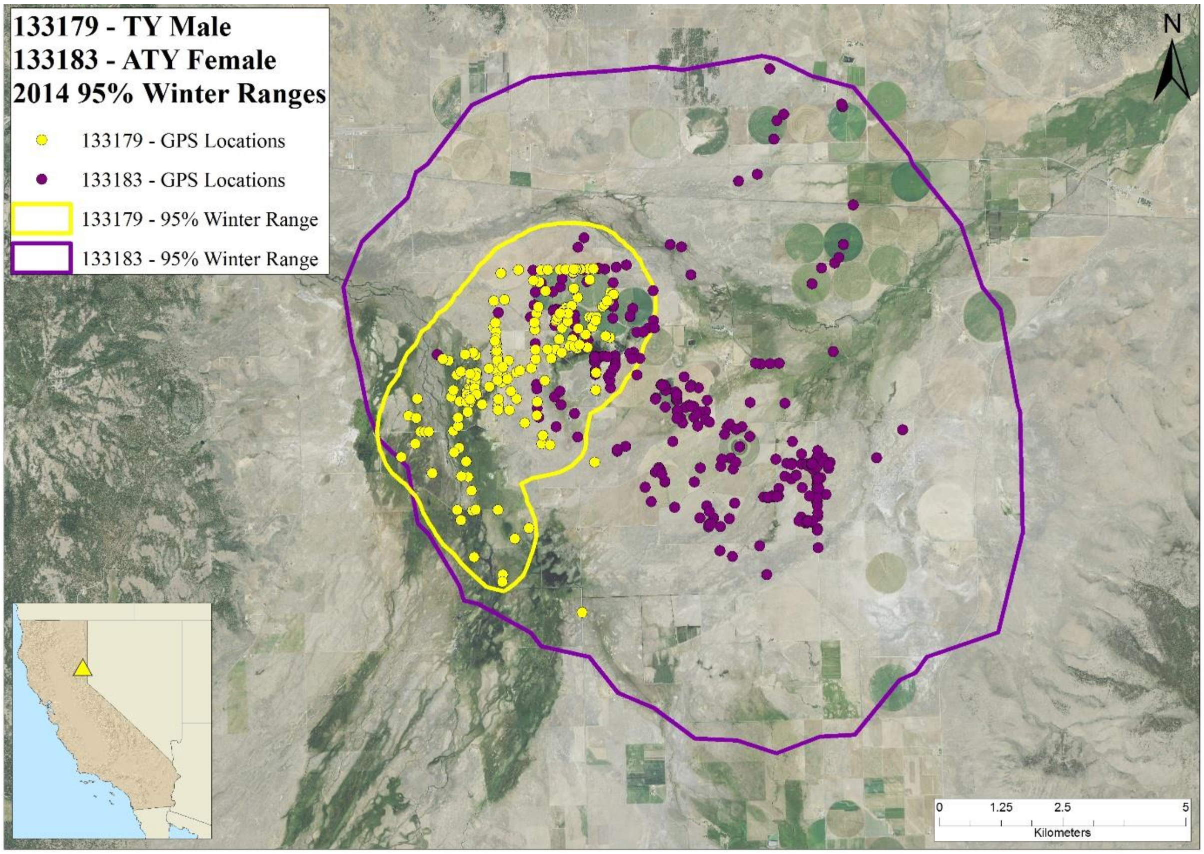

Figure 6. Overlapping 95% winter ranges between 133179 (TY Male) and 133183 (ATY Female) rough-legged hawks during the winter of 2014 in Sierra Valley, California. NAIP 2015 imagery and U.S. Census 2013 State Cartographic Boundaries.

Site Fidelity

Four out of the nine hawks trapped in 2014 survived to the next winter and had functioning transmitters in 2015. Of these four hawks, three exhibited wintering site fidelity (n = 2 males and n = 1 female). Male 133179 (fourth year, FY bird) was trapped in Sierra Valley, California in 2014 and initially returned to Sierra Valley in 2015 (distance between 2014 and 2015 range centroid points was 9.94 kilometers), but then moved north into Oregon and spent the remainder of the winter at the Klamath Marsh

National Wildlife Refuge. Female 133180 (FY bird) was trapped in Petrolia, California in 2014 and returned to the same coastal grasslands in 2015. Her 95% winter ranges in 2014 and 2015 had almost a complete overlap in area (91% overlap; distance between range centroid points was 0.34 kilometers). Male 133182 (AFY bird) was trapped in Fallon, NV in 2014 and returned to the initial wintering area (Stillwater National Wildlife Refuge) in 2015. His 2015 range fell completely within the bounds of the 2014 range (100% overlap; distance between range centroid points was 2.27 kilometers). The one individual that returned in the winter of 2015 and did not exhibit site fidelity was FY female 133181. This hawk was initially trapped in Quincy during the winter of 2014 and wintered on the border of Idaho and Montana in 2015 (northern Beaverhead Mountains). One note-worthy point is that this female was one of the same birds that experienced the heavy snowfall event in Quincy and moved north of her initial winter range after this event during the winter of 2014.

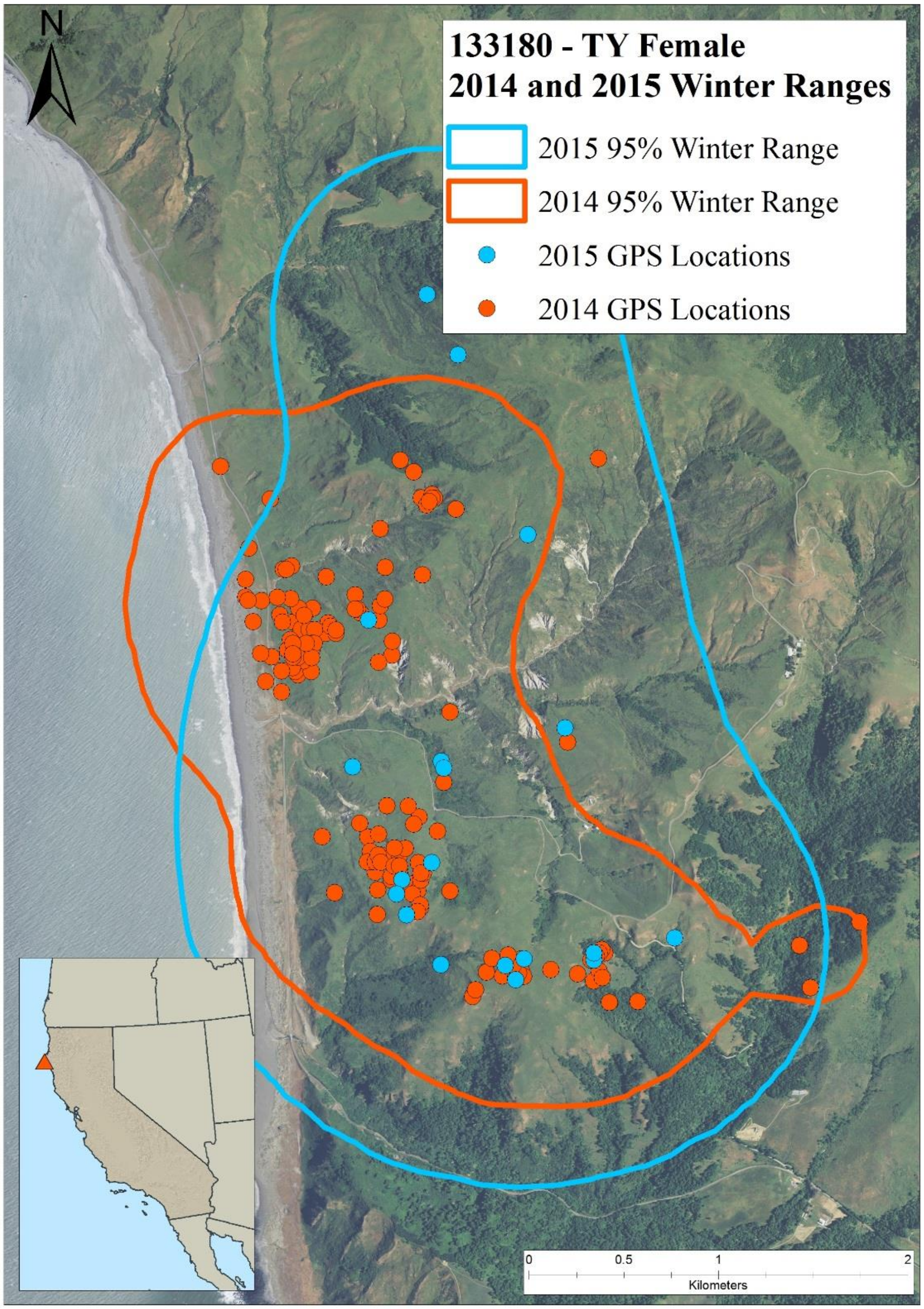

Figure 7. Site fidelity exhibited by rough-legged hawk 133180 (After third year, ATY, Female). 95% Fixed kernel winter ranges and associated GPS locations are shown for 2014 and 2015 in Petrolia, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

Discussion

Winter Ranges

The majority of the birds in this study had multimodal winter ranges (i.e. multiple areas of core use). This included birds that wintered in California, Nevada, and Idaho/Montana (range spanned the two states). This behavior had previously been observed in rough-legged hawks wintering in Montana (Olson 2006). Adult rough-legged hawks, for the most part, did not stray from their initial winter ranges, with the exception of one adult male and one adult female rough-legged hawk that were initially trapped around Quincy, California and moved to second winter ranges mid-winter. Watson (1986) also observed this behavior in rough-legged hawks wintering in Idaho. One hypothesis for this change in range use includes diminished ability for detect prey at the initial range site as a result of greater snow depths (Thiel 1985, Watson 1986, Pandolfino and Wells 2009). Juvenile birds tended to wander more than adults within their wintering areas. Although the sample size for juvenile birds was only n = 2, and more data is necessary to fully examine this possible age-related difference in range use, this finding confirms those of Olson (2006) on rough-legged hawks wintering in Montana.

Range Sizes

The typical 50% core winter range sizes for rough-legged hawks in this study were 15.04 km^2 ± 16.39 km^2 for males, 93.97 km^2 ± 176.82 km^2 for females, 80.38 km^2 ± 77.37 km^2 for juvenile (SY or first winter) birds, and 52.15 km^2 ± 136.24 km^2 for adult birds. In addition, I found that juvenile birds had significantly larger ranges than adult birds. Olson (2006) also observed this phenomenon in rough-legged hawks wintering in Montana. However, there was no significant different in 50% kernel core or 95% winter ranges sizes between years or sex for all birds. This contradicts Olson's (2006) finding that males had larger core ranges than females. Winter ranges were 192.30 km^2 ± 308.35 km^2 for males, 654.55 km^2 ± 935.06 km^2 for females, 1648.78 km^2 ± 846.67 km^2 for juveniles, and 333.04 km^2 ± 663.99 km^2 for adults. These findings were similar to those of Watson (1986) who found that wintering range sizes (Minimum Convex Polygon or MCP estimates likely capturing a combination of core use as well as complete range areas) varied from 70.2 km^2 ± 541.2 km^2 in Idaho. In comparison, Olson (2006) found that average maximum home ranges (100% MCPs) were 473 km^2, average primary home ranges (90% fixed kernel contour) were 69 km^2, and average core use areas (70% fixed kernel contour) were 17 km^2 for rough-legged hawks wintering in Montana. Some of my winter range estimates were larger than previously reported ranges, which is likely due to the fact that the use of high-accuracy GPS units captured a greater area of habitat use than was previously possible to capture with radio telemetry technology. Prey density may also affect winter range sizes at the scale of individual wintering sites, with smaller ranges reflecting areas of greater prey density (Temeles 1987).

Range Overlap

Winter ranges overlapped without any seeming difference between ages and sexes. The area of overlap ranged from 1.47 km^2 to 946.67 km^2 (mean = 199.98 km^2 ± 264.82 km^2). The percentage of overlap ranged from 0.09% to 100.00%. Although total range areas overlapped for most of the study species in both the winters of 2014 and

2015, habitat selection analysis results indicated that sex-specific habitat use was occurring at all spatial scales.

Site Fidelity

Site fidelity, or the return of an animal to a previously occupied area, is a well-documented phenomenon in scientific literature (Greenwood 1980, Giuggioli and Bartumeus 2012). Posited reasons for site fidelity include but are not limited to territoriality, predator avoidance, higher survival, increased reproductive success, and the efficient use of resources in heterogeneous landscapes (Switzer 1993, Brown et al. 2000, Shiu et al. 2006, Sergio et al. 2007, Musilová et al. 2011, Paruk et al. 2015). Fidelity to nest sites and breeding territories has been well documented in several species of raptors, including artic breeders (Booms et al. 2011). Fewer papers have examined wintering site fidelity for raptor species, although this behavior has been documented in bald eagles, grey-faced buzzards, honey buzzards, red-tailed hawks, and prairie falcons (Harmata and Staklecker 1993, Shiu et al 2006, McKinley and Mattox 2010).

Sylvén (1978) provided initial evidence for winter site fidelity for one rough-legged hawk that wintered in southern Sweden for a period of four years. Watson (1984) studied wintering rough-legged hawks in Idaho and identified two distinct wintering behavior strategies. Some of his study animals existed as transients or “floaters” within a season while other birds inhabited a distinct wintering territory. Using radio telemetry, Watson was able to establish intra-season site fidelity for six rough-legged hawks over a period of three winters (Watson 1986). Garrison and Bloom (1993) provided evidence that rough-legged hawks returned to previous wintering ranges in California via four band returns. Olson studied wintering rough-legged hawks in Mission Valley, Montana and also provided evidence for site fidelity in his study subjects (Olson 2006). McKinley and Mattox (2010) re-sighted one rough-legged hawk less than 3 kilometers from its original capture location near Boise, ID five years after it had been banded. However, no papers have examined rough-legged hawk winter site fidelity at larger spatial scales than the scale of an individual population.

Four out of the initial nine rough-legged hawks trapped in California and Nevada 2014 returned to their wintering grounds and had functioning transmitters in 2015. Of these four individuals (two females and two males), three birds provided strong evidence for site fidelity (one female and two males) by returning to the exact same wintering area in 2015 with complete or nearly complete range overlap (although one of the males ultimately wintered north of his 2014 range in 2015 after spending a few weeks at the 2014 range site). This supports earlier evidence for rough-legged hawk wintering site fidelity observed by Garrison and Bloom (1993) in California, McKinley and Mattox (2010) and Watson (1986) in Idaho, Sylvén (1978) in southern Sweden, and Olson (2006) in Montana. The fourth bird that returned in 2015 (an adult female) wintered much further north of her 2014 winter range. This was the same bird trapped in Quincy that left her initial range after a large snowfall event. One possible theory for site fidelity is that rough-legged hawks who successfully wintered in a particular area will return to that same area the following year. However, in the event of a reduced prey base or bad weather, they may choose to winter in a different area the following year.

Literature Cited

Booms, T. L., S. L. Talbot, G. K. Sage, B. J. McCaffery, K. G. McCracken, and P. F. Schempf. 2011. Nest-site fidelity and dispersal of gyrfalcons estimated by noninvasive genetic sampling. The Condor 113:768–778.

Boyce, M. S. and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology & Evolution 14:268-272.

Brown, D. R., P. C. Stouffer, and C. M. Strong. 2000. Movement and territoriality of wintering hermit thrushes in southeastern Louisiana. The Wilson Bulletin 112:347–353.

Dytham, C. 2011. Choosing and using statistics: a biologist's guide. Third edition. Wiley-Blackwell, Hoboken, New Jersey, USA.

Garrison, B.A., and P.H. Bloom. 1993. Natal origins and winter site fidelity of rough-legged hawks wintering in California. Journal of Raptor Research 27:116-118.

Giuggioli, L., and F. Bartumeus. 2012. Linking animal movement to site fidelity. Journal of Mathematical Biology 64:647–656.

Greenwood, P. J. 1980. Mating systems, philopatry and dispersal in birds and mammals. Animal Behaviour, 28:1140-1162.

Harmata, A. R., and D. W. Stahlecker. 1993. Fidelity of migrant bald eagles to wintering grounds in southern Colorado and northern New Mexico. Journal of Field Ornithology 64:129–134.

McKinley, J. O., and B. Mattox. 2010. Winter site fidelity of migratory raptors in southwestern Idaho. Journal of Raptor Research 44:240–243.

Musilová, Z., P. Musil, R. Fuchs, and S. Poláková. 2011. Territory settlement and site fidelity in reed buntings *Emberiza schoeniclus*. Bird Study 58:68–77.

Olson, C. V. 2006. Ecology and roosting behavior of rough-legged hawks (*Buteo lagopus*) wintering in the Mission Valley of northwestern Montana. Thesis, University of Montana, Missoula, Montana, U.S.A.

Pandolfino, E. R., and K. S. Wells. 2009. Changes in the winter distribution of the rough-legged hawk in North America. Western Birds 40:210-224.

Paruk, J. D., M. D. Chickering, D. Long, H. Uher-Koch, A. East, D. Poleschook, V.

Gumm, W. Hanson, E. M. Adams, K. A. Kovach, and D. C. Evers. 2015. Winter site fidelity and winter movements in common loons (*Gavia immer*) across North America. The Condor 117:485–493.

Sergio, F., J. Blas, M. G. Forero, J. A. Donázar, and F. Hiraldo. 2007. Sequential settlement and site dependence in a migratory raptor. Behavioral Ecology 18:811–821.

Shiu, H.-J., K. Tokita, E. Morishita, E. Hiraoka, Y. Wu, H. Nakamura, and H. Higuchi. 2006. Route and site fidelity of two migratory raptors: grey-faced buzzards *Butastur indicus* and honey-buzzards *Pernis apivorus*. Ornithological Science 5:151–156.

Switzer, P. V. 1993. Site fidelity in predictable and unpredictable habitats. Evolutionary Ecology 7:533-555.

Sylvén, M. 1978. Interspecific relations between sympatrically wintering common buzzards *Buteo buteo* and rough-legged buzzards *Buteo lagopus*. Ornis Scandinavica 9:197-206.

Temeles, E. J. 1987. The relative importance of prey availability and intruder pressure in feeding territory size regulation by harries, *Circus cyaneus*. Oecologia 74:286-297.

Thiel, R. P. 1985. Snow depth affects local abundance of wintering rough-legged hawks. Passenger Pigeon 474:129-130.

Watson, J. W. 1984. Rough-legged Hawk winter ecology in southeastern Idaho. Thesis, Montana State University-Bozeman, College of Letters & Science, Bozeman, Montana, USA.

Watson, J.W. 1986. Range use by wintering rough-legged hawks in southeastern Idaho. The Condor 88:256-258.

APPENDIX C: ROUGH-LEGGED FIXED KERNEL WINTER RANGES DURING THE WINTERS OF 2014-2015 IN FIVE STATES IN WESTERN NORTH AMERICA

Table 13. Core range (50%) and winter range (95%) sizes (km^2) for rough-legged hawks wintering in two states western North America in 2014 (n = nine birds, four females, five males).

Transmitter	Age	Sex	Trapping location	Trapping date	Range Location	50 % hr area (km2)	95 % hr area (km2)
133177	ATY	M	Bridgeport, CA	2014 (JAN)	Bridgeport, CA	0.69	2.53
133178a	ATY	M	Quincy, CA	2014 (JAN)	Quincy, CA	3.24	15.58
133178b	ATY	M	Quincy, CA	2014 (JAN)	Quincy, CA	28.31	217.17
133179a	TY	M	Sierra Valley, CA	2014 (JAN)	Quincy, CA	6.79	36.10
133179c	TY	M	Sierra Valley, CA	2014 (JAN)	Quincy, CA	5.44	24.51
133180	TY	F	Petrolia, CA	2014 (JAN)	Petrolia, CA	1.76	7.90
133181a	FY	F	Quincy, CA	2014 (WINTER)	Quincy, CA	127.35	684.39
133181b	FY	F	Quincy, CA	2014 (WINTER)	Quincy, CA	80.95	727.30
133182	ATY	M	Fallon, NV	2014 (WINTER)	Fallon, NV	7.92	44.93
133183	ATY	F	Sierra Valley, CA	2014 (WINTER)	Sierra Valley, CA	22.78	144.60
133184	FY	M	Fallon, NV	2014 (WINTER)	Fallon, NV	15.83	147.91
133185	AFY	F	Cholame, NV	2014 (WINTER)	Cholame, NV	7.41	35.45

Table 14. Core range (50%) and winter range (95%) sizes (km^2) for rough-legged hawks wintering in five states in western North America in 2015 (n = 12 birds, six females, six males).

Transmitter	Age	Sex	Trapping location	Trapping date	Range Location	50 % hr Area (km2)	95 % hr Area (km2)
133179	FY	M	Sierra Valley, CA	2014 (JAN)	Chiloquin, OR	7.34	76.99
133180	FY	F	Petrolia, CA	2014 (JAN)	Petrolia, CA	2.89	13.01
133181	AFY	F	Quincy, CA	2014 (WINTER)	Beaverhead, ID/MT	660.09	2970.88
133182	AFY	M	Fallon, NV	2014 (WINTER)	Fallon, NV	1.71	8.09
133186	AHY	M	Sierra Valley, CA	2015 (JAN)	Sierra Valley, CA	2.85	35.61
135770	TY	M	Sierraville, CA	2015 (WINTER)	Sierraville, CA	14.80	101.06
135771	SY	F	Eureka, NV	2015 (JAN)	Eureka, NV	135.09	2247.47
135772	AHY	M	Eureka, NV	2015 (JAN)	Eureka, NV	61.63	407.77
135773	AHY	F	Eureka, NV	2015 (JAN)	Eureka, NV	42.87	210.72
HAUS03	AHY	F	Eureka, NV	2015 (JAN)	Eureka, NV	44.28	1411.55
HAUS04	AHY	F	Eureka, NV	2015 (JAN)	Eureka, NV	0.41	2.88
HAUS05	SY	M	Eureka, NV	2014 (DEC)	Eureka, NV	25.67	1050.10

APPENDIX D: GLM HABITAT SELECTION MODELS

Nocturnal Roosting Scale

Table 15. Top habitat selection models for eight female rough-legged hawks explaining habitat selection at the nocturnal roosting site scale in five states in western North America during the winters of 2014 and 2015. The models included 152 total GPS locations and 152 available locations for eight females. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 4	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD +DIST_LOCAL+ DIST_4WD	7	-165.05	344.11	0.00	0.74	0.74	N/A
Model 5	Area+TRI_VALUE	3	-170.08	346.16	2.06	0.26	1.00	2.79
Model 9	VEGTYPE+TRI_VALUE+DIST_LOCAL+ DIST_4WD	5	177.40	364.80	20.69	0.00	1.00	3.11e+4
Model 8	VEGTYPE+TRI_VALUE+DIST_LOCAL + DIST_RT	5	-177.65	365.29	21.19	0.00	1.00	3.99e+4
Model 11	VEGTYPE+Area+DIST_4WD	4	-199.66	407.31	63.20	0.00	1.00	5.30e+13
Model 12	VEGTYPE+Area	3	-202.34	410.68	66.57	0.00	1.00	2.86e+14
Model 14	VEGTYPE*Area	4	-202.34	412.68	68.57	0.00	1.00	7.77e+14
Model 13	VEGTYPE	2	-210.35	424.70	80.59	0.00	1.00	3.16e+17

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model ($w_{i/}$ w_j)

Table 16. Variables included in the top habitat selection model (Model 4) for eight female rough-legged hawks explaining habitat selection at the nocturnal roosting site scale for five states in western North America during the winters of 2014 and 2015. The model included 152 total GPS locations and 152 available locations for eight females. Model: VEGTYPE+Area+ TRI_VALUE+ DIST_PR_SD+ DIST_LOCAL+ DIST_4WD (models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	3.50	1.92	5.18
Scrub	-1.02	-1.79	-0.28
Grassland	-0.94	-1.96	0.05
Pasture	-1.10	-2.42	0.24
Patch Size	0.23	0.14	0.33
Nearly Level	-0.44	-1.24	0.37
Slightly Rugged	-2.62	-3.66	-1.65
Intermediately Rugged	-2.94	-4.13	-1.90
Moderately Rugged	-2.94	-4.02	-1.96
Distance to Major Roads	-0.23	-0.74	0.28
Distance to Local Roads	-0.09	-0.47	0.28
Distance to 4WD Tracks	0.54	-0.01	1.10

Table 17. Variables included in the chi-squared selection models for eight female rough-legged hawks explaining land cover and terrain selection at the nocturnal roosting site scale for five states in western North America during the winters of 2014 and 2015. The model included 152 total GPS locations and 152 available locations for eight females.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Evergreen Forest	0.185	0.309	0.104	0.267	-
	Grassland/ Herb.	0.199	0.132	0.115	0.282	0
	Mixed Forest	0.026	0.001	-0.007	0.060	0
	Pasture/Hay	0.132	0.018	0.061	0.204	+
	Shrub/Scrub	0.457	0.540	0.353	0.561	0
Terrain Ruggedness	Level	0.566	0.094	0.462	0.669	+
	Nearly Level	0.250	0.047	0.160	0.340	+
	Slightly Rugged	0.059	0.047	0.010	0.109	0
	Intermed. Rugged	0.046	0.080	0.002	0.090	0
	Mod. Rugged	0.079	0.732	0.023	0.135	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Table 18. Top habitat selection model for nine male rough-legged hawks explaining habitat selection at the nocturnal roosting site scale in five states in western North America during the winters of 2014 and 2015. The model included 194 total GPS locations and 194 available locations for nine males. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 12	VEGTYPE*Area+TRI_VALUE+DIST_PR_SD +DIST_4WD	14	-157.09	342.19	0	0.64	0.64	1.00
Model 11	VEGTYPE*Area+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL+DIST_4WD	15	156.84	343.68	1.5	0.30	0.94	2.11
Model 10	VEGTYPE*Area+TRI_VALUE+ DIST_4WD	13	-161.37	348.73	6.54	0.02	0.96	26.36
Model 5	VEGTYPE+TRI_VALUE + DIST_LOCAL+ DIST_4WD+DIST_RT	11	-163.48	348.96	6.77	0.02	0.98	29.56
Model 9	VEGTYPE*Area+TRI_VALUE+DIST_LOCAL+DIST_4WD	14	-161.29	350.58	8.36	0.01	0.99	66.51
Model 1	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL+ DIST_4WD	12	-169.06	362.12	19.93	0.00	1.00	2.12e+4
Model 14	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD +DIST_4WD	11	-170.30	362.61	20.42	0.00	1.00	2.71e+4
Model 2	VEGTYPE+TRI_VALUE+DIST_PR_SD +DIST_4WD	10	-172.49	364.98	22.80	0.00	1.00	8.92e+4
Model 15	VEGTYPE+Area+TRI_VALUE+ DIST_4WD	10	-173.76	367.53	25.34	0.00	1.00	3.18e+5
Model 16	VEGTYPE+Area+TRI_VALUE+ DIST_LOCAL +DIST_4WD	11	-173.22	368.45	26.26	0.00	1.00	5.03e+5
Model 8	VEGTYPE+Area+TRI_VALUE	9	-178.56	375.12	32.93	0.00	1.00	1.41e+7
Model 7	VEGTYPE+Area+TRI_VALUE+DIST_LOCAL	10	-178.33	376.65	34.47	0.00	1.00	3.05e+7

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model ($w_{i/}$ w_j)

Table 19. Variables included in the top habitat selection model (Model 12) for nine male rough-legged hawks explaining habitat selection at the nocturnal roosting site scale for five states in western North America during the winters of 2014 and 2015. The model included 194 total GPS locations and 194 available locations for nine males. Model: VEGTYPE*Area+ TRI_VALUE+DIST_PR_SD+ DIST_4WD (models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	3.48	1.63	5.47
Scrub	-4.83	-6.98	-2.86
Grassland	6.19	0.49	12.24
Herbaceous Wetlands	2.63	-1.27	7.61
Patch Size	0.40	0.12	0.72
Nearly Level	-2.40	-3.70	-1.24
Slightly Rugged	-3.48	-5.34	1.93
Intermediately Rugged	-2.76	-3.92	-1.74
Moderately Rugged	-4.65	-6.30	-3.26
Distance to Major Roads	-0.50	-0.86	-0.16
Distance to 4WD Tracks	-3.56	-5.27	-1.97
Scrub*Patch Size	-0.47	-0.81	-0.16
Grassland*Patch Size	0.70	-0.06	1.49
Herbaceous Wetlands*Patch Size	0.41	-0.14	1.05

Table 20. Variables included in the chi-squared selection models for nine male rough-legged hawks explaining land cover and terrain selection at the nocturnal roosting site scale for five states in western North America during the winters of 2014 and 2015. The model included 194 total GPS locations and 194 available locations for nine males.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Herb.Wetlands	0.167	0.006	0.097	0.236	+
	Evergreen Forest	0.156	0.222	0.089	0.224	0
	Grassland/Herb.	0.396	0.066	0.305	0.487	+
	Pasture/Hay	0.063	0.013	0.018	0.107	+
	Shrub/Scrub	0.219	0.692	0.142	0.296	-
Terrain Ruggedness	Level	0.768	0.329	0.690	0.846	+
	Nearly Level	0.052	0.145	0.011	0.092	-
	Slightly Rugged	0.026	0.123	-0.004	0.055	-
	Intermed. rugged	0.103	0.166	0.047	0.159	-
	Mod. Rugged	0.052	0.237	0.011	0.092	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Core Range Scale

Table 21. Top habitat selection model for eight female rough-legged hawks explaining habitat selection at the 50% core range scale in five states in western North America during the winters of 2014 and 2015. The model included 1,828 total GPS locations and 1,828 available locations for eight females. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 2	VEGTYPE+Area+DIST_PR_SD+DIST_LOCAL+ DIST_PRIVA+ DIST_4WD	12	-2374.05	4772.11	0.00	0.56	0.56	1.00
Model 3	VEGTYPE + DIST_PR_SD+DIST_LOCAL+ DIST_PRIVA +DIST_4WD	11	-2375.56	4773.12	1.01	0.34	0.90	1.66
Model 1	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL+DIST_PRIVA+DIST_4WD	16	-2372.00	4776.00	3.89	0.08	0.98	7.01
Model 8	VEGTYPE+DIST_PR_SD+DIST_LOCAL+ DIST_PRIVA	10	-2379.68	4779.37	7.26	0.01	0.99	37.75
Model 17	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD +DIST_LOCAL	14	-2382.53	4793.07	20.96	0.00	1.00	3.57e+4
Model 16	VEGTYPE+Area+TRI_VALUE+ DIST_LOCAL	13	-2387.71	4801.41	29.30	0.00	1.00	2.3e+6
Model 21	VEGTYPE+TRI_VALUE+ DIST_PR_SD +DIST_PRIVA+ DIST_RT	14	-2386.83	4801.66	29.55	0.00	1.00	2.6e+6
Model 4	VEGTYPE+DIST_4WD	8	-2393.90	4803.80	31.69	0.00	1.00	7.6e+6
Model 7	VEGTYPE	7	-2396.84	4807.68	35.57	0.00	1.00	5.2e+7

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model (w_i / w_j)

Table 22. Variables included in the top habitat selection model (Model 2) for eight female rough-legged hawks explaining habitat selection at the 50% core range scale for five states in western North America during the winters of 2014 and 2015. The model included 1,828 total GPS locations and 1,828 available locations for eight females. Model: VEGTYPE+Area+DIST_PR_SD +DIST_LOCAL+DIST_PRIVA+ DIST_4WD (models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	0.74	0.10	1.39
Forested	-1.38	-2.00	-0.79
Scrub	-1.35	-1.77	-0.95
Grassland	-0.85	-1.28	-0.43
Pasture	-0.20	-0.59	0.17
Cropland	-1.21	-1.75	-0.69
Herbaceous Wetlands	-0.96	-1.54	-0.39
Patch Size	-0.03	-0.07	0.00
Distance to Major Roads	0.22	0.11	0.34
Distance to Local Roads	0.19	0.12	0.26
Distance to Private Roads	-0.25	-0.37	-0.13
Distance to 4WD Tracks	-0.09	-0.15	-0.03

Table 23. Variables included in the chi-squared selection model for eight female rough-legged hawks explaining land cover selection at the 50% core range scale for five states in western North America during the winters of 2014 and 2015. The model included 1,828 total GPS locations and 1,828 available locations for eight females.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Cultivated Crops	0.024	0.019	0.015	0.034	0
	Open Space	0.055	0.014	0.040	0.069	+
	Developed/Low Intensity	0.002	0.004	-0.001	0.005	0
	Herbaceous Wetlands	0.020	0.008	0.011	0.028	+
	Evergreen Forest	0.024	0.309	0.015	0.034	-
	Pasture/Hay	0.470	0.126	0.439	0.501	+
	Shrub/Scrub	0.254	0.284	0.227	0.281	0
	Grassland/Herbaceous	0.151	0.237	0.129	0.173	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Table 24. Top habitat selection model for nine male rough-legged hawks explaining habitat selection at the 50% core range scale in five states in western North America during the winters of 2014 and 2015. The model included 1,968 total GPS locations and 1,968 available locations for nine males. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 3	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL	14	-2398.58	4825.16	0.00	0.87	0.87	1.00
Model 6	VEGTYPE+TRI_VALUE+ DIST_PR_SD	12	-2403.56	4831.13	5.97	0.04	0.91	19.79
Model 7	VEGTYPE+TRI_VALUE+ DIST_PR_SD +DIST_LOCAL+ DIST_RT	14	-2401.77	4831.55	6.39	0.04	0.95	24.43
Model 9	VEGTYPE+TRI_VALUE DIST_PR_SD+DIST_LOCAL	13	-2402.82	4831.63	6.47	0.03	0.98	25.45
Model 5	VEGTYPE+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL DIST_RL	14	-2402.66	4833.32	8.17	0.01	0.99	59.31
Model 17	VEGTYPE*Area+DIST_PRIVA	15	-2424.54	4879.08	53.92	0.00	1.00	5.11e+11
Model 12	VEGTYPE+TRI_VALUE+Area+ DIST_PRIVA	13	-2431.21	4888.43	63.27	0.00	1.00	5.47e+13

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model (w_i / w_j)

Table 25. Variables included in the top habitat selection model for nine male rough-legged hawks explaining habitat selection at the 50% core range scale for five states in western North America during the winters of 2014 and 2015. The model included 1,968 total GPS locations and 1,968 available locations for nine males. Model: VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL (top 5 models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	-0.56	-1.02	-0.11
Forested	2.15	0.96	3.57
Scrub	-0.81	-1.14	-0.47
Grassland	-0.01	-0.33	0.32
Pasture	0.73	0.40	1.06
Cropland	0.74	0.32	1.17
Herbaceous Wetlands	0.48	0.07	0.89
Patch Size	0.08	0.03	0.14
Nearly Level	-1.80	-2.29	-1.35
Slightly Rugged	-2.75	-4.24	-1.63
Intermediately Rugged	-2.68	-4.13	-1.51
Moderately Rugged	-3.66	-5.50	-2.25
Distance to Major Roads	-0.29	-0.36	-0.21
Distance to Local Roads	-0.09	-0.19	0.01

Table 26. Variables included in the chi-squared selection models for nine male rough-legged hawks explaining land cover and terrain selection at the 50% core range scale for five states in western North America during the winters of 2014 and 2015. The model included 1,968 total GPS locations and 1,968 paired random locations for nine males.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Cultivated Crops	0.095	0.156	0.073	0.118	-
	Open Space	0.078	0.029	0.057	0.098	+
	Developed/Low Intensity	0.018	0.009	0.008	0.028	0
	Developed/Medium Intensity	0.002	0.001	-0.001	0.006	0
	Herb. Wetlands	0.198	0.187	0.167	0.229	0
	Evergreen Forest	0.025	0.040	0.013	0.036	0
	Pasture/Hay	0.208	0.176	0.177	0.239	+
	Shrub/Scrub	0.151	0.169	0.124	0.179	0
	Grassland/Herb.	0.226	0.232	0.194	0.258	0
Terrain Ruggedness	Level	0.918	0.402	0.902	0.934	+
	Nearly Level	0.039	0.086	0.028	0.051	-
	Slightly Rugged	0.014	0.097	0.007	0.021	-
	Intermed. Rugged	0.015	0.170	0.007	0.022	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Winter Range Scale

Table 27. Top habitat selection model for eight female rough-legged hawks explaining habitat selection at the 95% winter range scale in five states in western North America during the winters of 2014 and 2015. The model included 2,467 total GPS locations and 2,467 available locations for eight females. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum . w_i	Evidence Ratio
Model 3	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL+DIST_PRIVA+ DIST_RT	17	-2998.31	6030.62	0.00	0.50	0.50	1.00
Model 4	VEGTYPE+Area+ TRI_VALUE+DIST_PR_SD+ DIST_PRIVA + DIST_RT	16	-2999.34	6030.67	0.06	0.49	0.99	1.03
Model 2	VEGTYPE+TRI_VALUE+ DIST_PR_SD+DIST_PRIVA	14	-3005.88	6039.75	9.13	0.01	1.00	96.27
Model 11	VEGTYPE+DIST_PR_SD+ DIST_RT	10	-3115.45	6250.89	220.27	0.00	1.00	6.78e+47
Model 10	VEGTYPE+Area+ DIST_PR_SD+DIST_RT	11	-3115.03	6252.05	221.43	0.00	1.00	1.21e+48
Model 8	VEGTYPE+Area+ DIST_LOCAL + DIST_RT	11	-3115.96	6253.91	223.29	0.00	1.00	3.0e+48
Model 9	VEGTYPE+DIST_LOCAL+ DIST_RT	10	-3117.33	6254.67	224.05	0.00	1.00	4.48e+48
Model 7	VEGTYPE+Area	9	-3124.23	6266.45	235.84	0.00	1.00	1.62e+51

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model ($w_{i/}$ w_j)

Table 28. Variables included in the top habitat selection model for eight female rough-legged hawks explaining habitat selection at the 95% winter range scale for five states in western North America during the winters of 2014 and 2015. The model included 2,467 total GPS locations and 2,467 available locations for eight females. Model: VEGTYPE+Area+TRI_VALUE +DIST_PR_SD+DIST_PRIVA+ DIST_RT (top 5 models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	1.02	0.51	1.55
Forested	-1.12	-1.63	-0.61
Scrub	-1.38	-1.77	-1.00
Grassland	-1.22	-1.62	-0.83
Pasture	-0.06	-0.42	0.29
Cropland	-0.65	-1.19	-0.11
Woody Wetlands	1.36	-0.40	4.30
Herbaceous Wetlands	-1.55	-2.05	-1.06
Patch Size	0.04	0.02	0.07
Nearly Level	0.05	-0.17	0.26
Slightly Rugged	-0.43	-0.75	-0.12
Intermed. Rugged	-1.44	-1.85	-1.06
Moderately Rugged	-1.85	-2.29	-1.43
Distance to Major Roads	0.29	0.21	0.38
Distance to Private Roads	-0.42	-0.52	-0.33
Distance to Red-tailed Hawks	-0.35	-0.59	-0.11

Table 29. Variables included in the chi-squared selection models for eight female rough-legged hawks explaining land cover and terrain selection at the 95% winter range scale for five states in western North America during the winters of 2014 and 2015. The model included 2,467 total GPS locations and 2,467 paired random locations for eight females.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Barren Land	0.005	0.021	0.001	0.009	-
	Cultivated Crops	0.026	0.013	0.017	0.035	+
	Open Space	0.041	0.010	0.030	0.051	+
	Developed/Low Intensity	0.003	0.002	0.000	0.005	0
	Herb. Wetlands	0.021	0.005	0.013	0.029	+
	Evergreen Forest	0.032	0.257	0.022	0.041	-
	Mixed Forest	0.003	0.000	0.000	0.005	0
	Woody Wetlands	0.004	0.002	0.000	0.007	0
	Pasture/Hay	0.389	0.071	0.362	0.416	+
	Shrub/Scrub	0.343	0.442	0.317	0.370	-
	Grassland/Herb.	0.134	0.174	0.115	0.153	-
Terrain Ruggedness	Level	0.85	0.37	0.832	0.868	+
	Nearly Level	0.08	0.09	0.069	0.096	0
	Slightly Rugged	0.03	0.11	0.026	0.044	-
	Intermed. Rugged	0.02	0.20	0.009	0.022	-
	Mod. Rugged	0.02	0.23	0.010	0.023	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Table 30. Top habitat selection model for nine male rough-legged hawks explaining habitat selection at the 95% winter range scale in five states in western North America during the winters of 2014 and 2015. The model included 2,845 total GPS locations and 2,845 available locations for nine males. Models with confidence intervals that overlapped 0 are not presented below.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 15	VEGTYPE+Area+TRI_VALUE+ DIST_PRIVA	13	-3421.59	6869.18	0.00	0.54	0.54	1.00
Model 11	VEGTYPE+Area+TRI_VALUE+ DIST_RT	13	-3421.75	6869.50	0.32	0.46	1.00	1.17
Model 20	Area+TRI_VALUE+DIST_PR_SD +DIST_LOCAL+DIST_4WD	9	-3558.23	7134.47	265.28	0.00	1.00	4.03e+57
Model19	VEGTYPE+Area+TRI_VALUE + DIST_LOCAL+DIST_PRIVATE	9	-3559.05	7136.10	266.92	0.00	1.00	9.13e+57
Model 16	Area+TRI_VALUE+DIST_PR_SD	7	-3568.27	7150.54	281.36	0.00	1.00	1.24e+61
Model 17	Area+TRI_VALUE+DIST_PRIVA	7	-3578.50	7171.00	301.81	0.00	1.00	3.45e+65
Model 10	VEGTYPE+Area	8	-3597.20	7210.40	341.22	0.00	1.00	1.24e+74

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model (w_i / w_j)

Table 31. Variables included in the top habitat selection model for nine male rough-legged hawks explaining habitat selection at the 95% winter range scale for five states in western North America during the winters of 2014 and 2015. The model included 2,845 total GPS locations and 2,845 available locations for nine males. Model: VEGTYPE+Area+TRI_VALUE+ DIST_PRIVA (top 5 models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	0.62	0.21	1.03
Forested	-2.18	-2.55	-1.82
Scrub	-1.04	-1.35	-0.74
Grassland	-1.00	-1.30	-0.70
Pasture	0.24	-0.16	0.65
Cropland	-0.08	-0.50	0.35
Herbaceous Wetlands	-0.81	-1.23	-0.40
Patch Size	-0.05	-0.08	-0.03
Nearly Level	-1.25	-1.64	-0.86
Slightly Rugged	2.22	1.60	2.92
Intermediately Rugged	1.96	1.56	2.37
Moderately Rugged	0.86	0.52	1.20
Distance to Private Roads	0.04	-0.06	0.14

Table 32. Variables included in the chi-squared selection models for nine male rough-legged hawks explaining land cover and terrain selection at the 95% winter range scale for five states in western North America during the winters of 2014 and 2015. The model included 2,845 total GPS locations and 2,845 available locations for nine males.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Barren Land	0.00	0.01	0.00	0.01	0
	Cultivated Crops	0.04	0.02	0.03	0.05	+
	Open Space	0.05	0.02	0.04	0.06	+
	Developed/Low Intensity	0.01	0.00	0.00	0.01	+
	Developed/Medium Intensity	0.00	0.00	0.00	0.00	0
	Herb. Wetlands	0.11	0.04	0.09	0.12	+
	Evergreen Forest	0.06	0.24	0.04	0.07	-
	Pasture/Hay	0.24	0.09	0.22	0.27	+
	Shrub/Scrub	0.32	0.49	0.29	0.34	-
	Grassland/Herb.	0.17	0.10	0.15	0.19	+
Terrain Ruggedness	Level	0.918	0.402	0.902	0.934	+
	Nearly Level	0.039	0.086	0.028	0.051	-
	Slightly Rugged	0.014	0.097	0.007	0.021	-
	Intermed. Rugged	0.015	0.170	0.007	0.022	-
	Mod. Rugged	0.014	0.246	0.007	0.021	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Ecoregion Range Scale

Table 33. Top habitat selection model for eight female rough-legged hawks explaining habitat selection at the 200% ecoregion scale in five states in western North America during the winters of 2014 and 2015.The model included 2,536 total GPS locations and 2,536 paired available locations for eight females.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 8	VEGTYPE+ TRI_VALUE + DIST_PR_SD+ DIST_PRIVA+ DIST_RT	15	-2343.30	4716.61	0.00	0.72	0.72	1.00
Model7	VEGTYPE+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL+ DIST_PRIVA+DIST_RT	16	-2343.25	4718.49	1.89	0.28	1.00	2.57
Model 18	VEGTYPE*Area+TRI_VALUE+ DIST_PR_SD+DIST_RT	22	-2467.32	4978.63	262.02	0.00	1.00	7.90e+56
Model 1	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL+DIST_4WD	16	-2492.92	5017.83	301.23	0.00	1.00	2.57e+65
Model 22	VEGTYPE*Area+TRI_VALUE	20	-2493.31	5026.61	310.00	0.00	1.00	2.07e+67
Model 4	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL+ DIST_RT	16	-2518.34	5068.68	352.08	0.00	1.00	2.83e+76
Model 11	VEGTYPE+Area+TRI_VALUE+DIST_LOCAL+DIST_RT	15	-2523.15	5076.29	359.68	0.00	1.00	1.27e+78
Model 5	VEGTYPE+Area+TRI_VALUE+ DIST_PR_SD+DIST_LOCAL+ DIST_RL	16	-2528.29	5088.58	371.98	0.00	1.00	5.93e+80
Model 6	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL	15	-2530.04	5090.09	373.48	0.00	1.00	1.26e+81
Model 21	VEGTYPE+TRI_VALUE	12	-2549.78	5123.57	406.96	0.00	1.00	2.34e+88

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model ($w_{i/}\ w_j$)

Table 34. Variables included in the top habitat selection model (Model 8) for eight female rough-legged hawks explaining habitat selection at the 200% ecoregion scale for five states in western North America during the winters of 2014 and 2015. The model included 2,536 total GPS locations and 2,536 available locations for eight females. Model: VEGTYPE+ TRI_VALUE + DIST_PR_SD+ DIST_PRIVA+ DIST_RT (top 5 models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	-6.29	-8.43	-4.14
Forested	-1.63	-2.16	-1.12
Scrub	-1.28	-1.73	-0.85
Grassland	-0.61	-1.09	-0.15
Pasture	0.53	0.05	0.98
Cropland	0.31	-0.42	1.09
Woody Wetlands	-1.35	-2.37	-0.34
Herbaceous Wetlands	-0.15	-0.82	0.53
Distance to Private Roads	-0.73	-0.81	-0.65
Nearly Level	-0.43	-0.64	-0.21
Slightly Rugged	-1.09	-1.37	-0.81
Intermediately Rugged	-1.77	-2.12	-1.45
Moderately Rugged	-1.85	-2.20	-1.52
Distance to Major Roads	0.39	0.30	0.48
Distance to Red-tailed Hawks	4.01	2.73	5.29

Table 35. Variables included in the chi-squared selection models for eight female rough-legged hawks explaining land cover and terrain selection at the 200% ecoregion scale for five states in western North America during the winters of 2014 and 2015. The model included 2,536 total GPS locations and 2,536 available locations for eight females.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Barren Land	0.008	0.020	0.004	0.013	-
	Cultivated Crops	0.022	0.007	0.014	0.029	+
	Open Space	0.056	0.005	0.044	0.068	+
	Developed/Low Intensity	0.003	0.002	0.000	0.006	0
	Herb. Wetlands	0.022	0.004	0.014	0.030	+
	Evergreen Forest	0.040	0.295	0.029	0.050	-
	Mixed Forest	0.003	0.001	0.000	0.007	0
	Woody Wetlands	0.004	0.004	0.001	0.008	0
	Pasture/Hay	0.361	0.017	0.336	0.386	+
	Shrub/Scrub	0.358	0.518	0.332	0.383	-
	Grassland/Herb.	0.123	0.127	0.106	0.140	0
Terrain Ruggedness	Level	0.851	0.240	0.831	0.872	+
	Nearly Level	0.085	0.121	0.069	0.102	-
	Slightly Rugged	0.042	0.121	0.030	0.054	-
	Intermed. Rugged	0.013	0.202	0.006	0.019	-
	Mod. Rugged	0.009	0.316	0.003	0.014	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

Table 36. Top habitat selection model for nine male rough-legged hawks explaining habitat selection at the 200% ecoregion scale in five states in western North America during the winters of 2014 and 2015. The model included 2,980 total GPS locations and 2,980 available locations for nine males.

Model #	Predictor Variables	df	logLik	AIC	ΔAIC	w_i	Cum. w_i	Evidence Ratio
Model 9	VEGTYPE+ TRI_VALUE+DIST_PR_SD+ DIST_4WD+DIST_RT	14	-2481.64	4991.27	0.00	0.53	0.53	1.00
Model 8	VEGTYPE+TRI_VALUE+ DIST_PR_SD +DIST_LOCAL+ DIST_4WD+DIST_RT	15	-2480.75	4991.50	0.23	0.47	1.00	1.12
Model 4	VEGTYPE+TRI_VALUE+ DIST_PR_SD+ DIST_4WD+DIST_RL	14	-2489.79	5007.57	16.30	0.00	1.00	3461.45
Model 3	VEGTYPE+TRI_VALUE+ DIST_PR_SD +DIST_LOCAL+ DIST_4WD+DIST_RL +	15	-2489.35	5008.71	17.43	0.00	1.00	6098.16
Model 2	VEGTYPE+TRI_VALUE+ DIST_PR_SD+ DIST_4WD	13	-2505.84	5037.69	46.41	0.00	1.00	1.20e+10
Model 1	VEGTYPE+Area+TRI_VALUE+DIST_PR_SD+ DIST_LOCAL+ DIST_4WD	15	-2505.70	5041.40	50.13	0.00	1.000	7.68e+10
Model 7	VEGTYPE+TRI_VALUE+DIST_PRIVA+ DIST_LOCAL+ DIST_4WD +DIST_RT	15	-2551.83	5133.65	142.38	0.00	1.000	8.27e+30
Model 5	VEGTYPE+TRI_VALUE+DIST_PRIVA+ DIST_LOCAL+ DIST_4WD+DIST_RL	15	-2557.93	5145.86	154.59	0.00	1.00	3.70e+33
Model 6	VEGTYPE+TRI_VALUE+DIST_PRIVA+ DIST_4WD+ DIST_RL	14	-2559.51	5147.03	155.75	0.00	1.00	6.63e+33

df: Degrees of freedom for the model
logLik: Log Likelihood of the model
AIC: Akaike's Information Criterion
ΔAIC: Change in the AIC value between the top model and each additional model.
w_i: Proportion of Akaike weight for each candidate model
Cum. w_i: Cumulative weight for all models
Evidence Ratio: the likelihood of a model in relation to the top model (w_i / w_j)

Table 37. Variables included in the top habitat selection model (Model 9) for eight male rough-legged hawks explaining habitat selection at the 200% ecoregion scale for five states in western North America during the winters of 2014 and 2015. The model included 2,980 total GPS locations and 2,980 paired random locations for eight males. Model: VEGTYPE+ TRI_VALUE+ DIST_PR_SD+DIST_4WD +DIST_RT (top 5 models presented in Appendix D).

Variable	β Estimate	Lower 95% CI	Upper 95% CI
Intercept	-0.81	-1.32	-0.29
Forested	-1.10	-1.56	-0.66
Scrub	-1.63	-2.04	-1.25
Grassland	-0.69	-1.11	-0.29
Pasture	0.28	-0.21	0.78
Cropland	0.65	0.06	1.27
Herbaceous Wetlands	1.17	0.64	1.70
Nearly Level	-1.90	-2.19	-1.63
Slightly Rugged	-2.16	-2.51	-1.84
Intermediately Rugged	-1.90	-2.17	-1.64
Moderately Rugged	-2.15	-2.42	-1.88
Distance to Major Roads	-0.75	-0.83	-0.67
Distance to 4WD Tracks	-0.62	-0.74	-0.51
Distance to Red-tailed Hawks	0.35	0.25	0.45

Table 38. Variables included in the chi-squared selection models for eight male rough-legged hawks explaining land cover and terrain selection at the 200% ecoregion scale for five states in western North America during the winters of 2014 and 2015. The model included 2,980 total GPS locations and 2,980 paired random locations for eight males.

Chi-squared Test	Category	Proportional Use[a]	Proportional Availability[b]	Lower 95% CI	Upper 95% CI	Selection Trend
Habitat Selection	Barren Land	0.00	0.02	0.00	0.01	-
	Cultivated Crops	0.04	0.00	0.03	0.05	+
	Open Space	0.05	0.00	0.04	0.06	+
	Developed/ Low Intensity	0.01	0.00	0.00	0.01	+
	Developed/Medium Intensity	0.00	0.00	0.00	0.00	0
	Herb. Wetlands	0.11	0.01	0.09	0.12	+
	Evergreen Forest	0.06	0.21	0.05	0.07	-
	Woody Wetlands	0.00	0.00	0.00	0.00	-
	Pasture/Hay	0.22	0.01	0.20	0.24	+
	Shrub/Scrub	0.33	0.67	0.31	0.35	-
	Grassland/Herb.	0.17	0.06	0.16	0.19	+
Terrain Ruggedness	Level	0.865	0.512	0.850	0.880	+
	Nearly Level	0.032	0.083	0.024	0.039	-
	Slightly Rugged	0.026	0.089	0.019	0.033	-
	Intermed. Rugged	0.042	0.138	0.033	0.051	-
	Mod. Rugged	0.036	0.179	0.028	0.044	-

[a] Proportion of rough-legged hawk GPS locations within the habitat or terrain type.
[b] Proportion of available area for the habitat or terrain type.
-: Avoiding habitat or terrain type
+: Selecting for habitat or terrain type
0: No selection trend

APPENDIX E: ROUGH-LEGGED WINTER RANGE MAPS DURING THE WINTER OF 2014 IN TWO STATES IN WESTERN NORTH AMERICA

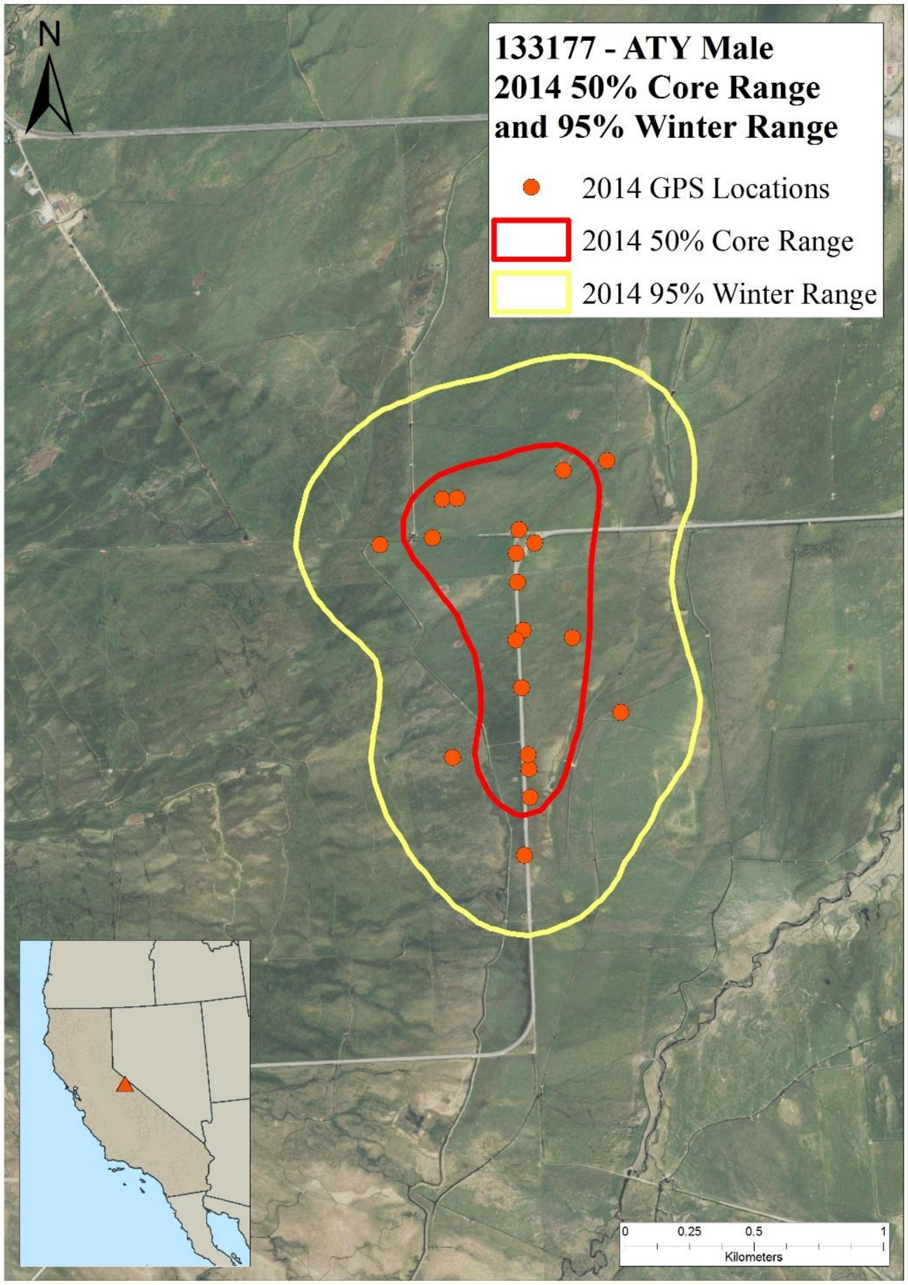

Figure 8. Rough-legged hawk 133177 (ATY - Male) 50% kernel core and 95% 2014 winter ranges in Bridgeport, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

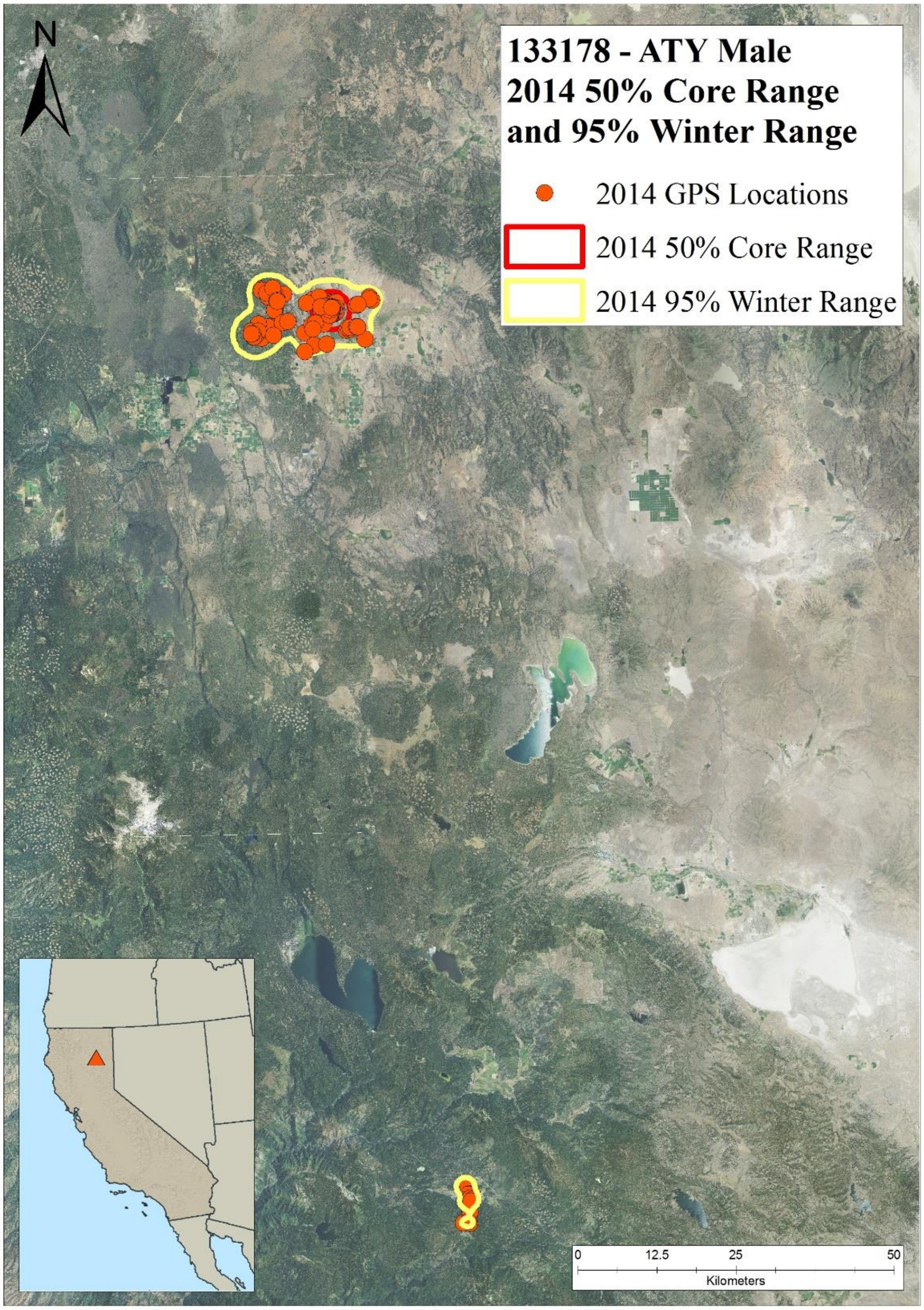

Figure 9. Rough-legged hawk 133178 (ATY - Male) 50% kernel core and 95% 2014 winter ranges in Quincy, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

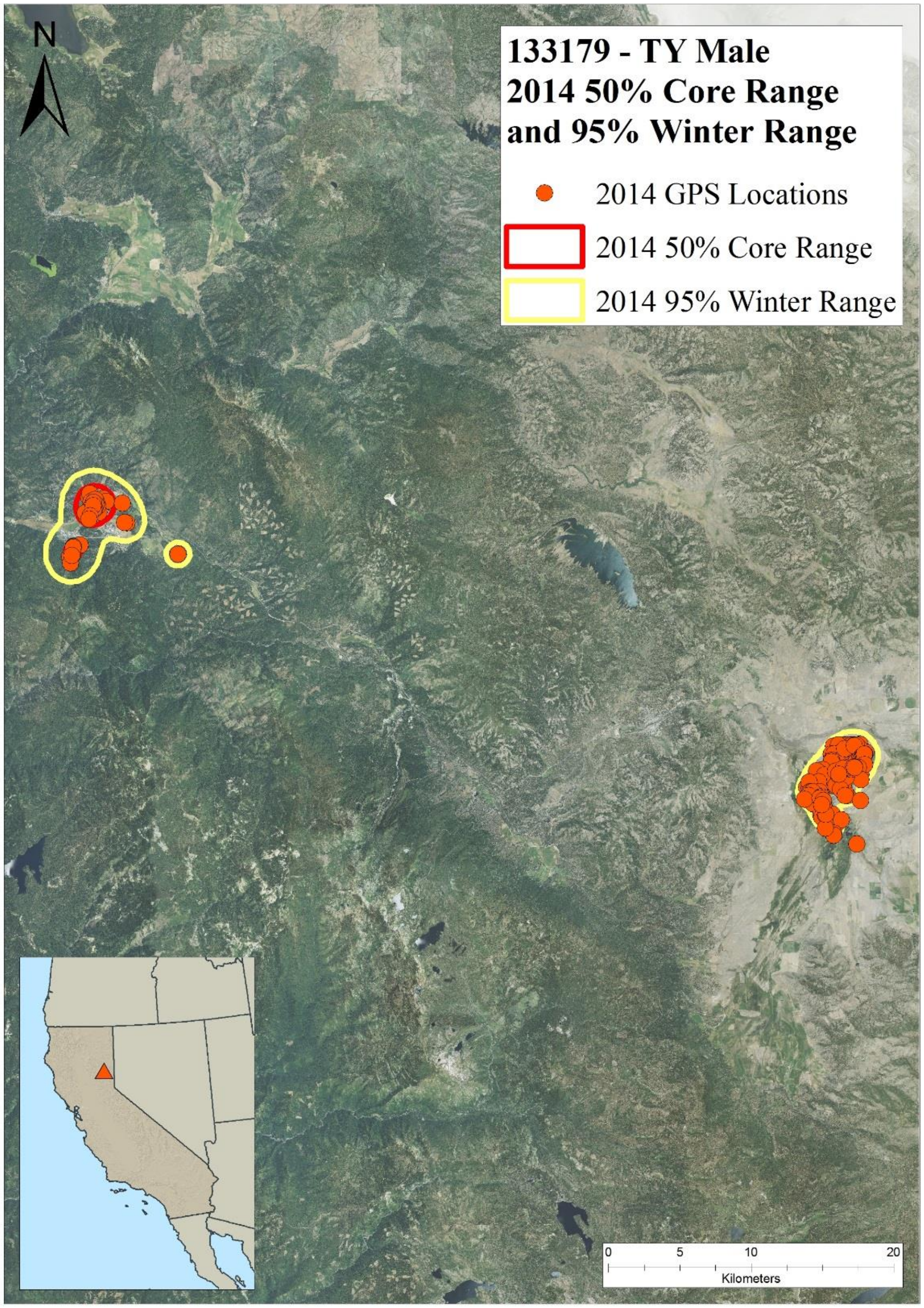

Figure 10. Rough-legged hawk 133179 (TY - Male) 50% kernel core and 95% 2014 winter ranges in Sierra Valley, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

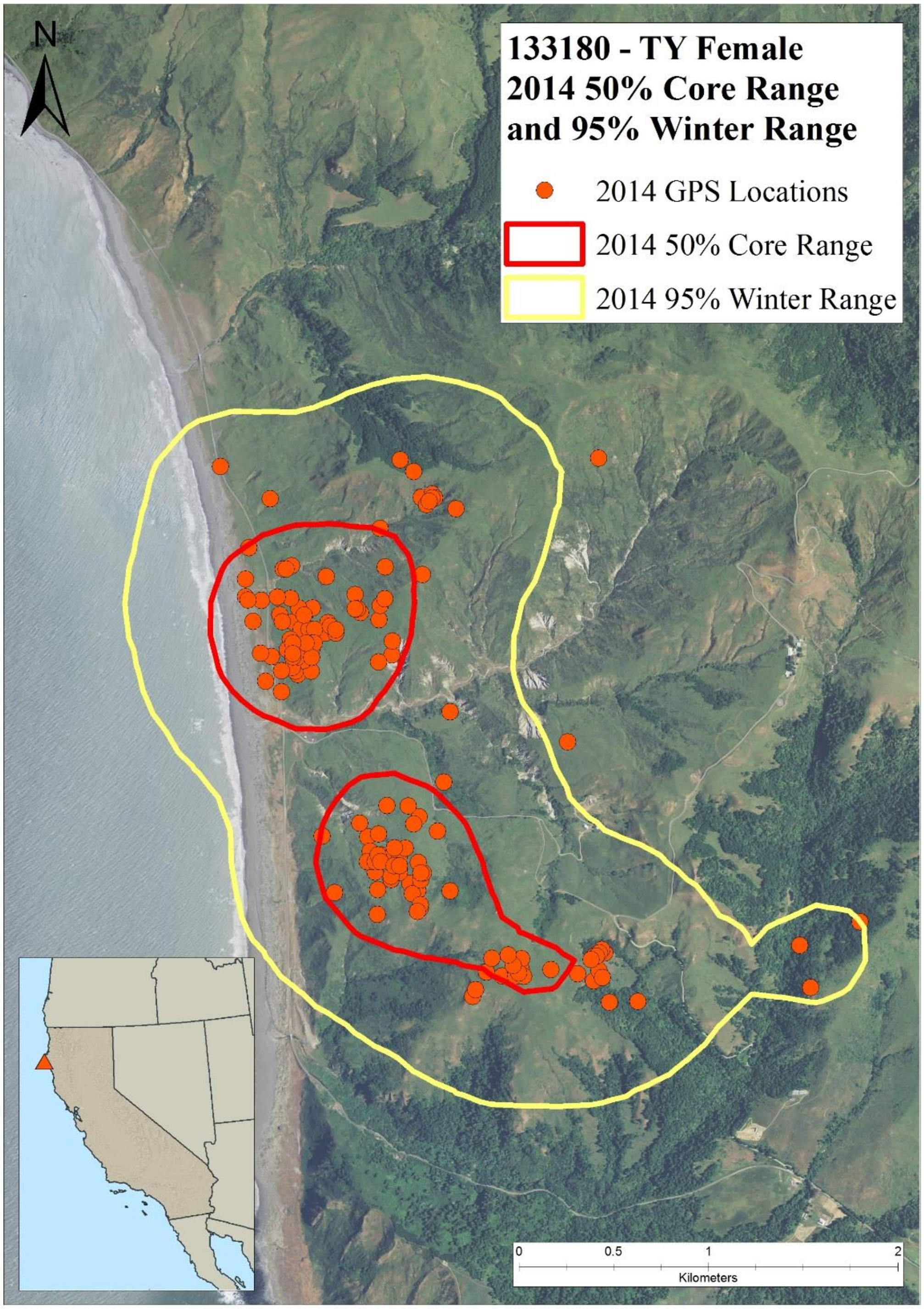

Figure 11. Rough-legged hawk 133180 (TY - Female) 50% kernel core and 95% 2014 winter ranges in Petrolia, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

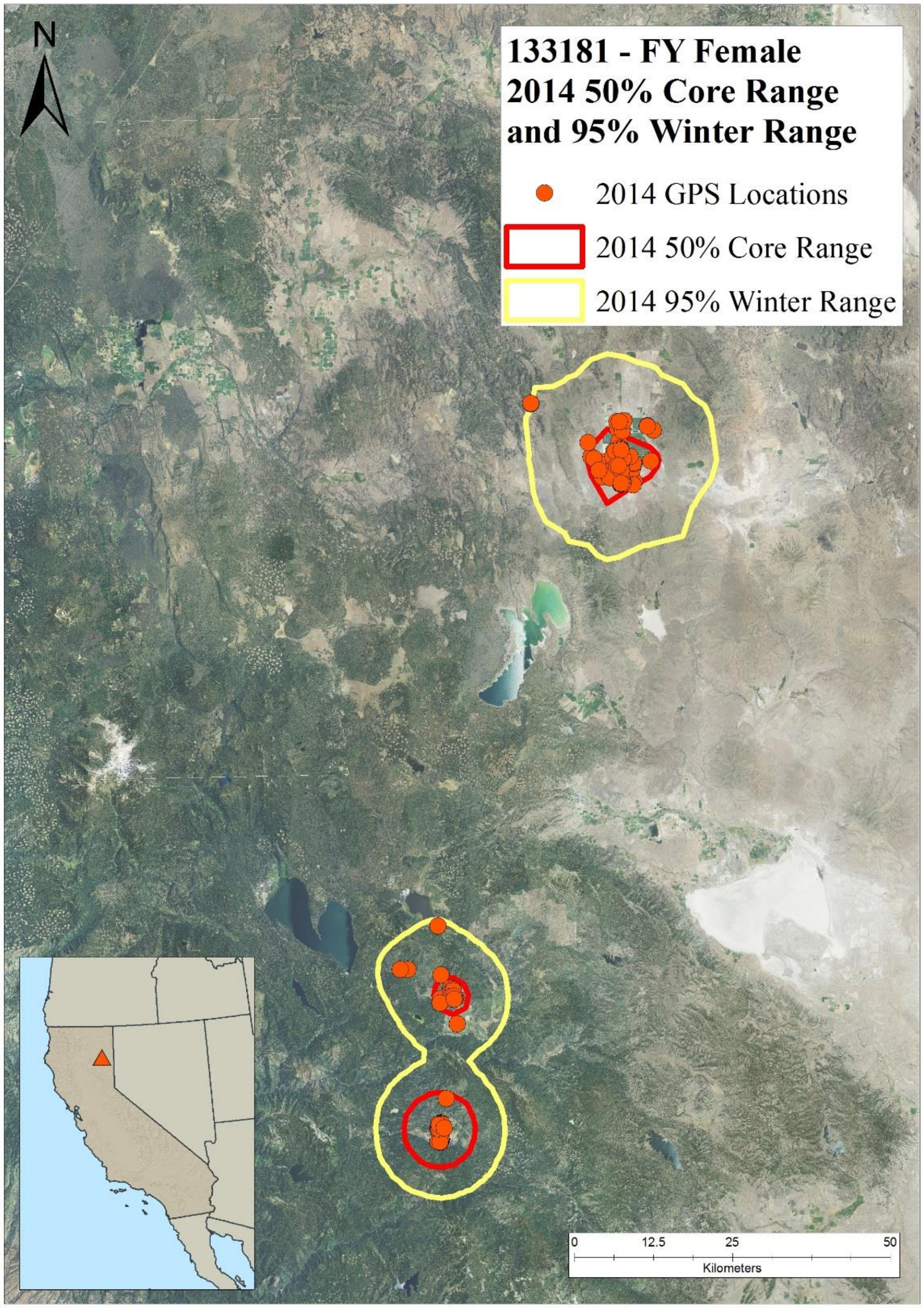

Figure 12. Rough-legged hawk 133181 (FY - Female) 50% kernel core and 95% 2014 winter ranges in Quincy, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

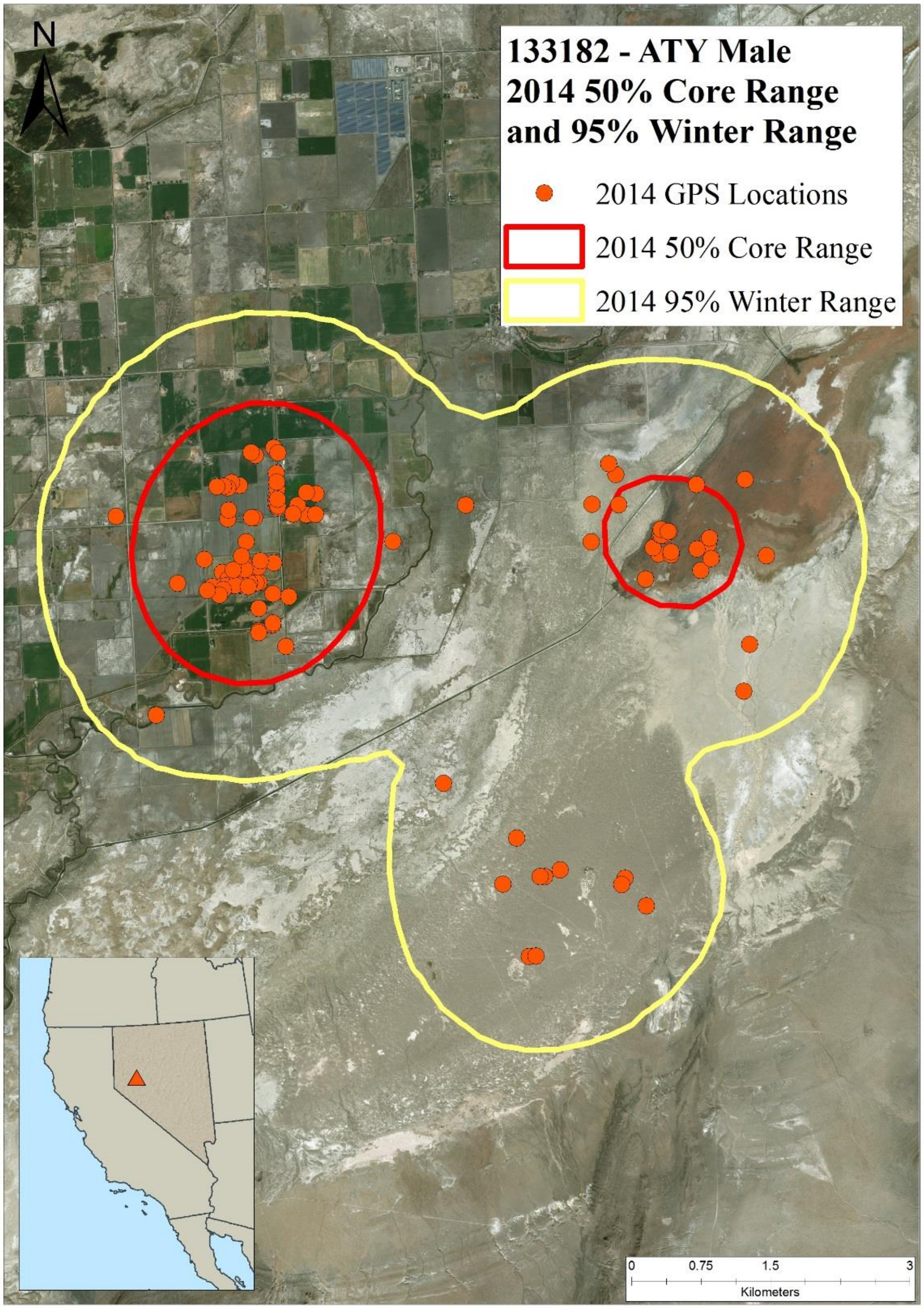

Figure 13. Rough-legged hawk 133182 (ATY Male) 50% kernel core and 95% 2014 winter ranges in Fallon, Nevada. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

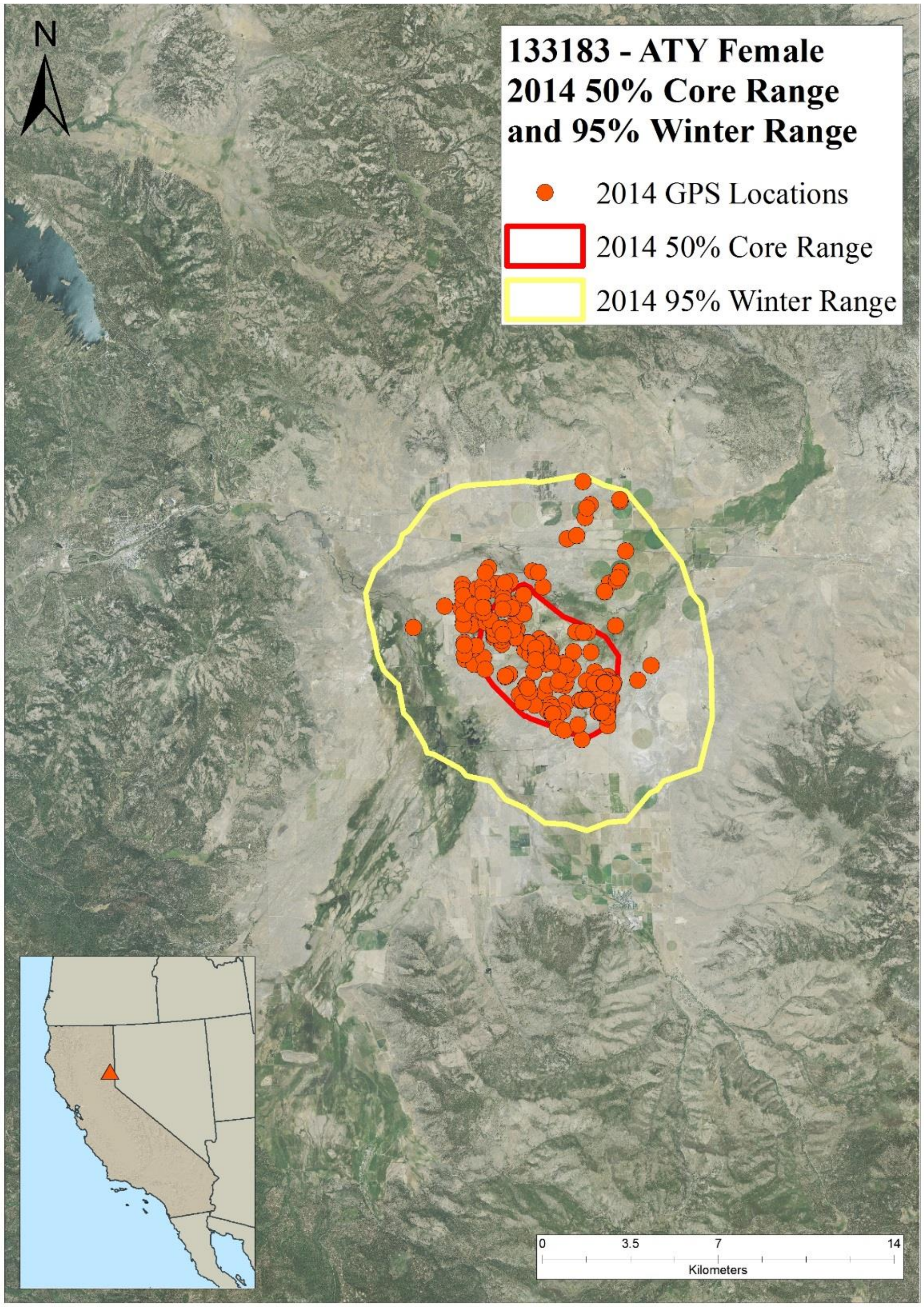

Figure 14. Rough-legged hawk 133183 (ATY Female) 50% kernel core and 95% 2014 winter ranges in Sierra Valley, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

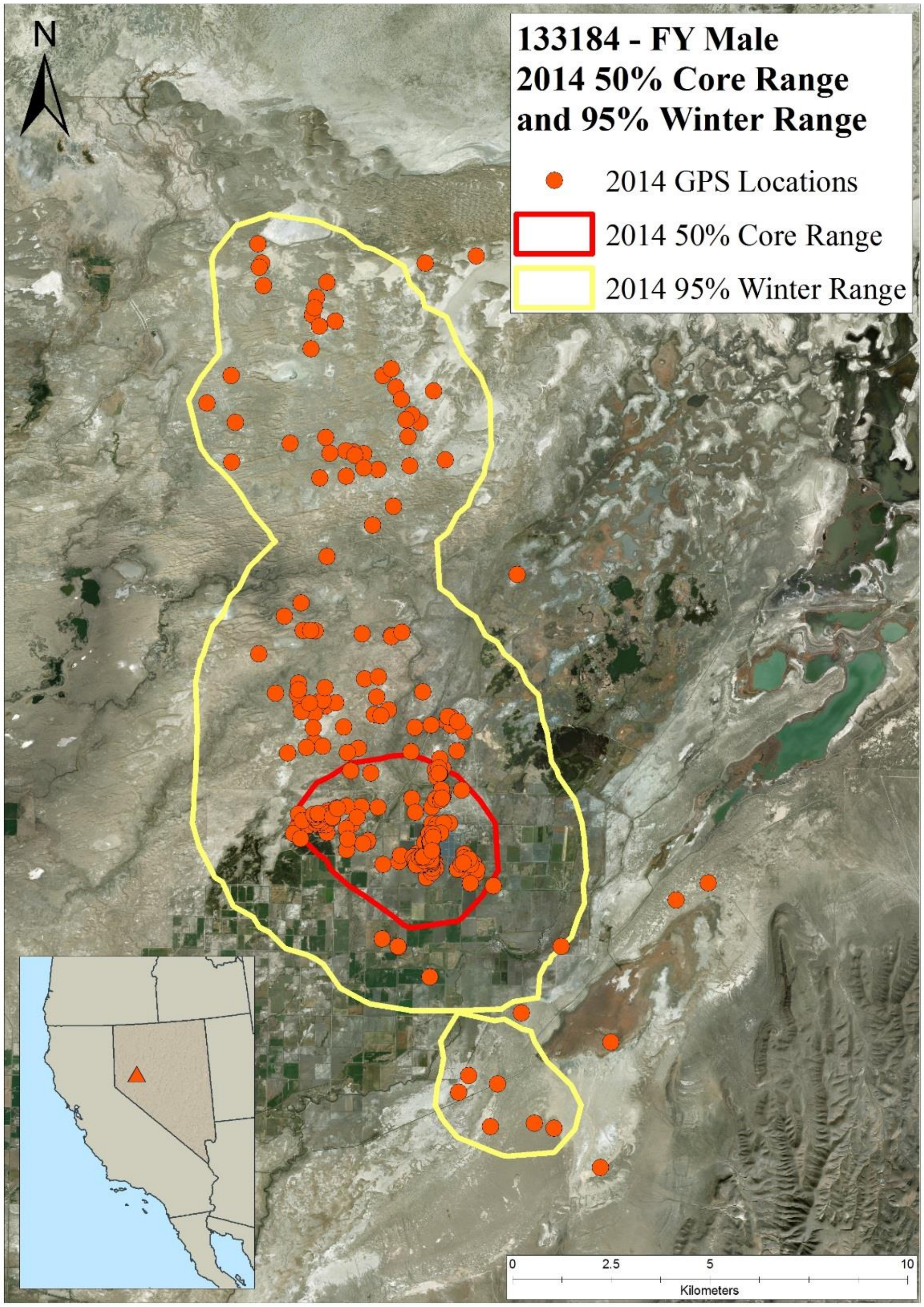

Figure 15. Rough-legged hawk 133184 (FY Male) 50% kernel core and 95% 2014 winter ranges in Fallon, Nevada. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

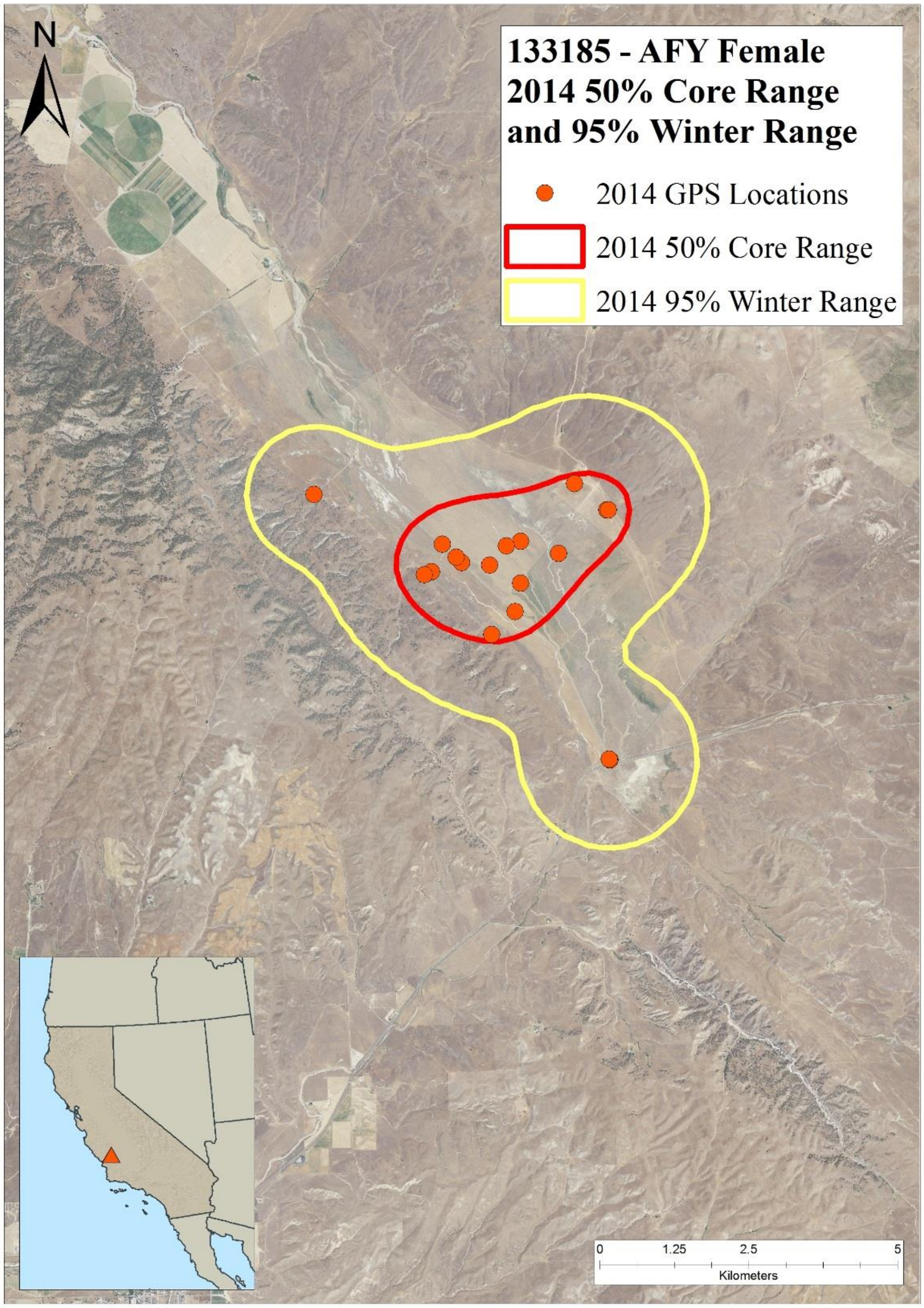

Figure 16. Rough-legged hawk 133185 (AFY Female) 50% kernel core and 95% 2014 winter ranges in Cholame Valley, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

APPENDIX F: ROUGH-LEGGED HAWK WINTER RANGE MAPS DURING THE WINTER OF 2014 IN TWO STATES IN WESTERN NORTH AMERICA

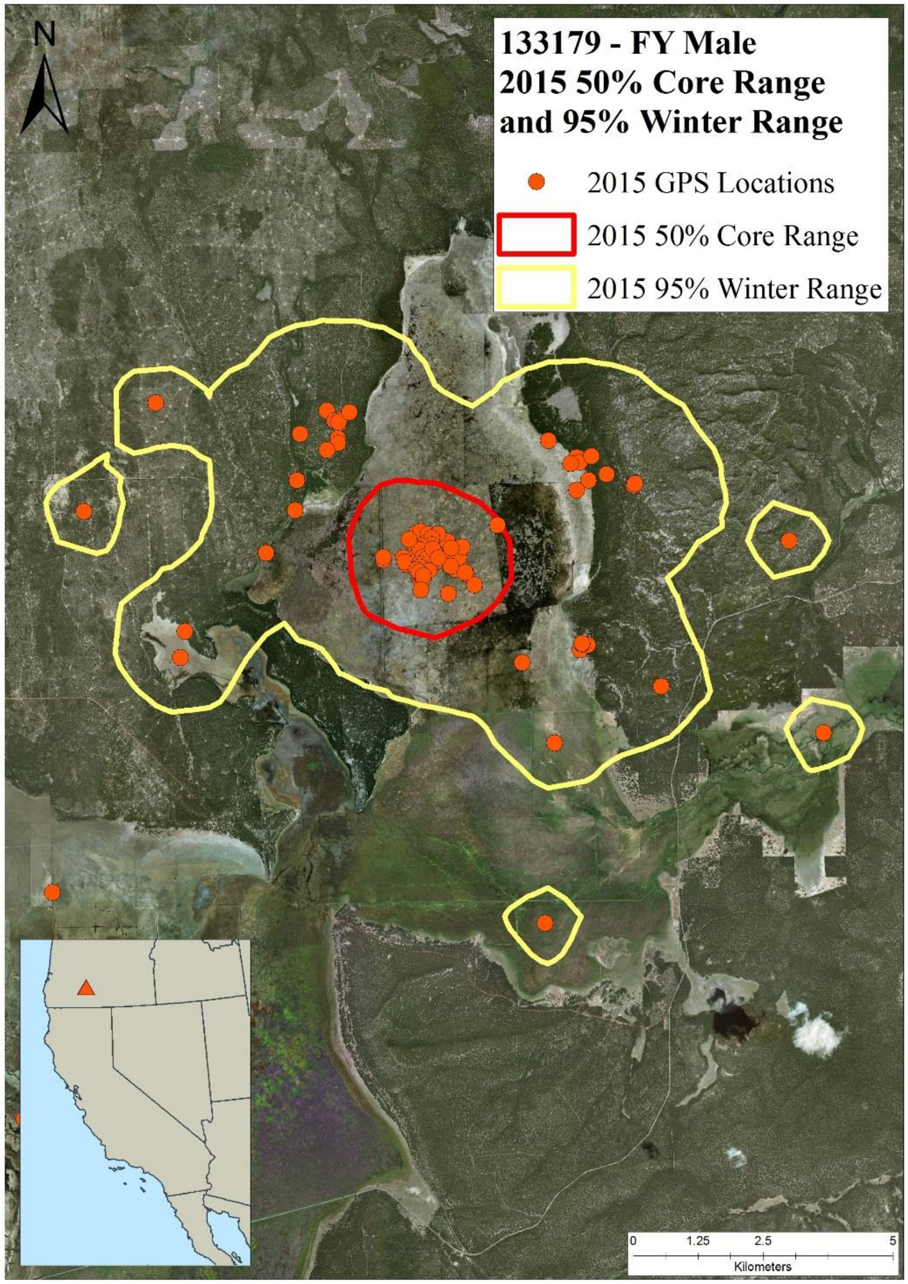

Figure 17. Rough-legged hawk 133179 (FY Male) 50% kernel core and 95% 2015 winter ranges in Klamath Marsh National Wildlife Refuge, Oregon. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

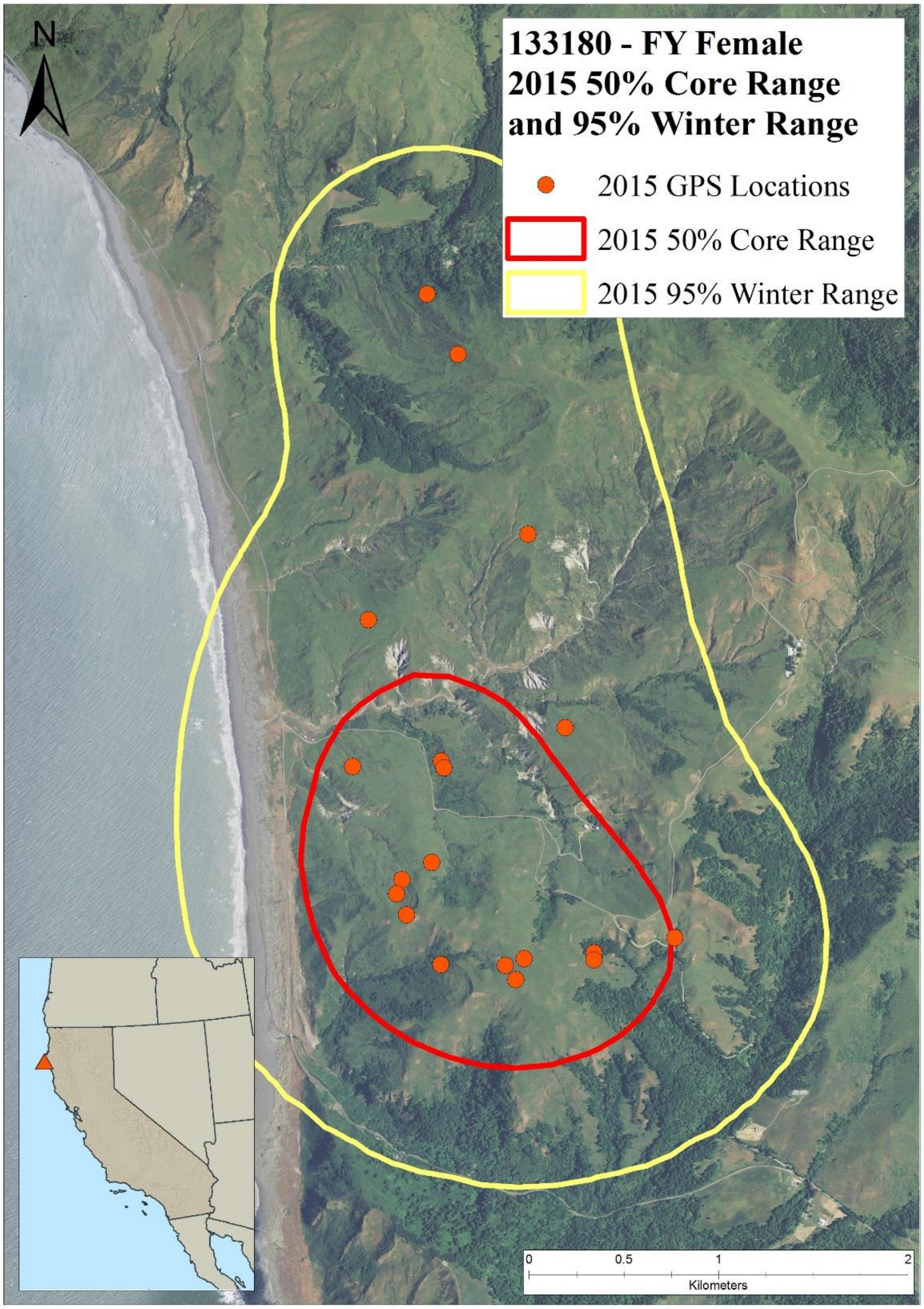

Figure 18. Rough-legged hawk 133180 (FY Female) 50% kernel core and 95% 2015 winter ranges in Petrolia, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

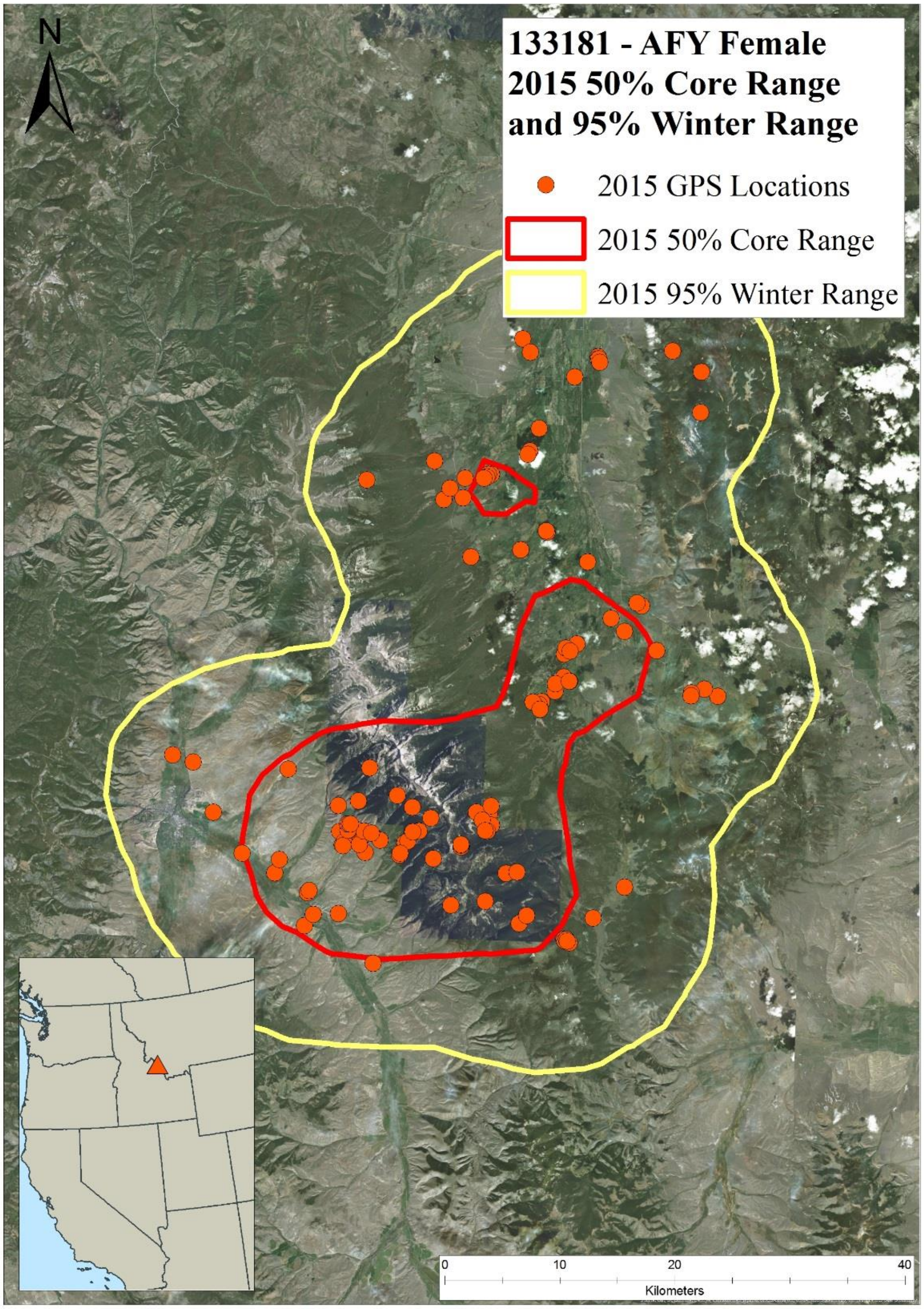

Figure 19. Rough-legged hawk 133181 (AFY Female) 50% kernel core and 95% 2015 winter ranges in the Beaverhead Mountains on the border of Idaho and Montana. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

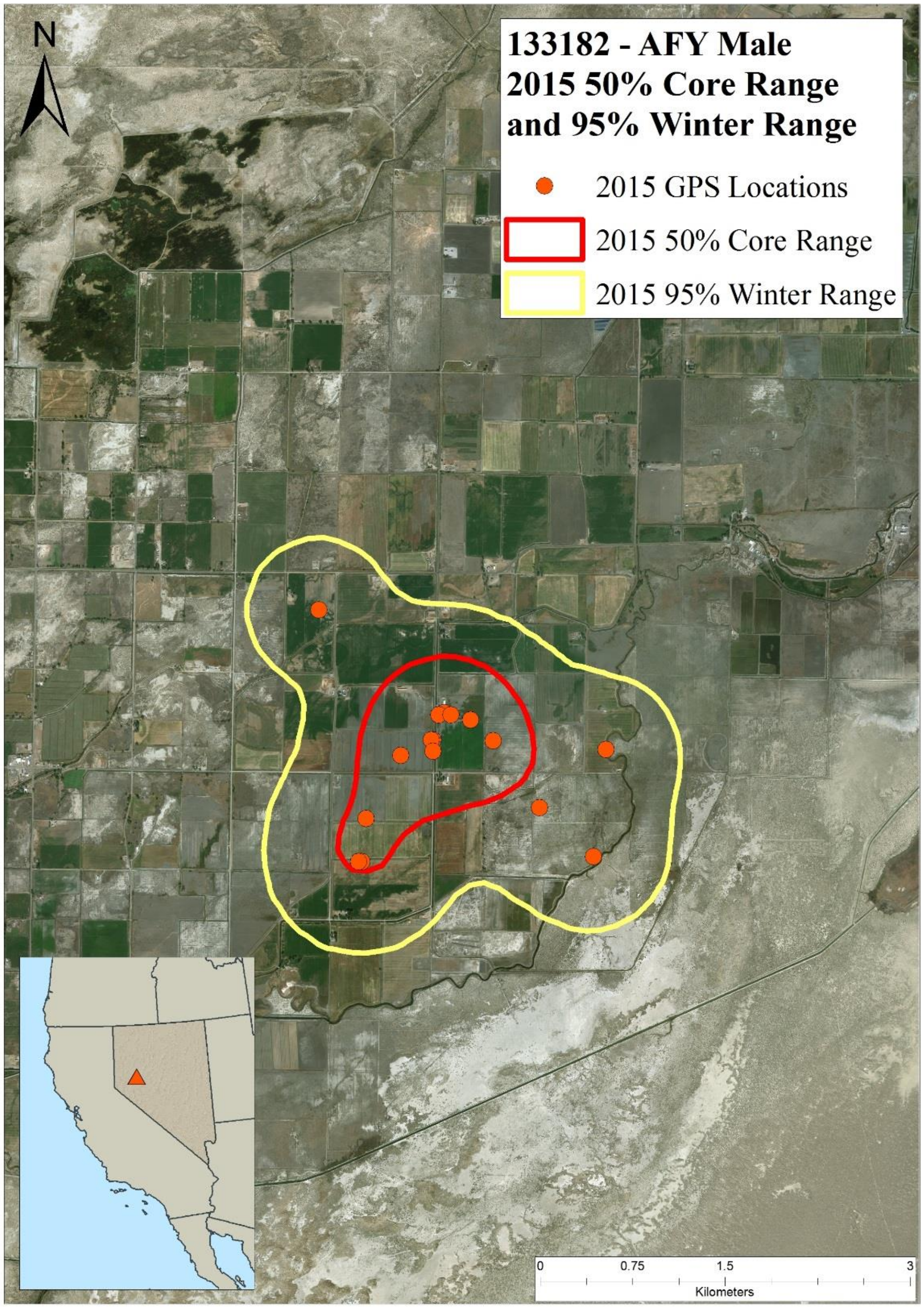

Figure 20. Rough-legged hawk 133182 (AFY Male) 50% kernel core and 95% 2015 winter ranges in Fallon, Nevada. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

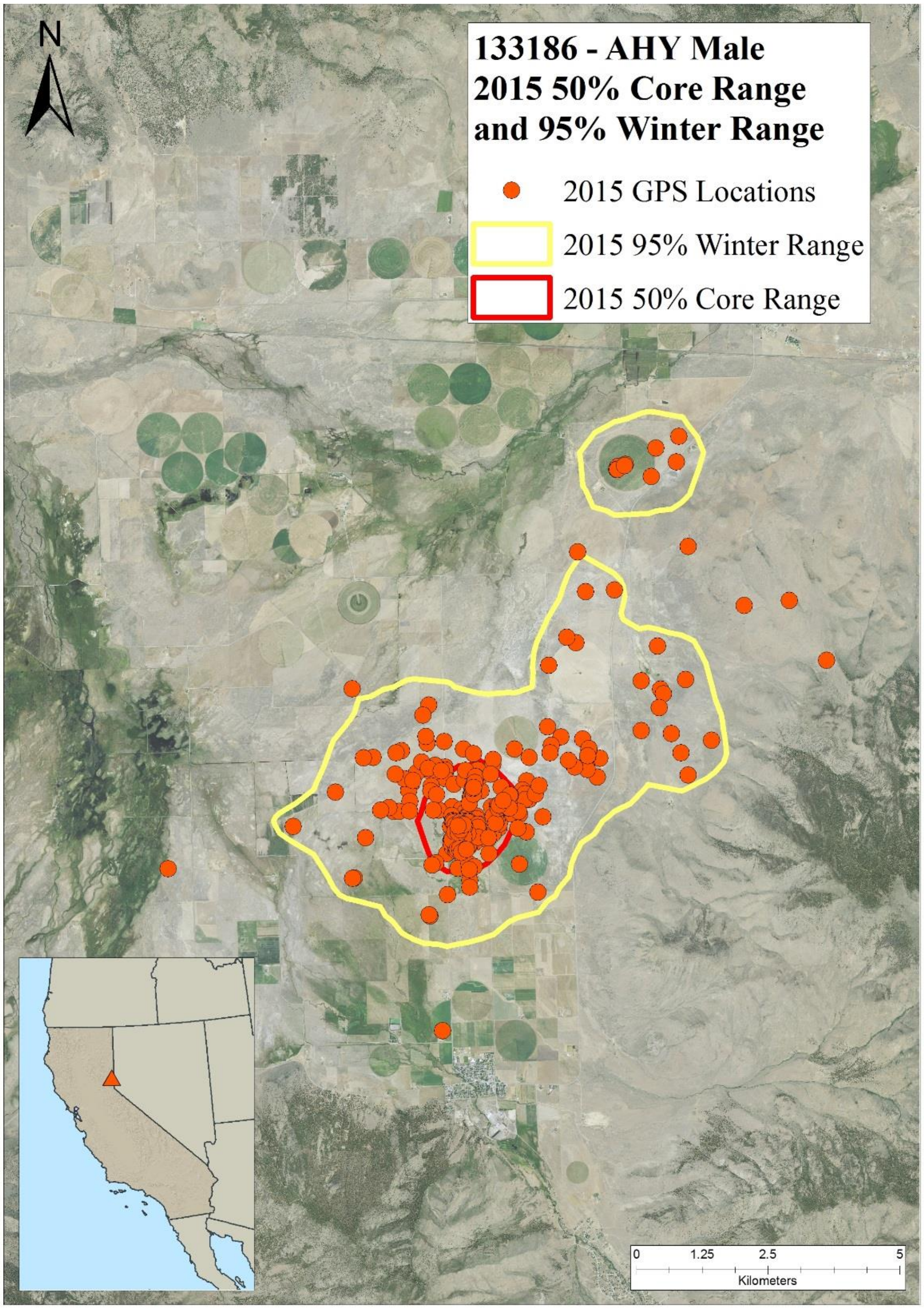

Figure 21. Rough-legged hawk 133186 (AHY Male) 50% kernel core and 95% 2015 winter ranges in Sierra Valley, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

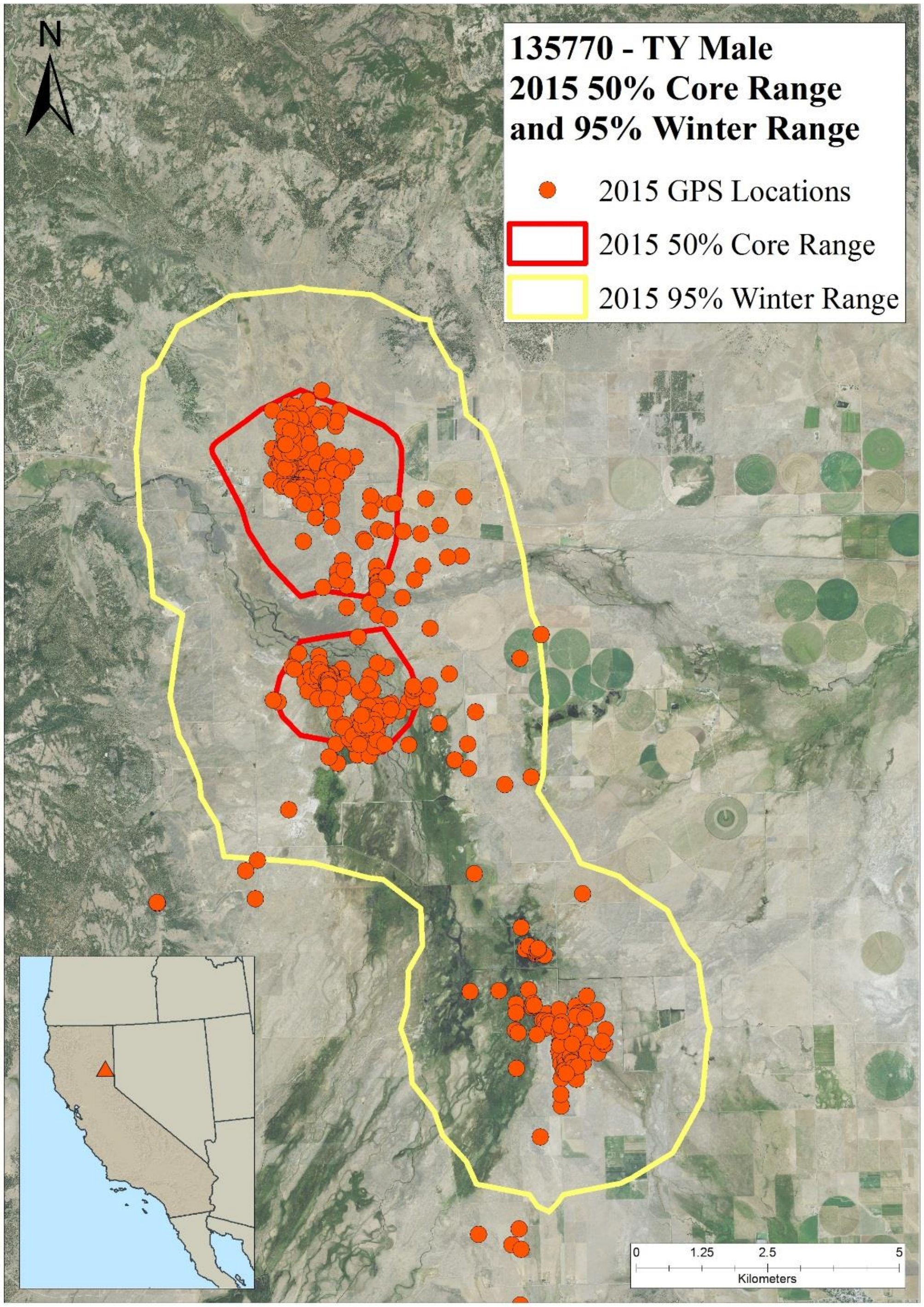

Figure 22. Rough-legged hawk 135770 (TY Male) 50% kernel core and 95% 2015 winter ranges in Sierra Valley, California. NAIP 2012 imagery and U.S. Census 2013 State Cartographic Boundaries.

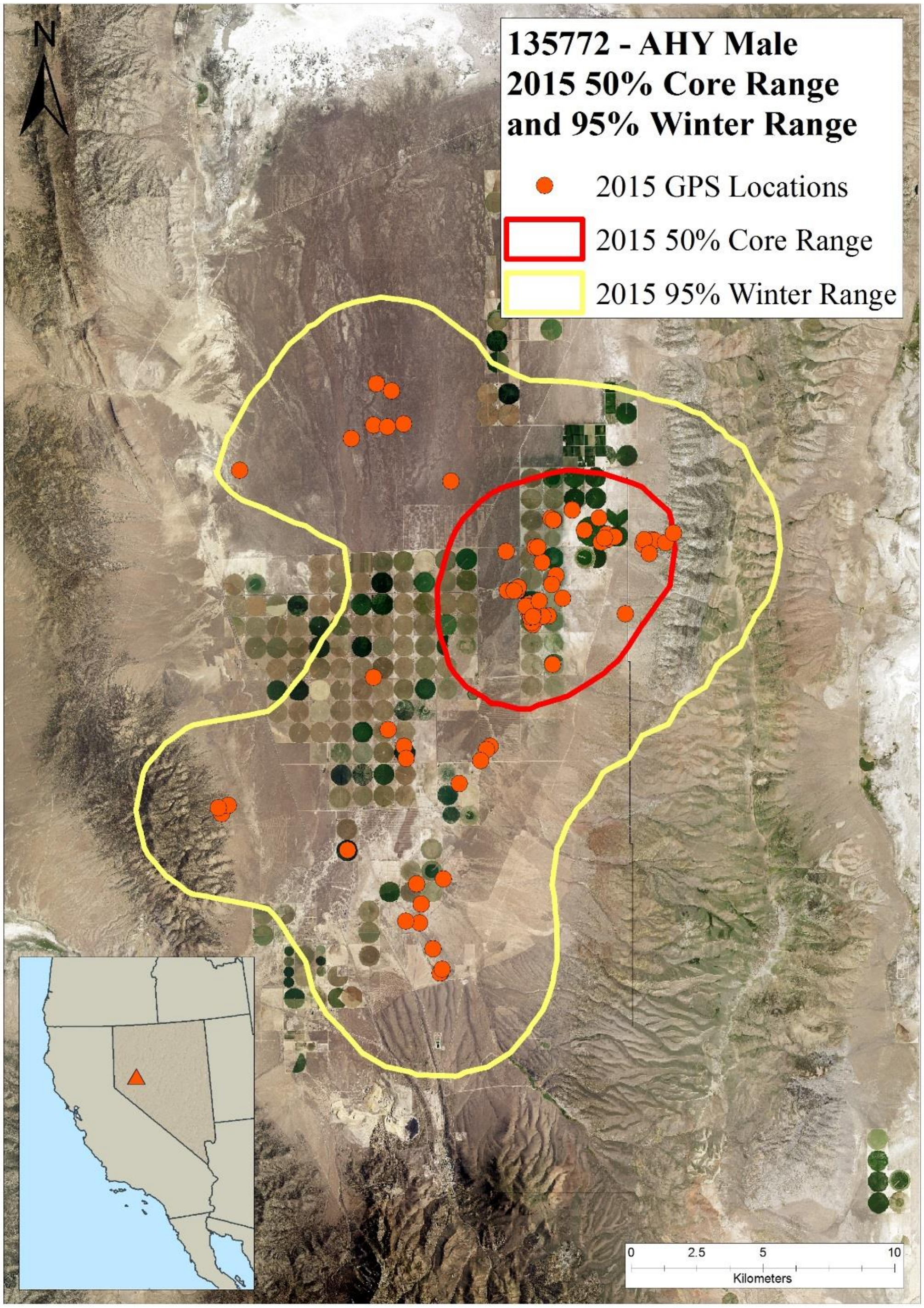

Figure 23. Rough-legged hawk 135772 (AHY Male) 50% kernel core and 95% 2015 winter ranges in Fallon, Nevada. ESRI aerial imagery and U.S. Census 2013 State Cartographic Boundaries.

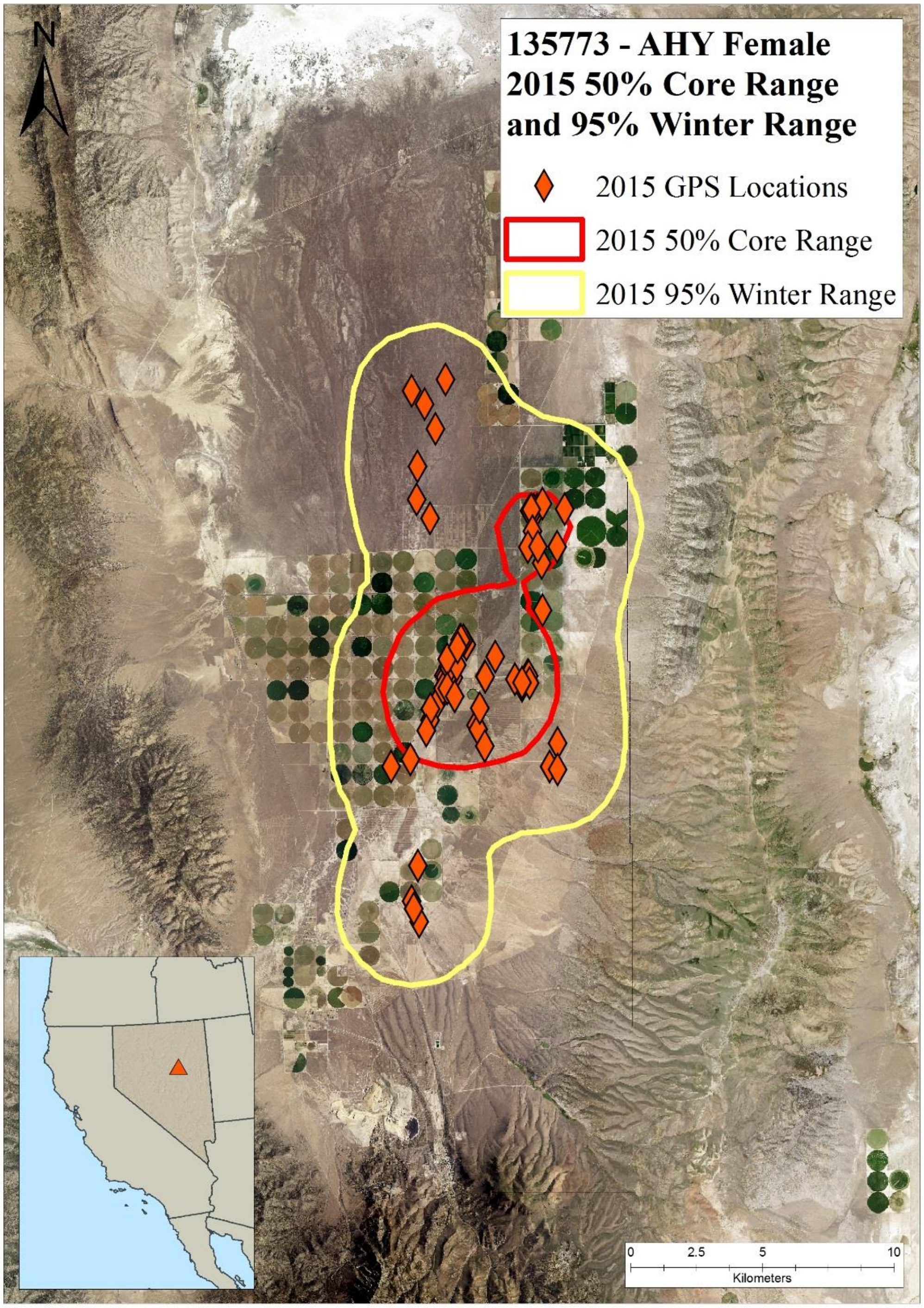

Figure 24. Rough-legged hawk 135773 (AHY Female) 50% kernel core and 95% 2015 winter ranges in Eureka, Nevada. NAIP 2015 imagery and U.S. Census 2013 State Cartographic Boundaries.

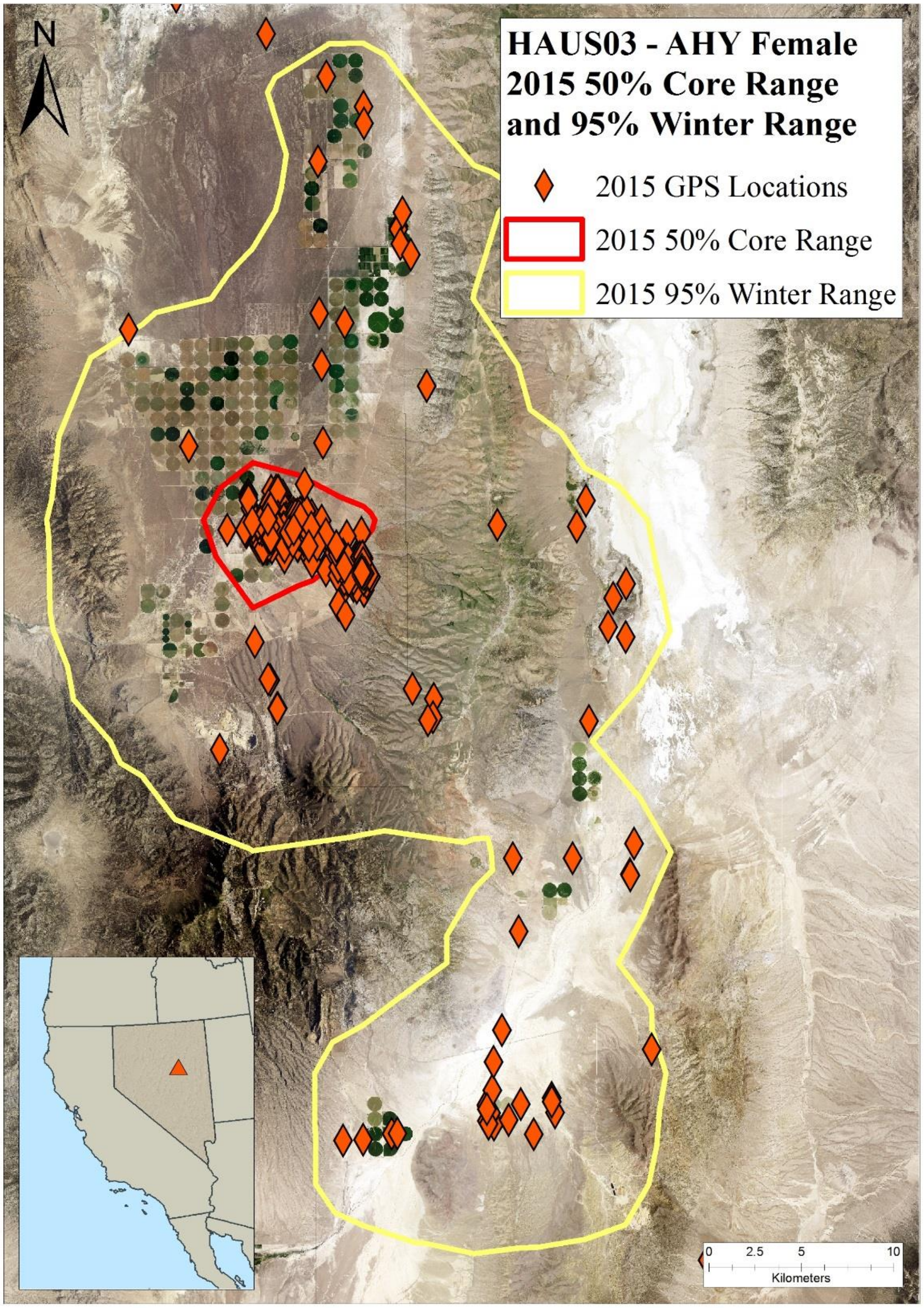

Figure 25. Rough-legged hawk HAUS03 (AHY Female) 50% kernel core and 95% 2015 winter ranges in Eureka, Nevada. NAIP 2015 imagery and U.S. Census 2013 State Cartographic Boundaries.

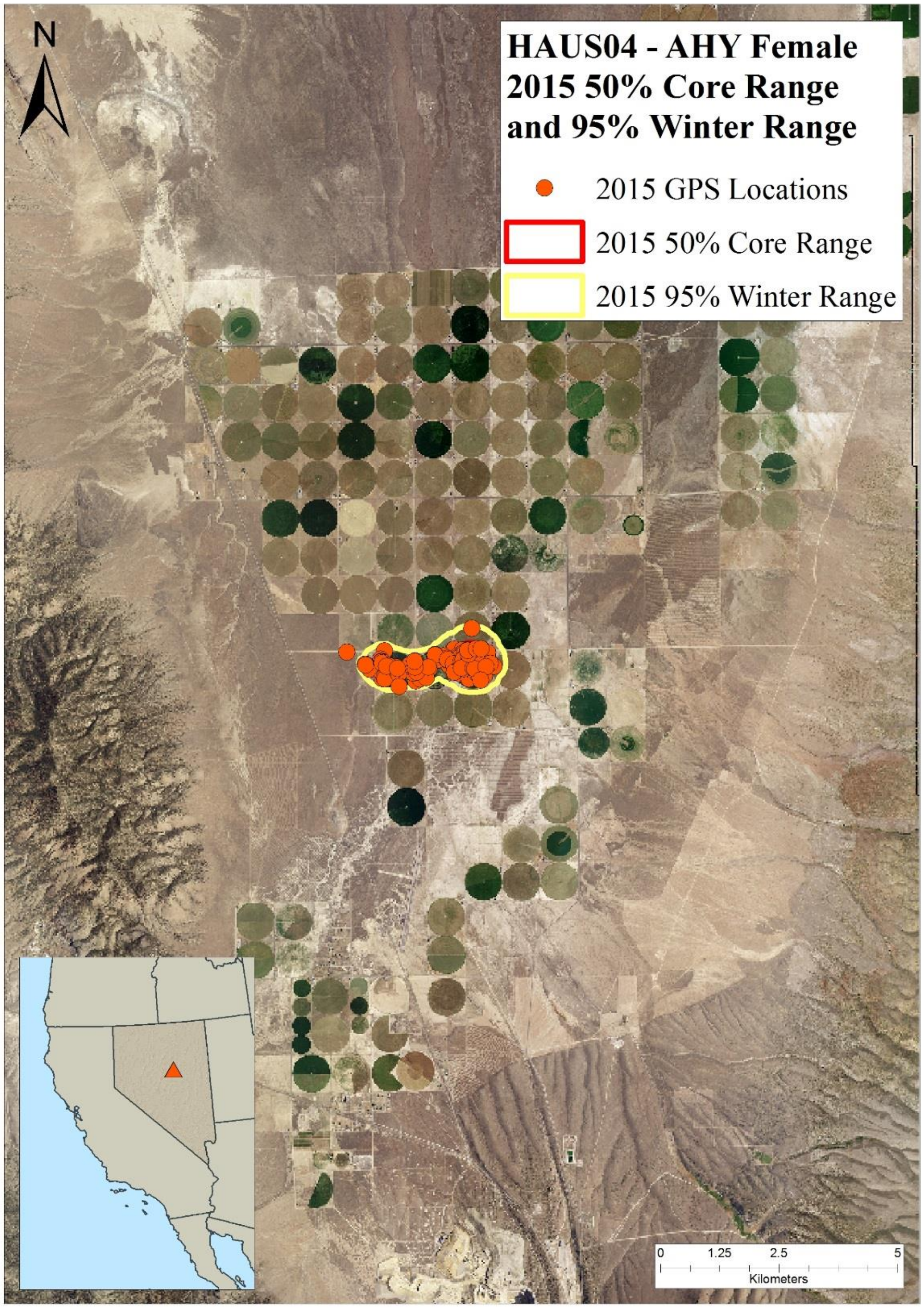

Figure 26. Rough-legged hawk HAUS04 (AHY Female) 50% kernel core and 95% 2015 winter ranges in Eureka, Nevada. NAIP 2015 imagery and U.S. Census 2013 State Cartographic Boundaries.

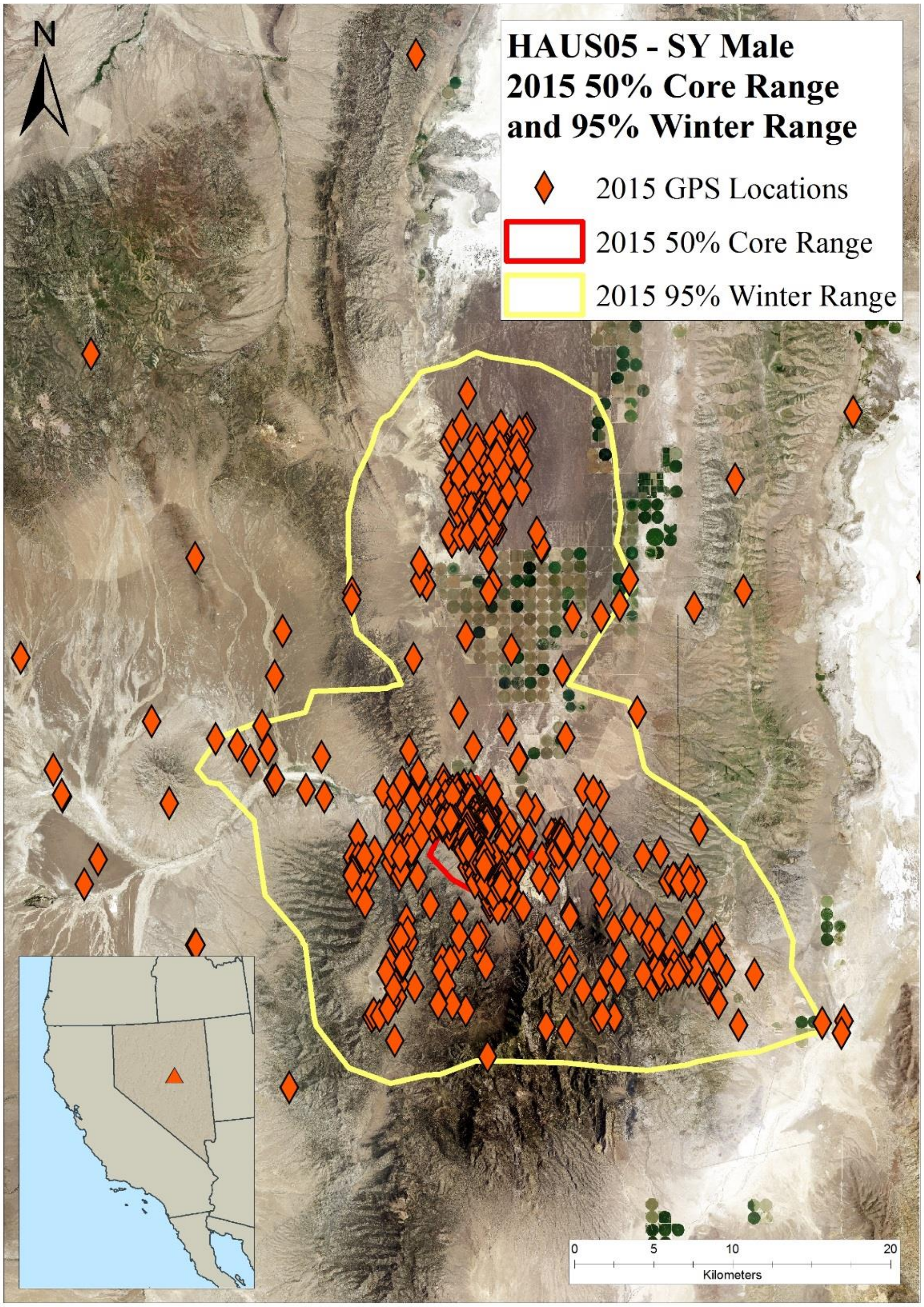

Figure 27. Rough-legged hawk HAUS05 (SY Male) 50% kernel core and 95% 2015 winter ranges in Eureka, Nevada. NAIP 2015 imagery and U.S. Census 2013 State Cartographic Boundaries.

APPENDIX G: ROUGH-LEGGED HAWK MORPHOMETRICS

Table 39. Morphometic measurements for twenty rough-legged hawks (n = 12 males, 8 females) trapped on their wintering grounds in western North America in 2014 and 2015.

	Females (Mean ± SD)	Males (Mean ± SD)
Wingspan (cm)	138.49 ± 3.88	132.81 ± 1.64
Winter Mass (grams)	1,065.63 ± 83.72	852.08 ± 93.22
Tarsus Depth (mm)	8.01 ± 0.52	7.17 ± 0.53
Tarsus Width (mm)	9.56 ± 0.45	8.23 ±0.40
Hallux (mm)	26.54 ± 2.28	24.69 ± 0.86
Culmen (mm)	24.60 ± 1.29	22.64 ± 0.96