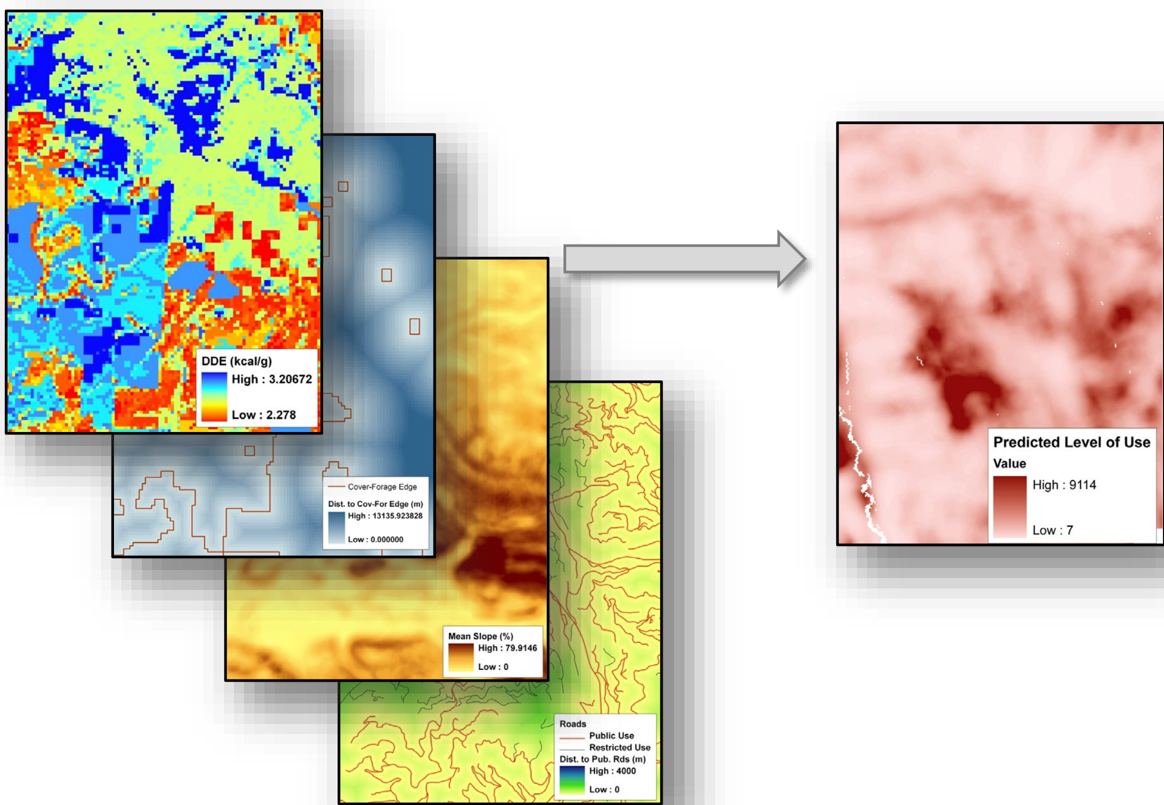
User Guidelines for
Westside Elk Nutrition and Habitat-use Models



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ABSTRACT

Scientists from State, Federal, private, and tribal entities developed two predictive models – nutrition and habitat use - tailored for management application on elk (*Cervus canadensis*) summer range in western Oregon and western Washington. The models provide managers with user-friendly tools to evaluate nutritional and habitat conditions for elk at landscape scales commensurate with all-lands management. Model users can not only quantify current nutritional conditions and predicted habitat use by elk in summer, but also evaluate effects of proposed management actions, such as thinning or road closures, on elk habitat and distributions. The nutrition and habitat-use models are combined in a single ArcGIS toolbox for streamlined application. These guidelines provide descriptions of the models and steps for (1) selecting appropriate regional and local analysis areas, (2) preparing input data, and (3) applying the models using ArcGIS software. The guidelines also describe the parameters and processes required for each of the four tools embedded within the toolbox and provide examples of data summaries for model outputs. This version is designed for U.S. Forest Service (FS) model users operating in the Citrix environment as well as FS- and non-FS users operating in a desktop ArcGIS environment.

Keywords: *Cervus canadensis*, elk, habitat use, land management, local landscape, models, nutrition, Oregon, regional analysis, spatial models, user guidelines, Washington, Westside

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INTRODUCTION

State, Federal, private, and tribal scientists and managers collaborated to develop and validate two models for elk (*Cervus canadensis*) - nutrition and habitat use - for management application on summer range in western Oregon and western Washington (Westside region, Fig. 1). Their objective was to provide resource managers with contemporary tools to evaluate nutritional and habitat conditions for elk at landscape scales (Rowland et al. 2018*b*). The models focus on summer range, because this period is characterized by nutritional limitations for elk in the Westside region (Harper 1987, Hutchins 2006, Cook et al. 2016). Specifically, the models are intended to depict elk nutrition and habitat use from June – August. The stand-alone nutrition model predicts dietary digestible energy (**DDE**; glossary terms are bolded at first use and defined in Appendix 1) that elk can acquire from various plant communities during summer and can be run independently, i.e., without application of the habitat-use model. Outputs from the summer nutrition model are integrated as one of several input variables used by the elk habitat-use model, which predicts use by elk based on the environmental conditions that most affect landscape-level habitat use by elk (Rowland et al. 2018*b*). These additional variables include distance to roads open to public access, percentage slope, and distance to cover-forage edge (Rowland et al. 2018*a*). The modeling process revealed that Westside elk preferred habitats that were relatively high in DDE, far from roads, close to cover-forage edges, and on gentle slopes (Rowland et al. 2018*a*)

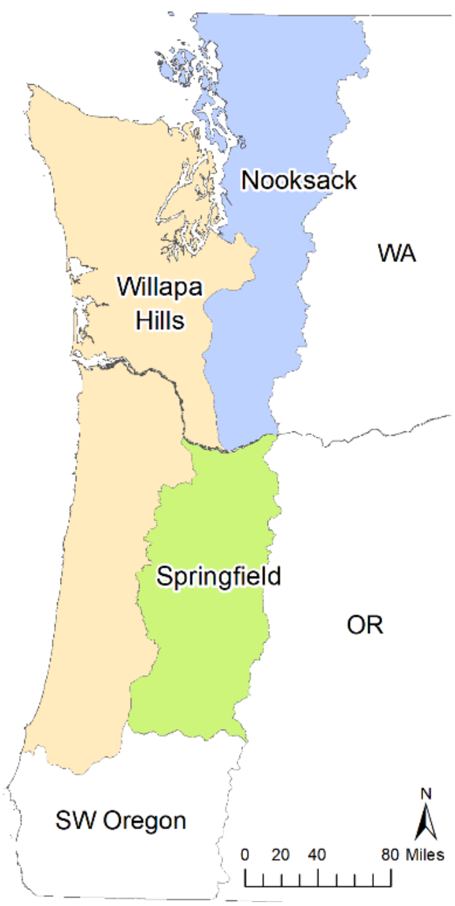


Figure 1—Westside elk modeling regions in western Oregon and Washington, the area of application for the elk nutrition and habitat-use models. Each region is associated with a different set of equations to predict nutrition.

To ensure that the models could be readily applied by land managers, the elk modeling team conducted extensive “beta-testing” of the models with biologists and GIS (Geographic Information System) staff from Region 6 of the U.S. Forest Service (FS), the Department of the Interior Bureau of Land Management (BLM; Oregon/Washington State Office), and Washington Department of Fish and Wildlife (WDFW; Appendix 2). The team used feedback from the beta testers to refine the modeling algorithms and final guidelines presented in this document.

The tools developed to run the Westside elk nutrition and habitat-use models can be used in a simple “exploratory” mode to see how they work and what kinds of outputs they create. There are example data and a project area polygon developed explicitly for this exploration. However, most users will want to apply the models in their own project area (with their own roads and local vegetation data) to create maps of predicted elk nutrition and habitat use, along with other data output by the tools. Model results can also support PAC proposals with the Rocky Mountain Elk

Foundation and Good Neighbor Authority project discussions and provide materials for communicating about elk with the public during scoping meetings.

These guidelines instruct model users in application and interpretation of the Westside elk nutrition and habitat-use models. The basic steps, explained in detail later, are:

1. Define the desired analysis area(s) for model application, including both **regional** and **local landscape**(s) if necessary.
2. Obtain necessary spatial layers for model inputs.

   Note: *at a minimum, users will need to provide their project area boundary with and without a 2.5-mile (4-km) buffer, treatment areas (if planning to run vegetation management scenarios), and roads classified as open or closed – a total of 4 spatial layers unique to the user's project area.*
3. Create an ArcMap project (*.mxd) that links model input layers and the Westside Elk Habitat Model ArcToolbox. There is an example map project provided with the other modeling files that is a good place to start, especially for new users.
4. Optional:
   - Run the Create 30m Lidar rasters Tool (hereafter referred to as the LiDAR Tool) - Run this tool if LiDAR data are available in your project area for the appropriate time period and the LiDAR data (specifically, canopy cover and stand height) are preferable to those available from the gradient nearest neighbor (**GNN**) dataset or other locally available data. See the LiDAR Tool section for more details.
   - Run the Update Vegetation Tool - If needed, update the base condition vegetation data to be used in the models (specifically canopy cover, stand height and/or percentage hardwoods) to account for changes between the time period represented by the available data (e.g., 2017 GNN) and current conditions.
5. Run the Nutrition Tool - Run the Nutrition Tool and explore model outputs.
6. Run the Habitat Use Tool - Run the Habitat Use Tool and explore model outputs.
7. If desired, make changes to the roads and vegetation layers, or both, to predict changes in elk nutrition or predicted use by elk under various management alternatives. (Use the Update Vegetation Tool for simulating thinning projects or other vegetation manipulation.)
8. Re-run the Nutrition and Habitat Use Tools as needed for each alternative of interest.
9. Summarize results for existing conditions and management alternatives.

For more details about model development and validation, model users are referred to the *Wildlife Monograph* describing the Westside elk models (https://www.fs.usda.gov/treesearch/pubs/57491); chapter 4 is especially relevant in providing example model applications and caveats about usage.

SPATIAL AND TEMPORAL EXTENTS FOR MODEL APPLICATION AND SUMMARIES

Two spatial extents are relevant for applying and summarizing results of the Westside elk models: (1) the regional landscape, an area ≥25,000 acres; and (2) the local landscape, an area ≥2,000 acres nested within the regional landscape, in which the Nutrition Tool can be applied alone or in which a subset of results from the regional landscape analysis of habitat use can be summarized. Thus, the elk nutrition model can be run and summarized at both scales. The habitat-use model, however, **should only be run at a regional scale (i.e., >25,000 acres)**, to match the scale at which the models were developed and validated (Rowland et al. 2018*a*). Users can *summarize* habitat-use model outputs, however, at regional and smaller (local landscape) scales.

Users can also select more than one time period to apply the models and summarize outputs. For example, you can compare past conditions with current, or current with anticipated future conditions under different management scenarios. Users comparing multiple time periods will want to use the same data source, i.e., either all LiDAR or all GNN, for valid comparisons. As described above, these summaries can be completed for both regional and local landscapes. The modeler's specific objectives will guide selection of an analysis area. For example, a manager may only want a snapshot of current nutritional conditions for elk during summer within a set of game management units. Another may want to understand how a suite of proposed silvicultural treatments, coupled with road building or decommissioning, affect predicted use by elk in summer across multiple watersheds. Below we offer more details about the important step of defining analysis areas at regional and local extents.

Landscape

Boundary selection—Regional analyses with the Westside elk models typically address management of elk distributions across large areas and multiple land ownerships. The habitat-use model can be used to predict elk distribution, and the nutrition model can predict not only DDE but also measures of animal performance, such as body fat of female elk (Cook et al. 2018, Wisdom et al. 2018*b*). We strongly recommend collaborating with state wildlife agencies (Oregon Department of Fish and Wildlife [ODFW]; WDFW) when selecting regional landscape boundaries, to ensure best use of local knowledge about elk populations and distributions. The boundaries should reflect landscape-scale patterns of elk distribution and use across multiple land ownerships on summer range. For example, elk in one wildlife management unit may be located disproportionately on private lands, where they cause damage to agricultural crops and fences. Identifying regional boundaries that encompass the entire landscape of potential summer range across these ownerships will help ensure that model outputs are relevant.

Ecologically defined boundaries, rather than political ones, are preferable in selecting analysis areas. However, elk movements can be impeded by landscape features such as interstate highways, residential and commercial developments, or large river corridors; these barriers should be considered when defining an analysis area. Moreover, managers are often interested in modeling elk use in administratively defined areas such as a wildlife management unit, Ranger District, or BLM Resource Area. In this case, the models can still be applied across an ecologically defined area, but results summarized by administrative unit, analogous to a local landscape as described below. Regardless of the primary motivation in selecting a project area, model users should carefully consider local knowledge of elk distribution and movements.

Size of analysis area and buffer—To predict habitat use with the Westside model, we recommend that the regional analysis area be **at least 25,000 acres**. This scale corresponds to landscape use by multiple populations of summering elk (Wisdom et al. 2018*a*). Even if the objective is to evaluate potential effects of management actions (e.g., road closures) at a smaller scale (~2,000 acres), it is important to run the model at this larger extent to make predictions. The user can always "zoom in" and summarize model outputs within one or more local landscapes, but only after habitat use predictions are generated for the larger project area.

Before the habitat-use model can be applied, a 2.5-mile (4-km) buffer should be drawn around the regional landscape of interest (Fig. 2). The model is applied within this larger area (i.e., regional landscape plus buffer) to capture potential effects of roads and vegetation conditions adjacent to the analysis area. This buffer distance was based on prior research about elk response to **open roads** (e.g., Rowland et al. 2000, Witmer et al. 1985*a*) and explorations with the telemetry data used in model training (unpublished data on file) demonstrating that elk respond consistently to roads open to the public, but typically not beyond ~2.5 miles. Thus, an open road *in the buffer area* may affect behavior of elk *within the analysis area* and must be accounted for when the elk habitat-use model is applied. Likewise, the nearest cover-forage edge in some instances could occur in the buffer, thus potentially affecting elk use in the analysis area. To reiterate, *the habitat-use model is applied only at the regional landscape scale, but outputs can be summarized at smaller scales*.

Summaries—We recommend summarizing model outputs for your regional landscape first, and then for any local landscapes or administrative boundaries of interest (see Wisdom et al. 2018*b* for examples). Summaries can include percentage area by nutrition class under baseline and alternative scenarios, or acres that improve in predicted use under different scenarios. See "INTERPRETATION AND SUMMARY OF MODEL RESULTS" for more details.

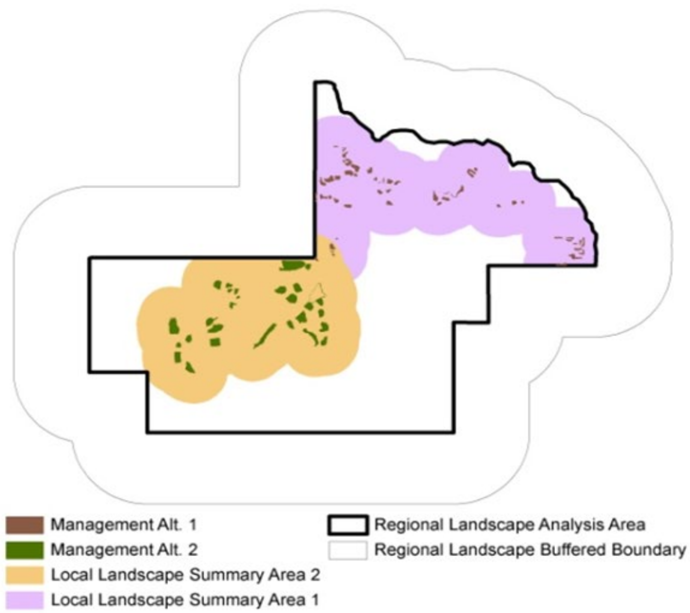


Figure 2—A regional analysis area, its 2.5-mile (4-km) buffer, and two local landscapes with treatment units displayed for each. The elk nutrition and habitat-use models are *applied* within the regional landscape and its buffered boundary; however, *data are summarized* only within the regional landscape boundary (that is, without the buffer included).

Local Landscape

Boundary selection—Analyses of local areas are more site-specific than regional analyses and are useful for management activities on a given area and land ownership. There is no hard and fast rule to guide the establishment of local landscape boundaries, within which results of the models are summarized. However, the way in which the boundary is drawn around the local analysis area will affect subsequent comparisons of model results (e.g., percentage of area by nutritional class) among potential management alternatives. Examples of local effects might be designing a set of commercial thinning units, paired with changes in road access, and evaluating how these activities might affect an elk herd on summer range in a small area typically used by 10-20 elk (e.g., 2,000 acres). If the proposed treatment units are near one another, the local landscape boundary should be drawn around the collection of units and model outputs summarized within this boundary (e.g., Fig. 2, Local Landscape Summary Area 1).

Size of analysis area and buffer—The minimum recommended size of a local landscape (including the buffer around treatment units; see explanation below) is ~2,000–2,500 acres, comparable to summer home ranges for elk in the Westside region (Witmer et al. 1985*b*, McCorquodale 2003). This size also reflects an ecologically meaningful scale of management. If the actual acreage treated is a very small percentage (e.g., <5%) of the local landscape, improvements in nutrition or changes in elk habitat use will be difficult to detect. The exact spatial arrangement and size of the treatment units within the boundary of the local analysis area will affect all summaries at this scale, so careful consideration is required in choosing the size of the analysis area and its boundaries to ensure that realized benefits of management treatments will be detected. As described for the regional level, a buffer should also be applied around the project area, because elk behavior may be influenced by conditions near but outside the actual treatment sites. A buffer of 1.0 mile is recommended for local landscape analysis; this distance was based on explorations of potential elk response to changes in distance to cover-forage edge and other aspects of forest structure from typical thinning units (Wisdom et al. 2018*b*). In this case, elk habitat may improve in the buffer, such as shortened distances to nearest cover-forage edge.

Summaries—Local-scale summaries complement the regional-scale analyses, and model results can be compared across project sites or to the regional landscape results (see "INTERPRETATION AND SUMMARY OF MODEL RESULTS"). In most cases, local landscape summaries will be calculated for a collection of small treatment units, summarized within one boundary. For example, if the proposed action is thinning 20 small units, a polygon should be drawn around these units and model outputs summarized within this boundary (local landscape summary boundary; Fig. 2).

Extents for nutrition model application only—The Westside nutrition model can be applied independently of the habitat-use model, and unlike that model, can be run at any desired spatial scale ranging from a single stand to multiple watersheds. The smallest area for analysis will depend on the origins of the input data but can be as small as a few acres if local, field-based data are used. (See "Special Considerations for Running the Nutrition Model Only" for more details.)

APPLYING THE WESTSIDE ELK MODELS

The Westside elk habitat and nutrition models are designed to run in ESRI's ArcGIS on Citrix (https://citrix.fs.usda.gov/Citrix/StoreWeb/) for Forest Service users or standalone on a PC using a desktop version of ArcGIS.

CITRIX: Working in Citrix provides easy access to project workspaces and the necessary FS spatial data available on the T drive. When working in the Citrix environment, we recommend that users follow established workflows to avoid a hung ArcMap session. A hung session can occur when map documents are not closed properly and can result in schema locks and other Citrix issues. The Best Practices When Using Citrix document and other useful information can be viewed on the Citrix home page. More general GIS information can be found on the FS SharePoint site for GIS best practices: https://usdagcc.sharepoint.com/sites/fs-gmo-gisbp/SitePages/FS-GIS-Best-Practices.aspx.

DESKTOP: Users outside the agency or FS users who prefer to run the models in desktop ArcGIS will download all files, including sample spatial data, from the Westside elk model tools website: https://www.fs.usda.gov/pnw/tools/westside-elk-model-toolbox.

Where to Find the Model Files

CITRIX: The files needed to apply the Westside Elk Models in the Citrix environment are stored in three Region 6 folders on the T drive:

- **T:\FS\NFS\R06\Program\Wildlife-2600\GIS\WestsideElkHabitatModel**. This folder houses two relevant subfolders: 1) the **LayerFiles** subfolder, containing layer files with symbology, and 2) the **WestsideExampleData** subfolder, which contains the example data (WS_ElkHabModel_ExampleDataset.gdb) and three template ArcMap project files created for various ArcGIS versions (WS_ElkModel_Example_10-X.mxd). The main folder also contains a template ArcMap project file (Citrix_WS_ElkModel_RegionalData.mxd) that accesses regional data layers and the current version of the user guide.
- **T:\FS\Reference\GIS\r06\LayerFile\Wildlife\WildlifeHabitatMaps**. This folder contains a single layer file that references all the data layers (WS_ElkHabModelRegionalLayers.lyr).
- **T:\FS\Reference\GeoTool\r06\Toolbox\WestsideElkModel**. The modeling toolbox (Westside_Elk_Habitat_Model_vXX.pyt) is located here, along with documents describing model tool processing steps and tool help.

DESKTOP: The files need to apply the Westside Elk Models in desktop ArcGIS can be downloaded from the elk modeling tools website or individually from the following links:

- WestsideElkModelUserGuide_vX.X.pdf. (https://data.fs.usda.gov/research/pnw/tools/westside-elk-modeling/WestsideElkModelUserGuide.pdf). This URL links to the most current version of the Westside Elk Model User Guide.
- WestsideData.zip (https://data.fs.usda.gov/research/pnw/tools/westside-elk-modeling/WestsideData.zip). This file houses the regional spatial data layers in 2 geodatabases (RegionalData.gdb and GNNdata.gdb) and several template ArcMap project files linking to the regional data, depending on which version of ArcGIS is installed (e.g., ArcGIS 10.3, ArcGIS 10.5, or ArcGIS 10.7).
- WestsideExampleData.zip (https://data.fs.usda.gov/research/pnw/tools/westside-elk-modeling/WestsideExampleData.zip). This file houses the example spatial data in a geodatabase (WS_ElkHabModel_ExampleDataset.gdb) and several template ArcMap project files linking to the example data, depending on which version of ArcGIS is installed (e.g., ArcGIS 10.3, ArcGIS 10.5, or ArcGIS 10.7).
- WestsideToolbox.zip (https://data.fs.usda.gov/research/pnw/tools/westside-elk-modeling/WestsideToolbox.zip). This file includes the latest version of the modeling toolbox (Desktop_Westside_Elk_Habitat_Model_vXX.pyt), plus two documents, one describing model tool processing steps and a second with instructions on changing the default projection if desired.

When working in Citrix, certain parameters within each tool are pre-populated with links to the appropriate input data, or they have checkboxes to pre-populate parameters. When working with the desktop tools, those same parameters are blank and will need to be populated with data the user provides or data from the supplied geodatabases (RegionalData.gdb, GNNdata.gdb, and WS_ElkHabModel_ExampleDataset.gdb). Please refer to section "Baseline Data Needed" for a list of specific data layer requirements.

Please note—All FS Users are strongly advised to work solely in the Citrix/T drive environment (including creating and saving your ArcMap project in your own personal folder on the T drive) OR solely on their desktop. PLEASE DO NOT DOWNLOAD AND RUN THE TOOLS FROM YOUR LOCAL DESKTOP WHILE ACCESSING DATA FROM THE T DRIVE. Connecting to corporate data layers from your local desktop will (1) make the models run very slowly and possibly hang up, and (2) slow down the network for everyone else.

Baseline Data Needed

The following spatial layers are needed to execute the Westside Elk Models. A summary of the format requirements is provided in Table 1.

Project Area: the project area boundary is a polygon that defines your project area. Define the desired analysis area(s) for model application, including both **regional** and **local landscape**(s) if necessary, using guidance described above in SPATIAL AND TEMPORAL EXTENTS FOR MODEL APPLICATION AND SUMMARIES. We recommend that the project area be at least 25,000 acres for applying the habitat-use model.

Project Area Buffer: this separate polygon is the project area buffered out to 2.5 miles (4 km) to include any open roads and cover-forage edges that might influence elk habitat use inside the project area. Most model outputs extend to this buffered area.

Treatment Units: this feature layer contains polygons that define treatment areas that need to be updated either to (1) accurately represent baseline vegetation conditions, and/or (2) reflect proposed future alterations. Polygons used to update the base condition or represent treatment areas can be included in the same layer using multiple sets of attributes (e.g., BASE_CC, BASE_STNDHGT, BASE_HW; T1_CC, T1_STNDHT, T1_HW, etc.). When populating the canopy cover, stand height, and hardwood attribute values, use a Null or negative value to exclude a polygon from being used for an update. For example, when creating an update to reflect base conditions, populate the base condition attribute fields with the appropriate values to reflect current landscape conditions while leaving treatment area polygons as either Null or negative values. This will ensure that the updated base condition layers will reflect only the base condition change polygons. The base condition outputs could then be used in subsequent applications to create updates reflecting post-treatment conditions.

Roads: this layer includes all road segments, attributed as either closed or open to the public during summer (June-August). An open road is any road or trail that is used by *motorized traffic* (e.g., ATVs, motorcycles, or vehicles). This attribution should be made for the entire buffered project area boundary because roads in the buffer can affect elk use within the project area boundary.

Most road layers that include attributes to delineate open or closed status are attributed as policy mandated from the land stewards, but they may not accurately represent "on the ground" use in some areas. This situation requires the model user to work with those who know the landscape well enough to help you delineate which roads are being used by the public during summer, regardless of whether the use is legal. Some closed roads may be used by the public, but the opposite may also be true, whereby roads designated as open are known to have essentially no use by motorized traffic due to physical barriers or other reasons. Whatever your source for roads, this layer should contain a field in the attribute table that describes the status of each road segment as either open or closed. This attribute field can contain text or numeric data. You will need to create an SQL statement (examples below) when you run the Habitat Use Tool that uses the attribute that defines the open roads.

For text attributes: <*Road Status Column Name*> = 'open'
For numeric (if 1 = open): <*Road Status Column Name*> = 1

The roads layer, used only in the habitat-use model, is often the most time-consuming to prepare. If your project area falls entirely or mostly within National Forest System lands, work with your local GIS staff to obtain a roads layer for your project area. The ground transportation network (**GTRN**) roads data provided by the BLM are often a good starting point for roads across all land ownerships, especially in Oregon (Appendix 3). If you want to compare current habitat use with predicted use by elk resulting from various travel management alternatives that involve road status changes, such as opening a closed road or closing an open road, you will need an alternate road status column in your road layer's attribute table and populate it as described above.

Canopy Cover: percentage of overstory tree canopy cover as defined by the existing vegetation layer. This data is provided by GNN or LiDAR, or the user can use another source. For CITRIX users, the 2017 GNN data are located here: T:\FS\Reference\RSImagery\ProcessedData\r06\GNN\gnn_grids_2017.gdb. For DESKTOP users, the 2017 GNN data are in GNNdata.gdb as part of the WestsideData.zip download.

Stand Height: stand height (meters) as defined by the existing vegetation layer. This data is provided by GNN and LiDAR, or the user can locate another source.

Hardwood: percentage of hardwoods. This data is derived using 2 GNN attribute layers: trees per hectare of live hardwoods ≥2.5 cm dbh (TPHH_GE_3)/trees per hectare of live trees ≥2.5 cm dbh (TPH_GE_3)*100.

DEM: A digital elevation model is an elevation raster (meters). The DEM parameter is pre-populated within the tools using the layer provided from the T drive. If you prefer to use a different elevation raster, you will need to contact your GIS specialist or download a file from another source such as that listed in Appendix 3.

PNV: defines the potential natural vegetation zones and subzones used in the elk nutrition model. For CITRIX, most users will access PNV through the layer file described above (WS_ElkHabModelRegionalLayers.lyr). For DESKTOP users, this layer is found in the RegionalData.gdb and should not be altered. The nutrition equations rely on the underlying PNV zones for the Westside region. In developing the equations, most Westside PNV zones were crosswalked to the 2 primary zones used in the equations, silver fir/mountain hemlock (**SFMHZ**) and western hemlock (**WHZ**). Areas classified as "no data" depict locations where the PNV type was too dissimilar to SFMHZ or WHZ to validly apply the nutrition model; these pixels are excluded from any nutrition or habitat-use model predictions. See Table 1 for codes used in the PNV attribute table.

Elk Habitat Mask: This raster is derived from classes in the 2016 National Land Cover Database (NLCD) and used to assign values to each pixel as **M**asked Out (M), **H**abitat appropriate for modeling (H), or **A**gricultural lands (A). The masked classification signifies pixels that are not considered elk habitat, e.g., developed areas or water; these pixels are ignored when running the models. By contrast, "Habitat" includes those pixels that will be assigned valid model outputs. Ag lands are a special case, in that they are assigned a default value of DDE (2.825 kcal/g) by the nutrition model rather than being assigned a value from the regional nutrition equations. CITRIX users will access the layer through the Westside layer file (WS_ElkHabModelRegionalLayers.lyr); for DESKTOP users this layer is found in the RegionalData.gdb and should not be altered.

<u>Model Regions</u>: There are 3 Westside modeling regions (Fig. 1), one associated with each of the three sets of nutrition equations. The ModelRegions layer should be used in all applications of the Nutrition Tool, as these boundaries are fixed. CITRIX users will access the layer through the Westside layer file ((WS_ElkHabModelRegionalLayers.lyr); for DESKTOP users, this layer is found in the RegionalData.gdb and should not be altered.

Additional ArcGIS details about the layers, software versions, and licenses are noted below and are important to keep in mind when preparing and exploring data layers. Consult your local GIS expert if you have questions:

- **Raster** (i.e., grid) files generated by the models are 30-m resolution. Input rasters should also be 30 m (other than the **DEM**, used to calculate slope, which is sometimes available at finer resolutions and can be successfully entered in the habitat use model at these resolutions).
- The modeling toolbox (*.pyt file) should run in ArcGIS versions from 10.0 forward, with ArcInfo License and Spatial Analyst Extension. The current version of the toolbox was revised using ArcGIS 10.7. Users working with earlier versions of ArcGIS should be aware of potential conflicts.
- All input raster and feature layers should have the same projection and match the ArcMap project data frame coordinate system to prevent any shifts or erroneous calculations.
- Some model outputs (e.g., mean_slp) are summarized within a 350-m radius circle surrounding the center pixel. This is the scale at which the models were developed and validated and should not be changed (see Rowland et al. 2018*a* for more details).

Table 1. Summary of format requirements for model input layers.

	Data Type	Values	Units; Resolution
Provided by the User			
Project area	Polygon feature	n/a	n/a
Project area buffer (2.5 mi, or 4 km)	Polygon feature	n/a	n/a
Treatment units (optional)	Polygon feature	n/a	n/a
Roads	Line feature	Open; Closed	n/a
Provided on the T Drive (CITRIX) or GNNdata.gdb (DESKTOP)			
Canopy cover	Raster; Integer or Float, Continuous	0-100	Percentage; 30 m
Stand height	Raster; Integer or Float, Continuous	>=0	Meters; 30 m
Hardwood	Raster; Integer or Float, Continuous	0-100	Percentage; 30 m
Provided on the T Drive (CITRIX) or by the User (DESKTOP)			
Digital elevation model	Raster; Integer or Float, Continuous	>=1	Meters; *
Provided on the T Drive (CITRIX) or in the RegionalData.gdb (DESKTOP)			

PNV	Raster; Categorical	1 = WHZ; 2 = SFMHZ; -9 = no data	n/a; 30 m
Elk habitat mask	Raster; Categorical	H = Elk habitat; M = Masked out (not used in modeling); A = Agriculture	n/a; 30 m
Modeling Regions	Polygon feature	Nooksack, Springfield, Willapa Hills	n/a

* Recommended raster resolution is 30-meter, although the tools will run using a different DEM resolution. Note that a finer resolution may result in longer processing times.

Deciding How to Use the Models

The Westside elk nutrition and habitat-use models can be used to simply see how the tools work and the kinds of outputs they create. There are sample data and other files provided for this exploration, which we encourage for novice model users to gain familiarity with the modeling toolbox and process steps. But most model users will ultimately be applying the tools to their own project area (and likely with their own vegetation and roads data) to predict elk nutrition and habitat use, along with a host of useful intermediate outputs (for example, **accepted biomass** or cover-forage edges). For these applications, we describe how to use the toolbox with your own project area and input data to run both models (be sure to carefully review “Baseline Data Needed”).

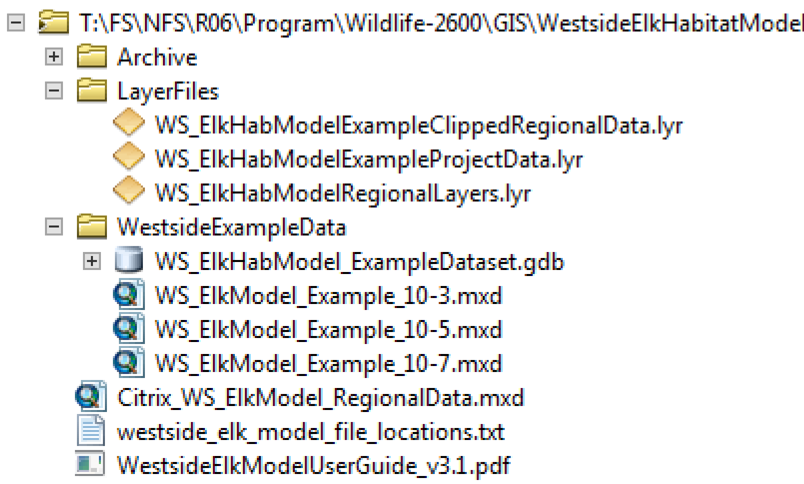
The Westside elk models can be used to help managers assess landscape suitability for elk in many ways. Most users will want to compare nutrition and predicted use by elk before and after vegetation treatments, map baseline elk habitat conditions, evaluate travel management options, or track progress of Forest Plan Implementation in Forest Plan biannual monitoring reports. In planning areas where elk are a featured species (e.g., management indicator species), model outputs can be used to evaluate elk habitat across alternatives. Users also can map recently burned areas (see Appendix 3 for post-fire data sources) or sites of other large-scale disturbance events and model nutrition and habitat use before and after. Subsequent model runs can explore effects of strategic open road closures under various scenarios to evaluate elk access to sites where the model predicts use would be high (e.g., high DDE, gentle slopes) but traffic on roads would deter elk use. Depending on the scale of disturbance, users should interpret results with caution, as elk may not return to prior herd ranges until sufficient forage and edge habitat are created. Given the recommendation by regional leadership of the FS and BLM for the Westside elk models to be used as “best available science” to evaluate elk habitat, project planning at all scales that involves quantifying summer habitat conditions for elk should prescribe use of these models to be consistent with Forest Service Handbook Policy.

Model Data Package

CITRIX: The WestsideElkHabitatModel folder contains the following folders/items:

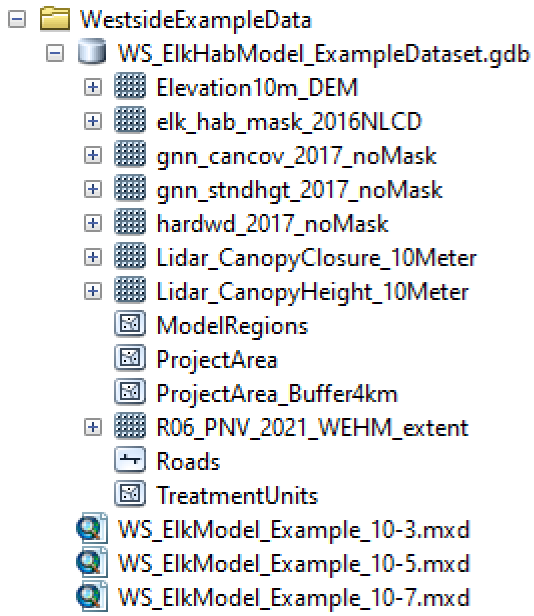
1. Archive folder - contains previous versions of data and the toolbox.
2. LayerFiles folder - contains Citrix layer files to add regional and example data to a map document.
3. WestsideExampleData folder - contains data associated specifically with an example project area in the Nooksack nutrition modeling region in Washington, including: a project area and buffered project area boundary, roads, and treatment unit polygons:

   a. WS_ElkHabModel_ExampleDataset.gdb with all regional data clipped to the example project area
   b. Map documents with the example data, in various versions of ArcGIS.
4. Citrix_WS_ElkModel_RegionalData.mxd map document - a map document with all Westside Elk Habitat Model regional data layers. Users will need to save a copy of the map document to their own workspace and can then add project specific layers, such as a project boundary.
5. Westside_elk_model_file_locations.txt file - A file location document listing the locations of the toolbox and data on the T drive.
6. WestsideElkModelUserGuide_vX.X.



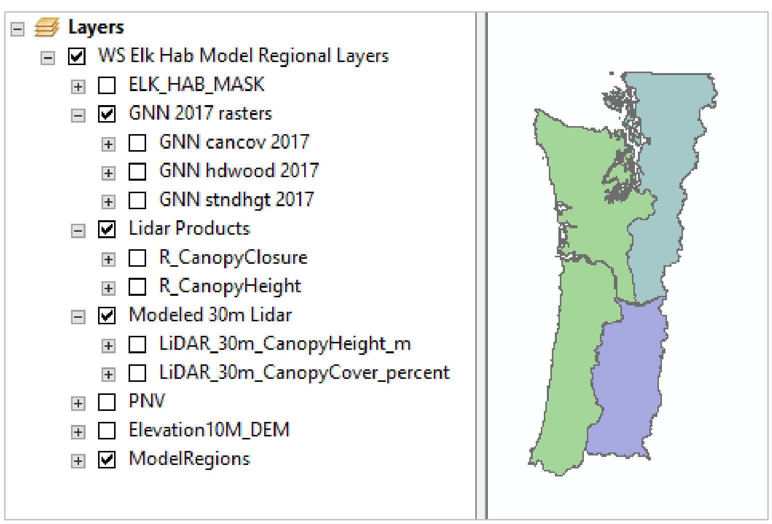
DESKTOP: The desktop version of the models is housed in the following zipped folders:

1. WestsideData folder contains:
   a. GNNdata.gdb - required GNN canopy cover, stand height, and hardwood data
   b. RegionalData.gdb - required PNV, elevation, elk_hab_mask, and model regions data
   c. WS_ElkModel_RegionalData_10-x.mxd - example ArcMap documents with relative paths to GNN and Regional data.
2. WestsideToolbox folder contains the toolbox, a processing steps document, and a document describing how to change the default projection is desired.
3. WestsideExampleData folder contains data associated with a specific example project area in the Nooksack nutrition modeling region in Washington, including: a project area and buffered project area boundary, roads, and treatment unit polygons:
   a. WS_ElkHabModel_ExampleDataset.gdb with all regional and example project data clipped to the project area
   b. Map documents with the example data, in various versions of ArcGIS.

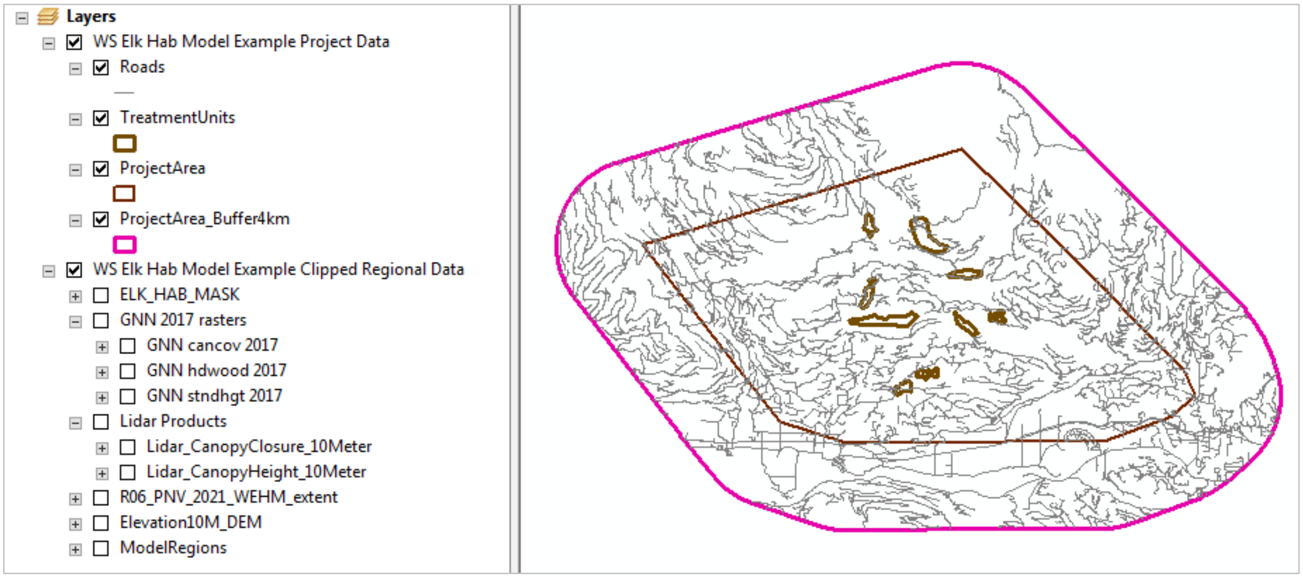


Either in Citrix or on your desktop, carefully explore these files in ArcMap before you start using the model. Regional data, including the Westside PNV raster, the elk habitat mask derived from NLCD, a DEM, and the regional modeling boundaries, can be viewed from the Regional Data map document. The example project data, for which all regional data are clipped to a specific area in the Nooksack nutrition modeling region, can be viewed from the respective (CITRIX or DESKTOP) Example map document.

Regional data map document (Note: Desktop users who want to use Lidar data need to provide their own):

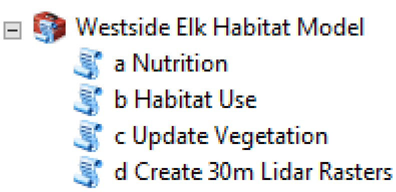


Example data map document:

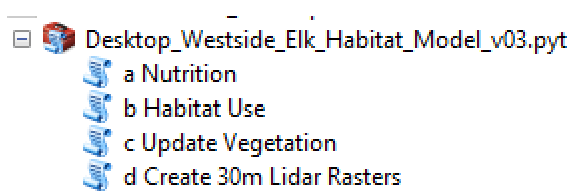


The Python toolbox contains four tools: Nutrition, Habitat Use, Update Vegetation, and LiDAR.

CITRIX:



DESKTOP:



<u>Quick tip</u>: For more detailed information about any of the four tools in the toolbox, right click on it in ArcCatalog and select "Item Description." Here you will find a wealth of information about proper usage and limitations of the tool, syntax used, and parameter descriptions.

The four tools work together to produce the key model outputs of nutrition and predicted use by elk (Fig. 3).

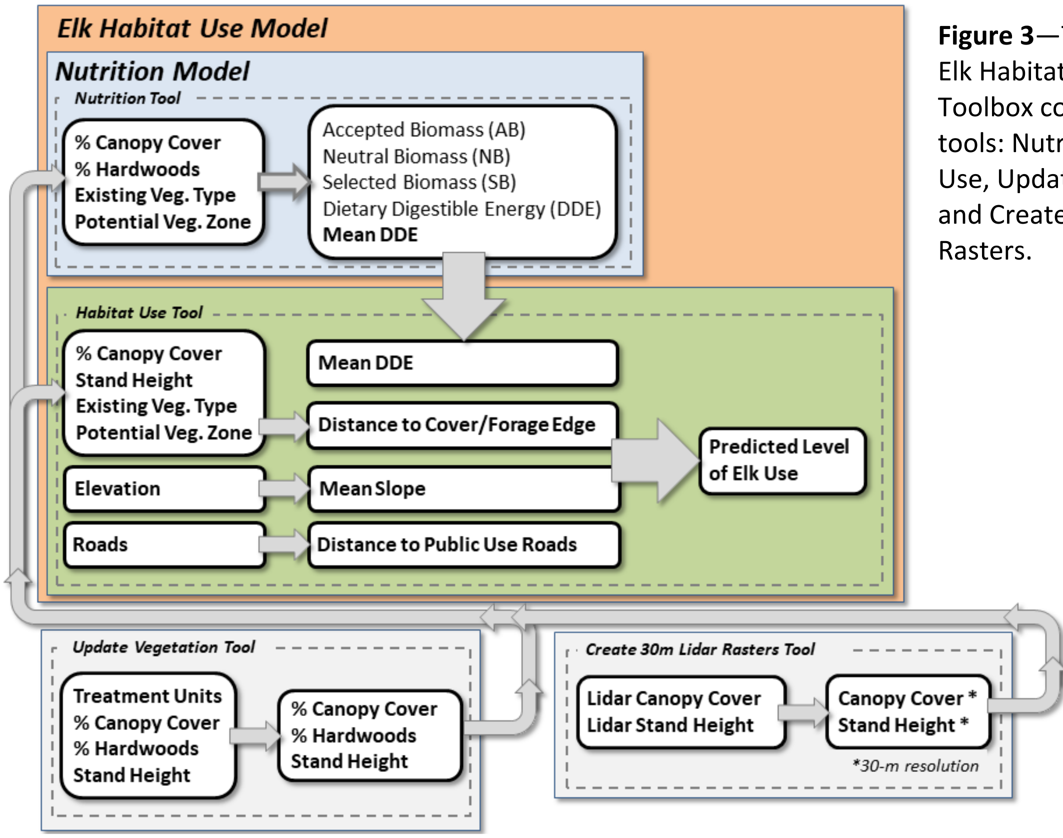


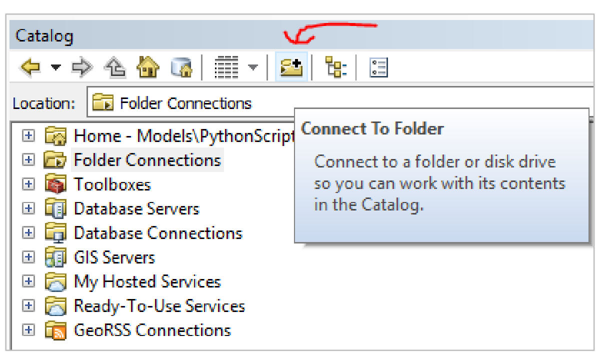
Figure 3—The Westside Elk Habitat Models Toolbox contains four tools: Nutrition, Habitat Use, Update Vegetation, and Create 30m Lidar Rasters.

Exploring the Example Dataset

The example ArcMap project can be used for training and model exploration. Copy the example folder to your workspace in either Citrix or on your Desktop as follows:

CITRIX:

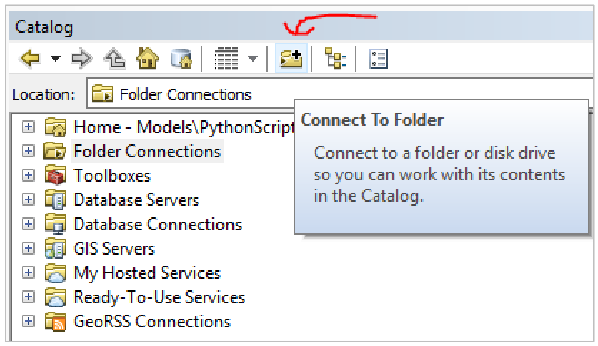
1. Navigate to Citrix/GIS (https://citrix.fs.usda.gov/Citrix/StoreWeb/), and log in.
2. Open ArcMap and use the **Connect to Folder** icon from the Catalog window, as demonstrated below, to connect to the R6 folder created for the Westside Elk modeling project:T:\FS\NFS\R06\Program\Wildlife-2600\GIS\WestsideElkHabitatModel.



3. Copy the entire example ArcMap project folder (WestsideExampleData) to your personal workspace on the T drive, using either Windows Explorer or the ArcMap Catalog window in Citrix. Remember to keep workspace folder names short with no spaces or special characters.

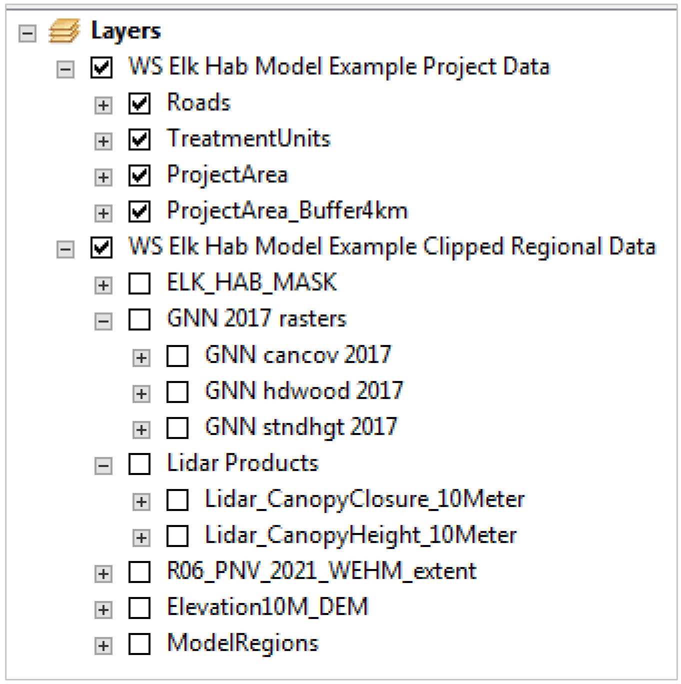
DESKTOP:

1. Download, copy, and un-zip WestsideData.zip, WestsideExampleData.zip (optional), and WestsideToolbox.zip to your local C drive in the same workspace folder of your choice.
2. Open up ArcMap and use the **Connect to Folder** icon from the Catalog window, as demonstrated below, to connect to the folder you chose in the previous step.

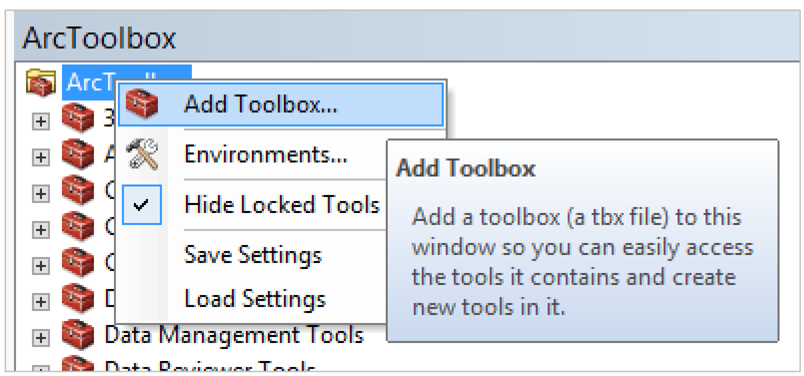


For both CITRIX and DESKTOP, continue:

3. Confirm that the Westside modeling Python Toolbox (Westside_Elk_Habitat_Model_vXX.pyt or Desktop_Westside_Elk_Habitat_Model_vXX.pyt) is in the same personal workspace where you have stored the example map. CITRIX: Copy the toolbox folder T:\FS\Reference\GeoTool\r06\Toolbox\WestsideElkModel. DESKTOP: Copy the toolbox folder from WestsideToolbox_Desktop_v03.zip.
4. Open the ArcMap project in your personal workspace. You will see the example project area displayed, along with other layers.
   a. Links to some of the needed input files should be maintained between the map and the spatial files. However, in the event they are broken (you will see red exclamation points) you will need to repair the links before continuing (right-click on layer and select “Data” and “Repair Data Source”).
   b. There are 2 groups of layers (feature classes and raster datasets) pre-loaded in the example map: Example Dataset and Westside Elk Habitat Regional Layers. Explore each layer, several of which will typically be visible (checked), including its attribute table, to understand its role in modeling.



5. Add the Westside Elk Habitat Model toolbox to the ArcMap project file. To do this:
   a. Open ArcToolbox, right-click on the "ArcToolbox" heading and select "Add Toolbox"
   b. Navigate to your personal workspace and select the "Westside_Elk_Habitat_Model_v03.pyt" file



Creating Your Own Modeling Dataset

Although the existing vegetation rasters (canopy cover; stand height; hardwood percentage) are provided from GNN or LiDAR, these are the most likely inputs that may need to be substituted with another source better suited for your project area. If these layers do not represent conditions in your project area well, consider editing or replacing these layers with other sources. Ensure the substituted layers match the format of the provided layers before using them in the tools. Refer to the "Baseline Data Needed" section and Table 1 for details regarding formatting requirements of each layer. Be mindful of the resolution of the layers, as well as their coordinate system, before using them.

The roads layer is the other one that users will need to create or prepare. Be sure the roads layer spans the entire project area and buffer, and that the open attribute represents actual motorized use during summer going on in "real life," not just how roads are officially classified. Refer to the "Baseline Data Needed" section for more details.

Running the Models with the Example Dataset

The example dataset has been developed to allow users to become familiar with the required data and modeling approach and to explore outputs before investing a lot of time developing the spatial layers for their project area. This dataset can also be used for training. For this example, all referenced layers are in the WS_ElkHabModel_ExampleDataset.gdb geodatabase, including LiDAR. The following sections refer to the primary model outputs. Model users are referred to the "Westside Elk Habitat Model Tool Processing Steps_v03.docx" document for details on intermediate products and at what point in the modeling process each output is created (located in the T:\FS\Reference\GeoTool\r06\Toolbox\WestsideElkModel folder (CITRIX) or the WestsideToolbox.zip file (DESKTOP).

Tool Output File Structure

The Nutrition, Update Vegetation, and Habitat Use tools have all been designed to offer the user some flexibility in how data are organized. Users can provide the output geodatabase name as well as a project area code prefix that will be appended to all output layers. This flexibility offers some different options for organizing outputs when the models will be run multiple times. Some options for users are to:

1. Create a new folder to hold all outputs for each model run.
2. Use the same folder for all outputs but alter the output geodatabase name for each model run.
3. Use the same folder and output geodatabase name for all model runs and use the project area code prefix to differentiate outputs between model runs.
4. *Note*: users who decide to use method 1 or 2 above are still advised to use different project area code prefixes for each model run. Doing so will help the user stay organized when adding layers from different model runs to a map.

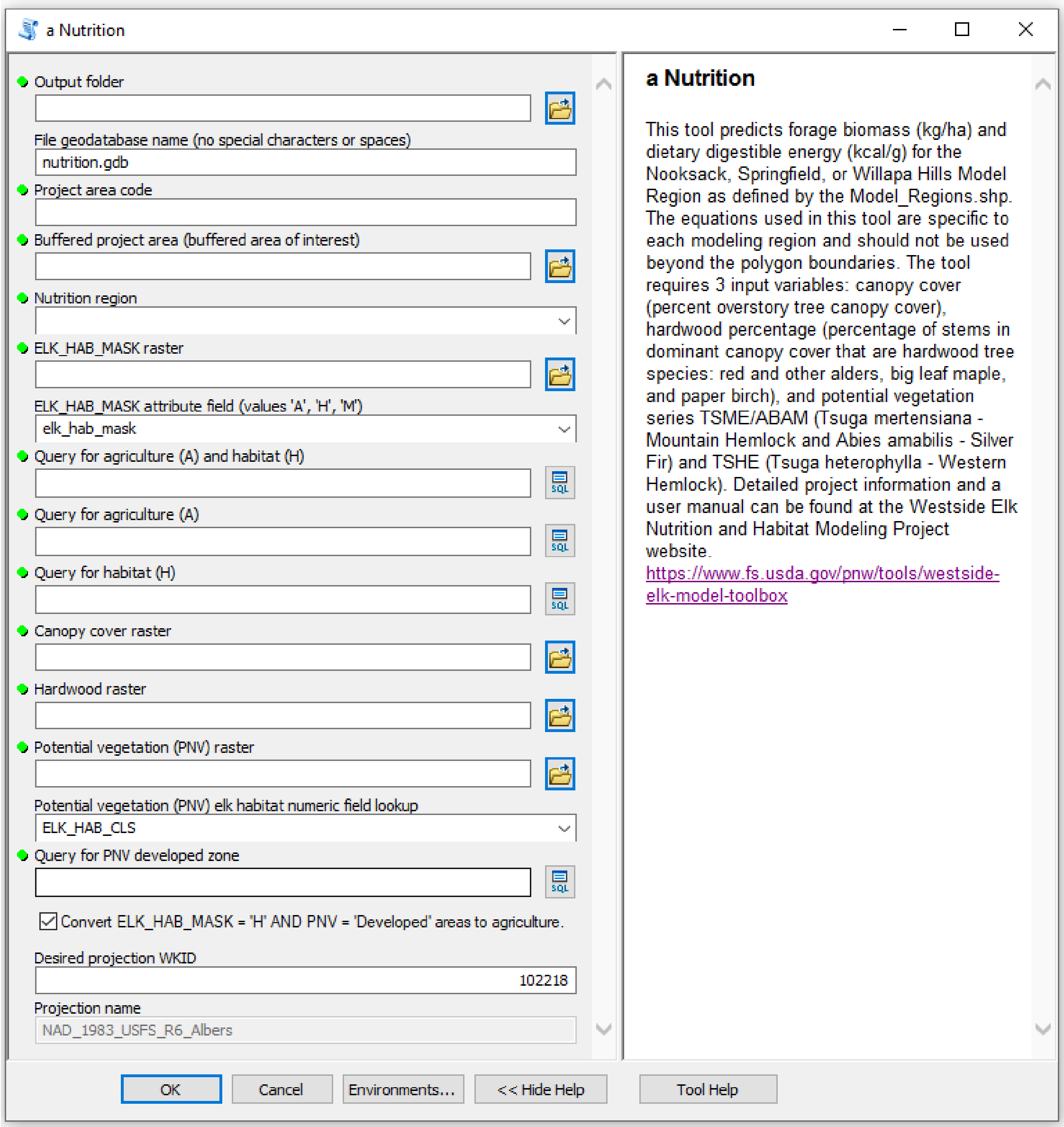
THE NUTRITION TOOL

Running the Nutrition Tool

The Nutrition Tool outputs specific nutritional values (DDE in kcal/g and several biomass estimates) for each 30-meter pixel within the modeling project area boundary based on PNV zone, model region, forest canopy cover, and percentage of trees that are hardwoods (Fig. 3). The Nutrition Tool is always run before the Habitat Use Tool because mean DDE is one of four required inputs of the habitat-use model. If you are only interested in predicting nutrition, you don't need to run the Habitat Use Tool. Also, you will need to run the Update Veg Tool (described below) before the Nutrition Tool if you need to update your canopy cover or hardwood layers to reflect current conditions, and/or the LiDAR Tool if you plan to use those data as inputs to predict nutrition instead of GNN data.

<u>*Quick tip*</u>: *To populate the parameters in all tools, an easy way is to drag and drop files or folders from the Catalog window into the blank parameter box, versus navigating via the drop-down arrow. Another*

suggestion to help document your work, understand model outputs, and prepare for subsequent runs is to take a screen shot of the fully populated tool before clicking "OK" to run the model.



1. Open the Nutrition Tool. This tool includes several parameters used to predict forage biomass and digestible energy.
   a. Make sure the help tips for the tool are showing on the right-hand side by clicking "Tool Help" on the bottom right of the window.
2. Enter model parameters (preferably sequentially from top to bottom, as some parameters will not populate properly unless a prior one has been filled in correctly; also note the Citrix version has some pre-populated parameters in cases where the data sources are not likely to change:
   a. *Output folder*: the folder for final and intermediate model outputs. Click on the open folder icon to the right of this parameter to navigate to your personal workspace where you will be storing all your model outputs from this tool (and other Westside modeling tools). Pick a

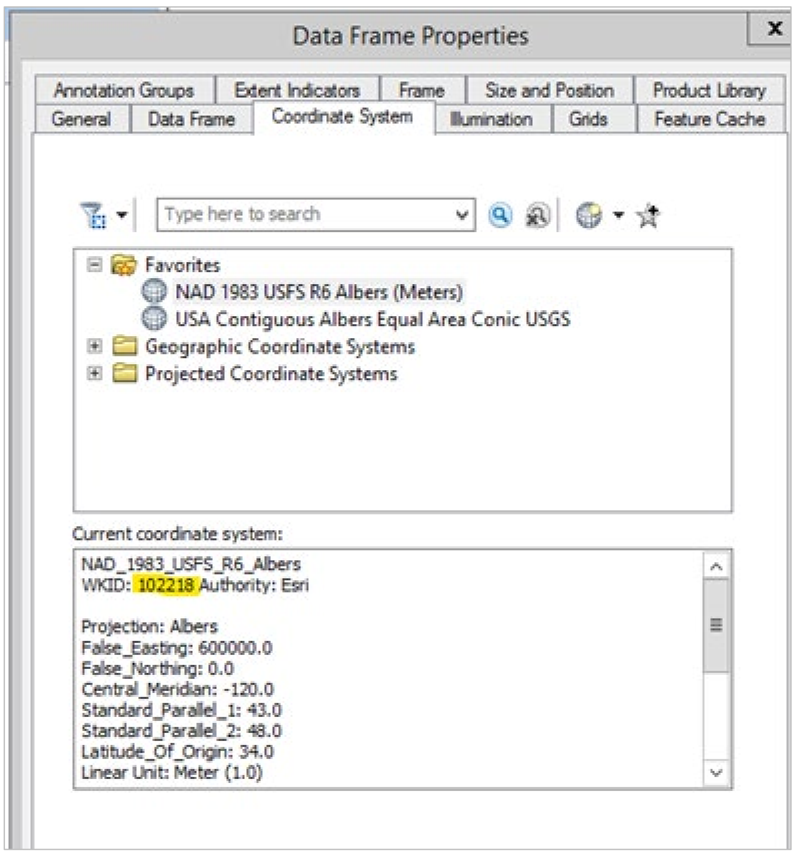
name that best describes the specific modeling session (e.g., ExampleModelOutputs). If you have not previously created this folder, you can do so now by clicking on the "new folder" icon in the upper right of the scree n. Once you have set this location, all output files will be directed there.

b. *File geodatabase name*: the name you assign to the file geodatabase that will be created to house your nutrition model outputs. Pick a meaningful name (e.g., NutrEx1) and do not use any special characters or spaces. A name has been pre-populated (nutrition.gdb), but this can be modified or replaced entirely with the name of your choice.
c. *Project area code*: the code you enter here will be the prefix of all output files in the nutrition geodatabase, so make it short but clear, e.g., "NK" for Nooksack. This code cannot begin with a number.
d. *Buffered project area (buffered area of interest)*: the buffered project area layer file. Select "ProjectArea_Buffer4km" from the example dataset gdb.
e. *Nutrition region*: from the dropdown list, select the region that applies to your project area so that the correct nutrition equations will be used by the tool. (For the example project, this is the Nooksack).
f. *ELK_HAB_MASK raste*r: this field is pre-populated with the path to the 2016 NLCD raster, used to assign pixels as agriculture, habitat, or masked (see below).
g. *ELK_HAB_MASK attribute field (values 'A', 'H', 'M')*: this is the lookup field (elk_hab_ma) from the NLCD raster used to assign each pixel as agriculture, habitat, or masked.
h. *Query for agriculture (A) and habitat (H):* a pre-populated query that extracts agricultural and habitat pixels from the ELK_HAB_MASK raster.
i. *Query for agriculture (A):* this pre-populated query isolates the agriculture pixels, which will be assigned a default value of nutrition in the tool.
j. *Query for habitat (H):* this pre-populated query identifies the habitat pixels, which will be assigned values from the appropriate nutrition equations in the tool.
k. (CITRIX Only) *Checkbox for "Use default GNN CANCOV raster"*: This checkbox is a shortcut for populating the next parameter, *Canopy cover raster*, if the user intends to use the 2017 GNN data. Clicking this box will pre-populate the next parameter.
l. *Canopy cover raster*: the raster used to input canopy cover. If you choose to use the default 2017 GNN canopy cover raster, check the box above this parameter to pre-populate the path to this grid. If you have another canopy cover raster (e.g., if you ran the LiDAR tool and created a canopy cover raster as an output, or ran the Update Vegetation Tool first), navigate to that raster through the folder option at the right of the parameter.
m. *Hardwood raster*: the raster used to input percentage of hardwoods. When opening the tool, the default 2017 GNN hardwood raster will populate. If you have another hardwood raster you prefer to use (e.g., if you ran the Update Vegetation Tool first), either select the layer from the dropdown list if it is in ArcMap or navigate to the layer through the browse folder option.
n. *Potential vegetation (PNV) raster*: the potential natural vegetation zone raster. This parameter is pre-populated with the raster for PNV, in which each potential vegetation zone or subzone has been assigned an appropriate value for the nutrition equations.
o. *Potential vegetation (PNV) elk habitat numeric field lookup*: the PNV zone column name for reclassified potential vegetation as used in the nutrition model (i.e., ELK_HAB_CLS). As with the PNV raster, this parameter is pre-populated with the appropriate field from the PNV raster.
p. *Query for PNV developed zone*: This pre-populated query extracts the zone "Developed" from the PNV raster and includes both agricultural and human-modified landscapes (e.g.,

urban areas, roads). This query is pre-populated to extract the appropriate zone type from the PNV raster

q. *Checkbox for "Convert ELK_HAB_MASK = 'H' and PNV = 'Developed' areas to agriculture*: Although the NLCD raster is the primary source for selecting agricultural pixels, some pixels identified as habitat by NLCD are marked as "Developed" by the PNV grid, and explorations in NAIP imagery show most of these as being agriculture. If you check this box, all agricultural areas, including those identified by both the NLCD and PNV layers, will be stamped with the relevant DDE and biomass values. Unchecking the box will result in removing those pixels from the analysis. For confirmation, the potential ag raster in the intermediate workspace can be used to perform a visual check using NAIP imagery.

r. *Desired projection WKID*: The "Well-Known ID" (WKID) number for the project's projection. If different than the default for R6 Albers, look up the WKID by viewing the "Data Frame Properties" in ArcMap and looking at the desired coordinate system's details in the "Coordinate System" tab.



3. Check to make sure all the parameters are populated and then select "OK" to run the tool. For the example project area, the model should take approximately 11 minutes.

Exploring Nutrition Model Outputs

This tool creates two geodatabases; nutrition.gdb (the primary outputs) and nutrition_intermediate.gdb, which contains all the intermediate process outputs not essential to the user's evaluation of the tool. Users can alter the output gdb name if desired. There are 9 rasters in the primary nutrition geodatabase, defined below (Table 2). The most important is the raster ****_mean_dde, representing the mean value of DDE within a 350-m radius circle around each pixel (Rowland et al. 2018*a*). (The **** indicates the user provided project area code). Mean DDE values are incorporated as 1 of 4 input variables in the habitat-use model. Using the mean values provides a smoothed version of digestible energy across the landscape. Another useful output is the ****_6class grid, which depicts DDE classes that are helpful for visualizing, summarizing, and comparing results. These classes also relate to key metrics of elk productivity (Table 3; see also Table 13 in Wisdom et al. 2018*b*).

Table 2. Nutrition Tool primary output files. All abbreviations contain the user-defined project area code prefix (****_). See glossary for definitions of bold text.

Output abbreviation	Description
****_6class	dietary digestible energy (DDE) classified into six nutrition categories: 1 = poor, 2 = low-marginal, 3 = high-marginal, 4 = low-good, 5 = high-good, 6 = excellent[a]
****_**ab**	accepted biomass (kg/ha)[b, c]
****_cc	percentage canopy cover
****_dde	raw DDE (kcal/g) value for each pixel
****_**hardwd**	hardwood percentage
****_mask	all pixels used for modeling; includes all existing vegetation types and potential natural vegetation zones modeled as elk habitat, but excludes agricultural lands
****_mean_dde	mean DDE (kcal/g) within a 350-m radius circle
****_**nb**	neutral biomass (kg/ha)[b]
****_**sb**	selected biomass (kg/ha)[b]

[a] See Table 3 for specific DDE values associated with each class.
[b] In rare instances, the model will predict negative values for biomass; in these cases, the biomass value defaults to 0.
[c] Model outputs are in kg/ha but can be easily converted to lb/acre by dividing by 1.121.

Table 3. Classes of dietary digestible energy (DDE) used to summarize nutrition modeling results for elk (modified from Cook et al. 2004); see text and Cook et al. (2018) for further explanation and Wisdom et al. (2018*b*) for example applications.

Class	Description	DDE (kcal/g)
1	Poor	<2.40
2	Low-marginal	2.40–2.58
3	High-marginal	>2.58–2.75
4	Low-good	>2.75–2.83
5	High-good	>2.83–2.90
6	Excellent	>2.90

Quick tip: When comparing different rasters in ArcMap, for example mean DDE created using LiDAR vs. GNN data, there are several ArcGIS tools that allow users to "swipe" between two layers to more clearly see where the outputs differ across the landscape. This site provides guidance on using the Swipe Layer tool: https://desktop.arcgis.com/en/arcmap/10.7/manage-data/raster-and-images/image-analysis-window-display-section.htm.

Add the ****_mean_dde and ****_6class rasters into your ArcMap project to explore the spatial distribution of DDE values. The areas with "no data" pixels not classified as habitat appear white. Now is a good time to explore all the nutrition rasters, referring to Table 2 for definitions of each. Note that the default color ramp and stretch type may not be useful, so select a color scheme that provides better discrimination across values and meets your objectives.

Special Considerations for Running the Nutrition Model Only

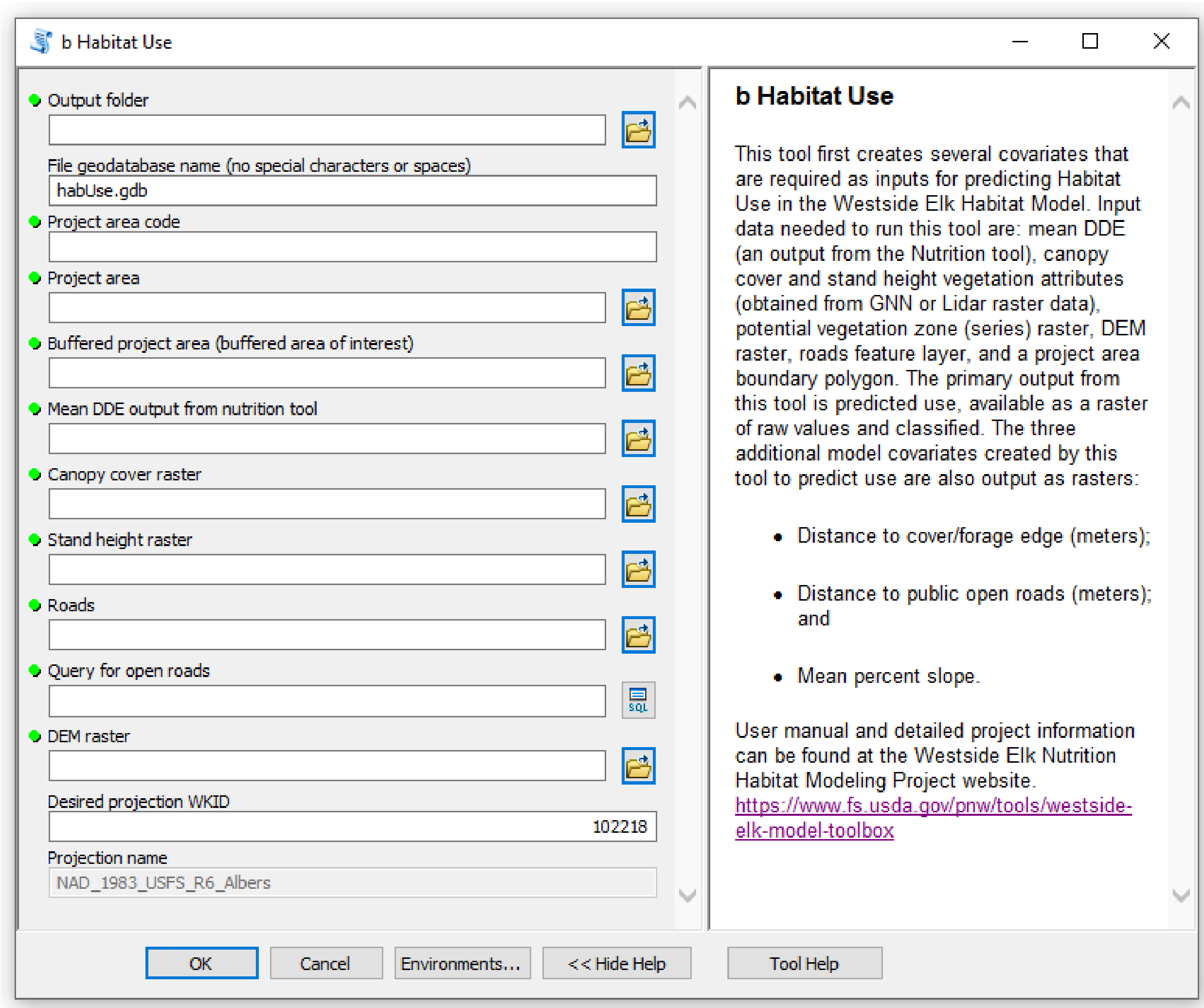
If biologists have field data available (e.g., biomass of elk forage species (Appendix 4) or plot data for tree canopy cover and hardwood percentage), the analysis area can be as small as a few acres. With these data on hand, equations can be used to estimate biomass and/or DDE without using the Nutrition Tool in ArcGIS. With local canopy cover and hardwood data, users can estimate biomass first (Appendix 5) and use the values generated to estimate DDE (Appendix 6). If local data on biomass by elk forage category have been collected, these values can be used directly to predict DDE (Appendix 6 equations). In either case, the field data need to be categorized correctly by specific PNV zone and modeling region.

The data used to develop the Westside nutrition model were collected in macroplots of at least 2.5 acres (Cook et al. 2016, 2018); thus, applying the nutrition model to areas smaller than this should be avoided. Note that if applying the nutrition model at this scale, it is inappropriate to use coarse-scale spatial data, for example the GNN rasters; such data are best used at a subwatershed scale or larger (i.e., a state wildlife management unit). By contrast, coarse-scale GIS data are adequate for applying the nutrition model over regional landscapes. If using model inputs derived from broad-scale layers, such as GNN, the area should be large enough to reflect conditions for a local population, i.e., about 2,000-2,500 acres or larger. If users are fortunate enough to have remotely sensed data along with local data, we suggest comparing the two products to better understand the quality of the remotely sensed layer. Generally, GNN and similarly derived broad-scale layers (e.g., NLCD tree canopy cover; https://www.mrlc.gov/data?f%5B0%5D=category%3ATree%20Canopy; Appendix 3) are suitable for regional-scale analyses, but often lack the accuracy needed for local or stand-level applications.

THE HABITAT USE TOOL

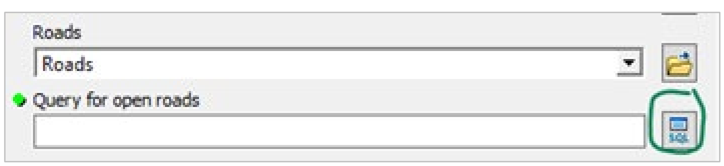
Running the Habitat Use Tool

The Habitat Use tool predicts probability of elk use across the example landscape, using the four input variables previously described: mean DDE, mean slope, distance to cover-forage edge, and distance to nearest open roads. Rowland et al. (2018*a*) provide more details about these variables and their value in predicting habitat use by elk. The following steps will guide you through running this tool.

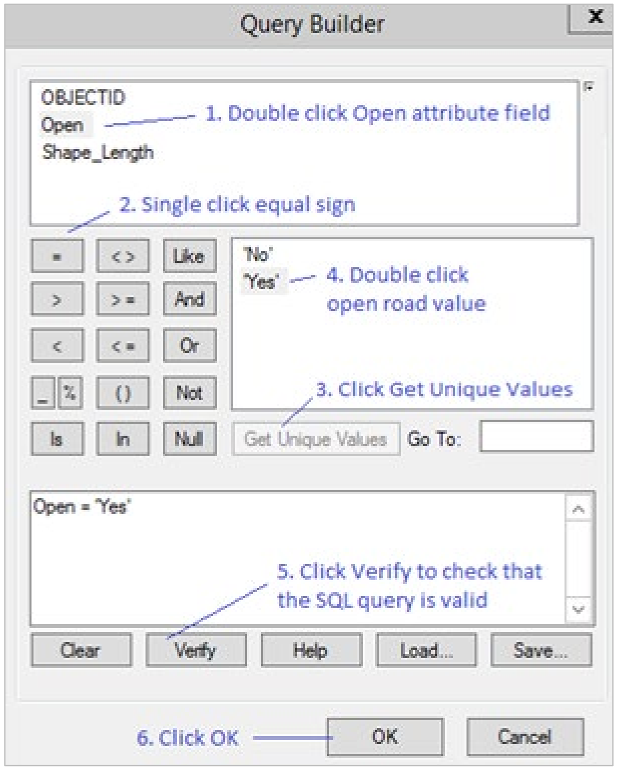


1. Open the Habitat Use Tool. This tool includes several parameters used to create model input variables like cover-forage edges or mean slope.
    a. Make sure the help tips for the tool are showing on the right-hand side by clicking “Tool Help” on the bottom right of the window.
2. Enter model parameters:
    a. *Output folder:* the folder for model outputs. Click on the open folder icon to the right of this parameter to navigate to your personal workspace where you will be storing all your model outputs from this tool (and other Westside modeling tools). Pick a name that best describes the specific modeling session (e.g., ExampleModelOutputs). If you have not previously created this folder, you can do so now by clicking on the “new folder” icon in the upper right of the screen. Once you have set this location, all output files will be directed there.
    b. *File geodatabase Name*: the name assigned to the file geodatabase that will be created to house your habitat use model outputs, so provide a meaningful name here also (e.g., HabUseEx1). A name has been pre-populated (habUse.gdb), but this can be modified or replaced entirely with the name of your choice.
    c. *Project area code*: the code you enter here will be the prefix of all your output files within the habitat use geodatabase, so make it short but clear, e.g., “NK” for Nooksack. This code cannot begin with a number.

d. *Project area*: this is the exact project area boundary without the buffer. Select your Project area layer file.
e. *Buffered project area (buffered area of interest)*: the buffered project area layer file. Select your buffered Project area layer file.
f. *Mean DDE output from nutrition tool*: this is the mean DDE raster created with the Nutrition Tool (as described above). Navigate to the output geodatabase created from the Nutrition Tool and select "****_mean_dde" (where **** denotes your project area code).
g. (CITRIX Only) *Checkbox for "Use default GNN CANCOV and STNDGHT rasters"*: This checkbox is a shortcut for populating the next two parameters, *Canopy cover raster* and *Stand height raster*, if the user intends to use the 2017 GNN data. Clicking this box will pre-populate the next two parameters.
h. *Canopy cover raster:* the raster used to input canopy cover. If you choose to use the default 2017 GNN canopy cover raster, check the box above this parameter to pre-populate the path to this grid. If you have another canopy cover raster (e.g., if you ran the LiDAR tool and created a canopy cover raster as an output, or ran the Update Vegetation Tool first), navigate to that raster through the folder option at the right of the parameter.
i. *Stand height raster:* the raster used to input stand height. If you choose to use the default 2017 GNN stand height raster, check the box above this parameter. If you have another stand height raster you prefer to use (e.g., if you ran the LiDAR or Update Vegetation Tool first), either select the layer from the dropdown list if it is in ArcMap or navigate to the layer through the browse folder option.
j. *Roads*: the road feature layer. Select the Roads layer in the example dataset, or the roads layer you have prepared for your project area, with attributes that define which roads are open during summer (June-Aug).
k. *Query for open roads*: this expression selects open roads, as defined for these models. Once the roads layer has been entered here, create an SQL query for open roads by doing the following:



   ii. Double click the attribute field for open/closed roads. The attribute field will appear in the query box at the bottom.
   iii. Single click the equals button. The equals sign will appear after the field name in the query box at the bottom.
   iv. Click the Get Unique Values button. Open/closed road values will appear in the middle box.
   v. Double click the value for open roads (e.g., 'Yes'). The open value will be added after the equal sign in the box below.
   vi. Click Verify to check that the SQL query is valid. If the query is not successfully verified, clear the query and create a new query.
   vii. Click OK to add the query as a parameter.



l. (CITRIX Only) Checkbox for "Use default USGS DEM 10 meter raster": This checkbox is a shortcut for populating the next parameter, *DEM raster*, if the user intends to use the DEM that is maintained on the T drive. Clicking this box will pre-populate the next parameter.
m. *DEM Raster*: the digital elevation model (DEM). If you choose to use the default DEM raster, check the box above this parameter. If you have another DEM source you prefer to use, select that laye*r.*
n. *Desired projection WKID*: The "Well-Known ID" (WKID) number for the project's projection. If different than the default for R6 Albers, look up the WKID by viewing the "Data Frame Properties" in ArcMap and looking at the desired coordinate system's details in the "Coordinate System" tab.

3. Check all your inputs to ensure they look correct, and then select "OK" to run the tool. This tool takes a bit longer to run than the Nutrition Tool; expect 15-20 minutes.

Exploring Habitat-use Model Outputs

In ArcCatalog, open the geodatabase you created in Step 2b above. You will see that 7 rasters have been created (Table 4). The primary output of interest is the raster ****_use (where **** indicates the project area code). This raster contains the predicted probability of use by elk across the area (Rowland et al. 2018*a*). Add this raster into your ArcMap project and select a color ramp that allows you to see the range of values in a useful way. Note that the values of predicted use from the model are very small and are not meaningful by themselves, but rather provide a relative ranking of predicted use by elk from low to high across the landscape. An easy way to view the spatial distribution of predicted use across the project area is the classified version (****_use_5bin_eqArea; Table 4), which distributes the predicted use values into 5 classes of equal size (i.e., each class is 20% of the modeled area). Bin numbers range from 1 to 5, with 5 equaling highest predicted use in the project area. Other rasters include ****_mean _slp, which you can use to view a smoothed version of the slope across your project area, ****_d_roads, which will display distance away from open roads, and ****_d_edge, which displays the distance to the nearest cover-forage edge in the area. See “INTERPRETATION AND SUMMARY OF MODEL RESULTS” for suggestions about displaying and interpreting results from this tool.

Table 4. Habitat Use Tool output files. All abbreviations contain the user-defined project area code prefix (****_).

Output abbreviation	Description
****_c3f3	Blocks (minimum of 3x3 cells) of cover and forage areas
****_d_edge	distance to the nearest cover-forage edge
****_d_roads	distance to the nearest road open to the public
****_dde_mask	areas where DDE and habitat use are calculated
****_mean_slp	mean percentage slope
****_use	raw predicted use values created from the habitat-use algorithm; the higher the number, the greater the predicted level of use
****_use_5bin_eqArea	raw values of predicted use classified into 5 equal-area bins for easy display and interpretation

THE UPDATE VEGETATION TOOL

Running the Update Vegetation Tool

The Update Vegetation Tool was designed to meet two primary objectives: (1) to change an existing vegetation layer to account for substantial canopy removal or growth between the date of the available base vegetation layer (e.g., 2017 GNN) and current conditions, or (2) to simulate the removal or growth of canopy cover or other stand conditions that will change through management prescriptions in designated treatment polygons (e.g., harvest areas) within a planning unit for comparison across management alternatives or with current conditions.

For the first objective - to change vegetation layers to existing conditions - the Update Vegetation tool must be run *before* running the Nutrition and Habitat Use Tools, because its primary outputs will be the new vegetation rasters that feed into those tools. This is sometimes necessary to match the timeframe of the modeling period with the available existing vegetation layers. Assessing imagery (e.g., NAIP, described in Appendix 3) from the modeling period compared to existing canopy cover layer can help determine if an adjustment is needed. It can be helpful to symbolize the canopy cover layer in 20% categories and swipe (as described in the “Exploring Nutrition Model Outputs Section”) the layer on/off to look for differences. Users may need to hand-digitize polygons around the areas where changes occur or obtain timber harvest boundaries from local land managers. Consult a local vegetation ecologist or GIS specialist if needed to determine best approach to match the vegetation conditions to the modeling period.

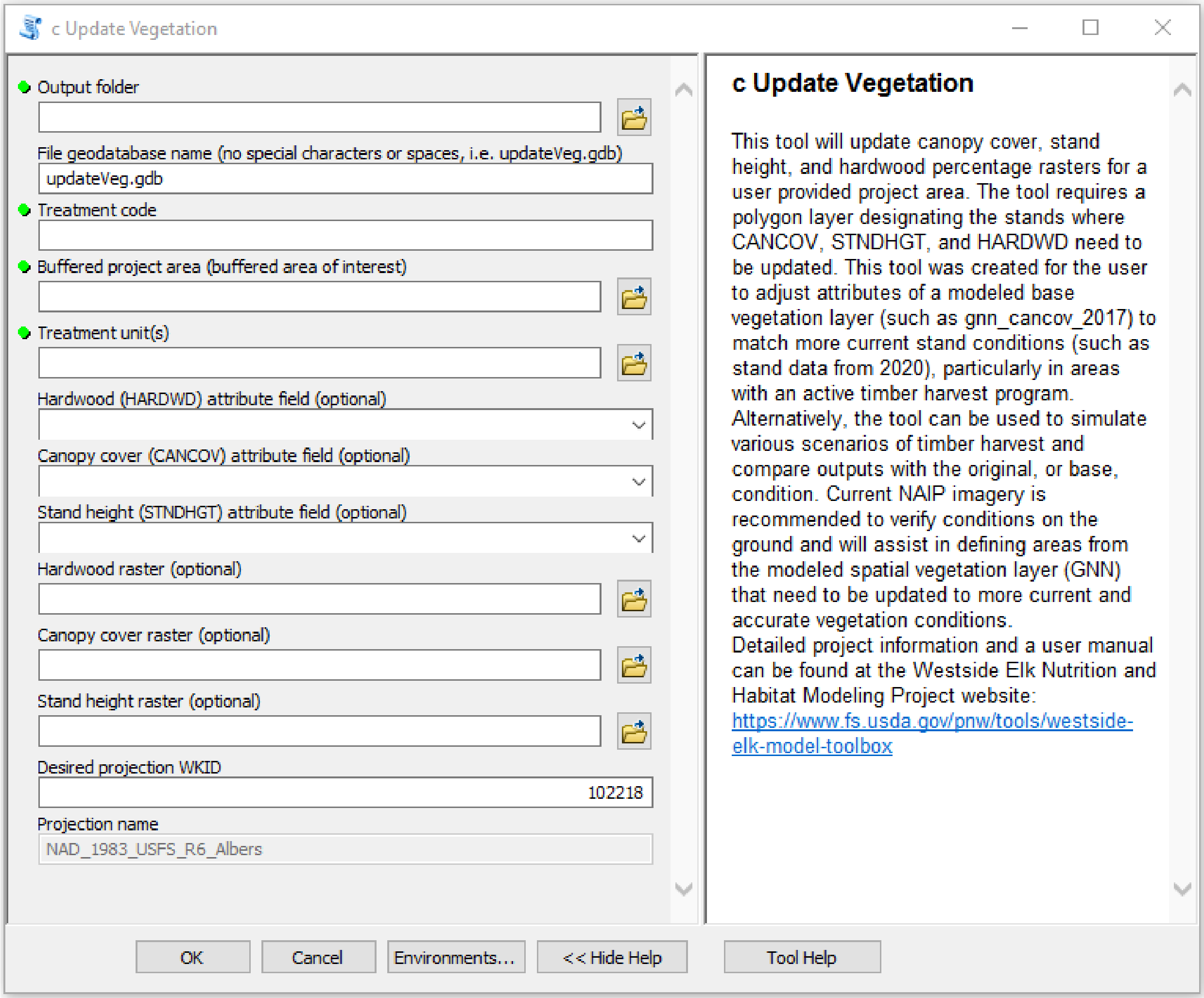
For simulation of various alternatives with current conditions, these can be modeled first, followed by running the Update Vegetation Tool to explore nutrition and habitat-use outputs under different management prescriptions. Both DDE and distance to nearest cover-forage edge, inputs to the Habitat Use Tool, are affected by changes in canopy cover, hardwood percentage, and/or stand height values.

This tool is *not* designed to update a vegetation layer pixel-by-pixel, but to update a raster at the stand level or larger by using vegetation change (treatment) polygons. It also assumes that all treatments (i.e., area where values will be updated) will be applied equally throughout each defined polygon (i.e., the same values will be assigned to every pixel in that unit). However, within a single model run of this tool, each vegetation change polygon can have different values by adding more fields to the attribute table to reflect the desired changes. If managers wanted to create a variable density thinning unit (e.g., a single stand that has gaps, leading to variable canopy cover), the user would need to create several smaller polygons within the single thinning unit. Each "sub-unit" polygon can have its own values for canopy cover, stand height, or hardwoods.

An example dataset reflecting treatment units (polygons) with updated values for specific attributes is provided below. Within the attribute table, the user can update the intended stand characteristics (canopy cover, stand height, hardwoods) by editing one or all of these three values for each treatment unit. The example below shows eleven treatment units, each with a different treatment prescription. Half of the treatments are intended for updating current conditions (yellow highlights), and the other half are intended for a treatment example (blue highlights). Users can continue adding multiple treatment options by adding more attribute fields (ex: T2_cancov, T2_stndhgt, T2_hardwood). When entering the parameters in the Update Vegetation tool, make sure you select the correct set of attribute fields in the table to reflect the update you are modeling. As described earlier in the Baseline Data Needed section above for the Treatment Unit layer, polygons with Null or negative attribute values will not be processed.

GIS_Acres	Trt_Description	Base_CC	Base_Stndht	Base_Hardwd	T1_cancov	T1_stndhgt	T1_hardwd
80.458869	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
14.257005	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
42.629072	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
7.882634	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
68.214303	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
64.833409	Base update Clearcut	0	0	0	<Null>	<Null>	<Null>
98.312639	Trt1 = 25% thin, target hardwd	<Null>	<Null>	<Null>	25	15	0
82.199773	Trt1 = 25% thin, target hardwd	<Null>	<Null>	<Null>	25	15	0
75.203833	Trt1 = 40% thin	<Null>	<Null>	<Null>	40	5	15
304.788267	Trt1 = 60% thin, exclude hardwd	<Null>	<Null>	<Null>	60	12	50
260.829053	Trt1 = clearcut	<Null>	<Null>	<Null>	5	5	0

This dataset demonstrates how vegetation management project alternatives should be formatted and populated with the intended post-treatment stand conditions for canopy cover (**CANCOV**), stand height (STNDHGT), and percent hardwood (HARDWD). Users can obtain realistic estimates of the input values for these conditions by working with their project silviculturist and or fuels specialist. The following steps guide you through using the example data to explore this important tool.



1. Open the Update Vegetation Tool.
    a. Make sure the help tips for the tool are showing on the right-hand side by clicking “Show Help” on the bottom right of the window.
2. Enter model parameters
    a. *Output folder:* Click on the open folder icon to the right of this parameter to navigate to your personal workspace where you will be storing model outputs from this tool. Pick a name that best describes the specific modeling session (e.g., ExampleModelOutputs). If you have not previously created this folder, you can do so now by clicking on the “new folder” icon in the upper right of the screen. Once you have set this location, all output files from this tool will be directed there.
    b. *File geodatabase name*: the name assigned to the file geodatabase that will be created to house your vegetation update outputs, so provide a meaningful name here also (e.g., UpVegEx1). A name has been pre-populated (updateVeg.gdb), but this can be modified or replaced entirely with the name of your choice.
    c. *Treatment code*: code that will be the prefix of output files in the update veg geodatabase; keep it short but clear, e.g., “trt1” for Treatment1. This code cannot begin with a number.
    d. *Buffered project area (buffered area of interest)*: the buffered project area layer file. Select the layer “ProjectArea_Buffer4km” from the example dataset.

e. *Treatment unit(s):* the treatment polygons with updated values of canopy cover, stand height, and percentage of hardwoods. Select the layer “TreatmentUnits” from the example dataset. This file has the boundaries of 5 example polygons that have been treated (e.g. clearcut or thinned to a variety of canopy cover values) after the base vegetation layer was created.
f. *Hardwood (HARDWD) attribute field (optional):* name of the field in the attribute table for the treatment units that contains the hardwood percentage post-treatment values, if different than baseline values.
g. *Canopy cover (CANCOV) attribute field (optional)*: name of the field that contains the canopy cover post-treatment values, if different than baseline values.
h. *Stand height (STNDHGT) attribute field (optional)*: name of the field that contains the stand height post-treatment values, if different than baseline values.
i. *Hardwood raster (optional)*: baseline value for hardwood percentage, prior to treatment. This parameter is pre-populated with the path on the T drive to the hardwood values from 2017 GNN (Citrix Version Only).
j. (CITRIX Only) Checkbox for “Use default GNN CANCOV and STNDHGT rasters”.
k. *Canopy cover raster (optional)*: baseline value for canopy cover, prior to treatment. If the checkbox for “use default GNN CANCOV and STNDHGT” rasters is checked, this parameter and the next will be pre-populated with the path on the T drive to the canopy cover values from 2017 GNN. (Note that these paths will not appear until the post-treatment fields in steps g and h above have been filled in). If not checked, then navigate to the file containing the baseline value you want to use.
l. *Stand height raster (optional)*: baseline value for stand height, prior to treatment.
m. *Desired projection WKID*: The “Well-Known ID” (WKID) number for the project’s projection. If different than the default for R6 Albers, look up the WKID by viewing the “Data Frame Properties” in ArcMap and looking at the desired coordinate system’s details in the “Coordinate System” tab.

3. Check to ensure all the parameters are populated then select “OK” to run the tool. For the example project area, the tool should run in ~4-5 minutes.

Exploring Update Vegetation Model Outputs

To explore the results, use ArcCatalog to navigate to your personal workspace folder and open the geodatabase you created in Step 2b above. Three outputs have been created: canopy cover, hardwoods, and stand height (Table 5); each raster reflects the values for those attributes across the entire project area after the updated values from the treatment units have been applied to the selected pixels.

Table 5. Update Vegetation Tool outputs. All abbreviations contain the user-defined project area code prefix (****_).

Output abbreviation	Description
****_cancov	Percent canopy cover post-treatment
****_hardwd	Percent hardwood post-treatment
****_stndhgt	Stand height in meters post-treatment

THE LiDAR TOOL

Running the LiDAR Tool

Many NFS-managed lands in the modeling region now have LiDAR data available for canopy cover and stand height, two key attributes of the Westside elk model that are generated directly from LiDAR point clouds. These datasets also provide canopy top digital surface models (DSM) and bare earth digital terrain models. For Forest Service users, you can see if your project area has LiDAR available by checking the Lidar status footprint:

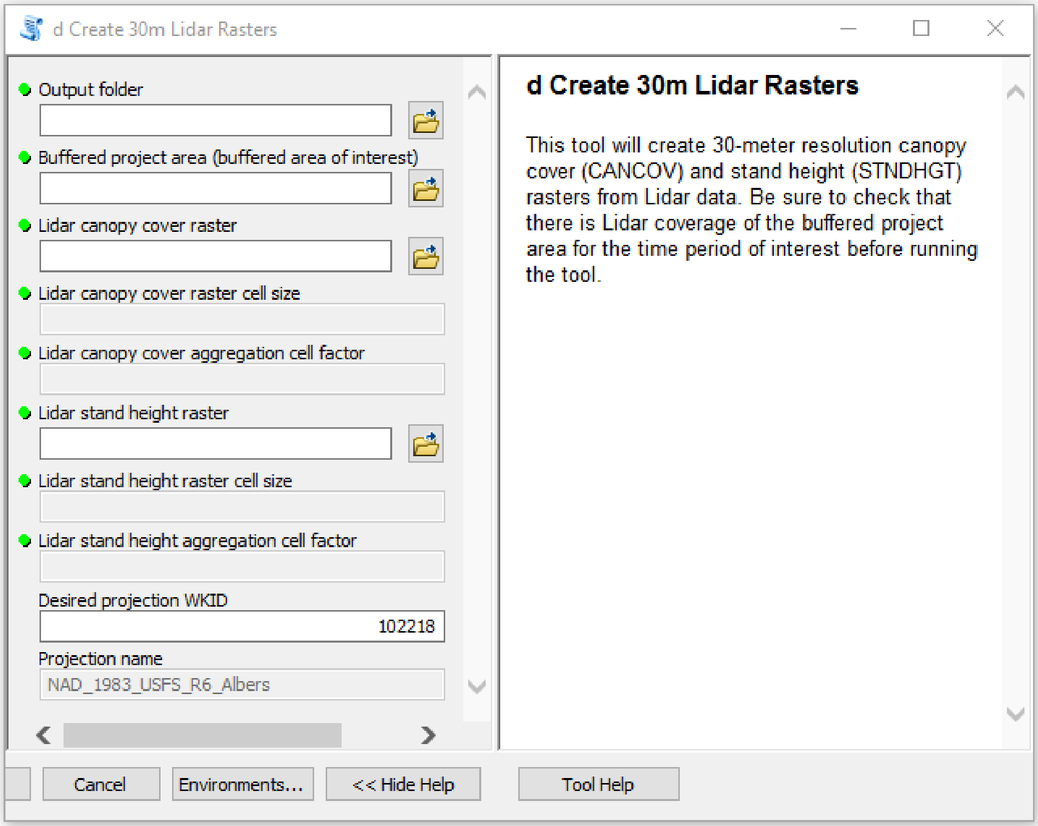
- T:\FS\Reference\GIS\r06\LayerFile\ImageryAndClassifiedImagery\LiDAR__Status_Region6.lyr.

If LiDAR data are available and you choose to use it, first check the existing **modeled** 30-m Lidar products to see if there is complete coverage in your area. Note that the modeled products footprint can differ from the LiDAR status footprint, because modeled products are not available for all areas. Modeled 30-m LiDAR canopy cover and stand height products can be viewed from the following layer files:

- T:\FS\Reference\GIS\r06\LayerFile\ImageryAndClassifiedImagery\LiDAR_30m_CanopyCover_percent.lyr
- T:\FS\Reference\GIS\r06\LayerFile\ImageryAndClassifiedImagery\LiDAR_30m_CanopyHeight_m.lyr

If the modeled 30-m LiDAR products cover the project area, they can be used as is in the Nutrition, Update Vegetation, and Habitat Use tools, and the LiDAR tool does not need to be run. However, if the modeled 30-m products do not cover the area but the LiDAR status layer indicates there is LiDAR data available, use the LiDAR Tool to generate the needed 30-m canopy cover and stand height LiDAR rasters. This tool will aggregate the higher resolution CANCOV and STNDHGT input rasters on the T drive to the 30-m resolution used by the remaining modeling tools. Remember if you are using the LiDAR Tool, you will need to apply it before using any other tools.

In informal comparisons of values of canopy cover and stand height from 2017 GNN vs. LiDAR data of the same (or nearly the same) vintage in the Westside modeling region, the latter almost always depicts lower canopy cover and stand height, likely reflecting more real-time conditions based on measured data as returned by LiDAR vs. modeled data from GNN. These differences will translate into somewhat higher values of nutrition (DDE) when using LiDAR data as inputs in the Nutrition Tool. When comparing LiDAR vs. GNN data in ArcMAP to decide which to use, be sure to use the same classification and symbology in the display properties for each to obtain a valid comparison.



1. Enter model parameters
    a. *Output folder*: the folder designated for outputs of the LiDAR tool. Click on the open folder icon to the right of this parameter to navigate to your personal workspace where you will be storing all your model outputs. This tool will create an output file geodatabase (Lidar_30m_rasters.gdb) in the designated output folder.
        i. Be sure the help tips are showing on the right-hand side by clicking “Show Help” on the bottom right of the window. This display will change as you click on each parameter in this tool and all others in the toolbox.
    b. *Buffered project area (buffered area of interest)*: the buffered project area layer file. Select the layer “ProjectArea_Buffer4km.”
    c. (CITRIX Only) *Checkbox for “Use default Lidar canopy cover raster*”: This checkbox is a shortcut for populating the next parameter, Lidar canopy cover raster, if the user intends to use the Lidar data available on the T drive. Checking this box will pre-populate the next parameter. NOTE – if using the default canopy cover and stand height rasters from the T drive, the validation that occurs in Steps e, f, i, and j may take a few minutes to process before you can continue.
    d. *Lidar canopy cover raster*: location of the LiDAR canopy cover raster. If the box above is checked, this parameter is pre-populated with the current LiDAR mosaic geodatabase on the T drive. The user can, however, can input other LiDAR canopy cover data if desired by navigating to that raster here.
    e. *Lidar canopy cover raster cell size:* This parameter is grayed out and will automatically populate “under the hood” with the cell size of the canopy cover raster.

f. *Lidar canopy cover aggregation cell factor:* This parameter runs an aggregation tool to resample the canopy cover raster cell size to the desired 30-m resolution required by the habitat use model. It is grayed out and will automatically populate.
g. (Citrix Only) *Checkbox for "Use default Lidar stand height raster:"* This checkbox is a shortcut for populating the next parameter, Lidar stand height raster, if the user intends to use the Lidar data available on the T drive. Checking this box will pre-populate the next parameter.
h. *Lidar stand height raster*: location of the LiDAR stand height raster. If the box above is checked, this parameter is pre-populated with the current LiDAR mosaic geodatabase on the T drive. The user can, however, can input other LiDAR stand height data if desired by navigating to that raster here.
i. *Lidar stand height raster cell size*: This parameter is grayed out and will automatically populate "under the hood" with the cell size of the stand height raster.
j. *Lidar stand height aggregation cell factor*: This parameter runs an aggregation tool to resample the stand height raster cell size to the desired 30-m resolution required by the habitat use model. It is grayed out and will automatically populate.
k. *Desired projection WKID*: The "Well-Known ID" (WKID) number for the project's projection. If different than the default for R6 Albers, look up the WKID by viewing the "Data Frame Properties" in ArcMap and looking at the desired coordinate system's details in the "Coordinate System" tab.

2. Check to ensure all the parameters are populated, then select "OK" to run the tool. For the example project area, the tool should run in ~14-15 minutes but can be up to 30 minutes.

Exploring LiDAR Tool Outputs

The LiDAR Tool creates a geodatabase with 2 rasters, canopy cover and stand height (Table 6). These files represent the original LiDAR data for the project area resampled to 30-m resolution for compatibility with other model inputs. To better understand the differences in values of canopy cover and stand height based on LiDAR data vs. GNN, bring these 2 grids into your map project and compare them with the GNN-derived data (e.g., GNN cancov 2017 and GNN stndhgt 2017, found in the Westside Elk Habitat Regional Layers group in the example mxd). For visual comparison, make sure both rasters are given the same classification and symbology. If the differences seem extreme (e.g., > 50% difference in values for large blocks of pixels), consult with NFS foresters or others who may have better insight into which data best represent current conditions.

Table 6. Outputs from the LiDAR Tool.

Output abbreviation	Description
Lidar_cancov_30m	Lidar canopy cover raster resampled to 30 meters.
Lidar_stndhgt_30m	Lidar stand height raster resampled to 30 meters.

INTERPRETATION AND SUMMARY OF MODEL RESULTS

Results from the Westside elk models can be summarized and displayed in many ways, for example to compare elk nutrition and predicted habitat use before and after multiple vegetation treatments or changes in open road access, or to compare and quantify outputs across various land ownerships. Below we describe some example summaries; readers are encouraged to peruse chapter 4 of the Westside elk monograph for additional examples and guidance (Wisdom et al. 2018*b*). As described previously, summaries of outputs from both models (i.e., nutrition and habitat use) can be made at two spatial extents: (1) the regional landscape, across which the habitat-use model is applied; and (2) local landscapes, if model summaries for smaller areas are part of modeling objectives.

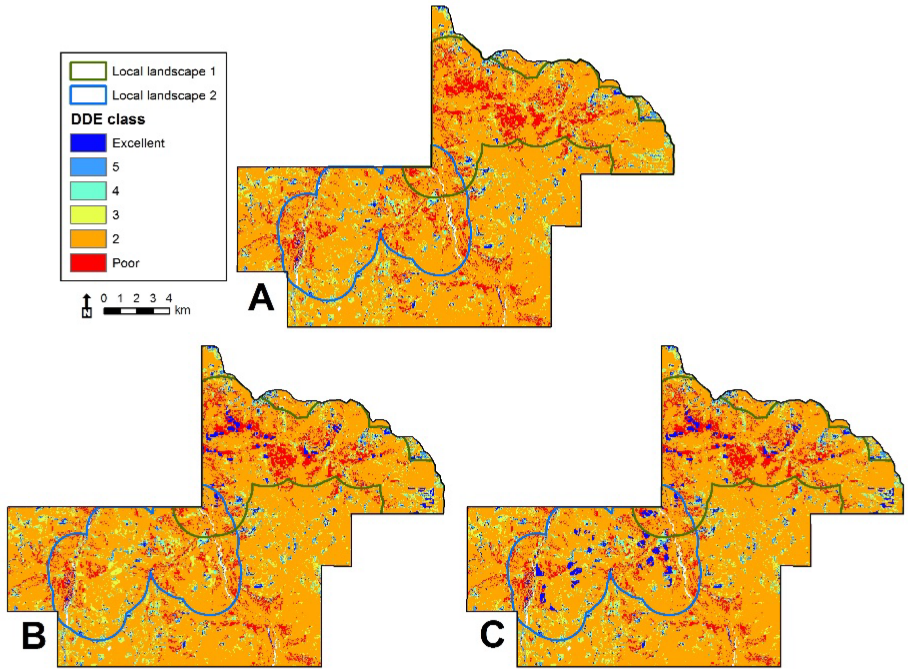
Nutrition Model

The Nutrition Tool predicts the DDE of forage available to elk for any specified area within the Westside regional boundaries identified in Figure 1. Predictions can be made for existing, past, or future conditions, and at scales as small as a stand. Dietary digestible energy not only helps predict occurrence by elk but also has a direct relation to animal performance, such as body fat or pregnancy rates (Cook et al. 2004, 2018). Cook et al. (2004) originally grouped DDE values into four classes, but many Westside landscapes have little habitat in the higher nutritional classes (i.e., excellent or good; Harper 1987; Cook et al. 2016, 2018). To better represent conditions more commonly found in western Oregon and Washington, we suggest that outputs from the nutrition model be summarized using six classes (Table 3). The classified raster (****_6class grid; Table 2) output by the Nutrition Tool uses these classes, making summaries easy to compile. To create six classes from the four original, the marginal and good DDE categories have been split into high and low divisions (Table 3), allowing better quantification of potential or real improvements in nutritional conditions in Westside landscapes.

To characterize nutrition across a project area, users should NOT CALCULATE the average DDE value (that is, the sum of all 30-m pixel raw DDE values for the analysis area divided by the total pixel count), whether for local or regional landscapes, because the high spatial variability in DDE makes this number ecologically irrelevant. However, mean DDE (****_mean_dde, a smoothed version of raw DDE used in the habitat use model) could be averaged across a local landscape if desired. A better approach, however, is to express results by DDE class or groups of classes. Even small increases in percentage area within the good or excellent nutrition classes can result in biologically meaningful increases in elk performance, as described by Cook et al. (2018) and Wisdom et al. (2018*b*). For example, especially at lower values for percentage of a study area in DDE classes 3 and above (e.g., 10%), an increase in this percentage from 10 to 15 is predicted to result in increased pregnancy rates from approx. 45% to about 75%. If summaries of DDE using the original four classes are desired, simply add the counts for low-marginal and high-marginal for the “marginal class” and low-good and high-good for the “good” class. Suggested ways to summarize and display Nutrition Tool outputs include:

1. Percentage of the landscape (and acres, if desired) by DDE class for existing (baseline) conditions and for each management alternative (using the 6-class DDE grid; Table 7).
2. Map of DDE classes across landscape (Fig. 4).
3. Map of “ramped” (non-classified) mean DDE values across the regional landscape using the ****_mean_dde grid.
4. Change map: created to compare DDE classes between base conditions and future management options; each pixel receives an integer value for the increase or decrease in DDE class between the 2 conditions. Display can be of integers or simply positive, negative, or no class change.

Figure 4—Elk nutrition displayed in 6 classes of dietary digestible energy (DDE), showing 2 local landscape boundaries and 3 management scenarios (A, B, and C). From Wisdom et al. (2018*b*).



Although we focus on DDE as the primary output of the Nutrition Tool, other metrics, such as accepted or selected biomass (Table 2, Appendix 1), may be of more interest to meet objectives, and can be easily summarized for regional and local landscapes. For biomass values, which are output in kg/ha, meaningful summaries might include total predicted biomass in the project area. Simply calculate the mean biomass value across all pixels and multiply by the size (in ha) of the area. Another choice is to create a histogram, or frequency distribution, of the biomass values in suitable classes.

Table 7. Percent area by dietary digestible energy (DDE) class for hypothetical regional and local landscapes for the current period (base) and under 2 management options (modified from Wisdom et al. 2018*b*). The summed percentages in classes 3-6 (for pregnancy rates) and 4-6 (for body fat of lactating females) are especially important comparisons, as even small increases in percentages in these classes can lead to biologically meaningful changes in elk performance (see Wisdom et al. 2018*b* for more details and examples).

	DDE class					
	1	2	3	4	5	6
	Poor	Low-marginal	High-marginal	Low-good	High-good	Excellent
Regional landscape						
Base	9.1	76.6	8.3	2.4	1.9	1.6
Option 1	8.6	75.7	8.8	2.4	1.9	2.6
Option 2	8.6	74.9	8.2	2.4	1.9	4.0
Local landscape						
Base	15.8	71.9	6.8	2.6	1.5	1.5
Option 1	14.6	69.9	6.7	2.5	1.5	4.8
Option 2	14.6	69.9	6.7	2.5	1.5	4.8

Tabular use of nutrition model: In addition to creating and using outputs from the Nutrition Tool in ArcGIS, you can also calculate DDE using the PNV- and model region-specific equations found in Cook et al. (2018; Appendices 5 and 6). The tabular application is not scale-dependent but can be used in "gaming scenarios" to understand potential effects on DDE values by changing overstory canopy cover and/or hardwood composition (Vales et al. 2017, Cook et al. 2018; see also Table 12 in Wisdom et al. 2018*b*). For example, a manager may want to evaluate how nutrition differs under 4 harvest prescriptions in conifer stands that reduce canopy cover to 0%, 20%, 40%, and 60% with either constant or varying levels of hardwood composition. The equations can also be used to calculate DDE if you have your own project area data, from field sampling, for each of the three biomass categories (Appendix 4 lists most common elk forage species and their selection class for these calculations). Data on hardwood percentage and canopy cover could also be obtained from field data or from available data sources like GNN or LiDAR and used in the equations. Note that the DDE equations rely on estimates of biomass (Appendix 6), which are in turn partly derived from canopy cover and hardwood percentage (Appendix 5).

Habitat Use Tool

The Habitat Use Tool predicts the relative distribution of elk within a given area. Predictions can be used to manage and forecast elk distributions across different land ownerships or project areas or under management alternatives for a proposed action. For example, actively managing open road systems will alter elk distributions because of the strong influence of this covariate on predicted elk use (Rowland et al. 2018*a*). Likewise, because where elk occur is strongly influenced by DDE levels, areas of higher use by elk reflect landscape conditions that confer positive benefits to animal performance (Cook et al. 2018). That is, the areas where animals spend more time (higher levels of predicted use) generally reflect portions of a given area that provide greater benefits to animal performance.

Predicted use values output by the Habitat Use Tool are very small numbers. The higher the values, the higher the predicted use by elk. Predictions are made for each pixel within a given landscape but are not standardized. The easiest way to visualize these is to map the 5-bin raster created by the Habitat Use

Tool, which will highlight areas of highest and lowest predicted use in your project area - a representation of relative habitat quality. Because every application of the Habitat Use Tool creates a unique set of values that are *relative* to one another, you cannot compare raw values from one area to another to determine where predicted use is "better."

Below we suggest ways for summarizing predictions of elk habitat use for management and interpretation. (Remember, valid values for habitat use are only from the project area, not the surrounding buffer.)

1. *Change maps*: for comparing habitat use in the same project area between different management prescriptions or summer periods (years), one easy way to display and quantify differences is to create a change map in ArcGIS from the baseline conditions. Each pixel can be color coded to represent an increase, decrease, or no change in predicted use (Fig. 5). These changes can also be quantified, e.g., 20% of the landscape improved in predicted use.
2. *Summed predicted use:* for comparisons within the same landscape, you can sum predicted use values for the baseline condition across the landscape (either regional or one or more local landscapes) and then for subsequent model runs under various scenarios. These differences can be represented as a % increase or decrease in use for each area; bar charts are often a good way to display these outcomes (e.g., Fig. 33, Wisdom et al. 2018*b*).
3. *Predicted use by landowner*: if the regional landscape run with Habitat Use Tool includes several land ownerships or wildlife management areas, for any single application of the tool you can sum predicted use by each area and calculate what percentage of total use occurs within each polygon. You can then compare these percentages with the land base occupied by each. For example, 10% of the predicted use may be on state lands but if they compose 25% of the landscape, this indicates that use by elk is lower than expected based on area alone.
4. *Predicted use, by class, under management scenarios:* The 5-class bins that are output from the Habitat Use Tool each represent 20% of the project area. To see how predicted use by elk changes under management scenarios, you can determine the values of predicted use (created by running the tool) that bound each of the 5 classes, i.e., the break points for the upper and lower limits of each bin, and then use these values to classify the raw predicted use values (****_use) under subsequent model runs into the 5 bins. In doing so, you can see what percentage of the landscape (or acres, by simply multiplying each percentage by your project area size) is in the 5 classes following treatment (Table 8).

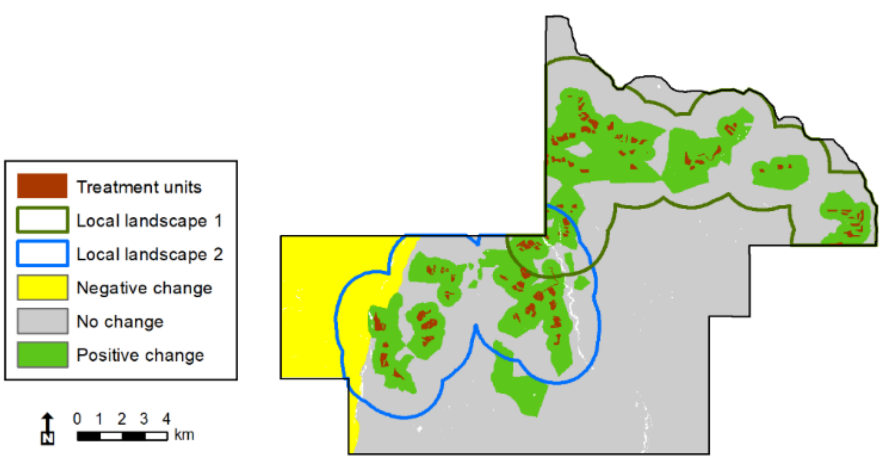


Figure 5—Areas where predicted use by elk is decreasing, increasing, or shows no change under a hypothetical management scenario. Adapted from Wisdom et al. 2018*b*.

Table 8. Five equal-area prediction classes for elk habitat use based on the existing regional landscape (Existing), and the percentage of the landscape in each class for the existing regional landscape and under three management alternatives.

Prediction Class	Predicted Level of Use	Percentage of Study Area			
		Existing	Alternative 1	Alternative 2	Alternative 3
Low	<0.0094	20.0%	20.7%	19.3%	13.7%
Medium-low	0.0094 to 0.0165	20.0%	19.6%	18.5%	17.6%
Medium	0.0166 to 0.0270	20.0%	19.6%	18.9%	19.8%
Medium-high	0.0271 to 0.0501	20.0%	21.1%	20.7%	21.1%
High	>0.0501	20.0%	19.1%	22.6%	27.8%

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Appendix 1. Glossary

ab—acronym for accepted biomass (kg/ha).

Accepted biomass—biomass (kg/ha) or abundance of selected and neutral plant species combined (see Appendix 4 for a list of common plants in western Oregon and Washington and selectivity categories). Cook et al. (2016, 2018) provide more detail.

CANCOV (cc) —percentage canopy cover of all live trees; an attribute from the GNN or LiDAR data used in the Nutrition, update Vegetation, and Habitat Use Tools.

DDE—dietary digestible energy (kcal/g), the primary currency of the nutrition model.

DEM—digital elevation model; a surface representing elevation in a geographic information system. The models are arrays of regularly spaced elevation values that reference a coordinate system; prior DEM's were typically 30-m, but 10-m and even 5-m elevation rasters are now available for many areas.

GNN—Gradient Nearest Neighbor; a modeling method used to produce a suite of >100 vegetation layers, including tree canopy cover and stand height, in Oregon, Washington, and California in support of the Northwest Forest Plan. Also used to refer to the data layers themselves; https://lemma.forestry.oregonstate.edu/data.

GTRN—ground transportation road network; roads layer developed by the Bureau of Land Management that can be used to map various road types "wall-to-wall," i.e., not only on National Forest System lands. Can be explored as a base layer for road covariate in elk habitat use model; note that some data layers are published for Oregon only; https://www.blm.gov/services/geospatial/GISData/oregon.

HARDWD—acronym for percentage of stems in dominant canopy layer that are hardwood tree species (e.g., red alder [*Alnus rubra*] and other alders [*Alnus* spp.], big leaf maple [*Acer macrophyllum*], and paper birch [*Betula papyrifera*]). Used in the Update Vegetation and Nutrition Tools.

Local landscape—area ≥2,000 acres nested within the regional landscape, in which the Nutrition Tool can be applied alone or for which a subset of results from the regional landscape analysis of habitat use can be summarized.

nb— acronym for neutral biomass (kg/ha).

Neutral biomass (kg/ha); biomass of elk forage species that elk neither significantly avoided nor selected (see Appendix 4 for a list of common plants in western Oregon and Washington and selectivity categories). Cook et al. (2016, 2018) provide more detail.

Nooksack—region defined as the northern Cascades near Mt. Baker, Washington (see Fig. 1) in which the Nooksack-specific equations are applied in the Nutrition Tool.

Open road— roads and trails that are known to have motorized use (ATVs, motorcycles, passenger vehicles, etc.), regardless of the management type assigned to the road (i.e., managed as open or closed, the road is considered "open" if there is known motorized use on it during summer).

PNV—potential natural vegetation; used to delineate the two primary modeling zones for which elk nutrition equations were developed: mountain hemlock/silver fir zone and western hemlock; https://ecoshare.info/category/gis-data-vegzones/.

Raster—matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as elevation.

Regional landscape—analysis area within which the Habitat Use Tool is applied; should be at least 25,000 acres, a scale compatible with the range of study areas used to develop and validate the elk habitat-use model.

sb—acronym for selected biomass (kg/ha).

Selected biomass—selected biomass (kg/ha); biomass of forage species for which elk demonstrated significant selection (see Appendix 4 for a list of common plants in western Oregon and Washington and selectivity categories). Cook et al. (2016, 2018) provide more detail.

Springfield (Sp)—modeling region defined as the central Cascades west of Springfield, Oregon (see Fig. 1), in which the Springfield-specific equations are applied in the Nutrition Tool.

SFMHZ—silver fir (*Abies amabilis*)-mountain hemlock (*Tsuga mertensiana*) zone, one of two primary potential vegetation zones used in developing the Westside elk nutrition model; see "PNV."

STNDHGT—stand height; a vegetation attribute in GNN used in the Update Vegetation and Habitat Use Tools to define areas as cover vs. forage.

Tool parameters—Input data needed for each modeling tool in ArcGIS; users select the parameters for most steps, but some are pre-populated with links to files on the T drive (Citrix Users Only).

WHZ— western hemlock (*Tsuga heterophylla*) zone, one of two primary potential vegetation zones used in developing the Westside elk nutrition model; see "PNV."

Willapa Hills (WH)—region defined as coastal foothills of Oregon and Washington west of Centralia, Washington (see Fig. 1) in which the Willapa Hills-specific equations are applied in the Nutrition Tool.

Appendix 2. Beta Testers for Westside Elk Modeling*

Name	Agency	Position	Locale
Kurt Aluzas	USFS	Wildlife biologist	Olympic NF, Quilcene, WA
Robert Alvarado	USFS	Regional wildlife biologist	R6 Regional Office, Portland, OR
Jon Belcher	USFS	GIS/Data Services Specialist	Willamette NF, Springfield, OR
Carol Chandler	USFS	Wildlife program manager	Gifford Pinchot NF, Vancouver, WA
Josh Chapman	USFS	Forest wildlife biologist	Umpqua NF, Roseburg, OR
Ray Davis	USFS	Wildlife biologist	Umpqua NF, Roseburg, OR
Joe Doerr	USFS	Wildlife biologist	Willamette NF, Springfield, OR
Andy Duff	WDFW	Westside GIS and Data Support Analyst	Wildlife Science Division, Olympia, WA
Alex Foster	USFS	Ecologist	PNWRS, Olympia, WA
Justin Hadwen	USFS	Wildlife technician	Umpqua NF, Roseburg, OR
Jeremy Hobson	USFS	GIS	Willamette NF, Springfield, OR
David Keenum	USFS	Geospatial systems specialist	Mt. Baker-Snoqualmie NF, Everett, WA
Cindy Lou McDonald	BLM	GIS specialist	BLM Oregon/Washington State Office, Portland, OR
Bryant Mecklem	BLM	GIS specialist	BLM Oregon/Washington State Office, Portland, OR
Arthur Miller	BLM	GIS specialist	BLM Oregon/Washington State Office, Portland, OR
Lisa Renan	BLM	Wildlife biologist	Roseburg District, Roseburg, OR
Todd Thompson	BLM	Wildlife biologist	BLM Oregon/Washington State Office, Portland, OR
Sonja Weber	USFS	Wildlife biologist	Willamette NF SO; Springfield, OR

*GIS = geographic information system; NF = national forest; USFS = U.S. Department of Agriculture, Forest Service; WDFW = Washington Department of Fish and Wildlife; BLM = U.S. Department of the Interior, Bureau of Land Management.

Appendix 3. Available Data Sources for Westside Elk Model Application

Available Data	Source	Description	Download link
Elevation	DEM	Digital Elevation Model; spatial grid of elevation used to derive the mean slope covariate in the Habitat Use Model. The original modeling project used the 1/3 second (~30-m) National Elevation Dataset from USGS.	http://ned.usgs.gov/
Existing Vegetation (canopy cover, stand height, and hardwood percentage)	GNN	"Gradient Nearest Neighbor" modeling method incorporates field data, Landsat imagery, and multivariate statistics and imputation to produce a variety of existing vegetation layers. The original elk modeling project used attributes from the March 2010 release of the GNN species-size model, developed for Northwest Forest Plan Effectiveness Monitoring. In the most recent version (2017) users can download commonly used attributes from the LEMMA website. Model users can request other variables or annual data from 1986-2016.	https://lemmadownload.forestry.oregonstate.edu/
	GAP	National Gap Analysis land cover data, current vintage 2011; this vegetation classification system is the same as that used in GNN for existing vegetation (the Ecological System Classification of NatureServe; Comer et al. 2003)	https://gapanalysis.usgs.gov/gaplandcover/data/download/
	LANDFIRE	LANDFIRE existing vegetation; the Remap project updated LANDFIRE products to 2016	https://www.landfire.gov/lf_remap.php
	NLCD	National Land Cover Data, 2016 (landcover types for existing vegetation to create elk habitat mask)	https://www.mrlc.gov/data
Roads	GTRN	Ground transportation network; roads and highways compiled by BLM, with most layers for Oregon only; includes BLM inventoried and non-inventoried roads. Attributes may not be well-populated. Model users are advised to first merge the highways and roads layers, add missing roads using appropriately dated aerial imagery, and then create a new road "status" field and populate as open (1) or closed (0), or "Yes" or "No.".	https://www.blm.gov/basic/services-geospatial-gis-data-oregon-transportation
	DNR	Department of Natural Resources, Washington State transportation layers. See GTRN for attribution advice, and always check local sources for actual road status.	https://data-wadnr.opendata.arcgis.com/
	Tiger	Line shapefiles of roads from 2007-2019. Nationwide coverage of roads developed by the U.S. Census Bureau. Files include primary roads (national), primary and secondary roads (state-level), and all roads (county-level).	https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html
Aerial photography for ground truthing	NAIP	U.S. Department of Agriculture's National Agriculture Imagery Program is a collection of aerial photographs. (See the USDA web site for more information: https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/ . Forest Service and BLM employees can access NAIP through the Image Server.	http://datagateway.nrcs.usda.gov/
Satellite imagery for updates	Sentinel	Sentinel-2 produces wall-to-wall, 10-m multispectral images every 5 days and works in Citrix or desktop ArcGIS. The imagery can be used to verify changes from recent fires or other	https://sentinel.esa.int/web/sentinel/missions/sentinel-2;

		disturbance. Using instructions in the T drive Sentinel2 folder, Citrix users can set the image service to show selected imagery over the most recent 14 months.	(Citrix Users: T:\FS\Reference\GIS\r06\ImageCatalog\Sentinel2)
Potential Natural Vegetation	PNV	Potential Natural Vegetation (PNV) zones are a required input to the elk Nutrition Model. The original modeling project used the 2010 OR/WA layers developed by Region 6 and cross-walked each zone to one of the two zones used to develop the nutrition equations (see Cook et al. 2018 for details). The PNV zone raster was produced through a modeling process incorporating field data and spatial data layers.	http://ecoshare.info/category/gis-data-vegzones/
Post-fire vegetation	RAVG	Rapid Assessment of Vegetation Condition after Wildfire (RAVG) provides data on vegetation mortality rates and fire perimeters (usually >1,000 acres) on NFS lands ~45 days after fire containment. Data include burn severity, % canopy cover loss, and satellite imagery pre- and post-fire. For more details see: T:\FS\Reference\GIS\r06\ImageCatalog\GEE_ba7\GEE Basal Area Mortality Products.docx (Citrix Users Only).	https://fsapps.nwcg.gov/ravg/content/home; (Citrix Users: T:\FS\Reference\GIS\r06\ImageCatalog\GEE_ba7\a_ba7\GEE_R06_ba7_masked)

Appendix 4. Selectivity of Elk Forage Species in Western Oregon and Washington

Selectivity indices (Ivlev [1961] and Chesson [1978], as reported in Manly et al. [1993]), percentage of diets, and selectivity category for plant species in elk foraging trials in western Oregon and Washington. Plant names are arranged alphabetically within three categories of decreasing order of selectivity. Biologists collected foraging data using captive elk during summer and autumn, 2000-2002 (see Cook et al. 2016 for more details).

Scientific name	Plant group[a]	Plant code	*n*	Ivlev	Chesson	Diet (%)	Selectivity[b]
Acer circinatum	DS	ACCI	62	0.626	0.091	11.39	S
Acer macrophyllum	DS	ACMA	28	0.474	0.102	4.86	S
Alnus incana	DS	ALIN	1	0.875	0.0757	1.50	S
Alnus rubra	DS	ALRU	36	0.232	0.033	1.69	S
Anaphalis margaritacea	Fb	ANMA	48	0.272	0.025	1.93	S
Bryoria spp.[c]	NV	BRYO	10			3.75	S
Buddleja davidii	DS	BUDA	11	0.435	0.079	1.72	S
Calamagrostis canadensis	Gr	CACA	1	0.966	0.2305	5.80	S
Carex spp.	Gr	CARE	70	0.237	0.043	2.05	S
Cinna latifolia	Gr	CILA	1	0.936	0.0527	3.00	S
Clintonia uniflora	Fb	CLUN	13	0.800	0.109	14.52	S
Corylus cornuta	DS	COCO	24	0.571	0.074	4.63	S
Galepsis tetrahit	Fb	GATE	2	0.550	0.008	0.35	S
Hypericum perforatum	Fb	HYPE	18	0.222	0.015	1.09	S
Hypochaeris radicata	Fb	HYRA	25	0.340	0.057	5.50	S
Iris tenax	Fb	IRTE	32	0.540	0.038	5.50	S
Ligusticum apiifolium	Fb	LIAP	1	0.974	0.1625	7.69	S
Linnaea borealis	ES	LIBO	13	0.506	0.030	2.88	S
Lolium perenne	Gr	LOPE	1	0.954	0.136	4.20	S
Lonicera ciliosa	DS	LOCI	4	0.565	0.028	1.23	S
Luzula spp.	Gr	LUZU	43	0.192	0.033	4.21	S
Maianthemum dilatatum	Fb	MADI	16	0.499	0.104	6.81	S
Mushroom[c]	NV	MUSH	14			0.02	S
Oplopanax horridum	DS	OPHO	12	0.526	0.080	4.73	S
Oxalis oregana	Fb	OXOR	13	0.671	0.109	9.15	S
Pedicularis spp.	Fb	PEDI	1	0.868	0.0212	8.50	S
Petasites fridigus	Fb	PEFR	6	0.524	0.059	1.53	S
Phalaris arundinacea	Gr	PHAR	4	0.903	0.104	4.75	S
Phleum pratense	Gr	PHPR	1	0.846	0.0242	1.20	S
Pyrus communis	DS	PYCO	1	0.984	0.2476	12.30	S
Pyrus fusca	DS	PYFU	1	0.857	0.0341	1.30	S
Rhamnus purshiana	DS	RHPU	24	0.329	0.046	1.73	S
Ribes sanguineum	DS	RISA	21	0.272	0.038	2.98	S
Rubus parviflorus	DS	RUPA	45	0.191	0.030	8.38	S
Salix spp.	DS	SALI	16	0.647	0.086	4.17	S
Smilicina spp.	DS	SMIL	10	0.368	0.038	1.44	S
Sorbus sitchensis	DS	SOSI	11	0.871	0.109	10.65	S
Spiraea douglasii	DS	SPDO	8	0.666	0.142	4.11	S

Scientific name	Plant group[a]	Plant code	*n*	Ivlev	Chesson	Diet (%)	Selectivity[b]
Symphoricarpos spp.	DS	SYMP	38	0.487	0.053	6.51	S
Tolfieldia glutinosa	Fb	TOGL	1	0.778	0.016	0.80	S
Trifolium spp.	Fb	TRIF	4	0.730	0.152	8.95	S
Vaccinium parvifolium	DS	VAPA	72	0.559	0.138	10.35	S
Valeriana sitchensis	Fb	VASI	4	0.534	0.064	2.25	S
Achlys triflora	Fb	ACTR	8	0.275	0.014	1.18	N
Adenocaulon bicolor	Fb	ADBI	14	0.189	0.013	0.86	N
Adiantum pedatum	Fn	ADPE	7	-0.197	0.038	0.70	N
Agrostis exarata	Gr	AGEX	11	-0.029	0.008	1.49	N
Agrostis sp	Gr	AGRO	32	0.199	0.060	3.55	N
Alnus sinuata	DS	ALSI	5	0.265	0.021	5.34	N
Amelanchier alnifolia	DS	AMAL	4	0.174	0.021	1.13	N
Anemone deltoidea	Fb	ANDE	5	-0.190	0.005	0.18	N
Angelica genuflexa	Fb	ANGE	1	0.000	0.0062	0.30	N
Antennaria spp.	Fb	ANTE	1	0.000	0.0038	0.10	N
Arctostaphylos columbiana	ES	ARCO	5	-0.267	0.006	0.14	N
Arenaria macrophylla	Fb	ARMA	2	0.741	0.132	1.00	N
Artemisia suksdorfii	Fb	ARSU	1	0.000	0.0016	0.20	N
Aruncus sylvester	Fb	ARSY	2	-0.200	0.003	0.20	N
Asarum caudatum	Fb	ASCA	6	-0.221	0.004	0.30	N
Astragalus spp.	Fb	ASTR	3	-0.444	0.008	0.67	N
Attached leaf lichens[c]	NV	ALLI	13			0.40	N
Bromus vulgaris	Gr	BRVU	41	0.047	0.042	2.32	N
Campanula scouleri	Fb	CASC	17	-0.175	0.006	0.20	N
Castanopsis chrysophylla	ES	CACH	8	0.024	0.022	0.79	N
Chrysanthemum leucanthemum	Fb	CHLE	20	-0.181	0.004	0.56	N
Cirsium spp.	Fb	CIRS	36	0.071	0.016	4.00	N
Cornus canadensis	DS	COCA	13	-0.018	0.016	2.02	N
Cornus nuttallii	DS	CONU	2	0.778	0.087	2.40	N
Cornus stolonifera	Fb	COST	1	0.333	0.0109	0.20	N
Crepis spp.	Fb	CREP	11	-0.232	0.004	0.33	N
Cytisus scoparius	DS	CYSC	3	-0.333	0.005	0.07	N
Dactylis glomerata	Gr	DAGL	5	0.541	0.125	6.34	N
Daucus carota	Fb	DACA	3	0.489	0.047	0.63	N
Dianthus armeria	Fb	DIAR	2	-0.500	0.001	0.05	N
Dicentra formosa	Fb	DIFO	14	0.170	0.027	0.74	N
Disporum spp.	Fb	DISP	19	-0.008	0.010	0.38	N
Dryopteris austriaca	Fb	DRAU	18	-0.113	0.014	0.38	N
Elymus glaucus	Gr	ELGL	16	-0.179	0.017	1.06	N
Elymus spp.	Gr	ELYM	40	-0.046	0.047	2.68	N
Epilobium angustifolium	Fb	EPAN	46	0.117	0.028	9.34	N
Equisetum spp.	Gr	EQUI	10	-0.106	0.013	2.04	N
Festuca occidentalis	Gr	FEOC	13	-0.295	0.004	0.14	N
Festuca sublulata	Gr	FESU	3	-0.115	0.004	0.83	N
Fragaria vesca	Fb	FRVE	5	-0.666	0.002	1.02	N
Fungi[c]	NV	FUNG	13			0.64	N

Scientific name	Plant group[a]	Plant code	*n*	Ivlev	Chesson	Diet (%)	Selectivity[b]
Galium oreganum	Fb	GAOR	4	0.257	0.018	0.55	N
Galium triflorum	Fb	GATR	40	0.048	0.015	2.21	N
Geum macrophyllum	Fb	GEMA	4	-0.600	0.002	0.10	N
Glyceria elata	Gr	GLEL	7	0.187	0.036	3.49	N
Glyceria spp.	Gr	GLYC	1	0.333	0.0041	0.20	N
Gymnocarpium dryopteris	Fn	GYDR	3	0.133	0.006	0.27	N
Hieracium albiflorum	Fb	HIAL	16	0.000	0.042	2.11	N
Holcus lanatus	Gr	HOLA	34	0.120	0.026	5.36	N
Holodiscus discolor	DS	HODI	23	0.226	0.035	2.20	N
Hydrophyllum fendleri	Fb	HYFE	2	0.000	0.004	0.10	N
Juncus spp.	Gf	JUNC	9	-0.369	0.007	0.21	N
Lactuca muralis	Fb	LAMU	36	0.029	0.032	4.67	N
Lathyrus spp.	Fb	LATH	9	0.254	0.015	0.46	N
Lilium columbianum	Fb	LICO	3	0.167	0.038	0.77	N
Lupinus spp.	Fb	LUPI	5	-0.115	0.004	0.34	N
Lysichitum americanum	Fb	LYAM	5	0.339	0.010	4.90	N
Melica bulbosa	Gr	MEBU	1	-0.739	0.0028	0.30	N
Mimulus moschatus	Fb	MIMO	1	0.000	0.0021	0.10	N
Monotropa uniflora	Fb	MOUN	3	0.367	0.010	0.27	N
Montia sibirica	Fb	MOSI	15	-0.176	0.012	0.39	N
Oemleria cerasiformis	DS	OECE	7	0.160	0.022	0.50	N
Penstemon spp.	Fb	PENS	7	-0.105	0.014	1.44	N
Phacelia hastata	Fb	PHHA	1	-1.000	0	0.00	N
Plantago spp.	Fb	PLAN	4	-0.017	0.007	0.18	N
Poa compressa	Gr	POCO	3	0.059	0.009	0.40	N
Populus trichocarpa	DS	POTR	3	-0.012	0.080	1.90	N
Prunus emarginata	DS	PREM	27	0.045	0.013	1.43	N
Ranunculus spp.	Fb	RANU	2	-0.030	0.032	1.60	N
Ribes bracteosum	DS	RIBR	2	-0.063	0.003	0.40	N
Ribes lacustre	DS	RILA	1	0.000	0.0055	0.10	N
Ribes spp.	DS	RIBE	1	-1.000	0	0.00	N
Rosa gynmocarpa	DS	ROGY	34	0.044	0.025	0.79	N
Rubus nivalis	DS	RUNI	3	-0.615	0.001	0.07	N
Rubus pedatus	DS	RUPE	9	-0.445	0.005	0.41	N
Rubus spectabilis	DS	RUSP	44	-0.047	0.017	9.03	N
Rumex occidentalis	Fb	RUOC	3	-0.556	0.001	0.07	N
Rumex spp.	Fb	RUME	13	-0.013	0.012	0.41	N
Sambucus spp.	DS	SAMB	38	0.076	0.061	2.68	N
Satureja douglasii	Fb	SADO	1	0.000	0.0051	0.10	N
Scutellaria galericulata	Fb	SCGA	5	-0.033	0.059	2.70	N
Scutellaria lateriflora	Fb	SCLA	2	-0.073	0.002	0.75	N
Senecio sylvaticus	Fb	SESY	6	0.037	0.011	0.37	N
Senecio triangularis	Fb	SETR	4	0.337	0.021	0.43	N
Solidago canadensis	Fb	SOCA	6	-0.056	0.004	0.15	N
Sonchus asper	Fb	SOAS	5	0.110	0.010	0.24	N
Sorbus aucuparia	DS	SOAU	4	0.054	0.012	0.03	N

Scientific name	Plant group[a]	Plant code	*n*	Ivlev	Chesson	Diet (%)	Selectivity[b]
Stachys cooleyae	Fb	STCO	2	0.614	0.033	1.10	N
Stellaria spp.	Fb	STEL	30	-0.008	0.010	0.39	N
Streptopus roseus	Fb	STRO	4	0.248	0.021	0.65	N
SyNthyris reniformis	Fb	SYRE	2	-0.333	0.005	0.10	N
Taraxacum spp.	Fb	TARA	3	-0.333	0.003	0.07	N
Thalictrum occidentale	Fb	THOC	1	0.000	0.0013	0.10	N
Tiarella trifoliata	Fb	TITR	18	-0.168	0.035	1.24	N
Tolmiea menziesii	Fb	TOME	10	-0.354	0.007	1.81	N
Trisetum cernuum	Gr	TRCE	5	-0.250	0.058	0.98	N
Typha latifolia	Gr	TYLA	1	0.857	0.106	1.30	N
Vaccinium alaskaense/ovalifolium	DS	VALOV	23	0.290	0.055	21.23	N
Vaccinium membranaceum	DS	VAME	6	-0.963	0.000	0.03	N
Vancouveria hexandra	Fb	VAHE	21	0.059	0.017	0.76	N
Veratrum viride	Fb	VEVI	7	0.035	0.007	0.31	N
Veronica officinalis	Fb	VEOF	12	0.011	0.023	0.76	N
Vicia spp.	Fb	VICI	3	-0.394	0.015	0.33	N
Viola spp.	Fb	VIOL	44	-0.165	0.010	0.55	N
Xerophyllum tenax	Fb	XETE	2	-0.727	0.001	1.80	N
Abies amabilis	Cn	ABAM	11	-1.000	0.000	0.00	A
Abies procera	Cn	ABPR	4	-1.000	0.000	0.00	A
Arbutus menziesii	ES	ARME	1	-0.412	0.0039	0.50	A
Athyrium filix-femina	Fn	ATFI	25	-0.255	0.008	1.72	A
Berberis nervosa	ES	BENE	64	-0.678	0.005	1.34	A
Blechnum spicant	Fn	BLSP	17	-0.920	0.000	0.04	A
Ceanothus velutinus	ES	CEVE	8	-0.500	0.005	1.86	A
Chimaphila menziesii	ES	CHME	2	-1.000	0.000	0.00	A
Circaea alpine	Fb	CIAL	5	-0.800	0.000	0.02	A
Clubmoss, liverwort, moss[c]	NV	MOSS	7			3.37	A
Deschampsia elongata	Gr	DEEL	15	-0.448	0.005	0.35	A
Digitalis purpurea	Fb	DIPU	18	-0.952	0.000	0.06	A
Epilobium paniculatum	Fb	EPPA	8	-0.521	0.003	0.08	A
Epilobium watsonii	Fb	EPWA	22	-0.322	0.005	0.58	A
Erechtites minima	Fb	ERMI	6	-0.448	0.002	0.17	A
Gaultheria ovatifolia	ES	GAOV	7	-0.952	0.000	0.07	A
Gaultheria shallon	ES	GASH	54	-0.247	0.035	9.25	A
Ilex sp.	ES	ILEX	3	-0.667	0.002	0.03	A
Mentha arvensis	Fb	MIAR	5	-0.600	0.002	0.04	A
Menziesia ferruginea	DS	MEFE	12	-0.887	0.000	0.04	A
Nothochelone nemorosa	Fb	NONE	1	-0.909	0.0002	0.20	A
Osmorhiza chilensis	Fb	OSCH	6	-0.460	0.001	0.08	A
Phododendron albiflorum	ES	RHAL	3	-0.867	0.000	0.03	A
Phyllodoce empetriformis	ES	PHEM	2	-1.000	0.000	0.00	A
Pinus monticola	Cn	PIMO	1	-1.000	0	0.00	A
Poa pratensis	Gr	POPR	15	-0.699	0.003	0.10	A
Poa sp.	Gr	POAS	8	-0.640	0.006	0.98	A

Scientific name	Plant group[a]	Plant code	*n*	Ivlev	Chesson	Diet (%)	Selectivity[b]
Polystichum munitum	Fn	POMU	76	-0.874	0.004	0.82	A
Prunella vulgaris	Fb	PRVU	7	-0.643	0.001	0.06	A
Pseudotsuga menziesii	Cn	PSME	57	-0.342	0.031	3.05	A
Pteridium aquilinium	Fn	PTAQ	71	-0.122	0.037	6.80	A
Pyrola spp.	Fb	PYRO	1	-1.000	0	0.00	A
Rhododendron macrophyllum	ES	RHMA	4	-0.883	0.000	0.55	A
Ribes divaricatum	DS	RIDI	8	-0.377	0.008	0.20	A
Rubus discolor	DS	RUDI	24	-0.305	0.011	2.46	A
Rubus laciniatus	ES	RULA	24	-0.505	0.005	0.48	A
Rubus leucodermis	DS	RULE	24	-0.563	0.002	0.40	A
Rubus ursinus	DS	RUUR	80	-0.587	0.003	1.94	A
Solanum dulcamara	Fb	SODU	4	-1.000	0.000	0.00	A
Tanacetum vulgare	Fb	TAVU	1	-0.778	0.0002	0.10	A
Taxus brevifolia	ES	TABR	5	-1.000	0.000	0.00	A
Tellima grandiflora	Fb	TEGR	5	-0.700	0.002	0.06	A
Thuja plicata	Cn	THPL	9	-1.000	0.000	0.00	A
Trientalis latifolia	Fb	TRLA	29	-0.412	0.003	0.13	A
Trillium spp.	Fb	TRIL	6	-0.417	0.003	0.07	A
Tsuga heterophylla	Cn	TSHE	31	-0.800	0.002	0.07	A
Tsuga mertensiana	Cn	TSME	5	-1.000	0.000	0.00	A
Urtica dioica	Fb	URDI	2	-1.000	0.000	0.00	A
Veronica americana	Fb	VEAM	2	-1.000	0.000	0.00	A
Whipplea modesta	Fb	WHMO	3	-0.897	0.000	0.07	A

[a] Plant group codes are: Cn = conifer; DS = deciduous shrub; ES = evergreen shrub; Fb = forb; Fn = fern; Gr = graminoid; NV = nonvascular plant.
[b] S = significantly selected, A = significantly avoided, and N = neither selected nor avoided.
[c] Biomass availability was not measured and thus no estimates of selection could be calculated. Dietary percentages are based only on those elk pens where the species occurred in elk diets. The selection category was based on the authors' general observations of elk response to these species.

Appendix 5. Equations to Predict Biomass (kg/ha) of Three Forage Classes for Elk

Equations were based on stand and forest overstory conditions by potential natural vegetation zones and three modeling regions (Nooksack [Nk], Willapa Hills [WH], and Springfield [Spr]) in western Oregon and Washington, USA. (Adapted from Table 6 in Cook et al. 2018).

Pacific silver fir/mountain hemlock zone, all modeling regions

$AB^{a} = 657.6 - 11.28(CC) + 0.0458(CC^2) + 553.06(HW)$

$NB = 527.8 - 6.09(CC) + 590.49(HW)$

$SB = 1/((0.00833 + 0.00062(CC))$

Western Hemlock Zone, by modeling region

$AB_{Nk} = 707.3 - 13.93(CC) + 0.0731(CC^2) + 383.2(HW)$

$AB_{WH} = 707.3 - 6.28(CC) - 0.0154(CC^2) + 383.2(HW)$

$AB_{Spr} = 490.5 - 11.70(CC) + 0.0731(CC^2) + 383.2(HW)$

$NB_{Nk} = 671.8 - 16.91(CC) + 0.1092(CC^2) + 268.1(HW)$

$NB_{WH} = 477.4 - 3.90(CC) - 0.0151(CC^2) + 268.1(HW)$

$NB_{Spr} = 308.5 - 7.59(CC) + 0.0473(CC^2) + 268.1(HW)$

$SB_{Nk} = 80.1 - 0.66(CC) + 99.83(HW)$

$SB_{WH} = 212.6 - 2.20(CC) + 99.83(HW)$

$SB_{Spr} = 166.2 - 1.68(CC) + 99.83(HW)$

[a] Forage class codes (variable names) are NB = biomass (kg/ha) of neutral plant species (those plants that elk neither significantly avoided nor selected), SB = biomass (kg/ha) of selected plant species (those plant species that elk significantly selected), and AB = biomass (kg/ha) of accepted species (SB and NB combined). Predictor variable codes are CC = overstory canopy cover (%); HW = proportion of stems in dominant canopy layer that are hardwood tree species (red and other alders [*Alnus* spp.], bigleaf maple [*Acer macrophyllum*], and paper birch [*Betula papyrifera*]). When using these equations independent of the Nutrition Tool, **values for hardwoods (HW) must be entered as a proportion, i.e., between 0 and 1, to obtain the correct estimates of biomass.**

Appendix 6. Equations to Calculate DDE from Forage Biomass

Equations to predict dietary digestible energy (DDE) for elk based on biomass (kg/ha) of three forage classes by potential natural vegetation zones and three modeling regions (Nooksack [Nk], Willapa Hills [WH], and Springfield [Spr]) in western Oregon and Washington, USA (adapted from Table 4, Cook et al. 2018).

Pacific silver fir/mountain hemlock zone, all modeling regions

$DDE = 2.44 + 0.000889(NB)^{a} + 0.00308(SB) – 0.00000546(SB \times NB)$

Western Hemlock Zone, by modeling region

$DDE_{Nk} = 2.362 + 0.00108(NB) + 0.000504(SB) – 0.00000361(SB \times NB)$

$DDE_{WH} = 2.278 + 0.00062(NB) + 0.00120(SB) - 0.00000172(SB \times NB)$

$DDE_{Spr} = 2.300 + 0.00108(NB) + 0.00129(SB) - 0.00000418(SB \times NB)$

[a] Forage class codes (variable names) are NB = biomass (kg/ha) of neutral plant species (those plants that elk neither significantly avoided or selected), SB = biomass (kg/ha) of selected plant species (those plant species that elk significantly selected), and AB = biomass (kg/ha) of accepted species (SB and NB combined). See Appendix 4 for a list of elk forage species in these preference categories.