Multi-scale Resource Selection of Ferruginous Hawk (*Buteo regalis*) Nesting in Eastern Washington and at the Horse Heaven Clean Energy Center, Benton County, Washington

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EXECUTIVE SUMMARY

Horse Heaven Wind Farm, LLC is proposing development of the Horse Heaven Clean Energy Center (Horse Heaven and/or Project) in Benton County, Washington. Horse Heaven contracted Western EcoSystems Technology, Inc. (WEST) to analyze factors that influence nest site selection for the ferruginous hawk (*Buteo regalis*), an endangered species in Washington. We used two decades of nest occupancy data and suite of environmental and anthropogenic covariates to create resource selection functions (RSF) modeling nesting probability across the hawk's nesting range in eastern Washington. Nest selection was modeled on the landscape (population) scale to identify characteristics hawks consider as important criteria within their home range and at a smaller nesting (individual) scale to identify characteristics in the species core range. Smaller scales of resource selection were applied at the Project to predict areas where hawks may nest in the future so avoidance and minimization measures could be strategically considered prior to project operation.

On a population scale, the strongest predictive covariates influencing relative nest site selection included increased habitat heterogeneity in land cover, higher quality prey habitat, flatter terrain with pronounced areas of topographic relief, and less disturbance indicated by the avoidance of various intensities of development.

On an individual scale, occupied nest sites were characterized by relatively higher-quality prey habitat of Washington ground squirrel (*Urocitellus washingtoni*) and black-tailed jackrabbit (*Lepus californicus*). Correspondingly, springtime vegetative productivity was selected, further indicating the close relationship between vegetative browse and prey abundance surrounding the nest site.

The highest probability of nest use was along the northern escarpment bordering the Project. Areas identified within this study in combination with other avoidance, minimization, and mitigation measures described by the Project (Horse Heaven Wind Farm, LLC 2021), can be implemented in the construction and operational phases of the Project to strategically reduce indirect and direct impacts to ferruginous hawk.

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REPORT REFERENCE

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Unit Conversions*

Imperial	Metric
1 foot	0.3048 meter
3.28 feet	1 meter
1 mile	1.61 kilometer
0.621 mile	1 kilometer
1 acre	0.40 hectare
2.47 acre	1 hectare

Common Conversions

Imperial	Metric
0.5 miles	800 meters
0.12 miles	200 meters
0.5 miles	0.8 kilometers
10 miles	16.1 kilometers

* units are used interchangeably and conversions are provided here for reference

1 INTRODUCTION

Horse Heaven Wind Farm, LLC (Horse Heaven) is proposing development of the Horse Heaven Clean Energy Center (HHCEC and/or Project) in Benton County, Washington. The breeding range of the state-endangered ferruginous hawk (*Buteo regalis*) overlaps the Project, and historical nests are located within 3.2 kilometers (km) of Project facilities. Horse Heaven contracted Western EcoSystems Technology, Inc. (WEST) to analyze nest site selection criteria to predict areas where ferruginous hawks might nest in the future so that minimization measures can be strategically considered prior to Project operation.

Identifying hotspots of spatial use by raptors within a wind project area is an important component of the risk-assessment process (US Fish and Wildlife Service 2013). Ferruginous hawk use across a landscape can be influenced by a variety of environmental characteristics (e.g., land cover, prey resources, terrain and disturbances; Collins and Reynolds 2005) and resource selection functions (RSF) have been identified as a powerful tool to predict how potential wind energy development may spatially relate to predicted ferruginous hawk nest selection and inform conservation planning (Squires et al. 2020).

In this study, we used an RSF framework to model biologically relevant covariates associated with occupied ferruginous hawk nests in eastern Washington from 2000–2022. Temporal and spatially explicit covariates included environmental and anthropogenic variables that were previously identified as important for nesting ferruginous hawks (Squires et al. 2020). We used the best performing covariates to model multi-scale nest site selection; at the nest site level and within the entire breeding range of ferruginous hawks in eastern Washington. Model results were applied to the Project to evaluate proposed wind development in relation to areas of predicted nest site selection. To our knowledge, this is the first landscape-scale assessment of ferruginous hawk nest site selection in Washington applied to a proposed wind energy project.

We used biologically relevant attributes from a similar study in Wyoming to identify factors influencing nest selection in Washington. Although landscape conditions differ between the two states, with a more robust population and comparatively unfragmented landscape in Wyoming, use of similar covariates can help differentiate factors that influence nest site selection in two geographically separated populations. Because of the highly modified landscape present throughout the breeding range in Washington we assumed ferruginous hawks would be more flexible in their selection of nest sites. We predicted that ferruginous hawk would: 1) not strongly avoid human development (e.g., roads, urbanization and energy) because of its uniform distribution across the landscape (Washington Wildlife Habitat Connectivity Working Group [WHCWG] 2012); 2) not strongly avoid agricultural areas considering the rate of land conversion over the past century and relationship between nest sites and agriculture in previous research (Leary et al. 1998; Sleeter 2012) and; 3) strongly select prey sources at all spatial scales considering the importance of food resources to nest success (Collins and Reynolds 2005, Hayes and Watson 2021).

2 ANALYSIS AREA

Our analysis extent consisted of two areas. We considered the Study Area where ferruginous hawk nest data and nesting habitat characteristics could be modeled on a landscape-scale and included the entire breeding range of the ferruginous hawk (Figure 1). Second, we considered a comparatively smaller Project Area that functioned as a model validation area where renewable energy development is proposed and where the relative probability of nest site selection could be compared with contemporary nest survey results.

2.1 Study Area

The Study Area included the shrub-steppe and grasslands of eastern Washington, which encompass the northwestern extent of ferruginous hawk nesting range in the United States. The Study Area comprised 23,790 square miles (mi^2) in eastern Washington within the geographic boundary of the Columbia Plateau Ecoregion (CPE) Level III Ecosystem (Omernik 1987; Figure 1 and 2). Part of the larger Great Basin Bird Conservation Region, approximately 74% of the CPE is located within Washington (Bird Studies Canada and U.S. North American Bird Conservation Initiative [NABCI] 2014). We used the CPE as the Study Area because it included suitable nesting habitat, all publicly available records of ferruginous hawk nests in Washington, and it is a focal area for renewable energy development in the region (Hayes and Watson 2021, Renewables Northwest 2022, Washington Department of Fish and Wildlife [WDFW] 2015).

The CPE is located in the northwestern extent of ferruginous hawk nesting in the United States. In general, the Washington breeding population arrives from the California Central Valley in late February to early March where adults start occupying nesting territories (Watson et al. 2018). Fidelity to previously occupied sites is high among breeding adults even when prey sources are scare due to drought conditions, suggesting that other factors are also important for nest site selection (Watson and Keren 2019).

The CPE is bound in all directions by comparatively more mountainous ecoregions in surrounding ecoregions (Figure 2). Rising approximately 4,500 feet (ft) above sea level, topography in the CPE is characterized by broad, flat plateaus, rolling hills with lakes and potholes, channeled scablands and bisected by steep canyons and river systems and reservoirs (Cleland et al. 2007). Annual precipitation averages 7 to 18 inches. Soils are derived from parent material resulting from erosion and re-deposition by great floods and strong winds across the relatively level lava plateau (Cleland et al. 2007). Windblown sediment (loess) covers most of the CPE providing deep fertile soil optimal for agriculture. Fertile soils in the CPE have resulted in approximately 80% of historical shrub-steppe habitat lost or degraded to cropland or other land uses (WDFW 2015). The rolling, mostly cropland-dominated topography of the CPE is interrupted by the geologic mayhem of the Missoula Floods that created areas of flood-scoured, channeled scablands, potholes, buttes and steep topography that provides suitable nesting habitat for ferruginous hawk (Alt 2001).

Grasslands and shrub-steppe form a mosaic of native vegetation that comprise the dominant habitat types within the CPE. Clinal variation in vegetation communities range from grasslands and shrub-steppe in lower elevations transitioning to landscapes dominated by trees in higher elevations (Figure 2). Introduced from Eurasia and the Mediterranean, cheatgrass (downy brome, *Bromus tectorum*) continues to be a major threat to biodiversity, functionally eliminating native plant species in areas, modifying wildlife populations and increasing the risk of wildfire, which burned approximately 800,000 acres of shrub-steppe habitat and affected five ferruginous hawk territories in 2020 (National Interagency Fire Center 2021, Pilliod et al. 2021).

2.2 Project Area

The Project Area consists of a 3.1-mile (mi) radius buffer surrounding a 113 mi^2 Project lease boundary, of which approximately 35 mi^2 (31%) includes micrositing corridors[1] where wind turbines, solar array and related infrastructure are proposed in a maximum build scenario (Horse Heaven Wind Farm, LLC 2021). The Project Area is located adjacent to the Tri-cities urban areas of Kennewick, Richland, and Pasco and included portions of exurban communities associated with Benton City and Highland.

A prominent topographic feature important to ferruginous hawk nesting is a broad, northeast-facing anticline ridge along the northern perimeter of the Project Area. The ridge consists of numerous highly eroded drainages and cliff-lined canyons (Badger Canyon, Coyote Canyon, Webber Canyon, Nine Canyon) where historical nests have been documented. South of the ridge, toward the interior of the Project, the landscape transitions to relatively rolling topography with shallow, meandering canyons that drain south into the Columbia River. Elevation within the Project Area was lowest toward the Columbia River to the east (approximately 350 ft), rising to above 2,000 ft at prominent features including Jump Off Joe (2,200 ft), Johnson Butte (2,043 ft), and Chandler Butte (2,046 ft), which all have radio and telecommunication facilities installed.

Land cover within the Project Area is a mosaic of dryland and irrigated cropland, shrub-steppe grasslands, and rural/urban development (Horse Heaven Wind Farm, LLC 2021). Cropland is the dominate land cover throughout the Project and surrounding area (>80%; Horse Heaven Wind Farm, LLC. 2020). Shrub-steppe is found in topographically steep areas and drainage bottoms where conversion to cropland was not possible. Portions of lands within the Project Area are enrolled in the US Department of Agriculture's Conservation Reserve Program.

Land use in the Project Area consists predominantly of actively managed dryland winter wheat (*Triticum aestivum*) and associated infrastructure including silos and warehouses. Historic land use is reflected in abandoned and working farmsteads scattered in low density throughout the landscape. New residential development encroaches into the foothills and on top of the Horse Heaven Hills ridge, indicative of a growing Tri-cities area population. Several rock quarries in the Project Area are actively used for on-going road and other construction projects. Electrical systems include radio and telecommunication towers, several high-voltage (115-500 kV) Bonneville Power Administration transmission lines bisecting the Project Area, and numerous low-voltage (34.5 kV) distribution lines servicing business and residential buildings. Portions of the 63 Turbine Nine Canyon Wind Project were located within or adjacent to the Project Area.

[1] Micositing corridors consisted of an 18.5 mi^2 Wind Energy Micrositing Corridor and 16.8 mi^2 of Solar Siting Area (Horse Heaven Wind Farm, LLC 2021).

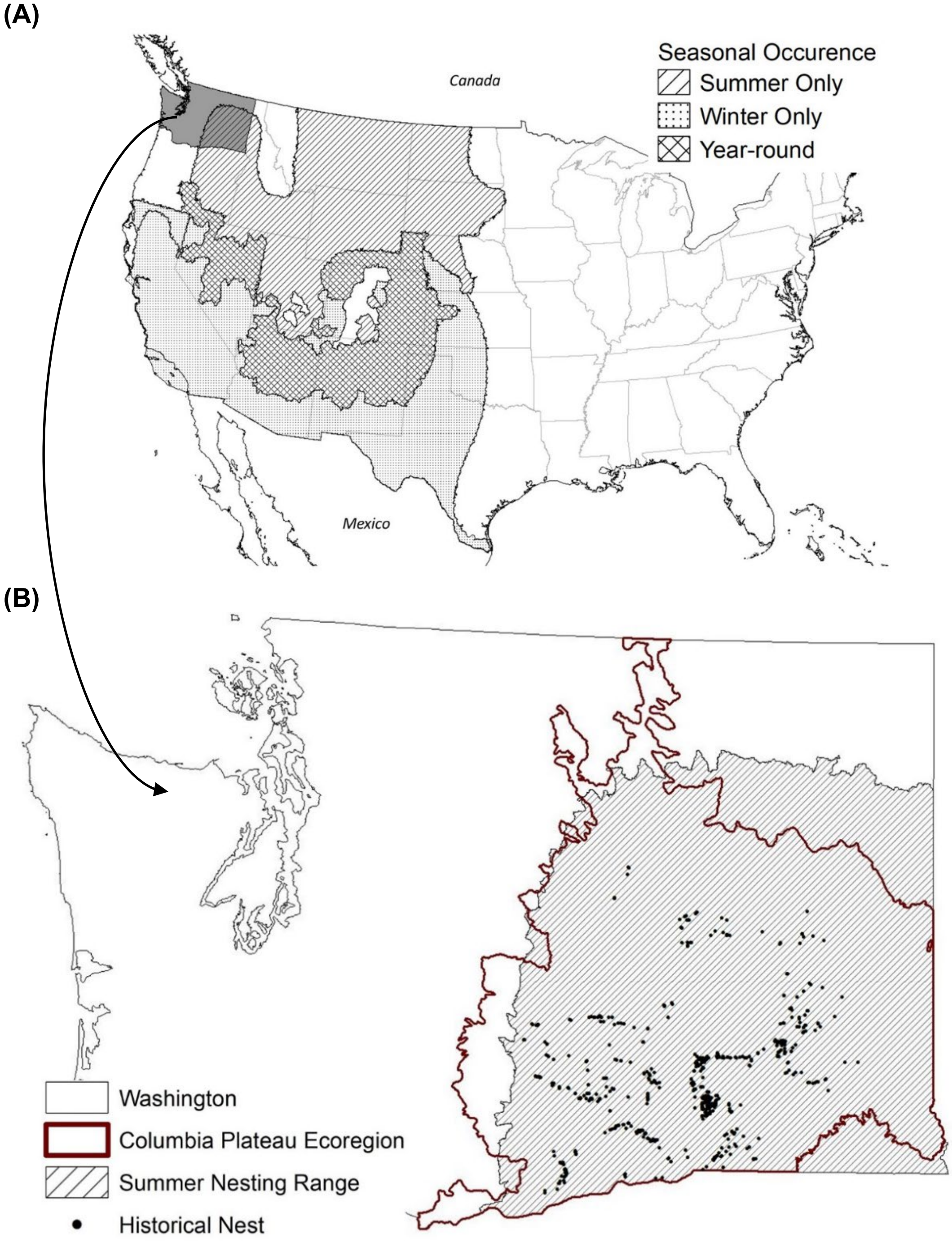


Figure 1. Seasonal distribution of ferruginous hawk in North America (A), and distribution of 677 historical ferruginous hawk nests within the Columbia Plateau Ecoregion (Study Area) in eastern Washington 1974−2020 (B).

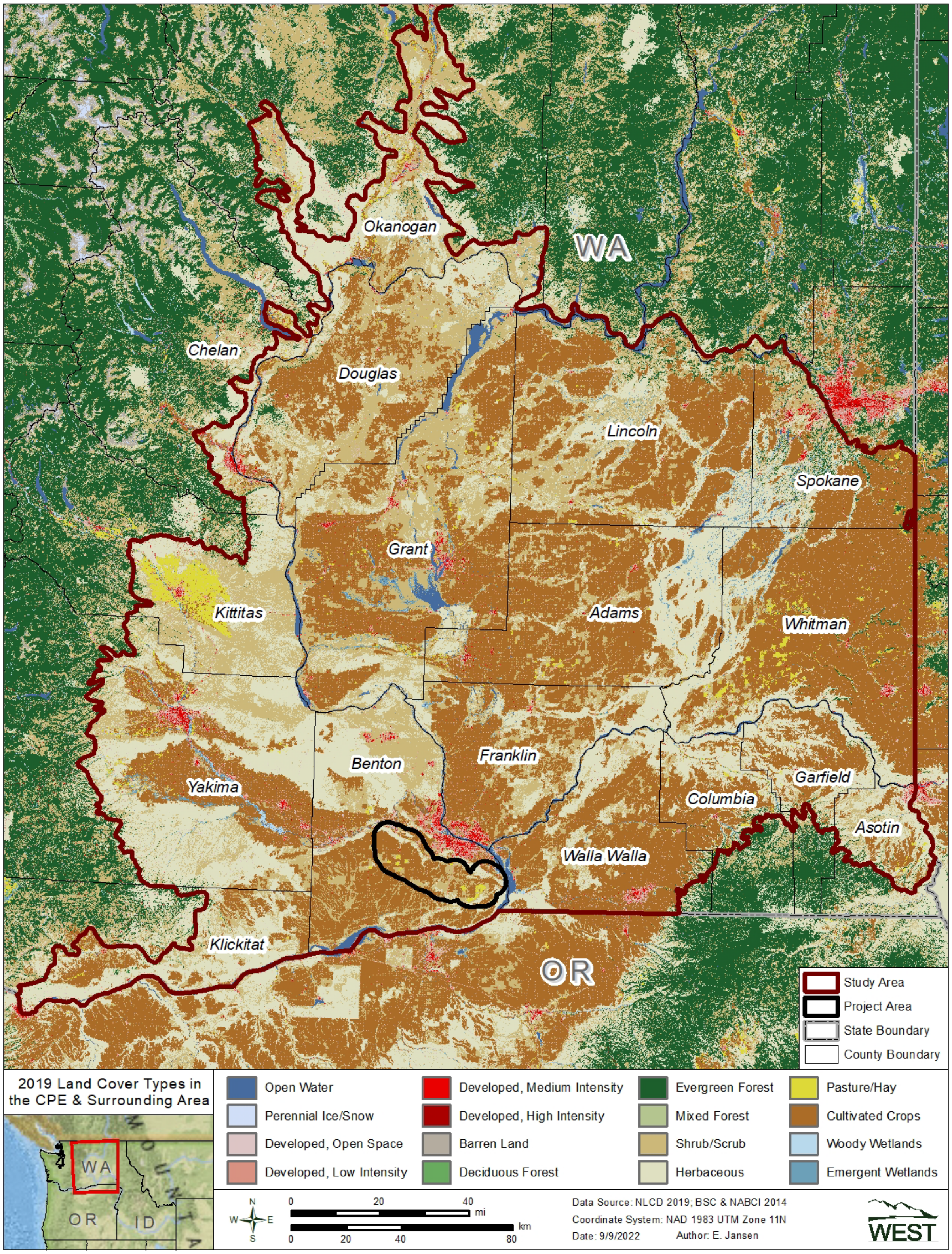


Figure 2. Land cover types within the Columbia Plateau Ecoregion.

3 METHODS

We use an RSF framework, a common and statistically rigorous method, to estimate ferruginous hawk nest site selection as a function of environmental and anthropogenic characteristics (Manly et al. 2002), to take a data-driven approach to predict the likelihood of ferruginous hawk nesting within the Study Area and Project Area. The following sections describe how nest occupancy combined with spatially explicit covariates informed relative nest site selection at various spatial scales.

3.1 Nest Data

We used historical ferruginous hawk nest data documented throughout the CPE as a basis to model landscape scale variables to predict the relative probability of site selection. WDFW collected the majority of nest data as part of their state-wide monitoring survey effort intended to assess the status of all nesting territories systematically, but were <100% due to access limitation, limited staff capacity, weather factors, or other conditions (Hayes and Watson 2021). Greater survey effort (≥ 70% of nesting territories surveyed) occurred in 1978, 1981, 1986, 1987, 1992−1997, 2002−2003, 2010, and 2016 (Hayes and Watson 2021). Annual WDFW nest surveys were not randomized but based on preselected nesting territories and areas that had a higher likelihood of documenting new territories in order to more effectively document the nesting distribution of a species with a small population size. Nest survey methodology is described by Hayes and Watson (2021). The nest database received from WDFW in fall 2021 contained 677 nests from 289 territories documented 1974−2020[2]. To align the nest status with the year when model covariates were derived (described below), we used nests documented as occupied during at least one visit within a survey year from 2000−2020.

3.2 Predictor Variables

We developed a suite of publicly available environmental and anthropogenic predictor variables based on natural history characteristics and previously identified as important for nesting ferruginous hawk (Table 1; Squires et al. 2020). Four groups of environmental covariates consisted of a combination of data representing vegetation, prey, climatic and topographic characteristics. Anthropogenic covariates consisted of one group of variables that characterized human disturbances across the landscape. All covariate datasets covered the entire Study Area (Appendix A). We conducted data processing, analyses, and visualization of spatially explicit covariates in ArcMap 10.7.1 (ESRI, Redlands, California) and R (R Core Team 2020).

3.2.1 Environmental Covariates

In Washington, ferruginous hawk nest in open, arid shrub-steppe grasslands with rock outcrop, cliffs, and isolated trees that provide suitable nest sites and abundant prey resources (Hayes and Watson 2021). Conversion of over half of Washington’s shrub-steppe habitat to agriculture has contributed to the loss of nesting and foraging habitat (Hayes and Watson 2021). Traditionally,

[2] Territory defined as an area that contains, or historically contained, one or more nests within the home range of a pair of mated birds (Postupalsky 1974). Unique WDFW territory defined by SiteName. A single territory can be comprised of many nests. Territories in the WDFW database consisted of 1−8 nests.

ferruginous hawk required large areas of native land cover for nesting and foraging but as availability of unfragmented native areas diminishes in Washington, hawks have been documented using agricultural landscapes as well (Berry et al. 1998, Leary et al. 1998, Watson et al. 2018). A 30 × 30-m land cover raster was used to characterize the land cover surrounding each nest by calculating the proportion of sagebrush, agriculture and bare ground (NLCD 2016, 2019). Shrub height was used as a metric of habitat quality and defined as all shrub species discriminated by the presence of woody stems and < 6 m in height (NLCD 2016). Taller shrub heights are indicative of more intact stands that receive relatively less grazing pressure and provide prey species for ferruginous hawk with protective cover and forage. We quantified the heterogeneity (expressed as standard deviation of the mean) associated with the proportion of agriculture, sagebrush, bare ground and shrub height. Integrated Normalized Difference Vegetation Index provided a metric of vegetative productivity during the growing season (Pettorelli et al. 2005, 2011). The index reflects the density of green growing vegetation and was calculated using package *MODIStsp* in R to obtain 16-day composite rasters at 250 m resolution (Busetto and Ranghetti 2016, Didan 2015).

Prey availability is an essential component of nest site selection and abundance can affect the ranging behavior as well as nesting success and productivity (Ng et al. 2020). In Washington, small to medium-sized mammals comprise the majority of prey items and include ground squirrel (*Urocitellus* spp.), hare (*Lepus* spp.), rabbit (*Sylvilagus* spp.), and northern pocket gopher (*Thomomys talpoides*). We used habitat value models of four common prey species in the CPE as covariates to inform nest site selection. Species included Townsend's ground squirrel (*U. townsendii*), Washington ground squirrel (*U. washingtoni*), black-tailed jackrabbit (*L. californicus*), and white-tailed jackrabbit (*L. townsendii*). Habitat value was modeled as an index ranging from 0 (non-habitat) to 1 (the best possible habitat) and were selected based on peer-reviewed literature, and expert opinion (WHCWG 2012).

Ferruginous hawk are sensitive to weather conditions during the nesting period (Wallace et al. 2016). Temperatures within the CPE have increased over the past half century and projected to continue over the next 30 years (Snyder et al. 2019). Changing climate conditions will undoubtedly affect vegetation, prey availability, and wildfire frequencies, which in turn, could affect hawks directly and indirectly (Shank and Bayne 2015). Typically considered a species that nests in arid, warm-weather climates, we considered mean spring temperature and precipitation to evaluate how nest-site selection was affected by relatively warmer and wetter regions throughout the CPE (Wallace et al. 2016). We used two decades of annual precipitation and temperature data from 2000–2021 at a 4-km scale to model the influence of climate on nest site selection.

Ferruginous hawk nest sites are often characterized by rugged terrain composed of prominent basalt rock outcrops, cliffs, cinder cones, spires or steep slopes that preclude access by ground predators and provide unobstructed vantages. Complementary to vegetation and climatic covariates, we characterized the physical terrain in the CPE. We used five indices of terrain to characterize potential nesting habitat including topographic position index, topographic roughness, slope, elevation and ruggedness that were derived from 90-m digital elevation models (DEM). We calculated roughness as the mean difference in minimum and maximum elevation between a cell and eight surrounding cells (or neighborhood; Wilson et al. 2007). We used the native rate of elevation change in a DEM to calculate percent slope. We used topographic indices of position and ruggedness to quantify topographic heterogeneity and identify terrain features that may be selected by nesting ferruginous hawk (Riley et al. 1999).

3.2.2 Anthropogenic Covariates

Anthropogenic stressors can influence the likelihood of nest site selection and ultimately result in population-level effects by affecting nesting success and productivity (Olendorff 1993, Kolar 2013, White and Thurow 1985; Keeley and Bechard 2011, Wallace et al. 2021, Collins and Reynolds 2005). Population growth and the underlying land management decisions to accommodate an expanding population are inextricably linked with changes in land cover, renewable energy development, and impacts to ferruginous hawk populations. We modeled the effect of human development as the proportion of land cover classified as low-, medium-, or high-intensity developed in NLCD to reflect the footprint of residential, commercial, and industrial development (i.e., urbanization) within the CPE. Transportation networks fragment habitat but may also have a positive effect by creating perches and open, foraging habitat (Watson 2020). We considered county, secondary and primary roads to model the effect of roads on nest site selection. County roads were defined as paved or unpaved (e.g., rock aggregate), publicly-accessible roads (WSDOT 2022). County roads typically receive lower volume traffic compared to secondary and primary roads. Secondary roads were defined as main paved arteries, usually in the U.S. Highway, State Highway, and/or County Highway system. Primary roads were defined as large, limited-access highways within the interstate highway system or under State management, and are distinguished by the presence of interchanges (Tiger 2021).

The rate of renewable wind energy development has steadily increased within the CPE since 2000 with substantial growth in 2010. Growth of wind energy development is anticipated to continue in the CPE as mandated by Senate Bill 5116, which directs electricity supply free of greenhouse emissions by 2045[3]. Despite the environmental benefits, wind energy may effect ferruginous hawk; Kolar (2013) found that the daily survival rate of ferruginous hawk nests decreased as the number of wind turbines within the home range increased. We used the USGS turbine database to model the effect of wind turbine density and distance to turbines (km) on nest site selection (Hoen et al. 2022).

[3] Washington Senate Bill 5116

Table 1. Covariates used to model ferruginous hawk nest site selection in the Columbia Plateau Ecoregion, Washington, USA, 2000–2021.

Covariate	Description	Reference
Vegetation		
Agriculture (*PropAg*)[a, b]	Proportion of cells containing agriculture. Included Hay/Pasture and Cultivated Crop classes	NLCD 2019
Bare ground (*Bare, BareSD*)[a]	Mean % and standard deviation of bare ground	NLCD 2016
Integrated Normalized Difference Vegetation Index (*INDVI*)[a, b]	Sum of INDVI annual values between March and May	Pettorelli et al. 2005, 2011
Prey[a]	Index of habitat quality (0-1) modeled for four common prey species: black-tailed jackrabbit, white-tailed jackrabbit, Townsend's ground squirrel, Washington ground squirrel	WHCWG 2012
Sagebrush (*Sage, SageSD*)[a, b]	Mean % and standard deviation of sagebrush cover	NLCD 2016
Shrub Height (*ShrubH, ShrubHSD*)[a, b]	Mean and standard deviation of shrub height (cm)	NLCD 2016
Climate		
Precipitation[a, b]	Cumulative monthly precipitation (mm) March−May each year	PRISM Climate Group 2022
Temperature[a, b]	Mean monthly temperature (°C) March−May each year	PRISM Climate Group 2022
Terrain		
Roughness[a]	Mean difference between maximum and minimum elevation of each raster cell and 8 surrounding cells	Wilson et al. 2007 Leu et al. 2008
Slope[a]	Average % slope	Leu et al. 2008
Topographic Position Index (*TPI*)[a]	Mean elevation of each raster cell compared to the mean elevation of the 8 surrounding cells	Guisan et al. 1999
Topographic Ruggedness Index (*TRI*)[a]	Mean of the absolute difference between elevation at each raster cell and 8 surrounding cells	Leu et al. 2008 Wilson et al. 2007
Anthropogenic		
Developed (*PropDev*)[a, b]	Proportion of cells containing development. Included Developed Low, Medium and High Intensity classes	NLCD 2019
Distance to Roads (*WSRoadDist, TIRoadDist*)[b]	Euclidean distance to county roads open to the public (*WSRoadDist*) and primary and secondary roads.	Tiger 2021 WSDOT 2022
Density of Roads (*WSRoadDens, TIRoadDens*)[a, b]	Density of (proportion of raster cells containing road) county roads open to the public (*WSRoadDist*;) and primary and secondary roads	Tiger 2021 WSDOT 2022
Wind Turbine Density (*TurbCount*)[a, b]	Count of operational wind energy turbines	Hoen et al. 2022
Distance to Wind Turbines (*TurbDist*)[b]	Euclidean distance to operational wind energy turbines (km).	Hoen et al. 2022

[a] Non-Euclidean distance covariates were estimated with 0.25-, 0.5-, 1.0-, 1.5-, 5.0-, and 10.0-km moving windows.

[b] Covariate data available for multiple years. Data appended to nests and available locations were time stamped to the nearest year of available data to accurately reflect conditions when nests were present.

3.3 Model Framework and Spatial Predictions

We assessed all non-distance based covariates across six moving windows: 0.25-km, 0.50-km, 1.0-km, 1.5-km, 5.0-km, and 10-km radii. Covariates were assessed across multiple windows to best represent spatial scales at which ferruginous hawk selected nest sites as described by Squires et al. (2020). We assumed smaller scales (0.25−1 km) were indicative of post-fledging areas as observed in other raptors (Kennedy et al. 1994). The smallest landscape scale (5-km radius) was based on a conservative estimate of a core area surrounding a nest site and the 10-km radius represented the average home range surrounding a nest site, based on telemetry data from studies in Oregon and Washington (J. Watson, WDFW, unpub. data). When covariate spatial data were available for multiple years (e.g., NLCD, precipitation, temperature, turbine), we appended data to occupied nests based on the nearest years represented in the spatial data to ensure that data accurately reflected conditions when nests were occupied.

We estimated ferruginous hawk nest site resource selection at population (second-order) and individual levels (third-order) with RSFs (Johnson 1980). Johnson's ecological framework described wildlife habitat selection along a gradient that begins on a broad geographical scale of a species (first-order) and transcends into finer preferences of habitat selection (fourth-order). Here, we consider nest site section of the breeding population in Washington (second-order) and surrounding conditions of an individual nest (third-order). We restricted nests that were identified on or after 2000 to best align with available covariate data. We also excluded nests that were located within 5 km of the Project to be used for independent model validation (described below). For each order of selection, we generated available nesting locations at a rate of 50 times the number of nest (use) locations. For the population level analysis, available nesting locations were generated within the CPE. At the individual level, available nesting locations were restricted to a 10-km buffer surrounding each nest location. The 10-km buffer represented the average home range during the nesting season (J. Watson, WDFW, unpub. data). To estimate each RSF, we used binomial generalized models with R statistical software. The RSFs took the following form:

$$w(x) = exp\left(\beta_1 x_1 + \beta_2 x2 + \ldots + \beta_n x_n\right)$$

where w(x) was proportional to the relative probability of selection, and $\beta_{n's}$ were coefficient estimates for each covariate. We used second-order Akaike's Information Criterion (AIC_c) to assess model support for all models (Burnham and Anderson 2002). Prior to model development, we performed initial variable screening procedures. Variables were centered and Z-transformed (Becker et al. 1988). We first ran univariate models and selected the variable scale that had the lowest AIC_c score for variables assessed across multiple moving windows and only retained variables when AIC_c scores indicated better model fit than intercept only models. We explored all variable combinations of covariates that were retained following initial screening, but did not allow variables in the same model when |r| >0.6. Model selection criteria used to rank and select the most informative model considered a combination of the lowest AIC_c score, highest model weight (w_i), and most parsimonious (Burnham and Anderson 2002). Models were limited to 10 covariates to reduce the potential for model overfitting (Burnham and Anderson 2002). Models were fitted with package *MuMIn* in R (Barton 2020).

3.4 Model Validation

We used 5-fold cross validations to evaluate the most informative population and individual level RSFs. We estimated predictions based on four of the five groups (training data) and compared them to the withheld group, and repeated this until the five withheld groups were evaluated (Johnson et al. 2006). We binned predictions into five equal-area (quartile) intervals (Wiens et al. 2008). Validations were performed by running simple linear regression models on the number of observed locations from the test group compared to expected locations generated from each RSF bin (Johnson et al. 2006). We considered models to be good predictors when linear regression models had high coefficients of determination ($r^2 > 0.9$) and 95% confidence intervals (CI) of slope estimates excluded zero and included 1 (Howlin et al. 2004). In addition, we evaluated model fit with nests located within 5 km of the Project that were excluded from RSF models. We calculated the proportion of nest locations that were in each RSF bin. If the model performed well, the bins corresponding to higher probability of nest site selection would contain more nest locations than the lower-probability bins. We used the best-supported RSF models to create spatially explicit maps of across the Study Area by using coefficients from the top models and distributed predictions into five equal area bins corresponding with increasing relative probability of selection (low, low-medium, medium, medium-high, high). Population level predictive maps were used to visualize patterns of relative nest site selection on the landscape scale, while individual level predictive maps were used to compare the patterns of nest selection to the locations of proposed wind and solar development within the Project Area.

4 RESULTS

4.1 Nest Data

Of the 677 nests in the WDFW database, we identified 194 (28%) occupied nests documented 2000−2020 with a known nesting year to model nest site selection across the range of ferruginous hawk in eastern Washington (Appendix B). Eighteen of the 194 nests (9%) documented as occupied and active were located within 5 km of the Project used for an independent model validation (Section 3.4).

4.2 Population Level RSF (Second-Order)

The most informative population level (second-order) model included 10 covariates, excluding the intercept (Table 2, Figure 3-5, Appendix C). At this order, models suggested that ferruginous hawk selected an array of vegetation, topographic, climactic, and anthropogenic characteristics. Ferruginous hawk selected nest sites with greater variability in bare ground (β = 0.47, 95% CI = 0.22 to 0.72) and less agriculture (β = -1.12, 95% CI = -1.46 to -0.81) within 0.25-km, and less variability in shrub height (β = -1.48, 95% CI = -1.86 to -1.13) within 10.0-km. Ferruginous hawk also select nest sites with higher habitat value for black-tailed jackrabbit within 1.5 km (β = 1.31, 95% CI = 1.03 to 1.61), greater precipitation within 10.0 km (β = 0.43, 95% CI = 0.13 to 0.73), and in areas demarcated by lower topographic ruggedness (β = -1.18, 95% CI = -1.65 to -0.74), but greater topographic position (β = 0.32, 95% CI = 0.08 to 0.55) within 10.0-km. Ferruginous hawk avoided development within 1.0 km (β = -0.70, 95% CI = -1.66 to -0.09), but selected nest locations closer to publicly accessible roads (β = -0.27, 95% CI = -0.48 to -0.06) and turbines (β = -0.47, 95% CI = -0.83 to -0.14; (Figure 4).

The spatial prediction of the population level RSF was a strong predictor of ferruginous hawk nest site selection (Figure 3; Appendix C). When we partitioned validation testing and training groups by nest, average r^2 = 0.99 (± < 0.001 standard error [SE]), and confidence intervals of slope estimates included one, with none excluded in four of the five folds. In addition, the percent of ferruginous hawk nest locations within 5 km of the Project that occurred in the two highest predicted relative probability of selection bins was 94.4%, indicating good model fit (Appendix D).

4.3 Individual Level RSF (Third-Order)

The most informative individual level (third-order) model included five covariates (Table 2; Figure 3, 4 and 6; Appendix C). At this order, models suggested that ferruginous hawk selected for vegetation and topographic characteristics. Ferruginous hawk selected nest sites with greater bare ground within 0.25 km (β = 0.45, 95% CI = 0.27 to 0.62), greater INDVI within 5.0 km (β = 0.20, 95% CI = 0.02 to 0.38), and greater habitat value for black-tailed jackrabbit (β = 0.37, 95% CI = 0.19 to 0.56) and Washington ground squirrel (β = 0.18, 95% CI = 0.00 to 0.37) within 1.0 km. Ferruginous hawk also selected nest sites with greater slope (β = 0.32, 95% CI = 0.26 to 0.38) at the local 0.25-km radii (Figure 4).

The overall spatial prediction of the individual level RSF was a strong predictor of ferruginous hawk nest site selection (Figure 3; Appendix C). When we partitioned validation testing and training groups by nest, average r^2 = 0.95 (± 0.01 SE), and confidence intervals of slope estimates included one in four of the five folds. The percent of nest locations within 5.0-km of the Project that occurred in the two highest predicted relative probability of selection bins was 72.2%, indicating good model fit near the Project (Appendix D).

4.4 Project Level RSF Assessment

Visual inspection of the third-order RSF at the Project identified a range of relative probabilities for nest site selection that was closely associate with terrain attributes and habitat quality for prey species. The highest probability of selection occurred along the ridge north of the proposed wind turbine (Turbine) array (Figure 7). Of the 244 proposed Turbines, the majority (162 Turbines, 66%) were located within low to low-medium RSF bins followed by medium (58 Turbines, 24%), medium-high (18 Turbines, 7%) and high (6 Turbines; 2%; Figure 8). The location of Turbines in relatively higher RSF bins were along the northern ridgeline (Figure 7). Narrow fingers of high probability extended south from the ridge following incised canyons and drainages that contained a greater proportion of native habitat. In general, areas further away from the ridgeline, interior to the Project, had relatively lower probabilities of nest site selection. Interior areas of higher probability south of the Project in the vicinity of a solar array reflected relatively higher quality habitat for Townsend's ground squirrel.

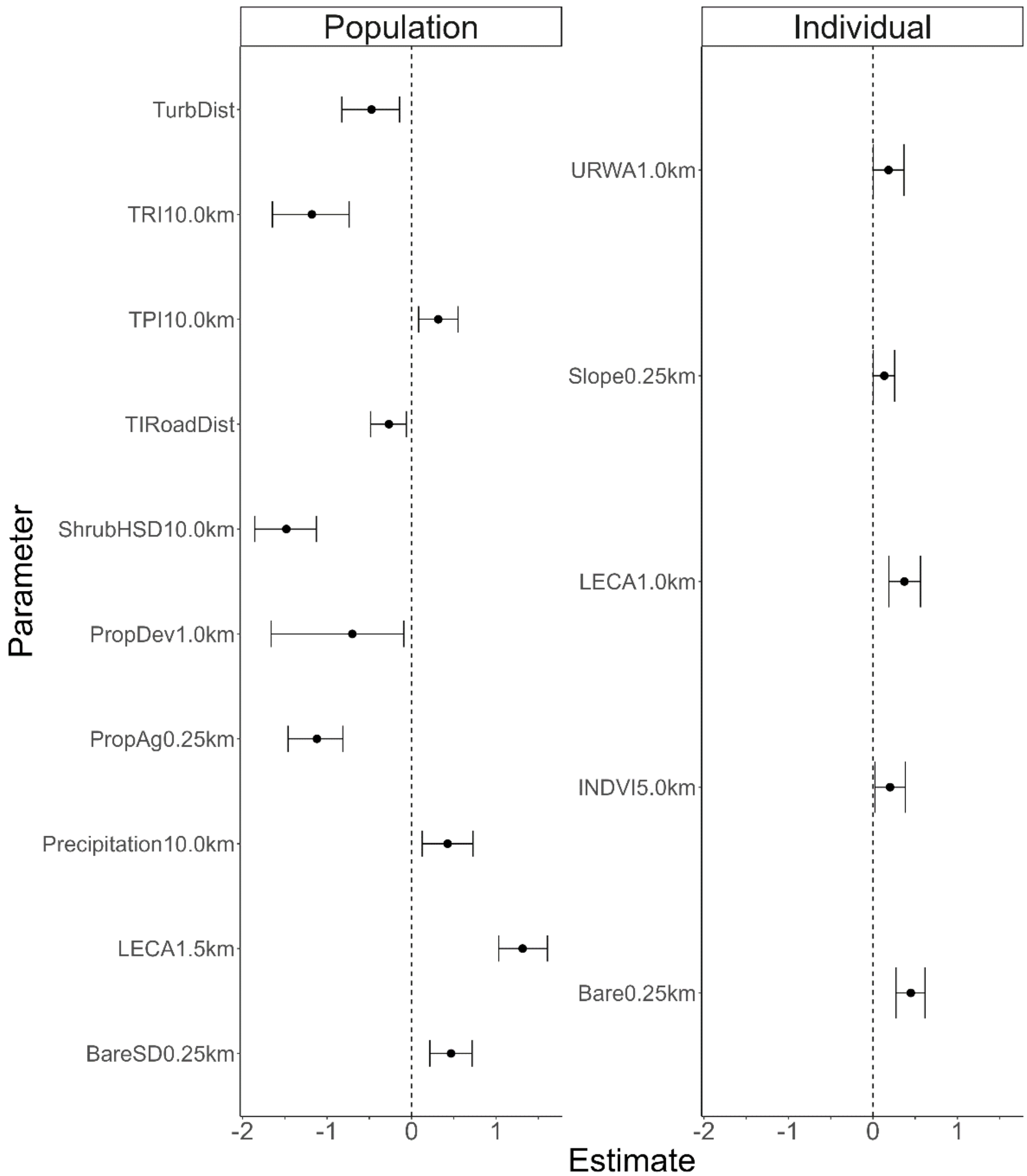
Two historical territories (Beck Road and Four Mile Road) were located in an area proposed for solar development (Figure 7). Both territories have a history of disturbance, inconsistent occupancy, and were unoccupied during Project nest surveys (Jansen 2022). The Beck Road

Territory was comprised of two nests sites, one of which was occupied in 1987 and removed by residential development in the early 1990's. A second Beck Road nest was located 0.5 mi east, with the last ferruginous hawk nestlings documented in 2013, and was refurbished in 2016 but the nest outcome was unknown. The nest was occupied in 2019 by common raven (*Corvus corax*) and Swainson's hawk (*B. swainsonii*) and unoccupied in 2022 (Jansen 2022). The West Four Mile Road Territory also comprised of two nests sites; one of which two adults were observed perching on in 2007 and destroyed the same year and a second nest that contained nestlings in 2006 was destroyed the following year and rebuilt and occupied by common ravens 2010−2016. WEST 2022 surveys documented a collapsed, inactive nest that did not show sign of recent activity.

Table 2. Coefficient estimates and 95% confidence intervals (CI) for variables in the most parsimonious models describing ferruginous hawk nest site selection at the population (second-order) and individual (third-order) levels within the Columbian Plateau Ecoregion. An asterisk (*) denoted covariates that were significant at the 95% confidence level.

		95 % CI	
Parameter[a]	**Estimate**	**Lower**	**Upper**
Population level selection (second-order)			
$BareSD_{0.25km}$	0.47*	0.22	0.72
$PropAg_{0.25km}$	-1.12*	-1.46	-0.81
$ShrubHSD_{10.0km}$	-1.48*	-1.86	-1.13
$LECA_{1.5km}$	1.31*	1.03	1.61
$Precipitation_{10.0km}$	0.43*	0.13	0.73
$TPI_{10.0km}$	0.32*	0.08	0.55
$TRI_{10.0km}$	-1.18*	-1.65	-0.74
$PropDev_{1.0km}$	-0.70*	-1.66	-0.09
TIRoadDist	-0.27*	-0.48	-0.06
TurbDist	-0.47*	-0.83	-0.14
Individual level selection (third-order)			
$Bare_{0.25km}$	0.45*	0.27	0.62
$INDVI_{5.0km}$	0.20*	0.02	0.38
$LECA_{1.0km}$	0.37*	0.19	0.56
$URWA_{1.0km}$	0.18*	0.00	0.37
$Slope_{0.25km}$	0.13*	0.00	0.26

[a] See Table 1 for description of model covariates. Prey covariates included: LECA = back-tailed jackrabbit, URWA = Washington ground squirrel



* Description of Parameters are provided in Section 3.2 and Table 1

Figure 3. Parameter estimates and 95% confidence intervals (CI) for predictor variables describing nest site selection of ferruginous hawk at population and individual levels of selection within the Columbian Plateau Ecoregion, Washington.

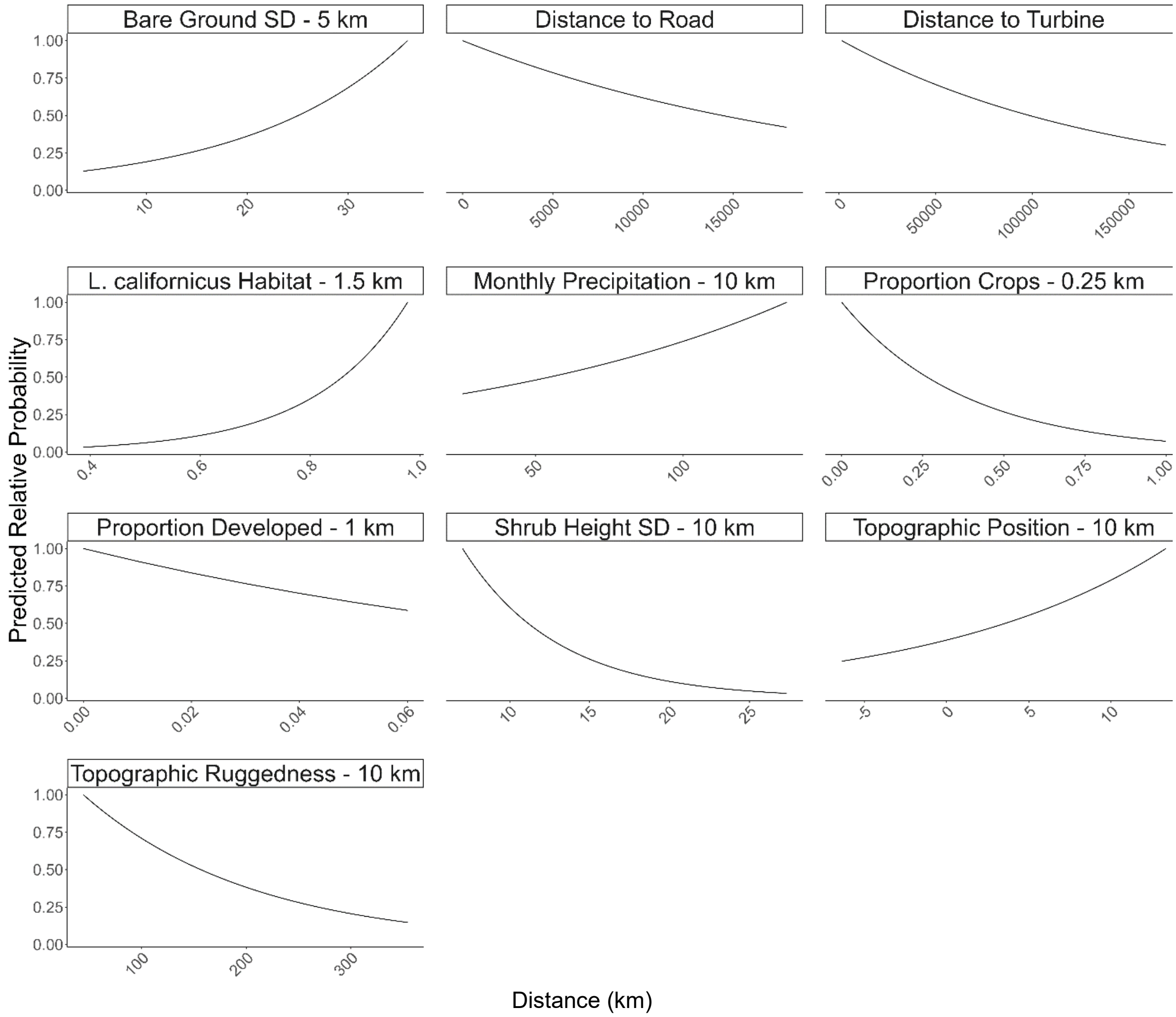


Figure 4. Marginal response curves of each population level (second-order) covariate in the most informative model of relative nest site selection within the Columbia Plateau Ecoregion, Washington. See Table 1 for a description of model covariates.

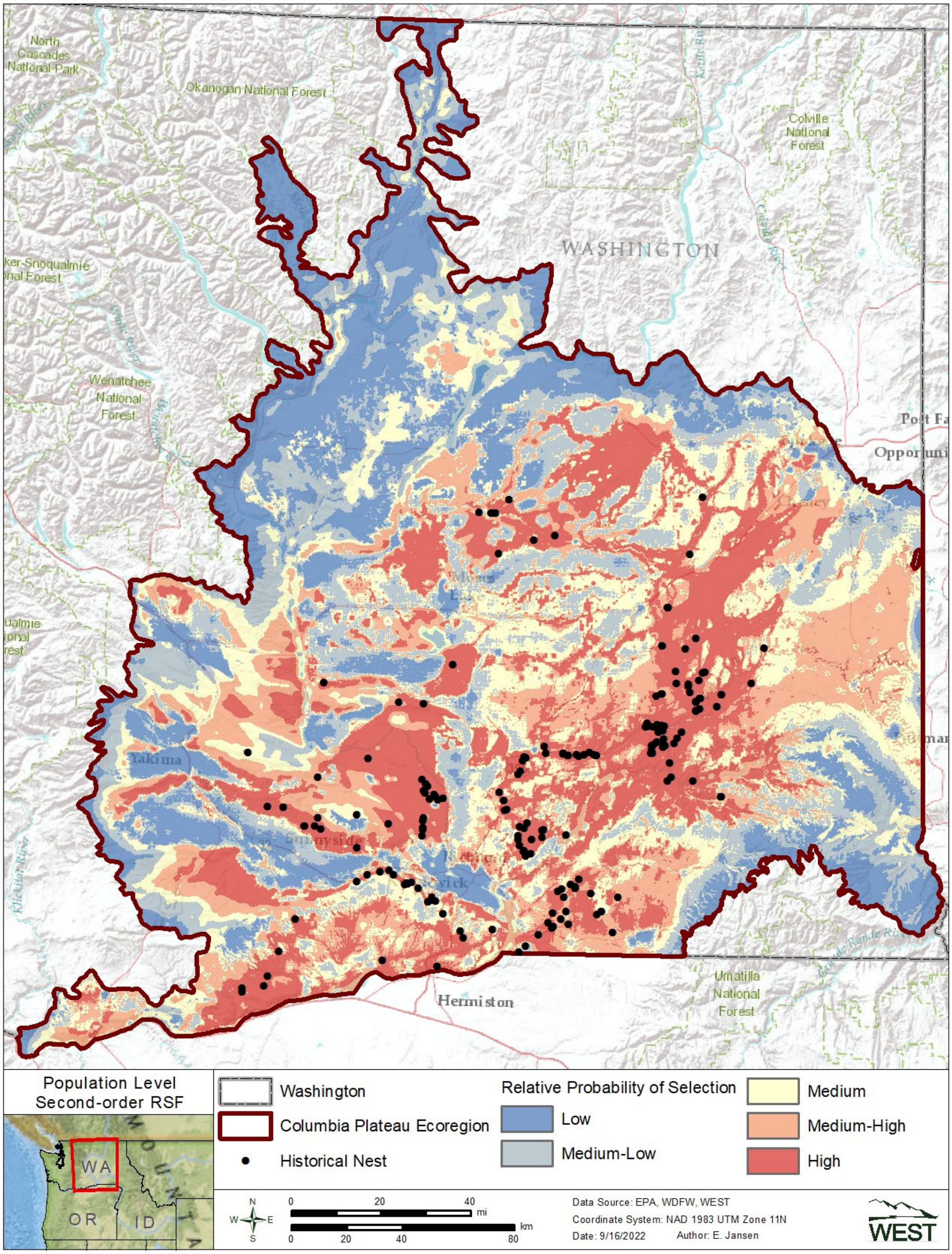


Figure 5. Predicted population level (second-order) ferruginous hawk nest site selection within the Columbian Plateau Ecoregion, Washington.

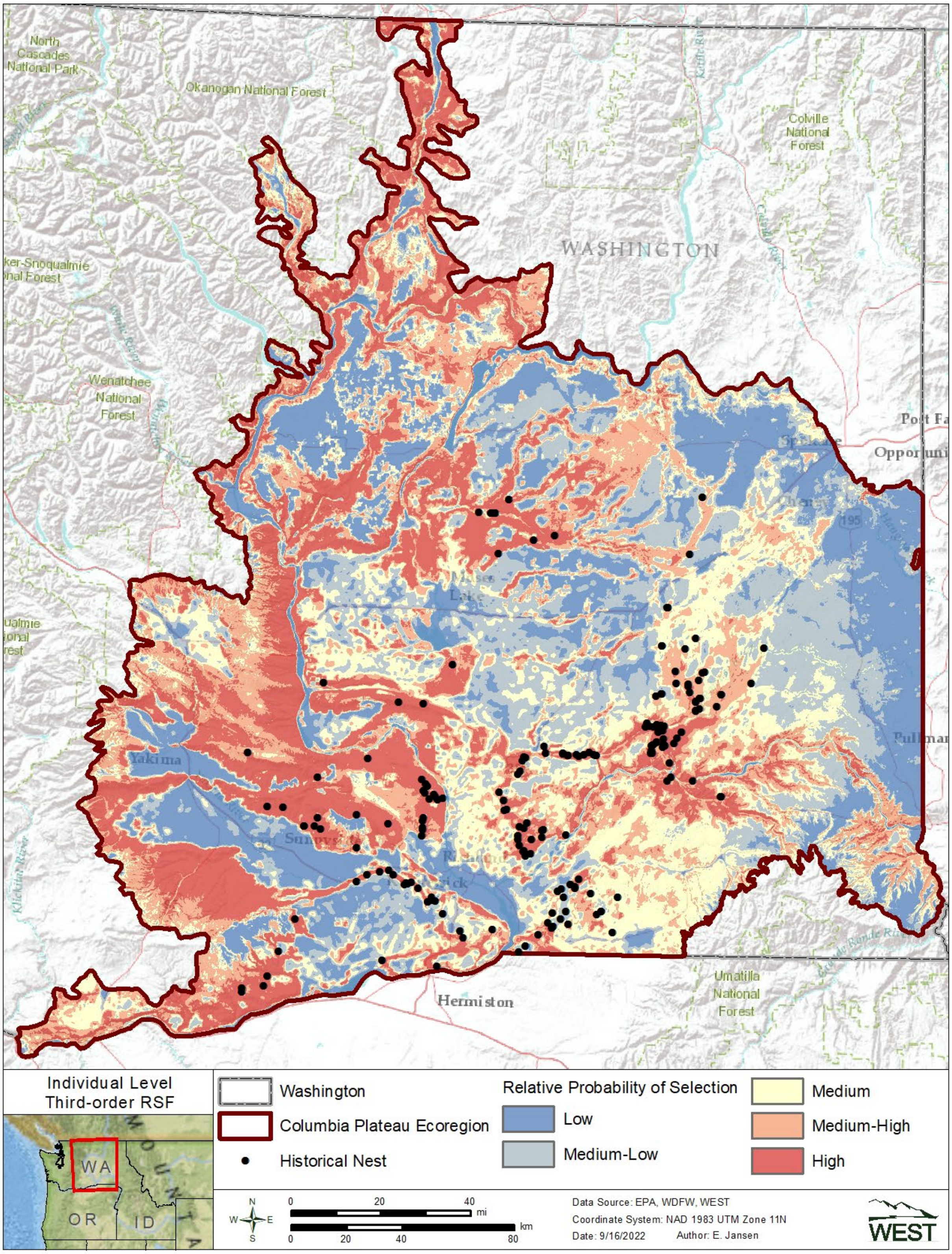


Figure 6. Predicted individual level (third-order) ferruginous hawk nest site selection within the Columbian Plateau Ecoregion, Washington.

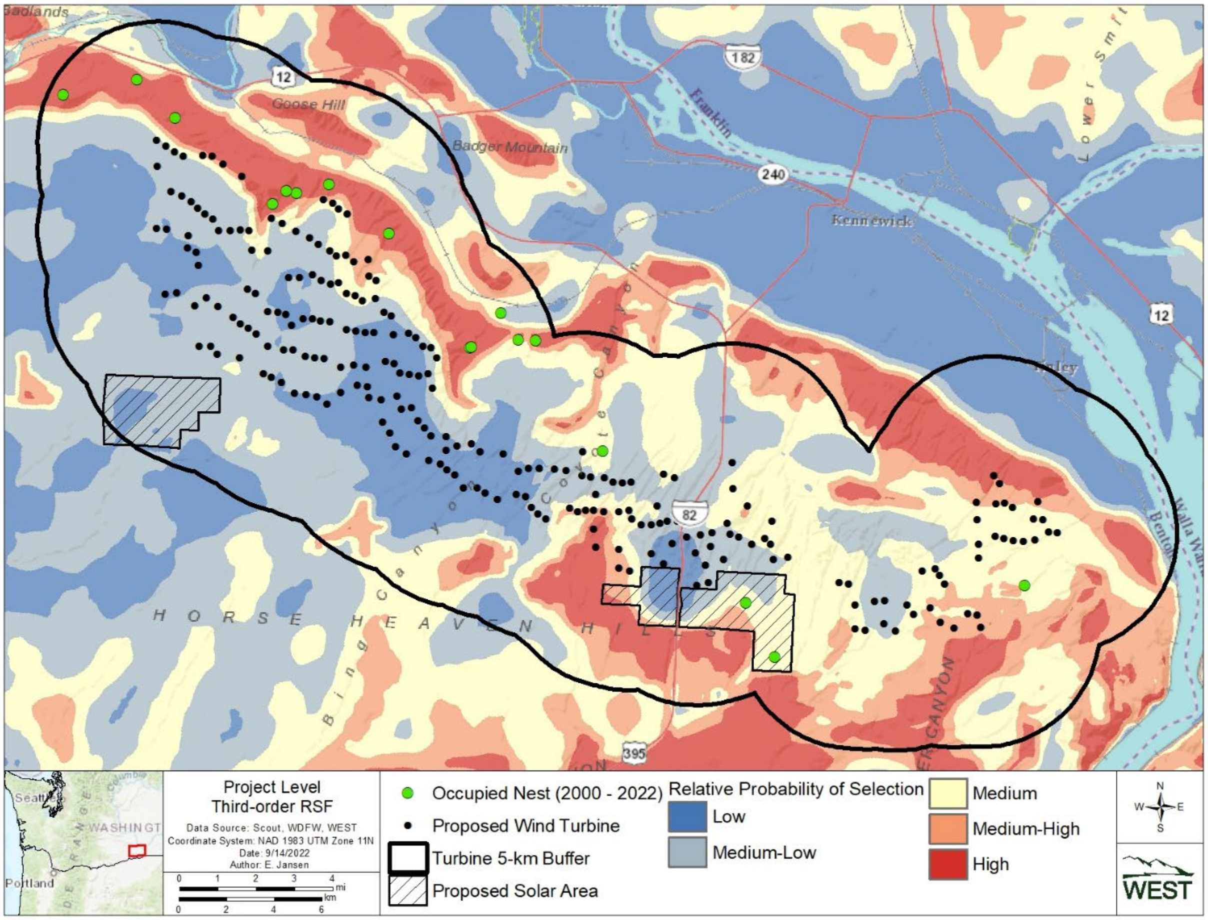


Figure 7. Predicted individual level (third-order) ferruginous hawk nest site selection within the Horse Heaven Clean Energy Center, Benton County, Washington.

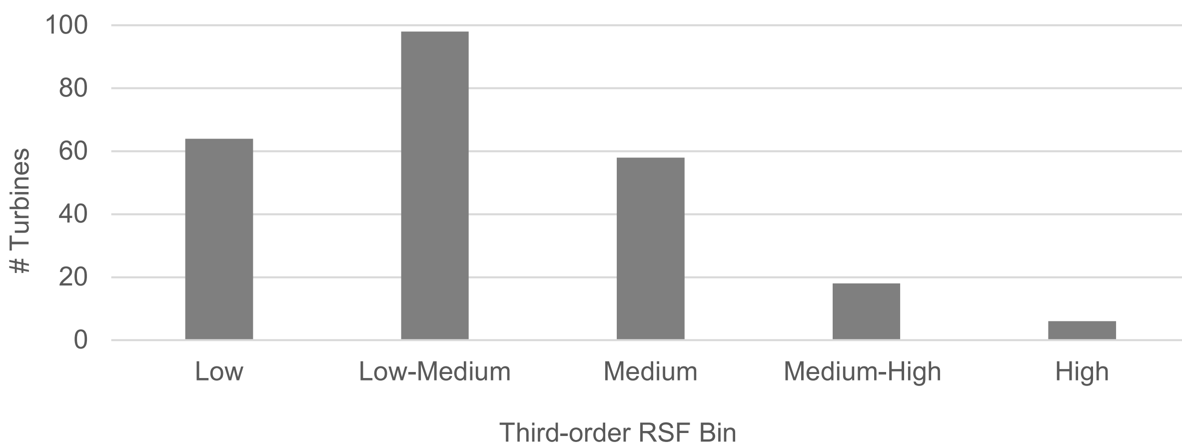


Figure 8. Distribution of Turbines in third-order RSF bins at the Horse Heaven Clean Energy Center, Benton County, Washington.

5 DISCUSSION

We evaluated factors influencing ferruginous hawk nest site selection in a declining population located at the edge of the species' range in the United States. Nest site selection by ferruginous hawk was explained by different variables at the population and individual level, and we found support for our predictions varied when we considered the level of analysis.

We found mixed support for our first prediction that ferruginous hawk would strongly avoid human disturbance at the population level, because nest sites were selected away from development but closer to publicly accessible roads and Turbines. We did not find support for this prediction at the individual level, as all variables in the best model were environmental.

We did not find support for our second prediction that ferruginous hawk would not strongly avoid agriculture at the population level, as the best model suggested that ferruginous hawk selected nest sites with less agriculture. We found no influence of agriculture on nest site selection on the individual level.

Finally, we found support for our third prediction at the population and individual levels that nest site selection would be associated with prey resources as nest sites were associated with a higher habitat value for black-tailed jackrabbits. Patterns of resource selection at both population and individual levels were effectively modeled with remotely sensed covariates based on the high confirmation in the model validation process.

Overall, results support evidence of a hierarchal decision-making process where nest site selection occurs over a broad perception of factors across a landscape and then finer-scale discrimination to include factors essential to nesting success (Mayor et al. 2009).

5.1 Vegetation

Vegetation characteristics influenced nest site selection at multiple scales. At the population scale, ferruginous hawk selected areas with lower heterogeneity in shrub height within 10 km, increased heterogeneity in bare ground within 0.25 km, and lower percent agricultural cover within 0.25 km of the nest. In addition, higher habitat quality for black-tailed jackrabbit within 1.5 km was a strong predictor of nest site selection. We interpret the dichotomous relationship between uniform shrub height and bare ground as an indicator of habitat patchiness or matrix that is characteristic to shrub-steppe grassland habitats (Azerrad et al. 2011). Increased habitat heterogeneity reduces shrub cover, which provide ferruginous hawk, a wait and ambush predator, with greater access to prey (Olson et al. 2017, Watson 2020). However, increased patchiness and loss of shrub cover can negatively affect black-tailed jackrabbit populations and coincides with a comparable decline with habitat during our 21-year study period (Ferguson and Atamain 2012, Sato 2012, Hayes and Watson 2021).

The proportion of agriculture at the population scale was avoided but at a smaller moving window than we expected (0.25 km, Table 1). As a shrub-steppe grassland species, we anticipated a stronger avoidance of agriculture because of the loss of land cover characteristics typical of ferruginous hawk nesting and foraging habitat (Schmutz 1987, Wiggen et al. 2014, Watson 2020). However, at the Hanford Nuclear Site in Benton and Franklin counties, hawks foraged at greater distances from the nest to exploit northern pocket gophers (*Thomomys talpoides*) in agricultural fields, which represents a scenario where agricultural fields were utilized and a shift from prey species considered in our modeling (Leary et al. 1998). Nevertheless, the importance of prey availability and nest selection in areas of higher-quality prey habitat was reflected in the individual models that included black-tailed jackrabbit and Washington ground squirrel (Table 2, Figure 3, Appendix C).

5.2 Climate

Although the range of ferruginous hawk in Washington is within the rain shadow of the Cascade Mountains, the amount of precipitation at a 10 km population scale was a single climate covariate in the final model. Precipitation increases along a gradient the further the distance from the Cascades but is comparatively low (<12−30 inches annually) and defined as arid (PRISM Group 2022). Although not statistically correlated with other covariates in our analysis, precipitation likely influences NDVI, which reflected vegetative productivity. Ferruginous hawk selected for intermediate levels of spring precipitation in Wyoming that also included prey covariates (Squires et al. 2020). A RSF study of two Arctic raptor species in Canada (rough-legged hawk [*B. lagopus*], and Arctic peregrine falcon [*Falco peregrinus tundrius*]) found strong signals for nest selection in models including NDVI at a population and individual scale. Climate projections for 2020 – 2050 in the CPE indicate that temperatures will continue to rise and precipitation levels will decrease (Snyder et al. 2019, Northwest Power and Conservation Council 2021). The effects of climate change on ferruginous hawk are unknown but patterns are anticipated to affect prey populations and availability, drought intensity and wildfire frequency. Frequent drought and fires can result in a shift from native shrub-steppe to invasive annual grasses that reduces prey availability and degrades ferruginous hawk nesting habitat (Smith and Johnson 1985, Van Horne et al. 1997, Van Horne et al. 1998, Yensen and Quinney 1992, Yensen et al. 1992).

5.3 Terrain

At a population level, ferruginous hawk showed weak selection for nest sites that were comparatively higher than their surrounding elevation within 10 km. Weiss (2011) suggested weak positive TPI values indicated a slope position of open cliff to cliff edge, which corresponds to 2017−2022 survey data and verified in the WDFW database where 54% of the 194 nests were located on a cliff or rock outcrop (Jansen 2022, WDFW 2021). We observed a stronger avoidance with rugged terrain, which indicates a selection for flatter topography at a landscape scale. Nest selection for elevated areas surrounded by a comparatively flatter landscape reflects topography in the CPE where deeply incised canyons and drainages are flanked by flat plateau or rolling valley bottoms that provide suitable foraging habitat. Our results were consistent with Squires et al. (2020) where nest selection sharply declined as topographic roughness increased and terrain became more jagged within 5 km.

5.4 Anthropogenic

5.4.1 Development

Ferruginous hawk avoided areas with a higher proportion of low, medium, and high intensity development within 1 km of a nest. However, the proportion of the developed area around the nest was highly variable, as seen in the wide 95% CI of the coefficient (Appendix C). High variability in the proportion of development could be due, in part, to the pooled intensity levels in the model. Throughout the species' range and Washington, urbanization has resulted in habitat loss, fragmentation, and degradation by increasing artificial food subsidies to nest predators (Hayes and Watson, 2021, Keeley et al. 2016, Watson et al. 2021).

Nesting success can be affected by nest disturbance and varies by the intensity and duration of the disturbance (Gaines 1985, Nordell et al. 2017). White and Thurow (1985) recommended limiting driving and walking within 0.25 km around nests to minimize desertion in ≤ 90% of the population, Nordell et al. (2017) observed nest disturbance nearly 1 km (mean = 130 m) from the nest, and Gaines (1985) documented lower reproductive success at nests within 2.5 km of residences. From 2020−2030, annual population growth within the CPE is projected to increase approximately 1% per year to approximately 1.9 million individuals, or 10.3% increase by 2030 (Washington Office of Financial Management 2018). Corresponding development to accommodate human population growth will likely add further stressors to the population, particularly in expanding exurban areas located on the fringes of growth management boundaries, where the intersection between historical nesting sites and human will meet (Gaines 1985, Ng 2019). Examples of encroachment into historical nesting sites have been documented proximate to the Project along the Horse Heaven Hills in Benton County (Jansen 2022), surrounding the Juniper Dunes Wilderness and along the Washtucna Coulee in Franklin County, and foothills of the Rattlesnake Hills in Yakima County (WDFW 1996, WDFW 2021).

5.4.2 Roads

Nest sites were located closer to county, secondary, and primary roads than expected; however, there are several potential explanations for this relationship. With the exception of several large roadless areas under state or federal ownership (e.g., Yakima Training Center, Hanford Reach/Nuclear, Lower Crab Wildlife Area), roads are located throughout the CPE. Convenience sampling along roads may increase detection of perched and breeding pairs of ferruginous hawk, thereby increasing the likelihood of detecting nests in the surrounding are (Anderson 2007). In Wyoming, ferruginous hawk nests were located closer to roads but were associated with oil and gas development and observed a preferential response to the associated power poles for perching (Squires et al. 2020). Similarly, in Colorado, nests were associated with areas closer to roads (Aagaard et al. 2021). Roads and fences may have a positive effect on habitat quality by creating perches and open foraging habitat, and ferruginous hawk may habituate to low levels of vehicular traffic, particularly on gravel roads which are prevalent in more rural areas of the CPE where historical nests are located (Nordell et al. 2017, Watson 2020).

5.4.3 Wind Turbines

At the population level, ferruginous hawk selected nest sites closer to operating Turbines, but did not select landscapes based on Turbine density. The finding that ferruginous hawk selected nest sites in areas nearer to Turbines than available locations was likely due to generating availability across the entire extent of the CPE, representing a more course analysis that does not infer selection for areas nearer to Turbines at finer scales. In support, the majority of ferruginous hawk nests were approximately 50 km from an operating Turbine (Figure 9). As of 2021, there are approximately 1,780 operating Turbines at 27 projects[4] in the CPE (Hoen et al. 2022). Turbine density was highest along the periphery of the CPE, adjacent to the Columbia River Gorge in Klickitat County and along the Snake River Breaks in Columbia and Garfield counties. Historically, ferruginous hawk nested at lower densities in these areas compared to the nesting stronghold in Franklin County, located toward the interior of the CPE. Despite this inconsistency, a decrease in nest occupancy and increase distance (i.e., displacement) of occupied nests from Turbines has been documented. In a regional study of 18 wind projects in the CPE of Oregon and Washington, ferruginous hawk nest occupancy declined approximately 68% during surveys conducted > 10 years post-construction (Watson et al. 2021). There was a proportional and statistically significant decrease in occupied nesting at a control area; thus, the causal mechanism affecting nest occupancy could not be separated from other regional trends that included an overall declining population trend, increasing common raven population or local factors including persistent drought that decreases prey availability. Spatial displacement of ferruginous hawk nests within 3.2 km of wind facilities increased approximately 43% post-construction (mean = 2.16 km 95%CI 0.81−3.5 km) but the difference of the distance was not statistically significant (Watson et al. 2021). Nevertheless, declines in the nesting population during the study period and regionally over the past half century, should indicate the covariates affecting nest site selection should be considered holistically during management and land use planning decisions.

5.5 Project Level Assessment

The majority of the proposed Project is located in areas modeled as low to low-moderate probability of nest site selection. Highest probability of nest site selection was along the northern escarpment bordering the Project. Historic nest sites, native land cover, terrain, and modeled prey habitat highlight areas where nest selection was relatively higher. Jansen (2022) provided an overview of nesting patterns of ferruginous hawk in the Horse Heaven Hills documented during surveys conducted 2017−2019 and 2022. Survey results indicted low and inconsistent nest occupancy with the majority of historic nests in poor condition, gone, or occupied by another raptor species/common raven (Jansen 2022). Despite an agriculturally dominated landscape bisected by transportation/electrical systems, and encroaching exurban development within 100 m of some historical nests, ferruginous hawk have nested within 3.2 km of the Project in recent years.

[4] Total number of projects includes individual phases despite similar project names (e.g., Big Horn I, Bird Horn II)

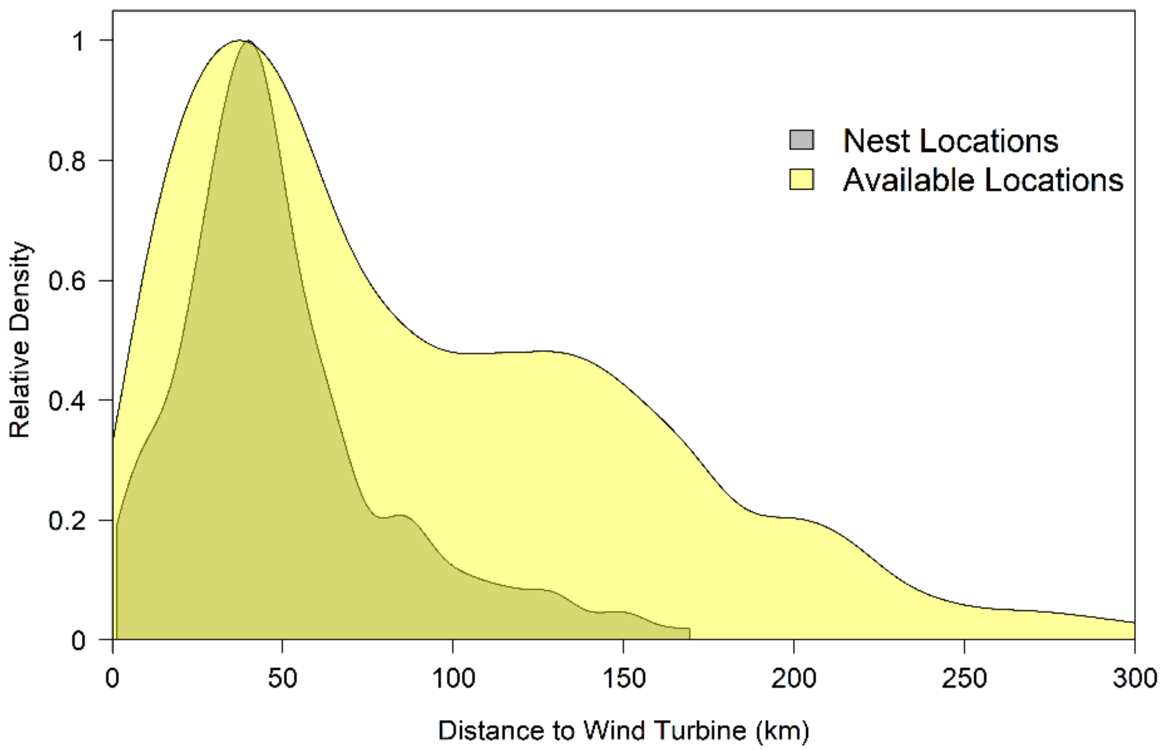


Figure 9. Density of nest locations used by ferruginous hawk (grey) and available locations across the CPE (yellow) relative to distance to Turbines. Density plots were relativized by dividing values by their maximum.

6 CONCLUSION

Nest site selection at the population level was influenced by a suite of biotic and abiotic factors and included expected relationships (e.g., positive association with prey habitat quality) and unexpected relationships (positive association with Turbines).

Nest site selection at the individual level was influenced by biotic factors, and our best model did not contain anthropogenic covariates found in the population level model including the proportion of agriculture, distance to roads, or distance to Turbines. We interpret the change in covariates between the levels to represent settlement decisions by the population of ferruginous hawk on the landscape to first select nest sites that contains anthropogenic features then for individuals to select nest sites that maximize reproductive potential. Our population level modeling results should not be interpreted that agriculture, roads, or Turbines benefit ferruginous hawk, or that the development of these features will create nesting habitat. In fact, our individual level analysis show that anthropogenic features were not included in the top model.

Overall, our model provides valuable information at the individual level for high probability nest sites that could be considered during renewable energy development siting. Methods used to identify areas of higher nest site selection identified within this study in combination with avoidance and minimization measures can be implemented during Project development phases to strategically reduce direct and indirect impacts to ferruginous hawk.

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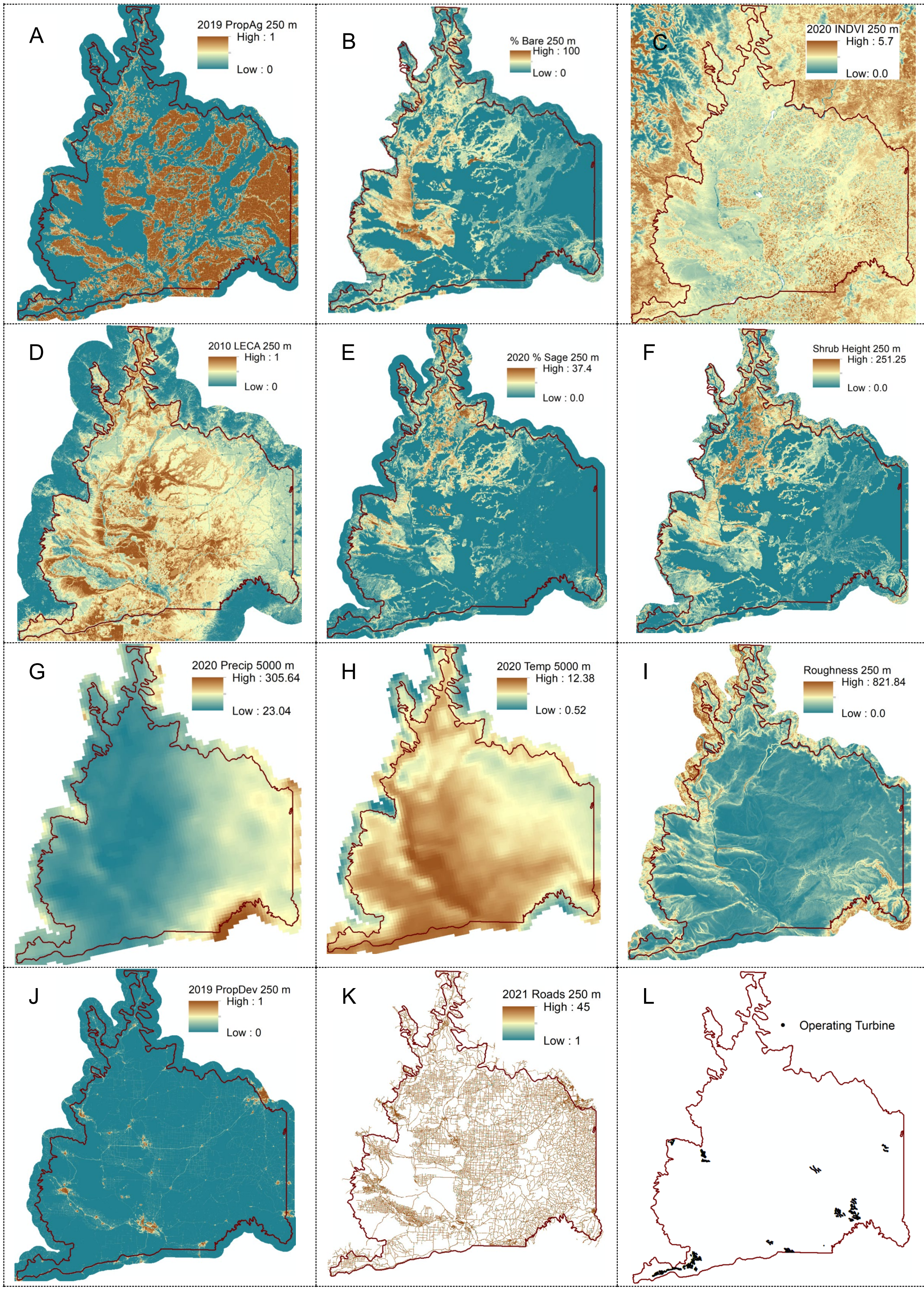
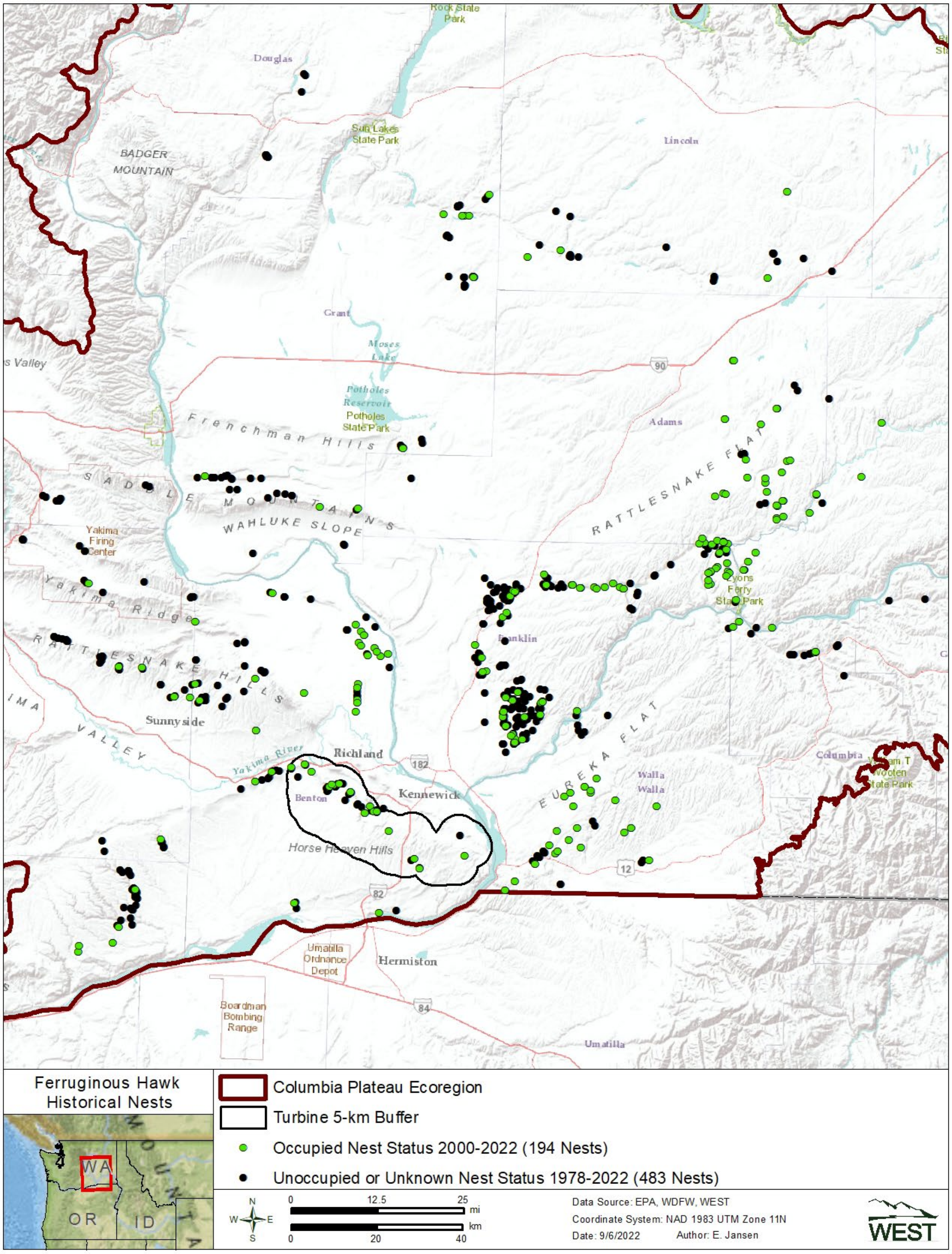
Appendix A. Example data layers used as spatial covariates to model ferruginous hawk nest selection within the Columbia Plateau Ecoregion of eastern Washington.

A full description and reference to remotely sensed spatial data layers are found in Section 3.2 and Table 1. Examples used for illustration include,

A) Agriculture 2019 layer at 250-m scale
B) Bare Ground 2019 layer at 250-m scale
C) Integrated Normalized Difference Vegetation Index 2020 layer at 250-m scale
D) Black-tailed Jackrabbit Habitat 2010 layer at 250-m scale
E) Sagebrush Land Cover 2020 layer at 250-m scale
F) Shrub Height 2019 layer at 250-m scale
G) Precipitation 2020 layer at 5,000-m scale
H) Temperature 2020 layer at 5,000-m scale
I) Roughness 2019 layer at 250-m scale
J) Development 2019 layer at 250-m scale
K) County, Secondary and Primary Roads 2021 layer at 250-m scale
L) Operational Wind Turbine 2021 layer


A
2019 PropAg 250 m
High : 1
Low : 0
B
% Bare 250 m
High : 100
Low : 0
C
2020 INDVI 250 m
High : 5.7
Low: 0.0
D
2010 LECA 250 m
High : 1
Low : 0
E
2020 % Sage 250 m
High : 37.4
Low : 0.0
F
Shrub Height 250 m
High : 251.25
Low : 0.0
G
2020 Precip 5000 m
High : 305.64
Low : 23.04
H
2020 Temp 5000 m
High : 12.38
Low : 0.52
I
Roughness 250 m
High : 821.84
Low : 0.0
J
2019 PropDev 250 m
High : 1
Low : 0
K
2021 Roads 250 m
High : 45
Low : 1
L
Operating Turbine

Appendix B. Distribution of ferruginous hawk nests used to model RSF models in eastern Washington.



Appendix B. Distribution of ferruginous hawk nests used to model RSF models in eastern Washington. Occupied nests were documented as occupied at least once during 21-year dataset.

Appendix C. Five best supported models used to assess ferruginous hawk nest site selection within the Columbian Plateau Ecoregion at the population (second-order selection) and individual (third-order) selection levels. Intercept only (Null) model included for comparison.

Appendix C. Five best supported models used to assess ferruginous hawk nest site selection within the Columbian Plateau Ecoregion at the population (second-order selection) and individual (third-order) selection levels. Intercept only (Null) model included for comparison. Italics denote most informative model used in RSF predictions.

Model[a]	Model Fit Statistic[b]		
	K	**ΔAIC_c**	**w_i**
Population Level Selection (second-order)			
$PropAg_{0.25km}$ + $BareSD_{0.25km}$ + $ShrubHSD_{10.0km}$ + $LECA_{1.5km}$ + $Precipitation_{10.0km}$ + $TPI_{10.0km}$ + $TRI_{10.0km}$ + $PropDev_{10.0km}$ + TIRoadDist + TurbDist	*11*	*0*	*0.03*
$PropAg_{0.25km}$ + $Bare_{0.25km}$ + $Sage_{10.0km}$ + $ShrubHSD_{10.0km}$ + $LECA_{1.5km}$ + $Precipitation_{10.0km}$ + $TPI_{10.0km}$ + $TRI_{10.0km}$ + $WSRoadDens_{1.5km}$ + $TurbCount_{10.0km}$	11	1.22	0.01
$PropAg_{0.25km}$ + $Bare_{0.25km}$ + $Sage_{10.0km}$ + $ShrubHSD_{10.0km}$ + $LECA_{1.5km}$ + $Precipitation_{10.0km}$ + $TPI_{10.0km}$ + $TRI_{10.0km}$ + TIRoadDist + TurbDist	11	1.23	0.01
$PropAg_{0.25km}$ + $Bare_{0.25km}$ + $Sage_{10.0km}$ + $ShrubHSD_{10.0km}$ + $LECA_{1.5km}$ + $Precipitation_{10.0km}$ + $TPI_{10.0km}$ + $TRI_{10.0km}$ + TIRoadDist + $TurbCount_{10.0km}$	11	1.68	0.01
$PropAg_{0.25km}$ + $Bare_{0.25km}$ + $Sage_{10.0km}$ + $ShrubHSD_{10.0km}$ + $LECA_{1.5km}$ + $Precipitation_{10.0km}$ + $Temperature_{10.0km}$ + $TPI_{10.0km}$ + $TRI_{10.0km}$ + $TurbCount_{10.0km}$	11	1.68	0.01
Intercept Only (Null)	1	564.99	0.00
Individual Level Selection (third-order)			
$Bare_{0.25km}$ + $INDVI_{5.0km}$ + $LECA_{1.0km}$ + $URWA_{1.0km}$ + $Slope_{0.25km}$	*6*	*0*	*0.02*
$Bare_{0.25km}$ + $BareSD_{0.25km}$ + $INDVI_{5.0km}$ + $LECA_{1.0km}$ + $URWA_{1.0km}$ + $Slope_{0.25km}$	7	0.67	0.01
$Bare_{0.25km}$ + $INDVI_{5.0km}$ + $LECA_{1.0km}$ + $URTO_{1.0km}$ + $Slope_{0.25km}$	6	1.01	0.01
$Bare_{0.25km}$ + $INDVI_{5.0km}$ + $LECA_{1.0km}$ + $URWA_{1.0km}$ + $Slope_{0.25km}$ + $PropDev_{1.0km}$	7	1.15	0.01
$Bare_{0.25km}$ + $BareSD_{0.25km}$ + $INDVI_{5.0km}$ + $LECA_{1.0km}$ + $URWA_{1.0km}$ +	6	1.25	0.01
Intercept Only (Null)	1	91.15	0.00

[a] See Table 1 for description of model covariates. Prey covariates included: LECA = back-tailed jackrabbit, URTO = Townsend's ground squirrel, URWA = Washington ground squirrel

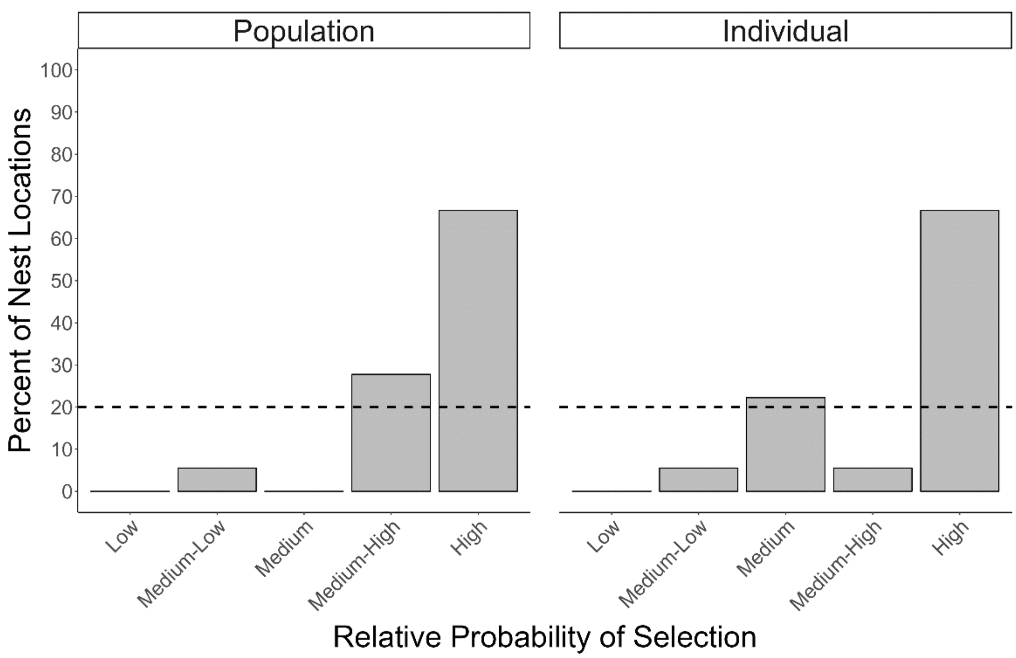
[b] *K* = number of model parameters (includes intercept), ΔAIC_c = difference in AIC_c units between models, w_i = Akaike model weight

Appendix D. 5-fold cross validation results of Population and individual level RSF models from withheld ferruginous hawk nest locations within 5.0-km of the Project.

Appendix D1. 5-fold cross validation results from ferruginous hawk nest site selection at the population (second-order) and individual (third-order) levels within the Columbian Plateau Ecoregion. We considered models (K) good predictors of nest site selection when they had a high coefficient of determination (r^2), and 95% confidence intervals (CI) surrounding slope estimates (B_1) that excluded zero and included 1.

K	r^2	B_0[a]	95% CI	B_1	95% CI
Population Level Selection (second-order)					
1	0.99	-1.25	(-4.37, 1.87)	1.17	(0.94, 1.41)
2	1.00	-0.49	(-1.64, 0.67)	1.07	(0.98, 1.16)
3	0.99	0.64	(-1.14, 2.42)	0.91	(0.77, 1.04)
4	1.00	-0.35	(-0.71, 0.01)	1.05	(1.02, 1.08)
5	0.99	-0.69	(-3.48, 2.09)	1.10	(0.88, 1.31)
Individual Level Selection (third-order)					
1	0.99	-3.28	(-5.76, -0.80)	1.46	(1.19, 1.72)
2	0.96	-1.26	(-5.41, 2.89)	1.18	(0.73, 1.63)
3	0.96	-2.49	(-7.12, 2.13)	1.36	(0.85, 1.87)
4	0.90	-3.86	(-12.53, 4.80)	1.55	(0.59, 2.51)
5	0.97	-1.97	(-5.96, 2.02)	1.28	(0.85, 1.71)

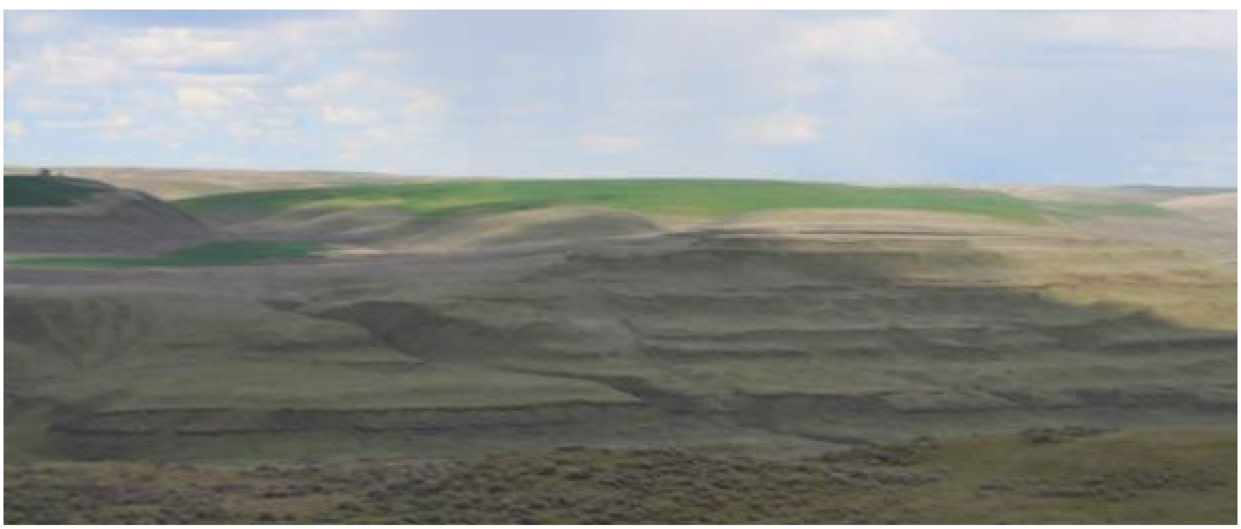
[a] Intercept



Appendix D2. Relative nest site model results from withheld nest locations within 5.0-km of the Project. Bars represent the percentage of nest locations within each RSF mode-predicted bin, from the lowest predicted probability of selection to the highest predicted probability of selection (left to right-most bins). The horizontal dashed line represents the expected percentage of nest locations within each RSF bin if the model performed no better than random.

Appendix E. Representative photographs of landscape covariates used to model ferruginous hawk nest selection within the Columbia Plateau Ecoregion of eastern Washington.

Nesting and foraging habitat within the shrub-steppe grassland matrix of the Saddle Mountains, Grant County, March 2018.



Sloped, basalt terraces within shrub-steppe grasslands provided nesting and foraging habitat in Adams County, March 2017.


Prominent cliffs of the Sentinel Bluffs provided nesting habitat in Grant County, April 2017.


Small rock outcrops also provided nesting habitat at this historical nest location in Benton County, March 2022.

Expanding urbanization decreased suitability for nesting and foraging at this historical nest site in Benton County, March 2022.

Urbanization fragmented, converted habitat and increased road densities in Benton County, May 2022.

Operational wind energy turbines and transmission infrastructure within the grasslands, cropland, and shrub-steppe land cover of the Horse Heaven Hills, Benton County. March 2022.

Operational wind energy turbines within an agricultural dominant landscape, Columbia County. March 2022.