Columbia White-tailed Deer Habitat Model and Methodology

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Contents

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Introduction

The Columbian White-tailed deer (CWTD) is an endangered subspecies of white-tailed deer. Once ranging over much of western Washington and Oregon, it now exists in two remnant populations—one near Roseburg, OR, and one near Cathlamet, WA. While the Roseburg population has been delisted, the Lower Columbia population has not yet recovered. Habitat in this area is highly fragmented, and barriers to population expansion prevent useable habitats from being pioneered. In addition, suitable habitats often have conflicting land-use objectives, so translocation to these areas may prove undesirable for biological, social, and/or political reasons.

Much of the recovery strategy for the lower Columbia River population has been the translocation of deer past habitat barriers to establish new subpopulations in suitable environments. The CWTD recovery plan (FWS 1983) sets overall population goals and the number of subpopulations needed on secure habitat as delisting requirements. While overall population goals have been met, the number of subpopulations must be increased. While many areas of potential habitat exist near the current range, land-use conflicts have delayed translocations to these areas. Habitat outside the immediate core range has never been quantified or evaluated for suitability and potential conflicting issues.

A map of potential habitat would provide a tool for managers to identify high quality environments and evaluate their locations with respect to potential land-use conflicts. The ultimate goal for habitat mapping is to create a tool that expedites population expansion and eventual delisting of the lower Columbia population of CWTD.

The Columbia White-tailed Deer (CWTD) habitat model (APPENDIX A) is an additive geospatial model based on distances from and densities of binary habitat variables both detrimental to and necessary for CWTD survival. These summed variables become mottled after applying several complex masks (APPENDIX B). The resulting landscape mosaic is then filtered and categorized. This final report seeks to explain the purpose of this model, detail the model's methodology, and show the results of the model. The appendices show a conceptual framework and model workflow to graphically explain and reproduce the model's results in the future.

Figure 1. Approximate modeling study area centered on the Willamette Valley, OR.

Purpose

Identification of high-quality CWTD habitat within the historical range of CWTD will assist in planning for the expansion of the population. The establishment of additional secure subpopulations is an element of recovery as listed in the CWTD Recovery Plan (USFWS 1983). It is hoped that by increasing habitat distribution, recovery goals can be met and eventual delisting will follow.

This geospatial model attempts to evaluate factors influencing habitat distribution of CWTD within their historic range. This model identifies potential suitable habitat for future reintroduction efforts, unintended migration potential, and general habitat quality mapping. The model uses existing regional datasets and categorizes them into habitat variables important to CWTD. The approximate historic home range (Figure 1) of the CWTD was estimated to extend from the lower elevations around Olympia, WA, south through the Puget Lowlands, Longview, WA, and from the leeward side of the coastal range across to the lower foothills of the Cascade Mountains. Their historic range continues following the Columbia River toward Portland, OR, and south through the Willamette Valley, to Eugene, OR, again

encompassing the area between the Coastal Range and the foothills of the Cascade Mountains. Historic documentation noted the deer existed within the Cowlitz, Willamette, Umpqua, and Lower Columbia Rivers' drainages in Oregon and Washington (Suring & Vohs, 1979).

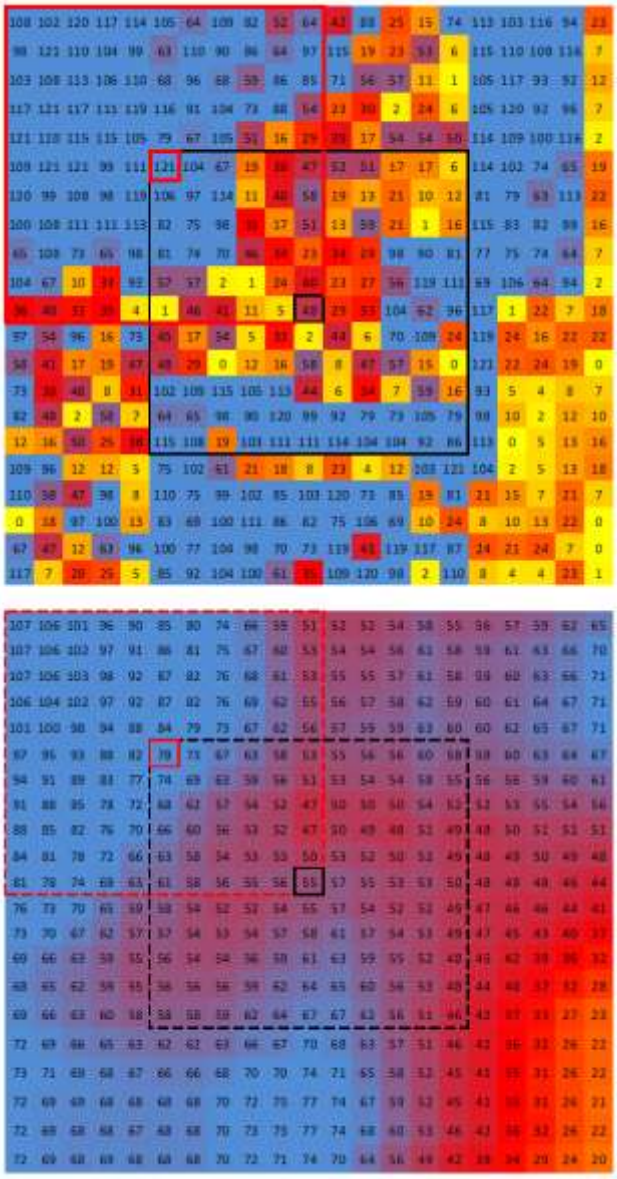

Figure 2. Density focal analyses (cell counts and density) of 11x11 original values (top) and averaged summed (bottom). Low values (yellow), mid-range values (red), and higher values (purple-blue) show regional trend rather than small-scale differences.

Methods

ERDAS Imagine 13 and ArcGIS 10 provided the processing and evaluation of the datasets. Most of the modeling used raster-based analysis of the original and derivative datasets. Two primary spatial analysis methods, Euclidian distance and focal density make up most of the model inputs. ArcGIS Spatial Analyst performed the distance function calculations, while due to limitations of raster size and processing times, ERDAS proved more efficient at performing focal density analyses. Both software platforms perform similar functions, which could be adapted for model processing.

The focal density function, illustrated in Figure 2, examines the predetermined area around the focus cell to perform an analysis. In the case of the CWTD model, the focal sum provided the sum of all binary input occurrences within the 11x11 kernel. Measuring the density of the model's respective habitat variables shows the homogeneity of the landscape and concentrations of positive and negatively correlated habitat dimensions/categories.

We tested several different kernel, or focal region, sizes to determine which fit the model best, while creating the model. Kernel sizes of 5x5, 7x7, and 11x11 produced varying results. Ultimately an 11x11 focal kernel size, resulting in 121 pixels (26.91 acres), appeared to give the best results. This kernel size

corresponds to slightly more than half of the home range sizes for the Southern CWTD population (~44.5 acres) (Ricca et al., 2003).

In the case of the Distance analysis inputs within the model, a Euclidian distance function in ArcGIS produced model inputs. The Euclidian distance function measured the distance from the binary model inputs, or model categories. As distance increases away from a positively or negatively correlated habitat variable, the effects diminish or increase. The effect mimics magnets either attracting or repelling another magnet. In the model, positively correlated features attract and features with negative influence repel the deer.

Model Datasets

Several different datasets were used for the CWTD habitat assessment. Digital Elevation Models (DEM) for Oregon and Washington, publically owned lands (provided by FWS Regional Office), previous CWTD survey data, National Land Cover Dataset (NLCD) Canopy Cover, and NOAA's Coastal-Change Analysis Program (C-CAP) (NOAA, 2013) for Oregon and Washington (Figure 3) were the primary inputs for the analysis. The raster inputs (DEMs, Canopy Cover, and C-CAP) have the same 30-meter pixel resolution. 30-meter model resolution decreased processing time, saved data space, and kept the data in its original resolution. Land ownership and CWTD survey data are distributed as vector data.

NOAA C-CAP

The model relies on readily available and recently updated C-CAP datasets for Oregon and Washington. C-CAP data is a standardized 30-meter spatial resolution national land cover and land change for coastal regions of the U.S. The dataset is a part of the National Land Cover Dataset (NLCD) (Homer et al., 2007). The data is derived from multi-date satellite imagery and updated about every five years. C-CAP for Oregon (1992-2006) and Washington (1992-2011) make up the core of the reclassified data for distance and density modeling. Washington was updated with 2011 imagery, which included the addition of more wetland and riparian features making the 23-class land use/land cover dataset more thematically accurate. 2011 Oregon data was not available at the time the model was run; Oregon was last updated with 2006 imagery. When updated, the inputs for the Oregon portion of the data may be re-run to reflect any changes.

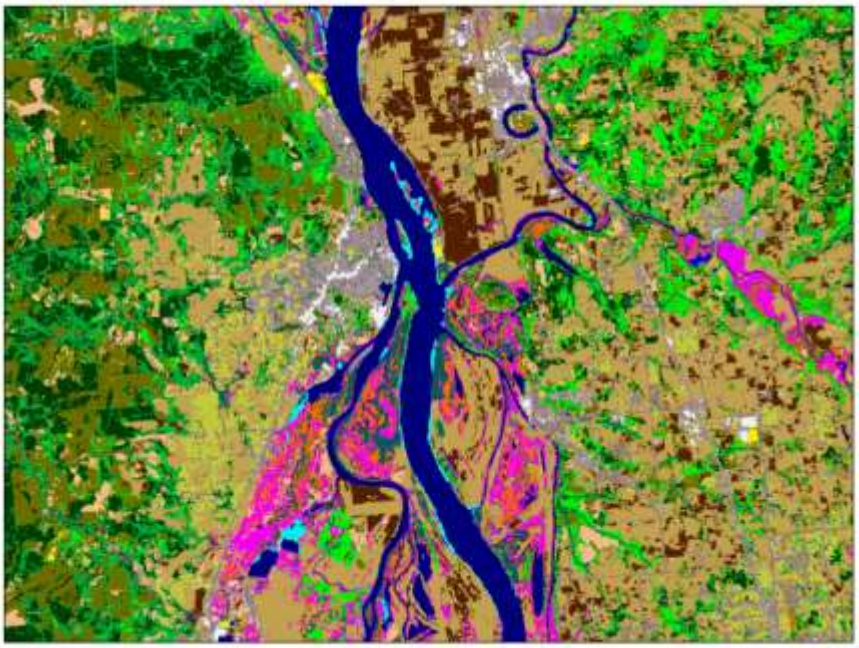

Figure 3. C-CAP dataset in its original classification showing the Columbia River around Ridgefield, WA., Ridgefield NWR, and Scappoose, OR.

The 23 thematic classes and their descriptions are described as follows (NOAA):

Unclassified

Background (0) – areas within the image file limits but containing no data values.

Unclassified (1) – areas in which land cover cannot be determined; these include clouds and deep shadow.

Developed Land

Developed, High Intensity (2) – contains significant land area that is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies < 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.

Developed, Medium Intensity (3) – contains areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.

Developed, Low Intensity (4) – contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.

Developed, Open Space (5) – contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.

Agricultural Land

Cultivated Crops (6) – contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

Pasture/Hay (7) – contains 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 and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

Grassland

Grassland/Herbaceous (8) – contains areas dominated by graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Forest Land

Deciduous Forest (9) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest (10) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Forest (11) – contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.

Scrub Land

Scrub/Shrub (12) – contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Barren Land

Barren Land (20) – contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.

Tundra (24) – is categorized as a treeless region beyond the latitudinal limit of the boreal forest in pole-ward regions and above the elevation range of the boreal forest in high mountains. In the United States, tundra occurs primarily in Alaska.

Perennial Ice/Snow (25) – includes areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.

Palustrine Wetlands

Palustrine Forested Wetland (13) – includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

Palustrine Scrub/Shrub Wetland (14) – includes tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.

Palustrine Emergent Wetland (Persistent) (15) – includes tidal and nontribal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. Plants generally remain standing until the next growing season.

Estuarine Wetlands

Estuarine Forested Wetland (16) – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Scrub / Shrub Wetland (17) – includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Emergent Wetland (18) – Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. Perennial plants usually dominate these wetlands.

Barren Land

Unconsolidated Shore (19) – includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.

Water and Submerged Lands

Open Water (21) – include areas of open water, generally with less than 25 percent cover of vegetation or soil.

Palustrine Aquatic Bed (22) – includes tidal and nontribal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.

Estuarine Aquatic Bed (23) – includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.

DEM for Oregon and Washington

10-meter digital elevation models (DEM) for Oregon and Washington were included in the analysis layers. DEM layers served two purposes: slope and elevation. Initially, the elevation-derived slope layer

contributed information to the model. Areas of high slopes were included in the initial mask layer. Upon evaluation of the slope layer's effects on the model and consultation with the project biologist, this information was omitted in later versions of the model. The upper elevation used to mask modeled areas, areas above 1500' (457.2 m), coincides with observations of biologists. Coincidently, this elevation range also corresponds with higher densities of evergreen tree species within the study area.

CWTD Surveys

CWTD survey data collected from 2009 to 2012 in and around JBH NWR helped inform the modeling efforts. These data points help determine estimates of the initial model category ranking/weighting. Calculated distances and densities of the model categories at and around these observations helped with input categories and model refinements. Model adjustments were based on project biologist's input and field observations of the various model categories through the various model versions.

2001 NLCD Canopy Density

2001 NLCD tree canopy density model was used to help make a determination of the relative density (canopy closure) of forested areas. In some areas, canopy closure is high and this is understood to negatively influence the whitetail deer presence and land use. A lack of understory forage, forest browse, and shrub browse may explain why denser canopies are selected against. Denser forest canopies could change competition with other species such as black-tailed deer and/or elk (Mould & Robbins, 1982).

Refuge Biologist Expertise

The last and potentially most important information sources are expert knowledge from refuge biologists and literature review. Refuge biologist—Paul Meyer and ODFW Biologist—Tod Lum provided several key pieces of information based on their experiences with the CWTD. This information helped fill data gaps and explain discrepancies between observed locations versus early model outputs. Their information was crucial to determining which model variables were important and ranking those variables.

Determination of Habitat Variables/Dimensions

In order to use the C-CAP data for the modeling process, we needed the information from the original land cover data to reflect biologically meaningful metrics or categories important to the CWTD. We chose to reclassify the data into different data dimensions representing CWTD-specific variables. Table 1 illustrates the model data dimensions (shown as column headers in Table 1) and identifies which C-CAP data classes contributed to these aggregated model categories. These new model categories, described below, make up the distance and density modeled variables.

Table 1. List of C-CAP land use classes and how they fit into the model as distance, density, and mask variables. Final mask layer classes and a list of the classes affected by Canopy (NLCD Canopy Density). A relative importance value attempts to convey frequency of model class and distance trend. *Evergreen density process detailed in Mask section. **Canopy density is derived from NLCD 2001 from 0-100% cover.

Land Use Classes (C-CAP)	Model Class / Model Class Type/ Land Use Class Category	Distance: Deciduous	Distance: Dense Urban	Density: Forage	Density: Shrub Browse	Density: Shrub Cover	Density: Forest Browse	Density: Forest Cover	Density: Wetlands	Density: Dense Urban	Density: Lower Density Urban	Density: Evergreen	Density*: Canopy	Density**: Mask	Importance	
Developed, High Intensity	Developed Land	-	X	-	-	-	-	-	-	X	-	-	-	X	0^{-}
Developed, Medium Intensity	Developed Land	-	X	-	-	-	-	-	-	X	-	-	-	X	0^{-}
Developed, Low Intensity	Developed Land	-	-	-	-	-	-	-	-	-	X	-	-	X	0
Developed, Open Space	Developed Land	-	-	X	-	-	-	-	-	-	X	-	X	-	1
Cultivated Crops	Agricultural Land	-	-	X	-	-	-	-	-	-	X	-	X	-	2
Pasture/Hay	Agricultural Land	-	-	X	-	-	-	-	-	-	X	-	X	-	2
Grassland/Herbaceous	Grass-land	-	-	X	-	-	-	-	-	-	-	-	X	-	1
Deciduous Forest	Forest Land	X	-	-	-	-	X	X	-	-	-	-	X	-	2^{+}
Evergreen Forest	Forest Land	-	-	-	-	-	-	-	-	-	-	X	X	X*	*
Mixed Forest	Forest Land	X	-	-	-	-	X	X	-	-	-	-	X	-	2^{+}
Scrub/Shrub	Scrub Land	-	-	-	X	X	-	-	-	-	-	-	X	-	2
Palustrine Forested Wetland	Palustrine Wetlands	X	-	-	-	-	X	X	X	-	-	-	X	-	3^{+}
Palustrine Scrub/Shrub Wetland	Palustrine Wetlands	X	-	-	X	X	-	-	X	-	-	-	X	-	3^{+}
Palustrine Emergent Wetland (Persistent)	Palustrine Wetlands	-	-	-	-	-	-	-	X	-	-	-	X	-	1
Estuarine Forested Wetland	Estuarine Wetlands	-	-	-	-	-	-	-	X	-	-	-	X	X	0
Estuarine Scrub / Shrub Wetland	Estuarine Wetlands	-	-	-	-	-	-	-	X	-	-	-	X	X	0
Estuarine Emergent Wetland	Estuarine Wetlands	-	-	-	-	-	-	-	X	-	-	-	X	X	0
Unconsolidated Shore	Barren Land	-	-	-	-	-	-	-	X	-	-	-	-	X	0
Barren Land	Barren Land	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Perennial Ice/Snow	Barren Land	-	-	-	-	-	-	-	-	-	-	-	-	X	-1
Open Water	Water and Submerged Lands	-	-	-	-	-	-	-	X	-	-	-	-	X	-1
Palustrine Aquatic Bed	Water and Submerged Lands	-	-	-	-	-	-	-	X	-	-	-	-	X	-1
Estuarine Aquatic Bed	Water and Submerged Lands	-	-	-	-	-	-	-	X	-	-	-	-	X	-1

The table also indicates the relative importance, or weight, of the classes used in the model (indicated in the far right column) relative to the model outputs. The importance factor number indicates the approximate number of times the class contributed to the model category. The number does not contribute to model calculations but conveys an idea of the influence the original classes have on model variables. If the class contributed to the categorical mask, one was subtracted. The factor also describes generally whether distances from a class negatively or positively influenced model outcome (superscript -/+). For example, Dense Urban proximity lowered the habitat variable rank; the superscript is negative. Deciduous distance had the opposite effect in the model (+).

Dense Urban

Initial models combined all urban areas into a single 'urban influenced' category. After evaluation of initial modeling efforts, splitting it into two categories; Dense Urban (highly human-influenced) and Lower Density Urban (lighter human impact, described in separate category below) categories, produced better model results. High Intensity and Medium Intensity Developed C-CAP classes make up the Dense Urban. High-densities of impervious surfaces, structures, and transportation offer little value in terms of forage and cover.

Lower Density Urban

Low Intensity Developed, Developed Open Spaces, Pasture/Hay, and Agriculture comprise the Lower Density Urban category. Intuitively, the deer live in areas of urban interface and pasture/agriculture settings. These areas typically have a mixture of forage and remnant forest cover, depending on the particular area and the local/regional affinity for wildlife. Light residential and parks/open spaces offer the deer options for forage and shelter, whereas highly developed areas (included in the Dense Urban category) typically offer greater hazards, less food, and less cover (Roseberry & Wolf, 1998).

Forage

The Forage habitat model category consists of four C-CAP classes: Developed Open Space, Agriculture, Pasture/Hay, and Grassland/Herbaceous. Parks and open spaces adjacent to developed and populated areas often offer grasses and forbs that are desirable for forage. Some managed parks and open spaces are planted with palatable species specifically to entice wildlife for public viewing. Many row-crops and planted agriculture are also desirable forage despite the inherent economic impacts associated with deer using these as forage. Grassland/Herbaceous and Pasture/Hay classes also generally have plant species CWTD find nutritious and edible at different times of the year. During model development and

refinement, agricultural row crops were included and excluded. Ultimately, row crops contributed to forage despite containing trees for pulp, Christmas trees, and orchards.

Deciduous

The Deciduous forest category (shown in Figure 4 with classes re-categorized) includes Deciduous Forest, Mixed Forest, Palustrine Forested Wetland, and Palustrine Scrub/Shrub Wetland classes. The Deciduous category includes Palustrine Scrub/Shrub Wetland because of species make up. Red Alder, Black Cottonwood, and *Salix spp*. tend to dominate much of the wetland and riparian areas of the study area (Society of American Foresters, 1980). Often the scrub/shrub classified areas contain young trees of these species. To a lesser extent, young *Sitka Spruce* saplings may exist in small pockets throughout the study area. Typically, these exist in coastal areas inland a few miles and along the Columbia River and other tidally-influence rivers. The Deciduous model category is one of two distance model components.

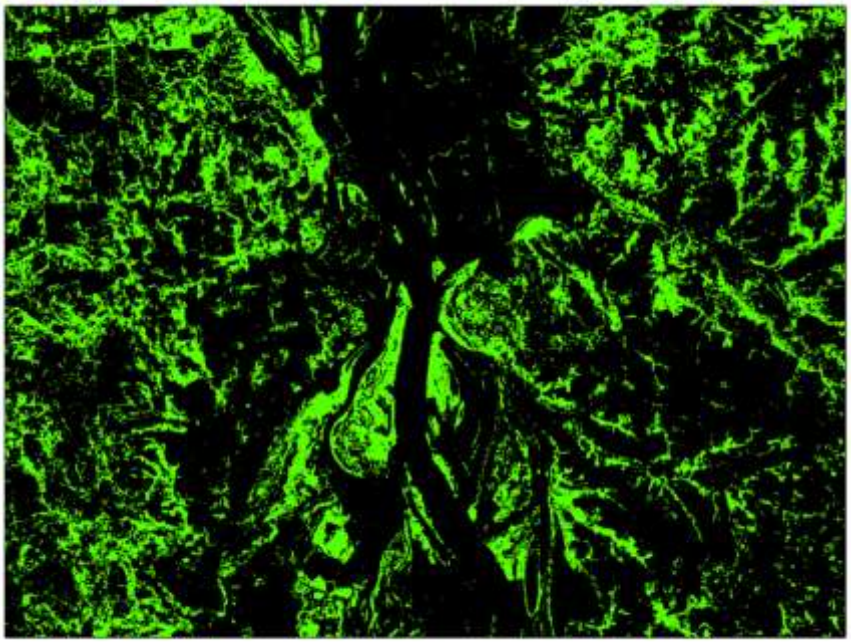

Figure 4. Example of deciduous forest category (green) and non-deciduous classes (black).

Browse Habitat

The Shrub Browse category includes the Scrub/Shrub and Palustrine Scrub/Shrub Wetlands CCAP classes. As mentioned above, the Palustrine Scrub/Shrub Wetlands class is also included in the Deciduous category. This land cover class' typical vegetation is representative of that category as well. The Forest

Browse category is limited to deciduous and mixed tree species, and as such includes the Deciduous Forest, Mixed Forest, and Palustrine Forested Wetland C-CAP classes.

Cover Habitats

The two categories of Cover habitat, Forest Cover and Shrub Cover, utilize the same C-CAP classes that were selected for the 'Browse' habitat categories. The Shrub Cover category includes the Scrub/Shrub and Palustrine Scrub/Shrub Wetlands CCAP classes, while the Forest Cover category is again limited to deciduous and mixed tree species, including the Deciduous Forest, Mixed Forest, and Palustrine Forested Wetland C-CAP classes.

Wetland Habitats

The Wetlands model category includes Palustrine Forested Wetland, Palustrine Scrub/Shrub Wetland, Palustrine Emergent Wetland, Unconsolidated Shore, Open Water, and Palustrine Aquatic Bed. Estuarine Forested Wetland, Estuarine Scrub/Shrub Wetland, Estuarine Emergent Wetland, and Estuarine Aquatic Bed also contribute to the wetland group but are largely outside the historic range. These classes also contribute to the model mask and therefore are not represented in the final model outputs.

The deer are currently found within primarily wetland or riparian habitats. Flood potential remains one of the threats to the deer throughout the Lower Columbia River. Half of the population died during a flood in 1996 (AP, 1996). These wet areas also create ideal habitat for Reed canary grass (*Phalaris arundinacea*). This species tends to create monocultures dominating the landscape, which does not provide ideal nutrition for the CWTD.

Canopy

CWTD in their current range and their estimated historic range utilize less dense deciduous forest areas (including mixed forest) for cover, browse, and accessible forage nearby. More densely canopied stands do not allow enough light to reach the canopy floor to provide herbaceous and shrub species for forage and browse. Stands of evergreen forest also typically form thick dense canopy. In some cases, trees planted close together make movement difficult. The model uses 2001 NLCD Canopy Density as another model category to capture canopy density variation. Unlike other density model variables, this standardized nationwide percent canopy cover dataset only needed reclassification into high, medium, and low rankings.

Discarded Model Variables

Several model categories were examined as potential model inputs in the early model iterations. Based on biologist consultation and initial model evaluation, distance to Human-Influenced classes, distance to Urban classes, distance to Wetland classes, and distance to Forest classes were omitted or changed. Distance to urban classes became distance to Dense Urban and Less-Dense Urban with the latter omitted as a distance variable.

Human influenced categories prevail across much of the landscape. Much of the potential forage habitat is composed of agriculture or pasture, but also in the form of managed lands. Those un-managed (i.e. without human influence) areas within the project area are rare. Therefore, the Human influenced model category was omitted.

Distance to forested classes became distance to deciduous (described above) and distance to evergreen forest. After reviewing and discussing initial model results, density of evergreen appeared to more accurately describe the how CWTD interact with evergreen. CWTD are not repelled by small amounts of evergreen amongst deciduous trees, rather CWTD tend not to exist and thrive in a monoculture of evergreen which tends to happen during succession (Short, 1986). Competing species such as elk or other deer species may also be more successful in dense evergreen (Krausman, 1978; Anthony 1977).

Model Data Evaluation

Evaluation of distance and density components of the model habitat variables both followed similar processing steps. Once identified, the initial model variables from the CCAP data were recoded into a binary raster dataset. The binary raster consisted of those C-CAP classes fitting into the model variables (1), described above, and the other classes not suited to the model variable (0).

Distance

ArcGIS calculated Euclidian distance for distance model variables (Deciduous and Dense Urban). The raster distance function in Spatial Analyst generated minimum Euclidian distances from each modeled habitat category (e.g. distance from Deciduous) variable (Figure 5).

These distances were evaluated and further reclassified as one (1) for marginal or no value/importance, three (3) for moderate value/importance, and five (5) for exceptional habitat value/importance based on minimum distance from to the model category (Figure 6). The early distance reclassification value breaks

were chosen by comparing existing deer surveys, literature, and expert opinion to the results of the distance outputs. Table 2 enumerates distance range reclassification values.

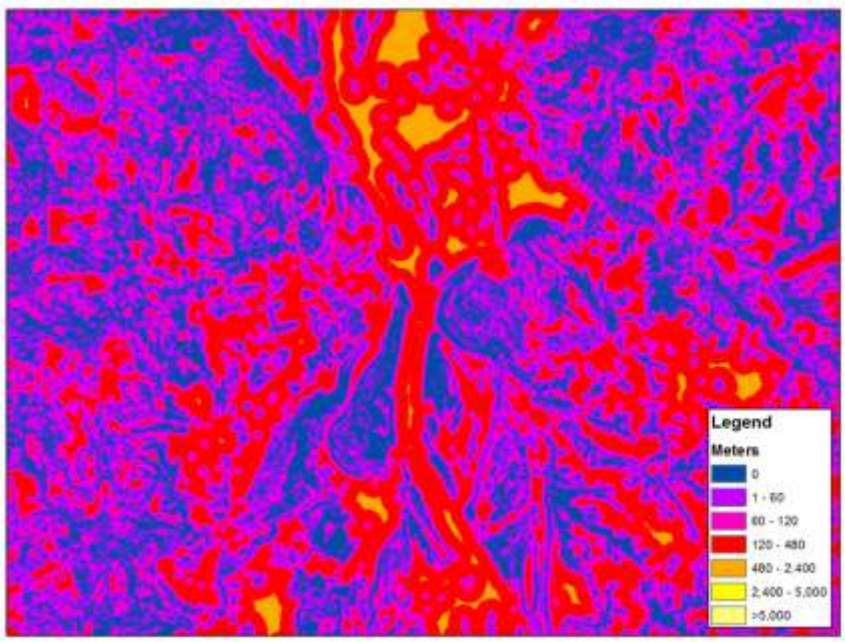

Figure 5. Distance from Deciduous (0 m distance == Deciduous-blue) model category.

Table 2. Reclassification table for Dense Urban and Deciduous Distance model variables.

Dense Urban	
Model Reclass	Distance (m)
1	0 - 400
3	400 - 1600
5	>1600

Deciduous	
Model Reclass	Distance (m)
5	0 - 50
3	50 - 120
1	>120

Density

The 11x11 focal densities (Figure 7) were calculated on each of the density binary model categories. Similar to the distance variables, the densities we reclassified into one (1) for marginal or no value/importance, three (3) for moderate value/importance, and five (5) for exceptional habitat value/importance based on density of the model category (Figure 8). Table 3 enumerates the density ranges values for reclassification.

Density reclassification ranges vary based on the particular function of the category with regard to CWTD. In the case of Wetland density, lower overall wetland composition on the landscape can be beneficial, whereas high densities become detrimental. Therefore, lower wetland densities receive higher

reclassification values; these values decrease as density increases. Some categories like Browse appear normal. Medium densities yield higher values while either high or low concentrations decrease model reclassification value.

Table 3. Model focal density reclassified values. *Evergreen and **Canopy variables are measured in percent cover not count as they were not calculated with 11x11 focal sum. *Evergreen density process detailed in Mask section and **Canopy is derived from NLCD 2001 from 0-100% cover.

Model Category	Forage	Shrub Browse	Shrub Cover	Forest Browse	Forest Cover	Wetlands	Dense Urban	Lower Density Urban	Evergreen*	Canopy**
Percent of total (count)	Density (Model Rank)								Density	
4% (5)	1	1	1	1	1	5	5	5	5	3
8% (10)	1	1	1	1	1	5	3	3	3	3
12% (15)	1	1	1	1	1	5	3	3	3	3
16% (19)	1	1	1	1	1	5	3	3	3	3
20% (24)	1	1	1	1	1	5	3	3	3	3
24% (29)	5	3	3	3	3	5	3	3	3	3
28% (34)	5	3	3	3	3	5	1	3	3	5
32% (39)	5	3	3	3	3	5	1	3	1	5
36% (44)	5	5	5	5	5	3	1	3	1	5
40% (48)	5	5	5	5	5	3	1	3	1	5
44% (53)	5	5	5	5	5	3	1	3	1	5
48% (58)	5	5	5	5	5	3	1	1	1	5
52% (63)	5	5	5	5	5	3	1	1	1	5
56% (68)	5	5	5	5	5	3	1	1	1	5
60% (73)	5	5	5	5	5	3	1	1	1	5
64% (77)	5	5	5	5	5	3	1	1	1	5
68% (82)	5	5	5	5	5	1	1	1	1	5
72% (87)	3	5	5	5	5	1	1	1	1	5
76% (92)	3	3	3	3	3	1	1	1	1	1
80% (97)	3	3	3	3	3	1	1	1	1	1
84% (102)	1	3	3	3	3	1	1	1	1	1
88% (106)	1	1	1	1	1	1	1	1	1	1
92% (111)	1	1	1	1	1	1	1	1	1	1
96% (116)	1	1	1	1	1	1	1	1	1	1
100% (121)	1	1	1	1	1	1	1	1	1	1

Mask Classes

Several individual mask classes contribute to the final model. Each mask has a different purpose and generally masked different areas. Details about the processing steps for Elevation, Evergreen and the C-CAP Class Mask follow. Appendix B shows the individual mask creation processes.

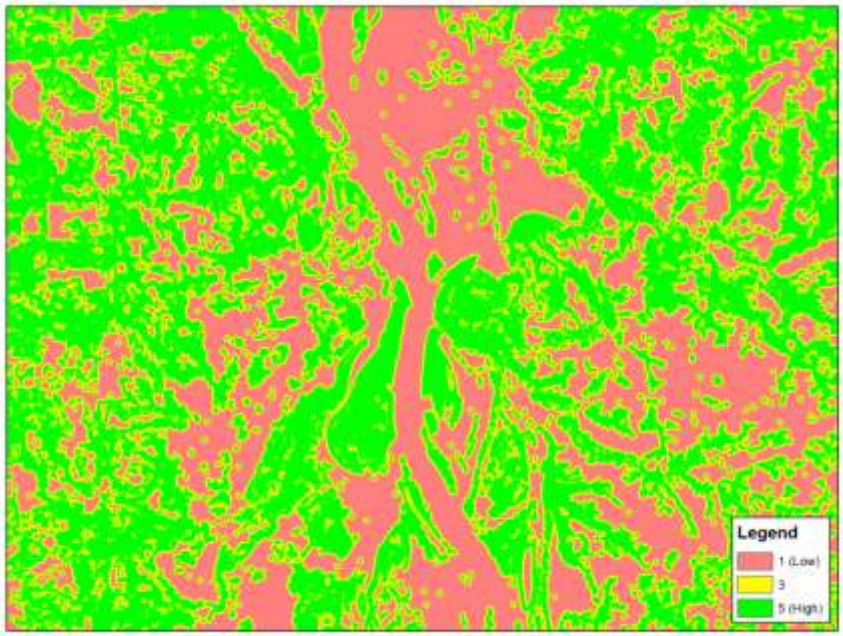

Figure 6. Shows the distance from Deciduous (Figure 6 info) reclassified for model input into low (red, long distance), medium (yellow, medium distance), and green (high, short or 0 distance) habitat values.

Elevation

CWTD in the southern Oregon population favor elevations less than 1500'. This elevation tends to be the upper elevation of oak woodlands transitioning more toward evergreen species like Douglas fir and ponderosa pine. Oregon and Washington 10 meter DEMs for were reclassified into values above and below 1500'. Resampling the data to 30 meters made it match the rest of the model datasets.

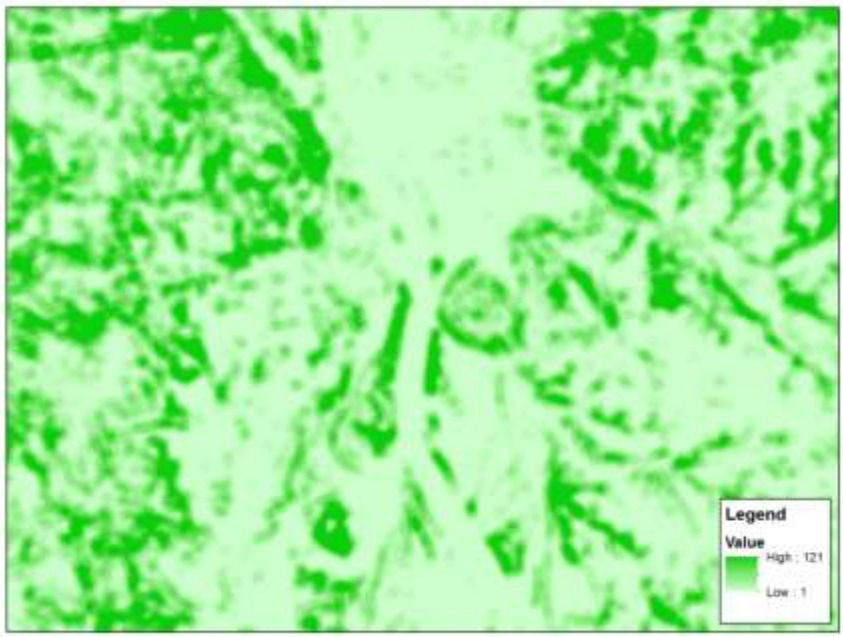

Figure 7. Shows the 11x11 focal density of Deciduous model input. Darker greens indicate higher deciduous proportions.

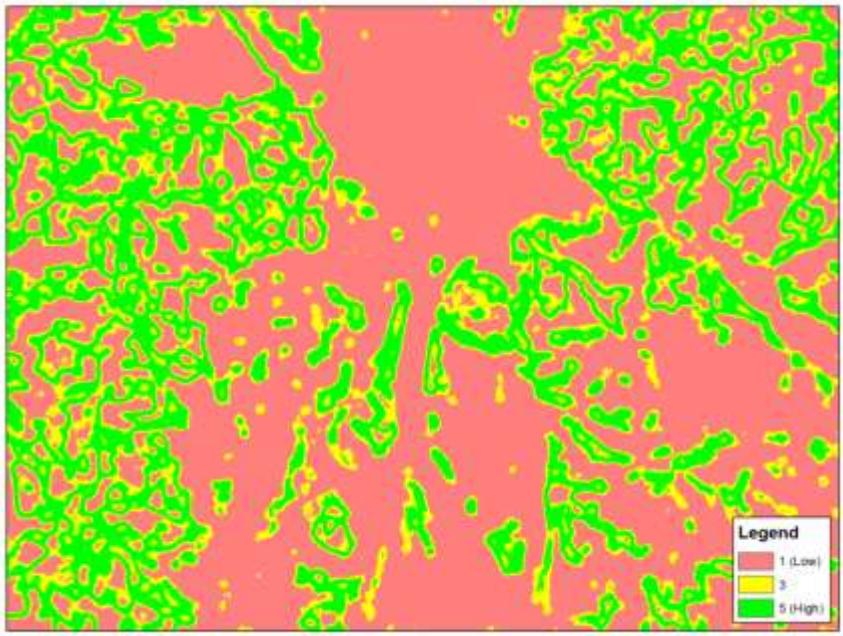

Figure 8. 11x11 focal density of Deciduous model input reclassified into low (red), medium (yellow), and green (high) habitat values.

Evergreen

The evergreen class contributed on two different levels to the model mask. The final Evergreen Mask groups C-CAP classes evergreen with other classes (scrub/shrub, grassland, and bare ground), based on overall density of historic extent (1996-2011) and size. Evergreen's historic extent is estimated based on the current and historic extent and known forest practices in the Pacific North West. For example, logged evergreen forests transition from bare ground or herbaceous/grassland into scrub/shrub. Finally, into forests as they regenerate. Areas classified as evergreen at any date of NLCD/C-CAP data, will likely remain evergreen because of forestry and silviculture practices. The historic extent (1996-2011) of land cover from C-CAP data helped determine if contiguous areas currently classified as bare land or shrub/scrub were ever classified as evergreen or were within distance of evergreen. Further, areas less than 400 acres within larger homogenous evergreen areas were classified as evergreen in the Evergreen Mask.

Evergreen species are not considered repellent to CWTD. Evergreen becomes less desirable to the deer as density increases, precluding beneficial land cover types. Therefore, areas of evergreen stands smaller than 100 acres (islands within non-evergreen matrix) were taken out of the Evergreen Mask (i.e. these areas were not masked out with Evergreen Mask). These smaller patches of evergreen had largely hospitable adjacent habitats. Essentially, dense evergreen reinforced the mask. Smaller broken up patches within more favorable modeled habitats were left out of the mask.

C-CAP Mask Classes

Many of the C-CAP classes are inhospitable or repellent to CWTD. Several of the original inhospitable C-CAP classes contributed to different model variables and omitted from the final model. Categories like Dense Urban distance contribute valuable information to the model, but the deer cannot exist within these classes. While these classes do not make it into the final model, the reclassified distance model variable next to these classes does have model input. Similarly, water and unconsolidated shore C-CAP classes contribute to wetlands--both inhospitable to deer. While the classes add information to the model as distances from Dense Urban and Wetland density, they cannot be considered habitat. Therefore, they become part of the class mask layer. Table 1 lists the masked classes.

Model Processing

The model is an additive model (Appendix A). It sums the ranked (reclassified) values (1-5) from each of the model inputs. Lower quality habitat ranges received lower ranks (1) while high quality habitats

garnered higher values (5). Reclassified density values and reclassified distance values from both types of model inputs contribute to the final output and produce larger number when summed.

Canopy density was also reclassified based on the method outlined above and added to the model. All of the reclassified categories summed to produce an interim modeling layer with values from 17-56 (minimum and maximum sums of possible reclassified values).

Applying the masks (Evergreen Mask, Elevation Mask and C-CAP Class Mask) eliminated large portions of the modeled project area and produced a mottled landscape (APPENDIX B). The final modeling step included determining sizes of remaining fragmented habitats across the landscape. The acceptable size for a viable population is 1000 acres, but several smaller patches proximally located could also provide enough habitat. The model keeps all areas over 100 acres for future analysis.

The final model includes three categories of rescaled data, converted into polygons. The model's original and re-scaled values are available in Table 4. These categories were chosen based on the fit of the model based on field visits.

Table 4. The three model category data ranges...

Category	Model Value Range	
	Orignal	Rescaled
1	35-56	52-100
2	30-56	40-100
3	27-56	34-100

After running the original model, the resulting layer had hundreds of thousands of small high quality habitat areas within large matrix of lower ranked habitats and vice versa. Filling in these smaller areas required a series of spatial analysis steps to identify the smaller areas and then quantify their size and eliminate them. This process required a series of binary masks based on model thresholds followed by the clump, sieve, and eliminate functions in ERDAS. The equivalent process in ArcGIS does not exist. Through a process of calculating zonal statistics, querying the data, selecting areas, and then deleting them, ArcMap could achieve similar results. However, this option would require substantially more effort.

Results

The model predicts large numbers of high quality habitat areas (Table 5). The high numbers of the polygons and their complexity prevented proximity analyses. Proximity tables could show which clusters of smaller habitat areas could potentially combine and contribute to a 1000-acre minimum area or identify areas less than minimum size close to larger areas.

Table 5. The number and total acreage of the three model categories.

Category	Number of Individual Areas	Total Area (acres)	Number of Individual Areas	Total Area (acres)
	> 100 acres		> 1000 acres	
1	3,018	1,642,390	286	887,391
2	2,166	3,131,269	377	2,605,502
3	1,759	3,721,498	348	3,298,220

Descriptions of lands generally ranked more highly by the model varied somewhat by their position within the study area. We sought to identify areas with cover, browse, forage, and limited human activity. What ended up scoring higher than the majority of the modeled area was a collection of somewhat diverse habitats. Areas of wetter deciduous forests in northern portions of the study area and drier oak woodlands to the south and east shared similar high rankings and densities of elevated quality habitat.

The model also identified numerous natural and semi-natural remnant habitats within the study area. Areas of deciduous forests and areas with edge access providing cover, close forage, and both forest and shrub browse potential have the theoretical combination for CWTD success. Those areas of homogenous dense canopy cover and the homogenous areas of agriculture and pasture without cover were consistently ranked lower. A mix of access to shrub and forest browse/cover coupled with distance from large roads or urban areas with low to moderate deciduous cover also provide potentially ideal habitats.

The final model scored high many areas of riparian habitats and bottomlands (streams and rivers) adjacent to developed lands (pastures and agriculture). It also ranked the lower elevation foothills throughout the Willamette Valley on both east and western edges of the valley highly. Both of these remnant and/or semi-natural habitat types persist despite development and intensive nearby land use.

Oak woodlands in the southern portions of the Willamette Valley also ranked high according to the model. This type of habitat is common around the Roseburg, OR, CWTD (Figure 9) reintroduced population. This habitat appears to at least partially contribute to their successful reintroduction. Oak woodlands were also identified in South Central Washington near the Klickitat River. These areas appear similar to the woodlands of Southern Oregon.

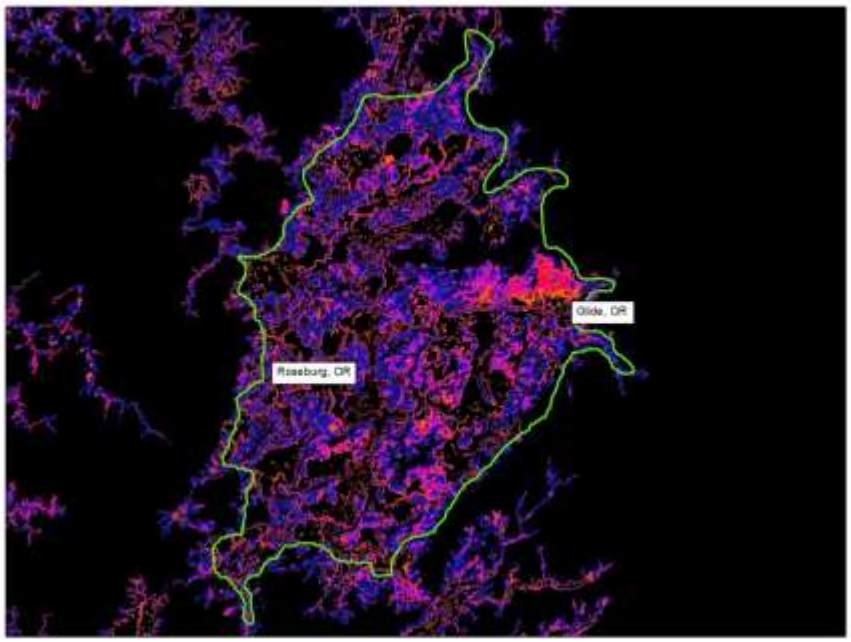

Figure 9. Model results for the Southern Oregon CWTD population (green) near Roseburg, OR. Higher habitat suitability values (blue-purple), medium (red) and lower suitability areas masked.

Habitats farther away from urban areas (cities, industrial areas, and major roadways) show an increase of habitat variables ranked more highly (i.e. the farther away from negative impacts the better off the CWTD fare). This increase in densities of forage present and proportions of cover and browse contribute to the overall modeled habitat quality increase. The magnitude of increase is positive as the distance from heavily developed areas increases.

The distance density model effectively identified several areas of potential habitat previously not considered as viable habitat. The most notable of these were the areas around Centralia Washington and near the Klickitat River in South-central Washington. Overall, the model rated areas which were agreed to have suitable habitat characteristics highly. The model largely categorized lower quality habitat much lower as well. Much of the former home range of the CWTD still shows high quality habitat remnants

theoretically capable of supporting deer populations (Figure 10).

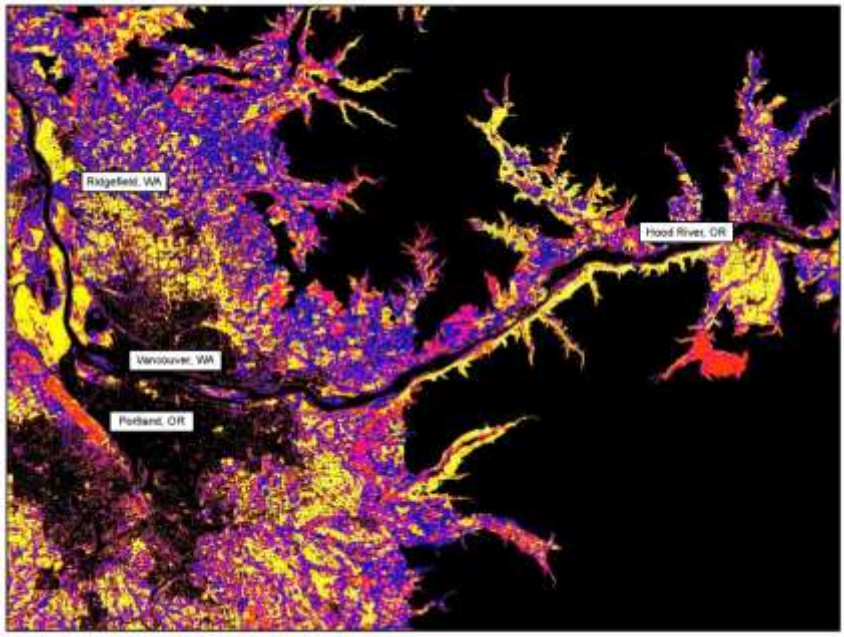

Figure 10. Model results for the Portland/Vancouver, OR/WA. area. Higher habitat suitability values (purple), medium (red), and lower suitability (yellow) with final cumulative mask overlay.

Discussion

The model is a regional planning dataset made with satellite imagery derived datasets designed for regional planning purposes (Flemming et al. 2004). As such, it is a planning tool to help focus translocation efforts. The errors and potential inaccuracies within the original datasets are somewhat mitigated by using distance and density functions to create the smoothed final model. The model predicts large amounts of high quality habitat (as defined by model categories) greater than 100 acres. In addition, there were large numbers of areas above the 1000-acre minimum threshold as well. The high number and complexity of the polygons prevented performing a proximity analysis.

While reintroduction is possible in the future, it is potentially hampered by a lack of government owned lands (local, state, tribal and federal) and low economic and political will for future reintroduction. Regardless, the model may be further validated and improved upon by comparing current reintroduction efforts in Washington to the model results and refining model ranking or model variables.

Field verification and model tuning (based on early models) happened simultaneously. By taking a computer, GPS, and the model inputs into the field, we saw what model parameters worked well and which could be improved, split/aggregated, or omitted altogether. Having access to model data and computer made taking notes and edits easier than past efforts involving GPS, field forms, and subsequent data transfer and conversion.

While creating and tuning the model, several potential wildlife habitat interactions were discussed for CWTD competition and predation. Currently the CWTD populations live adjacent to and around black-tailed deer and elk populations. The model does not factor in competition pressure when weighting the high quality habitat areas. Pressure from a competing species for better foraging sites would almost certainly play a role in the success of a population (Anthony & Smith, 1977). Predation is also a factor for the long-term success of CWTD. Coyotes, bears, and dogs are known to take animals and contribute to mortality (Ballard et al., 1999).

Competition and predation were discussed as potential model inputs. Finding data to use as such as predator/competitor surveys, population estimation models, or any other quantitative measure was not possible. Adequate maps of neither competitors nor predators presence/absence currently exist. An estimation of potential predation or potential competition based upon modeling may be possible over small areas at a gross level, but it is unlikely this type of estimation would be useful at the scale of the entire historical range.

Seasonality of CWTD habitat usage varies by both sex and age (Tufto el al., 1996). Males and females seek different forage, browse, and cover in different proportions depending on weather, offspring gestation/nutrient consumption, and mating. CWTD surveys collected points during the same time of year (Fall/Winter). Therefore they may give a false or incomplete overview of year-round habitat usage. In addition, this model seeks to describe yearly habitat suitability rather than seasonal suitability. Model categories could be modified based on known seasonal habitat use variation to create a more complex model. This may yield more accurate higher quality habitats because the model could account for seasonal use rather than aggregating all usage. Finally, limiting factors may exist in the environment (e.g., certain minerals or specific fawning habitat) that are not accounted for in the model.

Weighting the model categories/components based on field observations and statistical fit would produce more focused potential habitat list. The lack of observations limits performing this function with the model. Further, the original deer data points come from an isolated population. The model results seem

to reflect high quality habitat but having neither a large nor a dispersed population for comparison limits the ability to quantify/qualify the results.

Invasive species such as reed canary grass and Himalayan blackberry dominate the landscape in many areas identified as high quality. These species are both minimally beneficial (reed canary) and even detrimental (blackberry) to the CWTD. Even though these particular species and others are present and prevalent through much of the modeling area, no good datasets showing their extents on the landscape exist. Any method of identifying areas with high percent cover of these lower quality species could help make finer distinctions in the model.

The model, however, was designed to indicate rather than specify high-quality habitat. The necessity would still exist for biologists to conduct intensive site visits before any reintroduction could occur. By using this model to identify potential reintroduction areas prior to ground work, however, biologists and managers should be able focus site visits to those areas that are likely to succeed in a translocation effort. This map should also be used in conjunction with other GIS layers, such as property ownership and land-use maps that would further identify potential conflicts or social issues.

Finally, the model must be interpreted visually at the appropriate scale for the translocation effort. Optimum sites may contain a mosaic of high and low quality blocks. While the model cannot appropriately separate these mosaics into a new layer, a biologist familiar with the model's design should be able to recognize appropriately fragmented landscapes of medium cover (high quality) and open forage (low quality). While separately these two classifications are at odds, if available in the correct proportion they can create a synergy that raises the area to very high quality.

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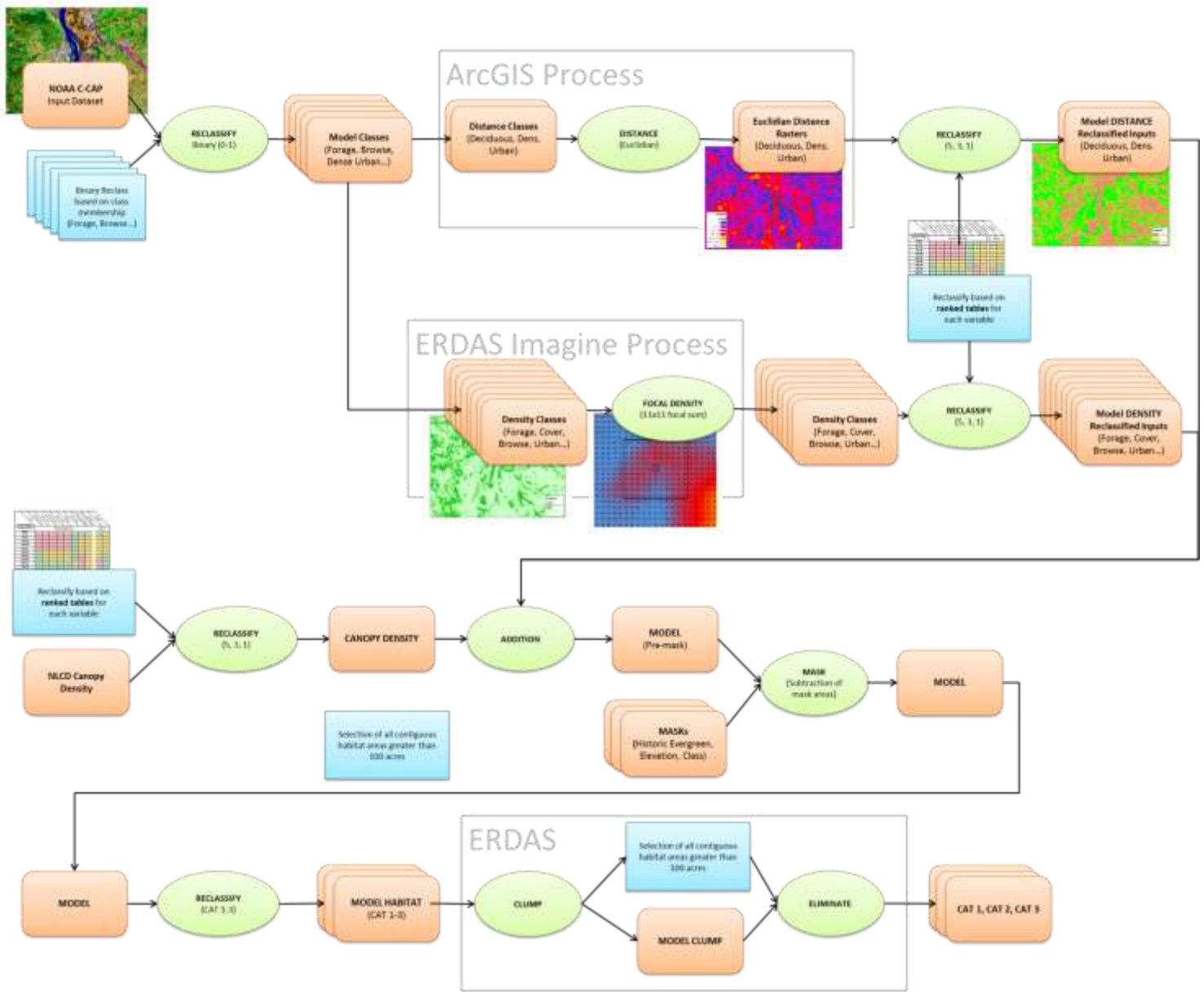
APPENDIX A: CWTD Habitat Model Process



APPENDIX B: CWTD Habitat Model Masks