

FIRE-BIRD: A GIS-Based Toolset for Applying Habitat Suitability Models to Inform Land Management Planning

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Abstract

Habitat suitability models can inform forest management for species of conservation concern. Models quantify relationships between known species locations and environmental attributes, which are used to identify areas most likely to support species of concern. Managers can then limit negative human impacts in areas of high suitability or conduct habitat improvements in areas of marginal suitability. Model applications are computationally intensive, requiring time and resources not available to most managers. We developed FIRE-BIRD, an ArcGIS toolbox, to streamline preliminary data processing and application of habitat suitability models to forest management planning for disturbance-associated woodpeckers of conservation concern. Tools are currently developed for black-backed (*Picoides arcticus*) and white-headed woodpecker (*Dryobates albolarvatus*) in Inland Northwest burned forests; black-backed, white-headed, and hairy woodpecker (*D. villosus*) in Northern Sierra burned forests; and white-headed woodpecker in Inland Northwest unburned forests. This manual provides tool operating instructions and guidelines to interpret resulting habitat suitability maps. The suite of species currently included makes this toolset best suited for postfire management and restoration treatments in dry mixed-conifer forests. Incorporating additional species and forest conditions in the future will broaden the scope of this toolset.

Keywords: decision support, disturbance-associated woodpecker, dry conifer forest, forest management, habitat suitability model, cavity nest, species distribution, species of conservation concern

Cover photos

Aerial view of recent wildfire in the Frank Church-River of No Return Wilderness (top left) (photo by Victoria A. Saab, USDA Forest Service); screenshot of dialog box for black-backed woodpecker tool (center left); habitat suitability index map for black-backed woodpecker at the 2015 Canyon Creek Fire, Oregon (bottom left); black-backed woodpecker (top right); Lewis's woodpecker (center right); white-headed woodpecker (bottom right) (woodpecker photos by Tom Kogut).

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1. Introduction

To conserve and promote biological diversity, land managers must identify suitable habitat for species of conservation concern. Managers can then restrict potentially detrimental activities (e.g., salvage logging) to areas of lower habitat suitability, and target beneficial activities (e.g., restoration) where habitat suitability is higher (Barrows et al. 2008; Brambilla and Saporetti 2014; Guisan et al. 2013; Hollenbeck et al. 2011; Latif et al. 2013, 2015). Land managers often rely on informal methods, such as verbal descriptions based on expert knowledge, for identifying habitat. These methods may have unknown reliability and limited ability to reflect complex habitat associations. In contrast, habitat suitability models (also called species distribution models; hereafter, “habitat models”) rigorously quantify suitable habitat by using data-driven algorithms capable of representing complex relationships with multiple environmental attributes (Elith and Leathwick 2009; Franklin 2009; Guisan and Thuiller 2005; Guisan et al. 2013). Such information can enhance planning effectiveness and is needed to make management decisions robust to legal scrutiny (e.g., *Defenders of Wildlife vs. Sally Jewell, U.S. Department of the Interior and Daniel M. Ashe, U.S. Fish and Wildlife Service*, 4 Apr 2016, Case 9:14-cv-00246-DLC, Document 108). Despite numerous publications describing new models, few models are applied (reviewed by Guisan et al. [2013]). Application of habitat models is computationally intensive, requiring time and resources not available to most natural resource specialists at land management agencies (hereafter, “managers”).

Managers currently rely heavily on geographic information systems (GIS) technology to develop and inform their decisions and planning. In particular, managers commonly use ArcGIS (Esri 2015) software, which provides a powerful set of mapping and spatial analysis tools through a relatively user-friendly graphic interface. Because much of the planning process takes place in an ArcGIS environment, managers must at some point translate habitat information into map layer(s) viewable in ArcGIS. Habitat models are fundamentally statistical entities developed by using statistical software packages (e.g., R; R Core Team 2016) whose outputs do not readily interface with ArcGIS. Analysts often develop habitat models, however, with remotely sensed environmental data to facilitate translation of model predictions into habitat maps. Recent versions of ArcGIS software increasingly allow users to develop custom tools to generate and process spatial data layers. We leverage these new features to develop ArcGIS tools that help users with limited time and technical resources to translate statistical model predictions into habitat maps.

We developed a series of ArcGIS tools for applying habitat models of woodpeckers associated with recent disturbances to guide management of dry conifer forests in western North America. Large-scale disturbances, especially wildfire and bark beetle outbreaks, strongly influence vegetation structure and composition in these forests. Anthropogenic land use and climate change have altered disturbance timing and severity, along with associated structural and wildlife habitat features (Franklin and Johnson 2012; Fulé et al. 2012; Hessburg et al. 2007, 2015; Schoennagel et al. 2004; Whitlock et al. 2003). In particular, many woodpecker species benefit from habitats generated and maintained by large-scale disturbances (Latif et al. 2013; Russell et al. 2007; Saab et al. 2009, 2014; Wightman et al. 2010).

State and Federal agencies are concerned with conservation of these woodpeckers and have legal requirements to document the effects of management actions on their habitats and populations. Forest managers must therefore consider the tradeoffs between land uses and wildlife habitat conservation in their planning documents. In recently disturbed forests, managers often try to meet conflicting objectives of conserving wildlife habitat while also providing economic opportunities through salvage logging. As new disturbances occur, model application tools targeting disturbed habitats could facilitate rapid identification of suitable habitat for woodpeckers and other disturbance-associated species. Additionally, GIS tools could help identify suitable habitat in disturbance-maintained dry forests for informing large-scale restoration and fuels reduction projects (e.g., those funded by the Collaborative Forest Landscape Restoration Program) (Mellen-McLean et al. 2013, 2015). Data used to develop models presented in this manual also helped the Forest Service successfully defend against litigation challenging commercial salvage logging after the 2002 Toolbox Fire in Oregon (Oregon Natural Resources Council Fund, et al., Plaintiffs, vs. Linda Goodman, et al., Defendants, 22 June 2004, Case No. 04-593-CO).

In this manual, we summarize the ecological basis and applicability of habitat models provided in ArcGIS application tools. We then provide step-by-step instructions for implementing these tools, which currently quantify postwildfire (hereafter, “postfire”) habitat for black-backed woodpecker (*Picoides arcticus*), white-headed woodpecker (*Dryobates albolarvatus*), and hairy woodpecker (*D. villosus*), along with unburned forest habitat, maintained by disturbance processes, for white-headed woodpecker. Finally, we describe how mapped predictions can be interpreted to appropriately inform forest management at the project scale.

2. Conceptual Basis for Habitat Suitability Models

2.1 Black-Backed Woodpecker in Burned Forests

Latif et al. (2013) developed habitat suitability index (HSI) models for nesting black-backed woodpecker with nest location data collected following wildfire in dry conifer forests of Oregon, Washington, and Idaho. Black-backed woodpeckers are disturbance specialists that favor forests burned by wildfire across much of their range (Dixon and Saab 2000). Within burned forests, these birds excavate nest cavities in snags in areas of relatively high snag densities, which provide foraging opportunities for their preferred prey (i.e., bark and wood-boring beetle larvae; *Scolytidae* and *Cerambycidae*, respectively). Models were therefore developed by using remotely sensed burn severity and prefire canopy data along with a topography variable (cosine aspect) found in previous work to be potentially important (table 2.1).

Table 2.1—Descriptions and descriptive statistics for environmental variables at nest and available sites used to develop habitat models for nesting black-backed woodpeckers. Descriptive statistics that equally weighted data from three surveyed wildfire locations (see Latif et al. 2013). Available sites represent survey units within which nest-searching occurred.

Variable (abbreviation)	Description	Mean, Median (95th percentile)	
		Nest	Available
Cosine aspect (cosasp) ^a	Pixel cosine-transformed aspect derived from digital elevation model (unitless)	0.34, 0.51 (-0.98, 1.00)	0.00, 0.00 (-1.00, 1.00)
Burn severity (locdnbr) ^b	Median index of burn severity (change in [delta] normalized burn ratio prefire to postfire) using Landsat TM satellite imagery for 2-acre (3×3-cell) moving window (unitless)	529.3, 515.2 (169.4, 862.3)	328.1, 297.1 (-59.6, 806.5)
Local canopy cover (loccc) ^c	Proportion of 2-acre (3×3-cell) moving window with >40% canopy cover recorded before fire	0.85, 1.00 (0.00, 1.00)	0.63, 0.89 (0.00, 1.00)
Landscape canopy cover (landcc)	Proportion of 776-acre (0.6-mile-radius) moving window with >40% canopy cover recorded before fire	0.65, 0.62 (0.39, 0.93)	0.59, 0.59 (0.17, 0.95)

^a Topography data were derived from digital elevation model data (LANDFIRE 2018).

^b The original HSI (ensemble) model was developed with “extended assessment” burn severity data (MTBS 2012), wherein postfire imagery was recorded the year following wildfire. We provide an alternate version developed with RAVG data, however, to support immediate postfire planning (for details, see Appendix A).

^c Canopy cover data were acquired from online sources as available for individual wildfire locations (LEMMA 2018; USFS 2018a).

2.1 Black-Backed Woodpecker in Burned Forests (continued)

Using different modeling techniques and different subsets of these data, Latif et al. (2013) developed a series of eight models and combined their predictions using an ensemble approach. Resulting predictions described the number of models (0–8) classifying a site as suitable for nesting (hereafter, “ensemble predictions”). Predictions were mainly shaped by nesting affinity for high-severity burned sites with moderate-to-high prefire canopy cover. Areas classified as suitable by more models are considered more suitable, and areas classified as suitable by some but not all models represent areas of uncertainty where further surveys could improve ecological knowledge and help refine models (Latif et al. 2013).

2.2 White-Headed Woodpecker in Unburned Forests

Latif et al. (2015) developed and evaluated habitat suitability models for nesting white-headed woodpeckers in unburned dry conifer forests of Oregon. White-headed woodpeckers favor forests dominated by ponderosa pine (*Pinus ponderosa*) and characterized by forest canopy mosaics. In particular, they establish nest sites in relatively open-canopy forests but forage largely in more closed-canopy forests (Hollenbeck et al. 2011; Latif et al. 2015). To quantify these habitat associations, Latif et al. (2015) developed models using variables describing topography, canopy cover, and coverage of ponderosa pine-dominated forest compiled at a 30-m resolution at nest and available sites (table 2.2). They developed and evaluated two different types of models, but one developed by using the Maxent modeling technique (Phillips et al. 2006) performed especially well. Maxent model predictions quantified affinity for nest sites with lower local canopy cover, higher landscape canopy cover, and a high percentage of ponderosa-pine dominance.

To expedite model application particularly over large landscapes, the ArcGIS tool applies a simplified version of the published model. The simplified model excludes edge density (density of edge between high and low canopy cover patches), because it is computationally intensive to calculate and contributed negligibly to performance of the published model. Additionally, simplified model HSIs represent one version of the model fitted to all available data (published HSIs were averaged across model replicates fitted to resampled data subsets). In short, the simplified model generates HSIs virtually identical to the published model but reduces the time required for data processing and computation.

2.2 White-Headed Woodpecker in Unburned Forests (continued)

Table 2.2—Descriptions and descriptive statistics for environmental variables at nest and available sites used to develop habitat models for nesting white-headed woodpeckers in unburned forests. Descriptive statistics were calculated for samples balanced across subsets of nest location data (described by Latif et al. 2015). Available sites represent areas within which nest-searching occurred.

Variable (abbreviation)	Description	Mean, Median (95th percentile)	
		Nest	Available
Slope (slp) ^a	pixel slope in % rise over run	3.7, 2.0 (0.0, 16.3)	4.5, 3.0 (0.0, 20.0)
Cosine Aspect (cosasp) ^{a,b}	pixel cosine-transformed orientation of slope (unitless)	0.05, 0.00 (-0.99, 0.98)	0.00, 0.00 (-0.99, 0.98)
Local canopy cover (loccc) ^c	percent canopy cover for 776-acre (3×3-cell) neighborhood	40.1, 40.6 (8.7, 68.4)	42.9, 42.4 (14.1, 73.8)
Landscape canopy cover (landcc) ^c	percent canopy cover for 776-acre (0.6-mile-radius) neighborhood	43.2, 42.0 (29.9, 60.1)	43.0, 42.1 (25.0, 62.3)
Ponderosa pine (pipo) ^c	Percent ponderosa pine-dominated forest ^d for 776-acre (0.6-mile-radius) neighborhood	80.3, 84.0 (49.3, 97.0)	73.3, 77.0 (28.0, 96.9)

^a Topography data were derived from digital elevation model data (LANDFIRE 2018).

^b cosasp = 0 when slp ≤ 2%.

^c Forest structure and composition data were derived from gradient nearest-neighbor data (LEMMA 2018).

^d A pixel was classified as ponderosa pine-dominated forest if dominated or codominated by ponderosa pine as classified by gradient nearest-neighbor data (LEMMA 2018).

2.3 White-Headed Woodpecker in Burned Forests of the Inland Pacific Northwest

White-headed woodpecker nest habitat relationships in recently burned forests are analogous to those in unburned forests, wherein canopy mosaics are favored for nesting (compare Wightman et al. 2010 with Hollenbeck et al. 2011 and Latif et al. 2015). Wightman et al. (2010) described a postfire habitat model for white-headed woodpeckers. With additional data from two wildfire locations in Oregon (Toolbox, 2002; Canyon Creek, 2015) (table 2.3.1), we revised the Wightman et al. (2010) model using the Maxent technique to generate a new model. We briefly summarize model structure, development, evaluation, and rationale here. Additional details will be reported in a peer-reviewed manuscript (Latif et al., in preparation).

In recently burned forests, we expected white-headed woodpeckers to use burned areas for nest placement near unburned forest for foraging (Wightman et al. 2010). We modeled these relationships using Maxent (Phillips et al. 2006) informed by remotely sensed data describing burn severity, prefire canopy cover, percent coverage of ponderosa pine-dominated forest, and

Table 2.3.1—Summary of sampling at two wildfire locations where white-headed woodpecker nest surveys were conducted to inform burned forest HSI model development and evaluation.

National forest	Fire name	Ignition year	Years surveyed	Full extent (acres)	Surveyed extent (acres)	No. nest pixels
Fremont-Winema	Toolbox	2002	2003–2007	82,565	2,114 ^a	46 ^a
Malheur	Canyon Creek	2015	2016–2017	110,340	10,737; 11,676 ^b	47

^a Non-nest sites were measured only in the 13 largest of the 22 survey units. Area surveyed = 1,971 acres, and 33 nests were located in these 13 units.

^b One survey unit was replaced between years. The smaller area was surveyed in 2016, and the larger in 2017.

topographic slope (table 2.3.2) at nest and available sites recorded at two wildfire locations, the 2002 Toolbox Fire (see Wightman et al. 2010) and the 2015 Canyon Creek Fire in Oregon.

We initially developed separate models at each wildfire location and applied them across locations to test predictive performance. We measured predictive performance using the area under the receiver operating curve (AUC) (Fielding and Bell 1997) assessing discrimination of nest from non-nest sites, whereby an AUC of less than 0.5 indicates discrimination no better than random and an AUC of 1 indicates perfect discrimination. Models developed at Toolbox and Canyon Creek locations performed well when applied across these two locations (table 2.3.3), so we combined data from these locations to develop a final model.

Unfortunately, models did not perform well at a third location, the Barry Point Fire (Oregon, 2011) (table 2.3.3), so we recommend restricting model application to conditions characteristic of the Toolbox and Canyon Creek locations but not Barry Point (described further in subsection 3.3 *White-headed Woodpecker Burned Forest Model Applicability*). The final model provided by the ArcGIS tool describes a positive relationship with moderate-to-high severity burns or open forest at the nest site scale (~2 acres) and a negative relationship with these features at the home range scale (776 acres) (table 2.3.2). Model HSIs designate suitable nesting habitat along burned forest edges and within mosaics of burned and unburned forest. Additionally, following relationships with ponderosa pine forest and topographic slope observed at individual wildfire locations (see also Hollenbeck et al. 2011, Latif et al. 2015), we suggest restricting model application to the range of LandPIPO and Slope values observed at nest locations (table 2.3.2) (described further in subsection 3.3 *White-headed Woodpecker Burned Forest Model Applicability*).

2.3 White-Headed Woodpecker in Burned Forests of the Inland Pacific Northwest (continued)

Table 2.3.2—Remotely sensed environmental variables used to model nesting habitat for white-headed woodpeckers in burned forest. Descriptive statistics (mean [SD]) are reported for the two study locations where the model was developed at nest sites and available sites representing the area surveyed.

Variable (abbreviation)	Description	Toolbox (Oregon)		Canyon Creek (Oregon)	
		nest	available	nest	available
Local-scale percent area burned or open (locbrnopn) ^a	Percentage of 2-acre (3×3-cell) neighborhood moderately to severely burned ($\Delta\text{NBR}^b >270$) or <10% prefire canopy cover	95.3 (13)	81.6 (32.4)	82 (26.8)	80.4 (28.9)
Landscape-scale percent area burned or open (landbrnopn) ^a	Percentage of 776-acre (0.6-mile-radius) neighborhood moderately to severely burned ($\Delta\text{NBR}^b >270$) or <10% prefire canopy cover	61.1 (19.7)	65.7 (21.5)	60.7 (14)	68.1 (13.7)
Landscape-scale percent area ponderosa pine forest (LandPIPO) ^c	Percentage of 776-acre (0.6-mile-radius) neighborhood dominated or codominated by ponderosa pine ^d	74.9 (7.9)	72.3 (10.6)	59.8 (10.1)	59.2 (10.5)
Slope ^c	pixel topographic slope as % rise over run	7.3 (5.6)	7.8 (6.6)	21.3 (12.9)	23.5 (11.4)

^a The original HSI (ensemble) model was developed with “extended assessment” burn severity data (MTBS 2012), wherein postfire imagery was recorded the year following wildfire. We provide an alternate version developed with RAVG data, however, to support immediate postfire planning (for details, see Appendix A).

^b Delta normalized burn ratio

^c LandPIPO and Slope do not directly inform modeling but are used for post hoc masking of the final HSI map to restrict model application to areas with LandPIPO >40% and Slope <40%, representing the minimum and maximum values, respectively, observed at nest locations.

^d A pixel was classified as ponderosa pine-dominated forest if dominated or codominated by ponderosa pine as classified by gradient nearest-neighbor data (LEMMA 2018).

2.3 White-Headed Woodpecker in Burned Forests of the Inland Pacific Northwest (continued)

Table 2.3.3—Predictive performance of white-headed woodpecker burned forest model(s) at individual wildfire locations. AUC \leq 0.50 indicates discrimination of nest from non-nest sites no better than random, whereas AUC = 1 indicates perfect discrimination. Boot-strapped 95% confidence intervals (parentheses) that overlapped 0.50 were considered indicative of poor performance. Models were developed at Toolbox (TB) and Canyon Creek (CC) study locations and applied at these plus Barry Point (BP).

Applied at:	Developed at:		
	TB	CC	TB and CC
TB	0.76 (0.68, 0.85)	0.72 (0.62, 0.81) ^a	0.72 (0.63, 0.81)
CC	0.61 (0.52, 0.7) ^a	0.64 (0.54, 0.73)	0.62 (0.53, 0.71)
BP	0.58 (0.39, 0.77) ^a	0.5 (0.31, 0.69) ^a	0.46 (0.27, 0.65) ^a

^a AUCs measuring discrimination outside where models were originally developed are especially important for assessing predictive performance.

2.4 Woodpeckers in Northern Sierra Burned Forests

We developed models for several woodpecker species to inform postfire forest planning and habitat conservation in the northern Sierra Nevada of California. Given regional differences in forest structure, tree species composition, and woodpecker behavior (e.g., Fogg et al. 2014), we did not expect models developed in other regions to be applicable here. We therefore developed a series of models specific to this region based on nest and non-nest location data for three target species (black-backed woodpecker, hairy woodpecker, and white-headed woodpecker) from three wildfires that occurred in the Lassen National Forest over a 5-year period (table 2.4.1). Nests were located by searching within a priori established 200-m (700-foot) wide belt transects following Dudley and Saab (2003).

Table 2.4.1—Summary of sampling at three wildfires in Lassen National Forest, California, for woodpecker nest locations to inform HSI model development and evaluation. Models presented here are for three woodpecker species: black-backed woodpecker (BBWO), hairy woodpecker (HAWO), and white-headed woodpecker (WHWO).

Fire	Timing		Nesting spp.	<i>n</i>	
	Ignition	Sampling		nest	non-nest ^a
Moonlight	2007	2009–2012	BBWO	24	337
			HAWO	46	274
			WHWO	30	325
Cub	2008	2009–2012	BBWO	19	100
			HAWO	27	79
			WHWO	20	112
Chips	2012	2013–2016	BBWO	28	41
			HAWO	24	40
			WHWO	38	45

^a Non-nest sites represented a random sample drawn from within survey units for nest searching.

2.4 Woodpeckers in Northern Sierra Burned Forests (continued)

We briefly summarize model structure, development, evaluation, and rationale, leaving additional details for a peer-reviewed publication (Campos et al., in preparation). We initially considered metrics of topography, burn severity, and prefire forest structure, although only the latter two appeared in selected models (table 2.4.2). These variables were drawn from available data sources (Mayer and Laudenslayer 1988; Miller and Thode 2007; Rollins and Frame 2006), reflected potentially informative environmental features described in the literature (Latif et al. 2013, 2015; Saab et al. 2009; Tingley et al. 2014; Wightman et al. 2010), and differed notably between nest and non-nest locations (table 2.4.3).

Table 2.4.2—Descriptions of environmental variables used to develop habitat models for nesting woodpeckers in burned forests of the northern Sierra Nevada Mountains. Local-scale variables quantified conditions at the nest site (3×3 cells; 0.81 ha), whereas landscape-scale variables quantified conditions approximating home range size inclusive of most woodpecker species (1-km radius circle; 314 ha).

Variable (abbreviation)	Description
Local burn severity (LocCCmort) ^a	Median percent canopy mortality (derived from relativized delta normalized burn ratio) for 2-acre moving window (%)
Landscape burn severity (LandCCmort) ^a	Percentage of 776-acre neighborhood with >64% canopy mortality (derived from relativized delta normalized burn ratio) (%)
Local canopy cover (LocCC) ^b	Percentage of 2.5-acre moving window with >40% canopy cover recorded before fire (CWHR density class M [40–60%] and D [>60%])
Landscape canopy cover (LandCC) ^b	Percentage of 776-acre moving window with >40% canopy cover recorded before fire
Local large-tree dominance (LocTrSize) ^b	Percentage of 2-acre moving window dominated by trees of d.b.h. > 61 cm (CWHR size class 5)

^a Burn severity data were acquired from the online repository for RAVG data (RAVG 2018).

^b Prefire forest structure data were acquired from the California Wildlife Habitat Relationships (CWHR) online repository (R5 Vegetation Classification and Mapping 2018).

Table 2.4.3—Descriptive statistics (mean [SD]) for environmental variables used to model habitat for nesting woodpeckers in burned forests of the northern Sierra Nevada Mountains. Nesting species are black-backed woodpecker (BBWO), hairy woodpecker (HAWO), and white-headed woodpecker (WHWO). Complete variable names and descriptions are in table 2.4.2.

Variable	BBWO		HAWO		WHWO	
	Nest	Non-nest	Nest	Non-nest	Nest	Non-nest
LocCCmort	72.8 (37)	51.4 (43.7)	77.7 (33.7)	49.4 (43.7)	60.1 (41.2)	49.8 (43.5)
LandCCmort	33.2 (30.3)	48.2 (32)	41.3 (35.7)	46.5 (31.3)	26 (25.9)	47.9 (32.4)
LocCC	94.8 (15.6)	87 (28.7)	89.1 (28.3)	85.9 (29.7)	78.3 (37.1)	85.2 (30.5)
LandCC	79.3 (15.8)	83 (12.7)	84.5 (13.5)	81.7 (13)	79.4 (14)	81.9 (13.7)
LocTrSize	32.6 (44.2)	58.5 (43.6)	46 (45.5)	55 (44.9)	29.2 (42.3)	55.3 (44.5)

2.4 Woodpeckers in Northern Sierra Burned Forests (continued)

We used weighted logistic regression to relate binomial nest location data (0 = non-nest; 1 = nest) with these variables (observation weights and rationale follows Latif et al. 2016). For each species, we constructed and fitted models representing all possible combinations of environmental variables limited by sample size (maximum number of variables = number of nests/10). We then selected one model for each species according to a series of criteria describing predictive performance, relative fit, model-estimated habitat suitability at nest locations, and parsimony (table 2.4.4).

The selected models described positive relationships with nest-site scale burn severity for all species, negative relationships with home-range scale burn severity by black-backed and white-headed woodpeckers, positive relationships with prefire canopy cover by black-backed and hairy woodpeckers at various scales, and a negative relationship with large-tree dominance for hairy woodpecker (table 2.4.5). Positive relationships with moderate- and high-severity burned nest sites are consistent with patterns described for other regions (Latif et al. 2013, 2016; Russell et al. 2007). Scale-dependent relationships with burn severity for white-headed woodpecker are consistent with their affinity for canopy mosaics also described elsewhere (Hollenbeck et al. 2011; Latif et al. 2015; Wightman et al. 2010).

Table 2.4.4—Performance criteria used to evaluate habitat models and select from candidate models for nesting woodpecker species surveyed in the northern Sierra Nevada Mountains.

Criterion	Description	How applied
RPI ^a	Mean correlation coefficient (-1–1 range; $n = 3$ wildfires) relating observations with model predictions for each wildfire when withheld from model fitting via spatial cross-validation	The model with highest mean RPI ($n = 3$ wildfires) that met all other criteria was selected.
ΔAIC_i ^b	AIC for the i^{th} model minus that of the top-ranked (lowest-AIC) model	Models where $\Delta AIC_i > 6$ were excluded.
Sensitivity ^c	Proportion of nests classified as suitable at a given wildfire using a classification threshold that maximized the sum of sensitivity (proportion nests suitable) + specificity (proportion non-nests unsuitable)	Models conferring minimum sensitivity at any one wildfire < 0.5 were excluded.
Parsimony ^d	Statistical support for model coefficients based on z-statistic	Models with statistically unsupported coefficients ($P > 0.05$) were excluded.

^a RSF plot index (where RSF stands for resource selection function) described by Wiens et al. (2008).

^b Akaike’s Information Criterion, described by Burnham and Anderson (2002).

^c Described by Liu et al. (2016).

^d Described by Wiens et al. (2008).

2.4 Woodpeckers in Northern Sierra Burned Forests (continued)

Table 2.4.5—Selected habitat models developed to inform habitat mapping for focal woodpecker species (black-backed woodpecker [BBWO], hairy woodpecker [HAWO], white-headed woodpecker [WHWO]) following wildfire in the northern Sierra Nevada Mountains. All environmental covariates were z-scored (centered on zero and divided by SD) prior to model fitting. Performance criteria used for model selection are reported here and described in table 2.4.4. Min sensitivity is the minimum proportion of nests classified suitable at any one of three wildfire locations using the classification threshold that maximizes sum of sensitivity and specificity (max SSS threshold).

Species	Model coefficients (mean estimates)	RPI ^a	ΔAIC _i ^b	Min sensitivity (max SSS threshold)
BBWO	Intercept (-0.86) + LocCCmort (1.77) + LandCCmort (-1.65) + LocCC (0.8)	0.976	2.239	0.63 (0.41)
HAWO	Intercept (-0.48) + LocCCmort (0.89) + LandCC (0.4) + LocTrSize (-0.47)	0.986	2.680	0.56 (0.51)
WHWO	Intercept (-0.56) + LocCCmort (1.5) + LandCCmort (-1.83)	0.942	0.000	0.53 (0.49)

^a RSF plot index (where RSF stands for resource selection function) described by Wiens et al. (2008).

^b Akaike's Information Criterion.

Other relationships observed here, however, may be unique to Northern Sierra forests. For example, negative relationships with home-range scale burn severity by black-backed woodpecker are not observed in other regions (Latif et al. 2013; Russell et al. 2007) nor in more pine-dominated portions of the Sierra Nevada (Tingley et al. 2014). Avoidance of large-tree dominated sites may also reflect a particular affinity for areas with higher densities of smaller trees in this region (Seavy et al. 2012). These region-specific relationships may enhance model predictive performance within sampled forest types of the northern Sierra Nevada but warrant some caution in application elsewhere (described further in subsection 3.4 *Applicability of Northern Sierra Models*).

3. Model Applicability

Models are restricted in applicability by the range of conditions within which they were developed. Applicability should ideally be tested with independent data before managers use model predictions in their planning and decisions (Bahn and McGill 2013; Heikkinen et al. 2012; Wenger and Olden 2012). Such testing is particularly critical when models are applied beyond the environmental range where they were originally developed. In light of these principles, we offer guidelines for applicability of habitat suitability index (HSI) models here. Additionally, we provide and describe application masks for particular models based on these guidelines.

3.1 Black-Backed Woodpecker Inland Northwest Model Applicability

Models for nesting black-backed woodpecker in burned forest were developed in dry conifer forests of western North America, so model applications should be restricted to these forests (Latif et al. 2013). We provide an application mask that excludes areas not characterized by dry conifer forests based on LANDFIRE-classified satellite imagery recorded in 2014 (existing vegetation types included in the mask are listed in metadata for the mask). More specifically, models were developed and are therefore most applicable in recently burned and unlogged forests (≤ 5 years postfire) of Idaho, Oregon, and Washington. Models presented here are therefore not applicable in unburned forest (e.g., Bonnot et al. 2009; Fogg et al. 2014), and we expect predictive value to be lower in areas affected by salvage logging. Nevertheless, several lines of evidence suggest broad applicability in recently burned dry conifer forests: (1) Ensemble HSIs consistently characterized nesting distributions across the three wildfire locations representing a relatively broad geographic extent where models were developed, (2) HSIs exhibited other desirable properties for prediction (for details, see Latif et al. 2013), and (3) HSIs effectively discriminated nest from reference sites at the Canyon Creek Fire (Oregon, 2015) (V.A. Saab, unpublished data)¹ (Appendix B).

3.2 White-Headed Woodpecker Unburned Forest Model Applicability

The HSI model for nesting white-headed woodpecker in unburned forests was developed in lower elevation dry conifer forests of the East Cascade Mountains in eastern Oregon, and model applicability was verified in the Blue Mountains of western Oregon (see Maxent model in Latif et al. 2015). The model was developed in forests unaffected within 10 years by wildfire or other disturbance (e.g., insect outbreak, logging) with environmental metrics specific to green forests. Separate models quantify nesting habitat for white-headed woodpeckers in burned forests (Latif et al., in preparation; Wightman

¹ Unpublished data on file with V.A. Saab at: USDA Forest Service, Rocky Mountain Research Station, Bozeman, MT.

3.2 White-Headed Woodpecker Unburned Forest Model Applicability (continued)

et al. 2010) (Appendix A). Nevertheless, canopy mosaics favored for nest placement are maintained largely by mixed severity fire, so applicability is expected to increase with increasing time since fire, assuming availability of contemporarily accurate environmental data. Application of this model should also be restricted to areas with sufficient ponderosa pine-dominated forest. We observed no nest locations with less than 10 percent coverage of ponderosa-dominated forest within a 0.6-mile-radius neighborhood (LEMMA 2018), so the mask accompanying this model accordingly restricts model application. This model should be applied with caution (i.e., predictive performance should be verified with independent data) in landscapes that deviate from conditions characterizing lower elevation conifer forests of Oregon. These include the North Cascade Mountains in Washington, where ponderosa pine is less dominant; forests of western Idaho, which are characterized by steeper and more rugged topography than Oregon forests; and southern California forests, where white-headed woodpeckers rely more heavily on large-seeded pine species other than ponderosa.

3.3 White-Headed Woodpecker Burned Forest Model Applicability

The HSI model for white-headed woodpecker in burned forests provided here was developed from data from two wildfire locations (Toolbox, 2002; Canyon Creek, 2015) in eastern Oregon. These wildfires burned areas consisting largely of lower elevation dry conifer forest strongly dominated by ponderosa pine (table 2.3.1). The final model exclusively quantifies white-headed woodpecker use of canopy mosaics (see subsection 2.4 *Woodpeckers in Northern Sierra Burned Forests*), a behavior generally characteristic of white-headed woodpeckers across their range (Hollenbeck et al. 2011; Latif et al. 2015; Wightman et al. 2010).

Despite representing a general pattern, we expect some limits to model applicability. Limited representation of burned locations ($n = 2$) across the species range restricts information for quantifying relationships with other potentially important habitat components. Specifically, ponderosa pine and topographic slope are identified as potentially important in previous work (Hollenbeck et al. 2011; Latif et al. 2015), and relationships with these features were retained in preliminary models developed at individual locations (i.e., an affinity for ponderosa pine-dominated forest at Toolbox and avoidance of steep slopes at Canyon Creek). Additionally, as for other postfire models, models are most applicable in dry conifer forest—the forest type in which they were developed. Accordingly, we offer an application mask that excludes areas with LandPIPO less than 40 percent and Slope greater than 40 percent, and that includes only dry conifer forest types identified based on LANDFIRE vegetation classifications.

We found poor predictive performance when applying this model at the Barry Point Fire in southern Oregon (2011) (table 2.3.3). Before fire, forests at this location were interspersed extensively with nonforest (shrubland and grassland) openings, so wildfire was probably less important for generating canopy mosaics. Mosaics were readily available, so white-headed woodpeckers may invest less effort seeking openings when selecting

3.3 White-Headed Woodpecker Burned Forest Model Applicability (continued)

nest sites, compromising the predictive value of our model. Additionally, coverage of ponderosa pine-dominated forest (0.6-mile-radius neighborhood) was relatively low (mean \approx 30 percent), which may have increased its value and led white-headed woodpeckers to focus more on ponderosa pine when selecting breeding territories and nest sites at Barry Point. Unlike at other locations, many nests at Barry Point were located in juniper (*Juniperus occidentalis*), further suggesting that habitat selection patterns differed at Barry Point.

We therefore caution against applying our model to areas like Barry Point characterized before fire by extensive nonforest openings, restricted coverage of ponderosa pine forest, and a large juniper component. Moreover, we suggest users compare descriptive statistics for their project areas with those at model-development locations. In addition to using an appropriate application mask (described earlier), users should avoid application in landscapes whose conditions differ substantially from the characteristics where models were developed (see table 2.3.2).

As with other postfire models in this series, nest locations were collected within 5 years of wildfire, and survey units were subjected to selective-cut salvage logging. Logging was limited in extent and intensity, and varied between locations. To avoid overfitting models to conditions at individual locations, models excluded logging variables. That models nevertheless showed predictive ability between Toolbox and Canyon Creek locations suggests logging was not extensive enough to negate model applicability. Yet too much logging would be likely to compromise accuracy of remotely sensed data upon which models depend. We expect this model (and others in this series) will be most useful for informing management planning before implementation of salvage logging.

3.4 Applicability of Northern Sierra Models

HSI models for woodpeckers in the northern Sierra Nevada were developed and are applicable in burned forests of this region. Models were primarily developed in Sierra Mixed Conifer, White Fir, and Red Fir forest types (designated by California Wildlife Habitat Relationship System [CWHR]) (Mayer and Laudenslayer 1988). Accordingly, we offer a mask that restricts application of Northern Sierra models to areas within 0.6 mile of relatively large forest patches (≥ 776 miles) of these types.

Models were developed and evaluated with data collected within 5 years following three wildfires that occurred in an approximately 50-mile-wide area (~ 6 –12-mile spacing between fire perimeters) (table 2.4.1). Sampled landscapes were affected to some extent by selective harvest salvage logging. Nevertheless, sampling avoided extensively logged areas and models did not quantify relationships with logging to avoid overfitting to conditions at surveyed fires. Thus, we intend models for application immediately after wildfire and before salvage logging to inform postfire management planning. Models may also be applied in areas affected by limited salvage logging (i.e., ≤ 20 percent of the landscape treated with selective harvest) (USDA Forest Service 2013a,b), whereas predictive performance would be likely to

3.4 Applicability of Northern Sierra Models (continued)

decline in more extensively treated areas. Some environmental relationships quantified by these models differed from those observed in forests of other regions dominated more so by pine (e.g., a negative relationship with home-range-scale burn severity for black-backed woodpecker, in contrast with Tingley et al. 2014). Therefore, we expect poorer applicability in pine-dominated forests in drier regions of the Sierra Nevada, and in other mountain ranges outside California.

4. Instructions for Tool Implementation

Application tools described in this manual are operated within an ArcGIS environment. Users must have access to ArcGIS 10, a basic understanding of how to operate this software, and spatial data layers for clearly defined study areas. Steps provided here detail how to retrieve and compile environmental data into GIS layers required as model inputs, and how to access and implement model application tools.

Currently, most tools are ideally operated within the Forest Service Citrix environment or another environment with access to the T drive (except tools for Northern Sierra woodpeckers). The optimal workflow for operating these tools relies on input generation tools to facilitate preliminary data processing, and some input generation tools require access to baseline data stored on the T drive. If you have access to the T drive, you can operate tools located at “T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX”. Alternatively, you can download and extract the entire folder structure needed to operate the tool at “T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\FIRE-BIRD_v0.12.zip” or from the Region 6 website (<https://www.fs.usda.gov/main/r6/plants-animals/wildlife>) under the heading “FIRE-BIRD: Habitat Model Application Tools for Disturbance-associated Woodpeckers”. Hereafter, the location “TOOLBOX” refers to either the folder on the T drive or the folder extracted from the FIRE-BIRD_v0.12.zip file to a personal workstation. If you do not have access to Citrix or the T drive, some input generation tools will be unavailable, in which case you will need to follow the alternate “optional” instructions for manual input generation provided where relevant in these instructions.

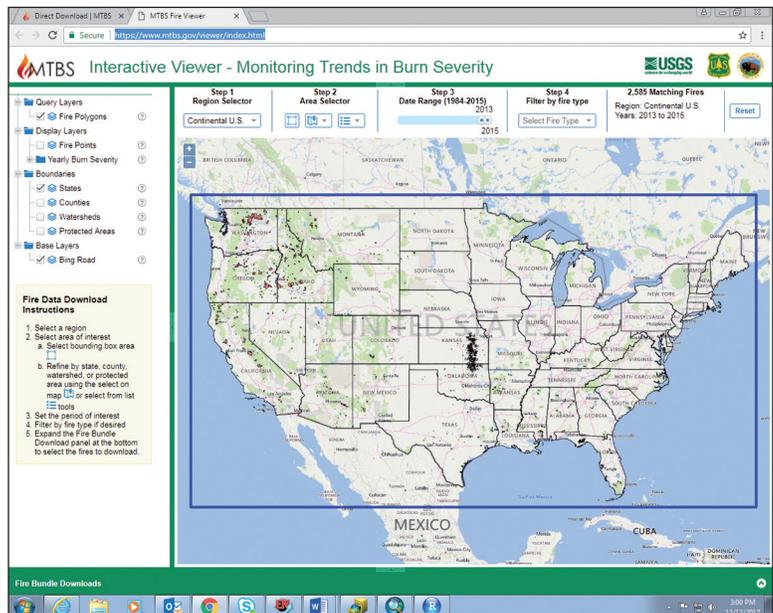
Once you have verified access to the toolbox on Citrix or extracted the toolset to an alternate location, you can follow the steps provided next for your tool of interest. Throughout these instructions, we suggest names for the various files in particular steps. These tools allow you to drag and drop input files required for operation. You are not required to follow our suggested naming convention, but we nevertheless suggest doing so to make it easier to follow our instructions.

The primary output provided by these tools are raster layers mapping the relative likelihood for species occurrence, that is, habitat suitability indices (HSIs). In section 5 *Guidelines for Application and Interpretation of Habitat Suitability Models*, we provide additional guidelines for interpretation of HSIs to inform forest planning.

4.1 Black-Backed Woodpecker Instructions for the Inland Northwest

The principal output generated by the application tool for nesting black-backed woodpecker in the Inland Northwest and northern Rocky Mountains describes a composite of predictions from multiple models, that is, ensemble predictions. Additionally, the tool allows optional generation of habitat maps from individual models that make up the ensemble. The study area must have been burned by relatively large wildfires (1,000 acres in the western United States) for the necessary data to be retrievable (Latif et al. 2013; Saab et al. 2007). You can choose among various file extensions indicating format for output layers, of which we recommend “.tif” or “.img” formats for flexibility in file naming (the more restrictive default ArcGrid format leaves off any filename extension).

- I. Retrieve and compile environmental data layers. In this step you will retrieve and process remotely sensed data to compile the variables listed in table 2.1. **Pathnames for data files cannot have spaces, so when saving the data layers, ensure that no parent folder names in the file path have spaces.** For example, “C:\GIS\Data\black-backed woodpecker\dnbr.tif” is an invalid pathname. Change the name of the “black-backed woodpecker” folder, for example to “black-backedwoodpecker” or “BBWO”.
 - A. Retrieve burn severity data:
 1. Go to the Monitoring Trends in Burn Severity interactive viewer for querying and downloading remotely sensed wildfire data: <https://www.mtbs.gov/viewer/index.html>



Screenshot of Monitoring Trends in Burn Severity interactive viewer.

**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

2. Follow Steps at the top of the viewer to locate your wildfire location. The example here shows retrieval of data for the 2015 Canyon Creek Fire in Oregon.
 - a. Select “Continental U.S.” in the drop-down menu under Step 1.



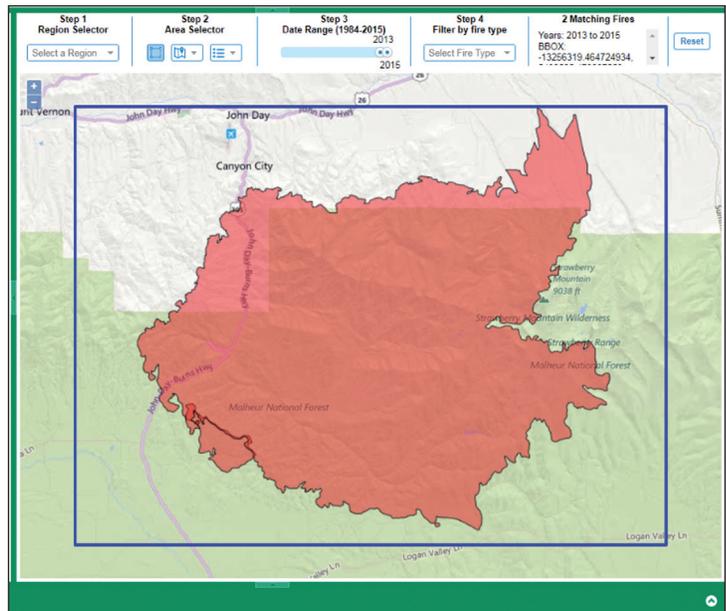
Screenshot of Step 1 in interactive viewer.

- b. When you hover your cursor over the first of three buttons under Step 2, the label “Select Bounding Box” will appear. Click on this button.



Screenshot of Step 2 in interactive viewer.

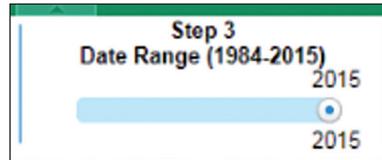
- c. In the map, drag a box over the geographic region in which the wildfire location of interest is located. You may do this several times until you have zoomed in to only the area containing the target wildfire location.



Screenshot of Step 3 results for area and dates selected in the interactive viewer.

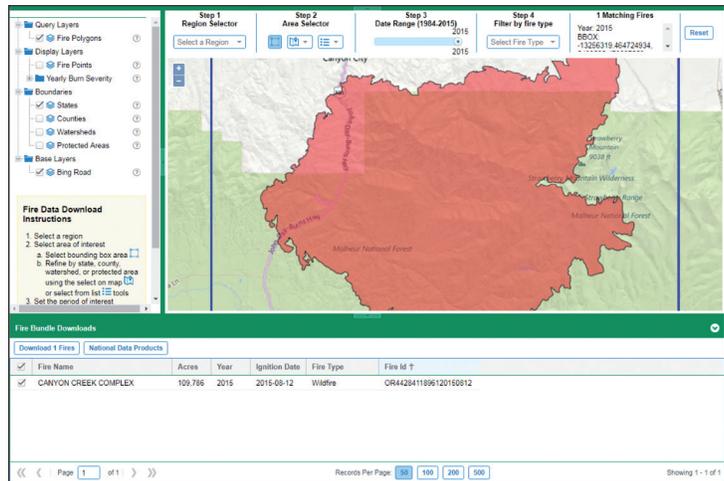
**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

- d. Under Step 3, adjust the scroll bar to include the ignition year for the wildfire of interest. The scroll bar can include multiple years, in which case multiple wildfire locations may appear in the map viewer. There will be a chance to select from among multiple locations later, but to make subsequent steps easier, adjust the scroll bar to include only the ignition year for your wildfire of interest.



Screenshot of Step 3 in the interactive viewer.

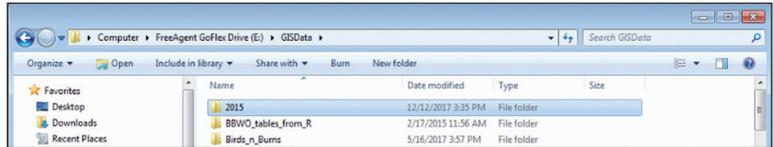
- e. At this point, there should be only one or a few wildfire locations displayed in the map filter. If there are more than one, you can set the “fire type” filter under Step 4 to “Wildfire” to further reduce the size of the query. Otherwise, click on the arrow at the bottom right to open up the “Fire Bundle Downloads” window. If multiple locations are displayed, toggle the check boxes on the left until only desired locations are check-marked. Click on the “Download Fires” button on the top left of the “Fire Bundle Downloads” window. Save the zip file to your computer.



Screenshot of Step 3 results for the year and area selected, and Fire Bundle Downloads window.

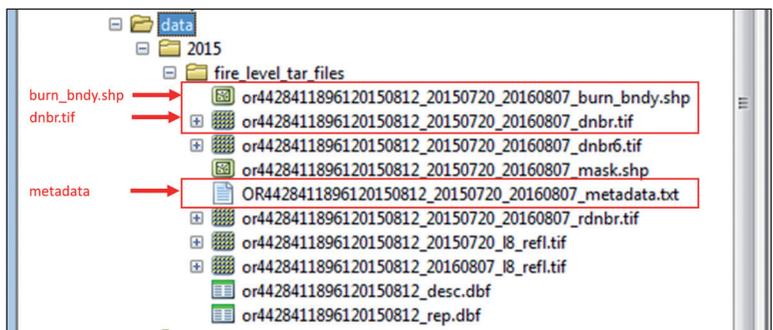
**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

3. Move the downloaded zip file to an appropriate location and unzip it with Winzip®, 7zip, or other file compression software. Right-click on the compressed file to find extraction options. The extracted folder will be named according to the ignition year of your wildfire location.



Screenshot of directory.

4. Within this folder, navigate to the folder named “fire_level_tar_files” to find the “...tar.gz” file corresponding to your wildfire location. The file name will begin with the two-letter State code in which the fire was located, followed by a long series of numbers and finally the “.tar.gz” extension. Extract this file using available software as outlined in the previous step (I.A.3).
5. Review extracted files. In ArcCatalog, navigate to the folder containing the extracted files. In general, the fire perimeter polygon shapefile will end in “...burn_bndy.shp” and the burn severity raster will end in “...dnbr.tif” (hereafter, “burn_bndy.shp” and “dnbr.tif”). Open the metadata.txt file and look under “Products List:” for explanation of the various other extracted files. Pay close attention to not select “...dnbr6.tif” as this will produce erroneous results.



Screenshot of directory for fire_level_tar_files.

Note on RAVG data: For assessment of recent fires where MTBS data are unavailable, we provide an alternate version of this (ensemble) model informed by RAVG data. We compare outputs derived from the MTBS- versus RAVG-derived version of this model in Appendix A. You can obtain RAVG data by using the online query tool at <https://www.fs.fed.us/postfirevegcondition/index.shtml>. See step I.A in subsection 4.4 Northern Sierra Instructions for retrieving RAVG data.

- B. Compile the four input variables needed to apply the published HSI (ensemble) model (Latif et al. 2013) using the associated input generation tool described here. **Note: This input generation tool can be operated only within the Forest Service Citrix environment or from an environment with access to the Forest Service T drive. If neither of these conditions is met, follow step I.C to compile inputs from alternate data sources.** This tool requires only the burn_bndy.shp and dnbr.tif files that you retrieved in step I.A. The tool develops required input layers (table 2.1) with these files and default topography and canopy cover data accessed automatically from the T drive. The default canopy cover layer provides 2012 gradient nearest neighbor (GNN) data from LEMMA (2018) where available (Oregon, Washington) and data from LANDFIRE (2018) where GNN data were not available (Idaho, Montana). These data may represent prefire canopy cover for wildfires that burned in 2012 or later unless additional disturbance occurred between recording the default imagery (after 2011 fire season but before 2012 fire season) and occurrence of the wildfire of interest. We have observed default imagery poorly representing prefire canopy cover at some locations for reasons unknown, so carefully inspect default canopy cover data to verify classification accuracy and reliability. In cases where default canopy cover data are deemed sufficient, proceed with steps I.B.1–6 to compile input layers. **For wildfires that occurred before 2012 or for which default imagery are unlikely to accurately represent canopy cover immediately before wildfire (e.g., due to additional disturbance in the interceding period), additional steps will be required to compile canopy cover inputs from an alternate source. If alternately sourced canopy cover inputs are needed, follow steps I.B.1–6 but then delete resulting loccc and landcc layers, then follow steps I.C.4–6 (i.e., skip I.C.1–3) to generate replacement inputs.**

1. From ArcCatalog, navigate to “TOOLBOX → Habitat Suitability Modeling.tbx → Input Development” and open the “Generate Inputs Black-backed Woodpecker Model” tool. As stated previously, this folder is located at “T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX.” You must either access this location when running ArcCatalog on Citrix or download this entire folder onto your local computer.
2. Identify or create a folder where you want model inputs to be stored. Under “Workspace”, navigate to this folder. Then click “Add”.
3. For “Fire Perimeter”, navigate to the burn_bndy.shp file downloaded from MTBS (step I.A). You can either navigate from outside the tool interface and drag and drop this file into the “Fire Perimeter” box, or navigate from within the tool and click “Add”.

4. For “dnbr”, use the dnbr.tif file downloaded from MTBS (step I.A). Either navigate from outside the tool interface and drag and drop dnbr.tif, or navigate from the “dnbr” box and click “Add.”
 5. Click OK (all outputs will be stored in the INPUTS folder in your workspace).
 6. Close this dialog when completed successfully.
- C. *Optional*—Steps for compiling input layers (locdnbr, loccc, landcc, and cosasp) from alternate data sources are provided here. **Follow these steps if you don’t have access to the Forest Service T drive, or if default canopy cover layers are insufficient.** These steps assume that you have obtained four layers for your project area: 1) dnbr.tif and burn_bndy.shp files retrieved in step I.A, 2) a 30-m-pixel elevation raster layer (e.g., a digital elevation model layer from LANDFIRE), and 3) a 30-m-pixel raster layer that either provides continuous canopy cover (percent) or classifies high (>40 percent) versus low (<40 percent). Raster layers (dnbr.tif, elevation, and canopy cover) should cover all areas inside the burn_bndy.shp file and extend at least 0.6 mile beyond (see step I.A.3). If this criterion is not met, layers should cover all areas within and at least 0.6 mile outside study units relevant to management planning or decisions; use a shapefile describing study unit boundaries in place of burn_bndy.shp in step I.C.2.d (following). If you have access to the T drive but require alternately sourced canopy cover data, follow steps I.B.1–5, but then delete resulting loccc and landcc layers. Then follow steps I.C.4–6 (i.e., skip step I.C.1–3) to generate replacement inputs. Note: We suggest following file naming directions as stated below to keep track of different files referenced in these instructions.
1. Identify or create a folder where you want model inputs to be stored. Place intermediate and final layers generated from steps I.C.2–4 below in this folder. The remainder of these steps will refer to this folder as your “workspace.”
 2. Apply the “Focal Statistics” tool to dnbr.tif (downloaded in step I.A.3) to generate the locdnbr input layer.
 - a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
 - b. Designate dnbr.tif as the “Input Raster”.
 - c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Median”. Name the resulting layer “lcdnbrpre”.
 - d. Clip lcdnbrpre to the fire perimeter to produce final locdnbr input layer. Open TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask. Designate lcdnbrpre as the Input layer and burn_bndy.shp as the mask. Designate your workspace as the output location and name the output file “locdnbr”.

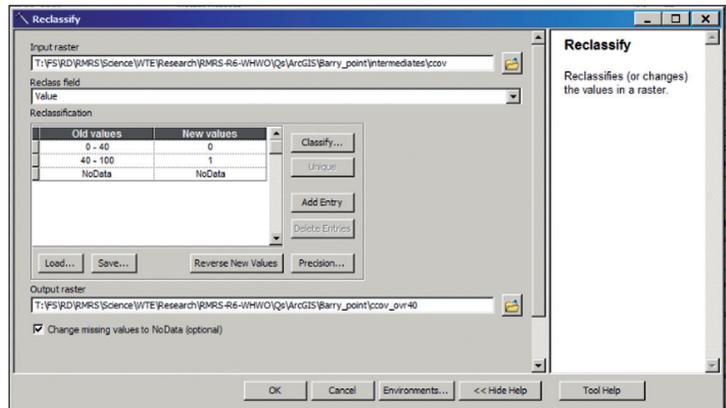
**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

3. Identify or create a folder where you want model inputs to be stored. Place intermediate and final layers generated from steps I.C.2–4 in this folder.
4. Apply the “Focal Statistics” tool to dnbr.tif (downloaded in step I.A.3) to generate the locdnbr input layer.
5. Identify or create a folder where you want model inputs to be stored. Place intermediate and final layers generated from steps I.C.2–4 (following) in this folder. The remainder of these steps will refer to this folder as your “workspace.”
6. Apply the “Focal Statistics” tool to dnbr.tif (downloaded in step I.A.3) to generate the locdnbr input layer.
 - a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
 - b. Designate dnbr.tif as the “Input Raster”.
 - c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Median”. Name the resulting layer “lcdnbrpre”.
 - d. Clip lcdnbrpre to the fire perimeter to produce final locdnbr input layer. Open TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask. Designate lcdnbrpre as the Input layer and burn_bndy.shp as the mask. Designate your workspace as the output location and name the output file “locdnbr”.
7. Generate cosine aspect input layer (cosasp) from raw elevation.
 - a. Before following these instructions, locate a raster layer that describes elevation at 30-m resolution (e.g., digital elevation model layer from LANDFIRE).
 - b. Apply the “Aspect” tool to this layer (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Aspect).
 - c. The resulting raster layer will be in degrees. You can calculate cosine aspect using the raster calculator tool included with ArcGIS software, but doing so requires conversion of aspect from degrees to radians. To make this step simpler, we recommend using the “Cosine (degrees)” tool that we have included under TOOLBOX → Habitat Suitability Modeling.tbx → Input Development. Double-click on the “Cosine (degrees)” tool, drag and drop the aspect raster generated in the previous step (I.C.7.b) as the input for this tool, and name the resulting tool “casppre”.
8. Begin with a raw canopy cover layer that either describes a continuous percentage or classifies high (>40 percent) versus low (<40 percent) canopy cover at a 30-m resolution. The available sources for retrieving such data will depend on wildfire timing and geographic region of your study location (e.g., LEMMA 2018; LANDFIRE 2018; USFS 2018a). Once you obtain this

**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

layer, carry out the following steps to compile loccc and landcc layers. If the raw canopy cover layer is categorical and classifies high (>40 percent) with raster value = 1 versus low (<40 percent) with raster value = 0, name this file “ccov_ovr40”, and skip to step I.C.9. If the raw layer does not match this structure exactly but contains sufficient information to discriminate high (>40 percent) from low (<40 percent) canopy cover, name it “ccov” and follow steps I.C.8.a–c, which direct use of the “Reclassify” tool to classify high (>40 percent) versus low (<40 percent) canopy cover. **If the raw canopy cover layer is not continuous and does not include the 40-percent cutoff for defining categories, you will need to seek an alternate data source (e.g., a forest- or region-specific data repository).**

- a. In ArcToolbox, navigate to TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify.
- b. Designate “ccov” as the “Input raster”. Adjust the “Reclassification” table to match the image below. If the raw layer is continuous, your table will look like the one depicted below. Otherwise, manipulate the table however necessary to generate two classes: value = 0 for <40 percent and value = 1 for >40 percent.



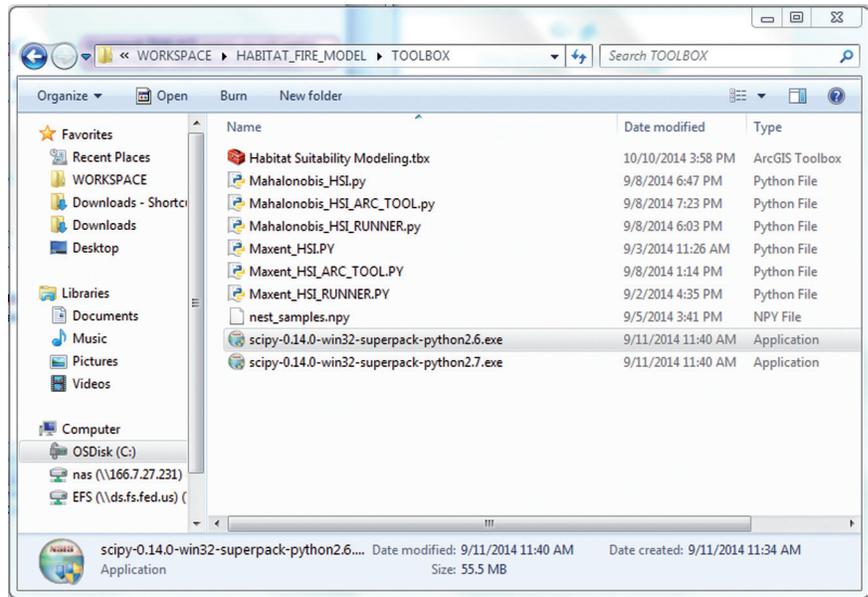
Screenshot of the Reclassify function in ArcToolbox.

- c. Select an appropriate location and name this file “ccov_ovr40”.
9. Apply the “Focal Statistics” tool to the “ccov_ovr40” layer to generate local- and landscape-scale canopy cover layers.
- a. Open the tool from ArcCatalog (Spatial Analyst Tools → Neighborhood → Focal Statistics).
 - b. Designate ccov_ovr40 as the “Input Raster”.
 - c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Mean”. Name the resulting layer “lccpre”.

**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**

- d. Apply a 1-km-radius neighborhood (select the “Circle” option under “Neighborhood”, select the “Map” option for “Units”, and use 1000 for the “Radius”), set “Statistics type” to “Mean”, and name the resulting layer “ldcpre”.
 - e. Verify that lccpre and ldcpre are proportions (range: 0–1) and not percentages (range: 0–100). Right-click on each layer, click “Properties” at the bottom of the drop-down menu, and scroll to the bottom. Inspect minimum and maximum values to verify each layer is a proportion.
10. Clip lccpre, ldcpre, and casppre using locdnbr (generated in step I.A.3) as a mask and snapping layer to generate the final loccc, landcc, and cosasp layers.
- a. Open the “Extract by Mask” tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask).
 - b. Designate the “locpre” layer as the Input Raster and locdnbr as the mask data. Open the “Environments” window.
 - c. Under “Output coordinates”, import the coordinate system from locdnbr.
 - d. Under “Processing Extent”, set locdnbr as the “Snap Raster”.
 - e. Click OK.
 - f. For “Output raster”, navigate to the location containing locdnbr and cosasp layers (i.e., INPUTS folder generated in step I.C.3) and name the output layer “loccc”.
 - g. Repeat steps I.C.10.a–f for ldcpre and casppre to generate landcc and cosasp input layers, respectively.
- II. Install scipy module (Note: If running the tool on Citrix, you can skip to step III): Before running the GIS model application tool, install the “scipy” Python™ module upon which the tool relies. Open the “TOOLBOX” folder from Windows® Explorer. We have provided two executable files in this folder for installing the “scipy” module. The correct file to run will depend on which version of Python is installed on your computer. If you have ArcGIS 10.1 or newer, double-click on the **scipy-0.14.0-win32-superpack-python2.7.exe**. If you have ArcGIS 10.0, double-click on the **scipy-0.14.0-win32-superpack-python2.6.exe**.

**4.1 Black-Backed Woodpecker
Instructions for the Inland Northwest
(continued)**



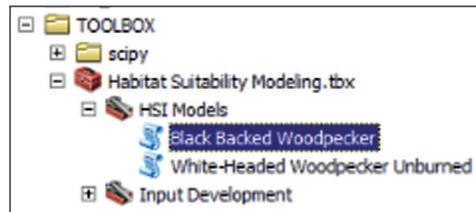
Screenshot of directory showing location of scipy Python modules.

Follow the install prompts. Ensure that the directory where you install the scipy package corresponds to the ArcGIS install locations:

- A. For ArcGIS10.0 – C:\Python26\ArcGIS10.0\Lib\site-packages
- B. For ArcGIS10.1 – C:\Python26\ArcGIS10.1\Lib\site-packages

III. Run model application tool:

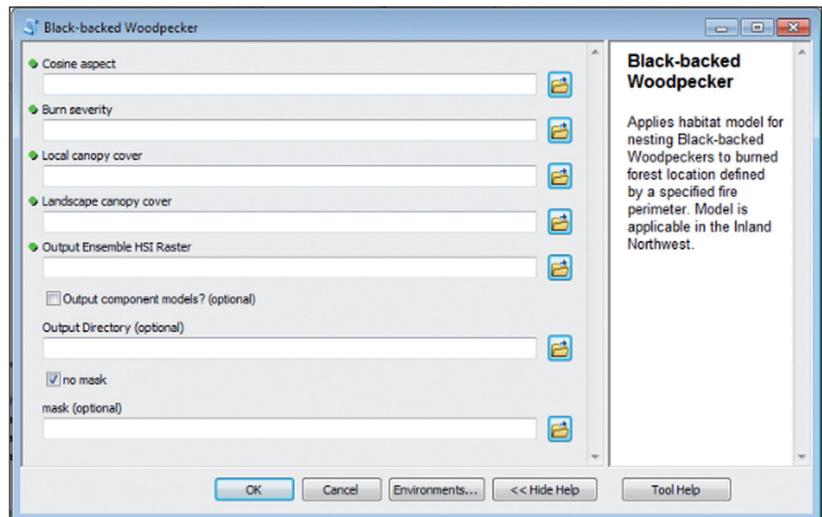
- A. From ArcCatalog, navigate to TOOLBOX → Habitat Suitability Modeling.tbx → HSI models, and open the “Black Backed Woodpecker” tool.



Screenshot of filepath showing location of tool for the black- backed woodpecker HSI model.

- B. For “Cosine Aspect”, “dNBR”, “Local canopy cover”, and “Landscape canopy cover” inputs, use cosasp, locdnbr, loccc, and landcc input rasters, respectively, located in the INPUTS folder in your workspace (see step I.B or I.C). Either navigate to the INPUTS folder from outside the “Black-backed Woodpecker” tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer.

4.1 Black-Backed Woodpecker Instructions for the Inland Northwest (continued)



Screenshot of dialog box for black-backed woodpecker tool.

- C. Designate an appropriate location and filename for the Output Ensemble HSI raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, such as “BBWO_ensemble_HSI.tif”. Again, you can specify alternate file formats for rasters, but we recommend “.img” or “.tif” because these allow longer filenames than the default ArcGrid format (which leaves off any filename extension).
- D. Select masking option. You must either check the “no mask” box or provide a raster layer to serve as a mask for the final HSI output layer. If neither is done, the tool will produce an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → BBWO → dcfmask. This mask includes all areas characterized as dry conifer forest, which we identified as 20 LANDFIRE vegetation types (listed in metadata) based on 2014 imagery. Alternatively, you may provide a comparable mask that covers your project area or check the “no mask” box, bearing in mind limitations to model applicability described earlier (see subsection 3.1 *Black-Backed Woodpecker Inland Northwest Model Applicability*).
- E. If you desire individual HSI model outputs (i.e., the components of the ensemble output), check the “Output component models?” box and designate a folder where you want these outputs to be stored. A folder named “OUTPUTS” will be automatically generated within the designated folder, and individual HSI model layers will be stored in the “OUTPUTS” folder. Click on OK to run the model. A series of progress bars will flash. If necessary, close the “Results” window once “succeeded” is displayed. To view the ensemble model output, navigate to the output file (“BBWO_ensemble_HSI.tif”), and select the preview pane tab. Select “Geography” in the drop-down menu at the bottom of the preview pane to preview the HSI map, or “Table” to view pixel counts for each suitability level (0–8; i.e., the number of models predicting each pixel as suitable).

4.2 White-Headed Woodpecker Instructions for Unburned Forests

The output generated by the application tool for nesting white-headed woodpecker in unburned forests is a 30-m-resolution raster layer with HSI values ranging from 0 to 1 (i.e., least to most suitable for nesting). We have posted habitat maps generated by this model for forest conditions recorded in Oregon (where the model was developed and evaluated) during 2002 and 2012 (T:\FS\RD\RMRS\Science\WTE\Research\RMRS-WHWO\Oregon_hsi_maps\WHWO_OR_HSI_maps.gdb). We intend the application tool for landscapes not reflected by default maps. Landscapes reflected by default maps include:

1. Landscapes requiring adjustment for disturbance between recording of default imagery and the time period of interest.
2. Landscapes just outside Oregon State boundaries but still within conditions similar to where the model was developed (e.g., southern Washington, western Idaho, and northern California). If you are applying the model outside of Oregon, be aware of the increasing need to evaluate the model with independent data from the targeted project area as one moves farther from Oregon.
3. Projected landscapes representing future or historical conditions under alternate climate or management scenarios.

In these situations, you will need to obtain relevant spatial data describing continuous percent canopy cover and the distribution of forests dominated by ponderosa pine.

There are two disclaimers for you to acknowledge before following instructions for this tool. First, additional data processing steps will be required if you are not operating ArcGIS within the Forest Service Citrix environment and if you do not have access to the Forest Service T drive (also true for Black-backed Woodpecker tool). We provide additional “optional” data processing instructions as we did for black-backed woodpecker in burned forest. Second, Python imposes memory limits on the implementation of ArcGIS tools. Unlike burned forest projects, unburned forest project areas could conceivably be large enough for memory to be limiting.

In such cases, you will need to break up your project area into subunits, implement the tool following our instructions for each subunit, and then stitch resulting subunit output layers together using one of two raster mosaic tools (ArcToolbox → Data Management Tools → Raster → Raster Dataset → Mosaic, or Mosaic to New Raster in same location). We have successfully implemented the tool for study areas whose input layers consist of about 16 million pixels (1.4 million ha, or 3.5 million acres) but failed with study areas consisting of ~30 million pixels (2.7 million ha, or 6.7 million acres). Thus, for large project areas, we suggest aiming for subunits no larger than 16 million pixels in extent. For irregularly shaped project areas, be aware that memory is limited by the entire extent of input layers, not just the area for which environmental values are compiled (i.e., including NoData pixels). Thus, you should check the total number of pixels contained in input raster layers (right-click on layer and see Properties) before implementing this tool or if an error is reported when you attempt implementation.

**4.2 White-Headed Woodpecker
Instructions for Unburned Forests
(continued)**

- I. Retrieve and compile data layers. In this step you will process remotely sensed data to compile the variables listed in table 2.2. Pathnames for data files cannot have spaces, so when saving the data layers, ensure that no parent folders in the file pathnames have spaces. For example, “C:\GIS\Data\white-headed woodpecker\cancov.tif” is an invalid pathname. Change the name of the “white-headed woodpecker” folder, for example to “white-headedwoodpecker” or “WHWO”.
 - A. Project_area shapefile—Obtain or create a polygon shapefile that delineates the entire area within which habitat suitability needs to be mapped. Label this shapefile “Project_area.shp”.
 - B. Canopy cover layer—Obtain or generate a raster layer that quantifies continuous canopy cover (percent) at a 30-m-pixel resolution for the landscape of interest. This layer needs to cover all areas inside the Project_area.shp boundaries and extend at least 0.6 mile outside this area. Name this layer “cancov”.
 - C. Ponderosa pine layer—Obtain or generate a 30-m-resolution raster layer that indicates whether or not each pixel is classified as forest dominated or codominated by ponderosa pine (PIPO). This layer should be valued so that 0 = non-PIPO and 1 = PIPO dominant or codominant forest. Additionally, this layer needs to cover all areas inside the Project_area.shp polygon and within 0.6 mile outside the Project_area.shp polygon boundaries. Name this layer “pipo_class”.
 - D. If operating in the Citrix environment or a local environment with access to the Forest Service T drive, run input generation tool. **If the T drive is inaccessible, skip to step E for guidelines on generating inputs without the input generation tool.**
 1. From ArcCatalog, navigate to the TOOLBOX → Habitat Suitability Modeling.tbx → Input Development, and open the “Generate Inputs White-headed Woodpecker Unburned Model” tool.
 2. Under “Workspace”, navigate to a folder where you want model inputs to be stored.
 3. Under “Project Area Boundary”, navigate to the Project_Area.shp file.
 4. For “Percent canopy cover”, use the cancov layer (step I.B), and for “Ponderosa pine”, use the pipo_class layer (step I.C).
 5. Click OK (all outputs will be stored in the INPUTS folder in your workspace).
 - E. *Optional*—Guidelines for generating inputs for White-headed Woodpecker model application tool for unburned forest without the input generation tool (i.e., when you do not have access to the Forest Service T drive):
 1. Apply the “Focal Statistics” tool to the “cancov” layer to generate local- and landscape-scale canopy cover layers.

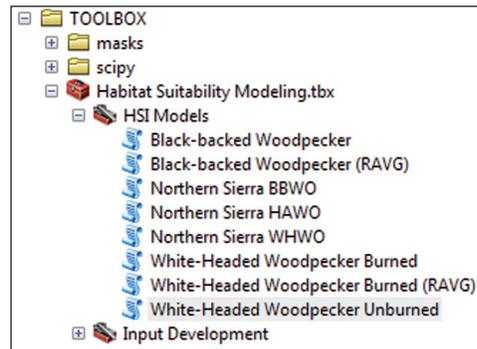
**4.2 White-Headed Woodpecker
Instructions for Unburned Forests
(continued)**

- a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
 - b. Designate `cancov` (see step I.B) as the “Input Raster”.
 - c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Mean”. Name the resulting layer “`lccpre`”.
 - d. Repeat steps I.E.1a–1c, and apply a 1-km-radius neighborhood (select the “Circle” option under “Neighborhood”, select the “Map” option for “Units”, and use 1000 for the “Radius”), set “Statistics type” to “Mean”, and name the resulting layer “`ldcpre`”.
2. Apply the “Focal Statistics” tool to the “`pipo_class`” layer to generate a layer describing the percent coverage of ponderosa pine-dominated forest.
- a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
 - b. Designate “`pipo_class`” (see step I.B) as the “Input Raster”.
 - c. Apply a 1-km-radius neighborhood (select the “Circle” option under “Neighborhood”, select the “Map” option for “Units”, and use 1000 for the “Radius”), set “Statistics type” to “Mean”, and name the resulting layer “`pipopre`”.
3. Clip `lccpre`, `ldcpre`, and `pipopre` using the “`Project_Area.shp`” polygon layer (which you created in step I.A).
- a. Open the “Extract by Mask” tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask). Designate the “`lccpre`” as the “Input Raster” and the “`Project_Area.shp`” file as the mask.
 - b. Open the Environments Window within this tool. Under “Output coordinates”, import the coordinate system from “`Project_Area.shp`”. Under “Processing Extent”, set “`cancov`” as the “Snap Raster”. Note: It does not matter which coordinate system or snap raster is used, as long as you use the same one for all input layers.
 - c. Designate an appropriate location for all input layers (e.g., an INPUTS folder in your workspace), name the output layer “`loccc`”, and click “OK”.
 - d. Repeat steps I.E.3a–3c for “`ldcpre`” and “`pipopre`” and name respective output files “`landcc`” and “`pipo`”.

4.2 White-Headed Woodpecker
Instructions for Unburned Forests
(continued)

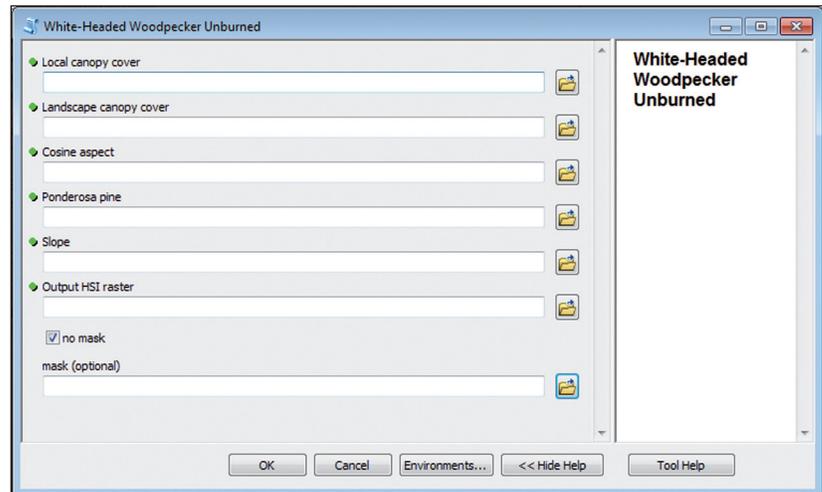
II. Run model application tool:

- A. From ArcCatalog, navigate to TOOLBOX → Habitat Suitability Modeling.tbx → HSI Models, and open the “White-Headed Woodpecker Unburned” tool.



Screenshot of the filepath for the tools for HSI models.

- B. For “Local canopy cover”, “Landscape canopy cover”, “Cosine aspect”, “Ponderosa pine”, and “Slope”, use loccc, landcc, cosasp, pipo, and slp input rasters, respectively, located in the INPUTS folder in your workspace (see step I.D or I.E). Either navigate to the INPUTS folder from outside the tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer.



Screenshot of the dialog box for the tool for the white-headed woodpecker in unburned forest HSI model.

- C. For “Output HSI raster”, designate an appropriate location and filename for the output raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, such as “WHWO_unburned_HSI.tif”. Again, you can specify alternate file formats for rasters, but we recommend “.img” or “.tif” because these allow longer filenames than the default ArcGrid format (which leaves off a filename extension).

4.2 White-Headed Woodpecker Instructions for Unburned Forests (continued)

- D. Select masking option. You must either check the “no mask” box or provide a raster layer to serve as a mask for the final HSI output layer. If neither is done, the tool will produce an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → WHWO_unb → mskpin10. This mask includes all areas with 10 percent or more ponderosa pine-dominated forest within a 0.6-mile-radius neighborhood and covers areas where GNN data are available (Washington, Oregon, and northern California). Alternatively, you may provide a comparable mask that covers your project area or check the “no mask” box, bearing in mind limitations to model applicability described earlier (see subsection 3.2 *White-Headed Woodpecker Unburned Forest Model Applicability*).
- E. Click on OK to run the model. A series of progress bars will flash. If necessary, close the “Results” window once “succeeded” is displayed. To view the ensemble model output, navigate to the output file (e.g., “WHWO_unburned_HSI.tif”) and select the preview pane tab.

4.3 White-Headed Woodpecker Instructions for Burned Forests

The principal output generated by the application tool for white-headed woodpecker in burned forests is a 30-m-resolution raster layer with HSI values ranging from 0 to 1 (i.e., least to most suitable for nesting). The study area must have been burned by relatively large wildfires (1,000 acres in the western United States) for the necessary input data to be retrievable. As with all ArcGIS tools, the user can choose among various file extensions indicating format for output layers, of which we recommend “.tif” or “.img” formats for flexibility in file naming (the more restrictive default ArcGrid file naming leaves off a filename extension). Additional data processing steps will be required if users do not have access to the Forest Service T drive. We provide “optional” data processing instructions for these users in step I.C.

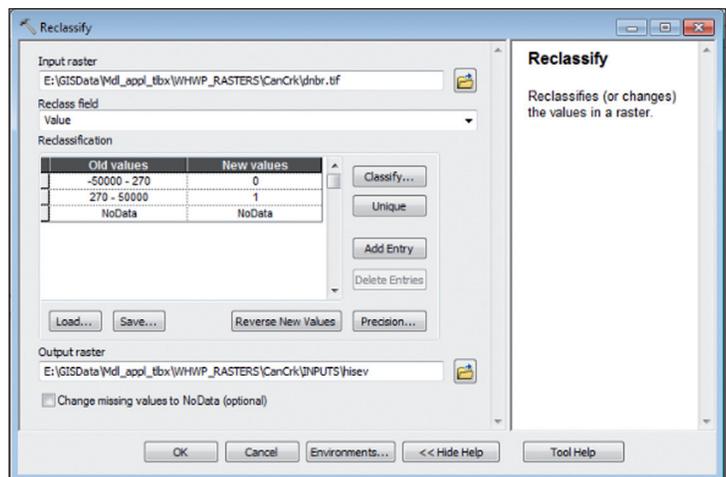
- I. Retrieve and compile data layers. In this step you will process remotely sensed data to compile the variables listed in table 2.3.2. Pathnames for data files cannot have spaces, so when saving the data layers, ensure that no parent folders in the file pathnames have spaces. For example, “C:\GIS\Data\white-headed woodpecker\cancov.tif” is an invalid pathname. Change the name of the “white-headed woodpecker” folder, for example to “white-headedwoodpecker” or “WHWO”.
 - A. Follow instructions in step I.A in subsection 4.1 Black-Backed Woodpecker Instructions for the Inland Northwest to retrieve MTBS burn severity data for the wildfire relevant to your project. As noted in subsection 4.1, the fire perimeter polygon shapefile will end in “...burn_bndy.shp” and the burn severity raster will end in “...dnbr.tif” (hereafter, burn_bndy.shp and dnbr.tif, respectively). **Note on RAVG data: For assessment of recent fires where MTBS data are unavailable, we provide an alternate version of this model**

informed by RAVG data. We compare outputs derived from MTBS- versus RAVG-derived models in Appendix A. You may obtain RAVG data using the online query tool available at <https://www.fs.fed.us/postfirevegcondition/index.shtml>. See step I.A in subsection 4.4 *Northern Sierra Instructions* for retrieving RAVG data.

- B. Compile the two input variables needed for model application (table 2.3.2) using the associated input generation tool described here. **Note: This input generation tool can be operated only within the Forest Service Citrix environment or from an environment with access to the Forest Service T drive. If neither of these conditions is met, follow step I.C for input compilation.** This tool requires only dnbr.tif and burn_bndy.shp files from the user (retrieved in step I.A), which it combines with default prefire canopy cover data to compile inputs. The default canopy cover data represent 2012 gradient nearest neighbor (GNN) data from LEMMA (2018). These data may represent prefire canopy cover for wildfires that burned in 2012 or later unless additional disturbance occurred between recording default imagery (after 2011 but before 2012 fire seasons) and occurrence of the wildfire of interest. We have observed default imagery poorly representing prefire canopy cover at some locations for reasons unknown, so you should carefully inspect default canopy cover data to verify they make sense and are reasonably accurate. In cases where default canopy cover data are deemed sufficient, proceed with steps I.B.1–6 to compile input layers. **For wildfires that occurred before 2012 or for which default imagery are unlikely to accurately represent canopy coverage immediately before wildfire (e.g., due to additional disturbance in the interceding period), follow steps in I.C to use data from an alternate source.**
1. From ArcCatalog, navigate to the TOOLBOX → Habitat Suitability Modeling.tbx → Input Development, and open the “Generate Inputs White-headed Woodpecker Burned Model” tool.
 2. Identify or create a folder where you want model inputs to be stored. Under “Workspace”, navigate to this folder. Then click “Add”.
 3. For “dNBR”, use dnbr.tif downloaded from MTBS (see step I.A). You can either navigate from outside the tool interface and drag and drop dnbr.tif, or navigate from the “dNBR” box and click “Add”.
 4. For “Fire Perimeter”, navigate to burn_bndy.shp downloaded from MTBS (step I.A). You can either navigate from outside the tool interface and drag and drop the burn_bndy.shp into the “Fire Perimeter” box, or navigate from within the tool and click “Add”.
 5. Click OK (all outputs will be stored in the INPUTS folder in your workspace).
 6. Close this dialog when completed successfully.

C. *Optional*—Steps for compiling input layers (locbrnopr and landbrnopr) from alternate data sources are described here. **These instructions are for users who lack access to the Forest Service T drive, or if default canopy cover layers do not cover project areas.** These steps assume you have obtained three layers for your project area: (1) a dnbr.tif file describing burn severity (see step I.A), (2) a burn_bndy.shp file delineating the fire perimeter (see step I.A), and (3) a 30-m-pixel raster layer that provides continuous canopy cover (percent). Raster layers (1, 3) should cover all areas inside and at least 0.6 mile outside burn_bndy.shp. If coverage does not meet this criterion, layers should cover all areas within and at least 1 km outside study units relevant to management planning or decisions, in which case you should use a shapefile describing study unit boundaries in place of burn_bndy.shp in step I.C.6 (following). Note: We suggest following file naming directions as stated below to more easily keep track of files referenced in these instructions.

1. Identify or create a folder named “INPUTS” in your workspace. Place intermediate and final layers generated from steps I.C.2–6 in this folder. The remainder of these steps will refer to this folder as the INPUTS folder.
2. Classify dnbr.tif (see step I.A) to generate an intermediate “hisev.tif” layer.
 - a. Open the Reclassify tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify).
 - b. Designate dnbr.tif as the “Input Raster”. Adjust the “Reclassification” table to match the image below to generate two classes: value = 0 for dNBR < 270 and value = 1 for dNBR > 270.

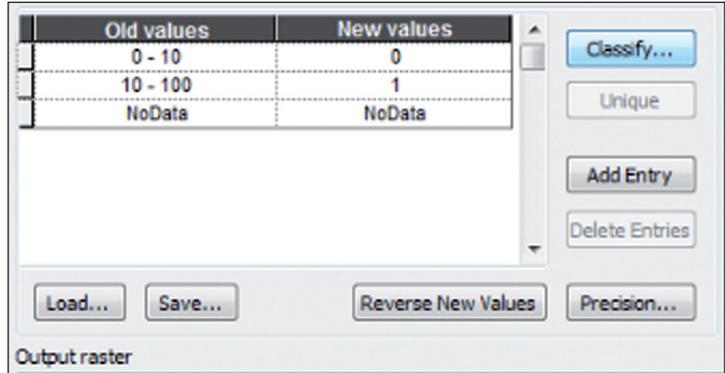


Dialog box for the Reclassify tool for burn severity.

- c. Browse to your INPUTS folder and name the output file “hisev.tif”.
3. Classify your continuous canopy cover layer (see step I.B) (hereafter, “cancov.tif”) to generate an intermediate “ccopen.tif” layer.

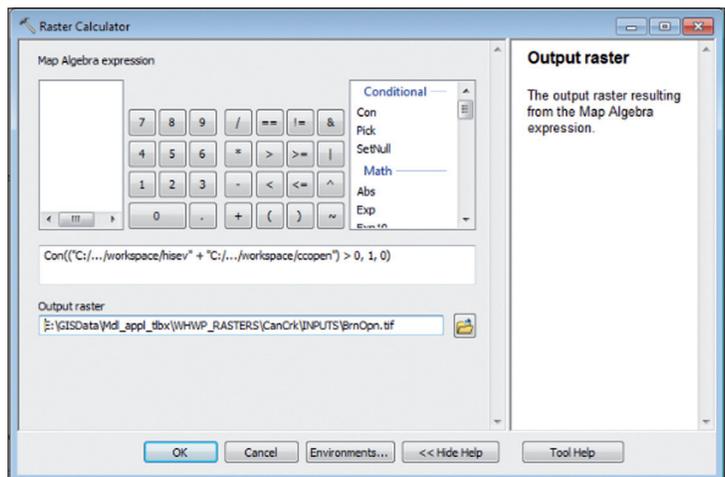
**4.3 White-Headed Woodpecker
Instructions for Burned Forests
(continued)**

- a. Open the Reclassify tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify).
- b. Designate “cancov.tif” as the “Input Raster”. Adjust the “Reclassification” table to match the image below to generate two classes: value = 1 for $\text{cancov} < 10$ and value = 0 for $\text{cancov} > 10$.



Dialog box for the Reclassify tool for the continuous canopy cover layer.

- c. Browse to your INPUTS folder and name the output file “ccopen.tif”. Click OK.
4. Calculate burn or open layer.
- a. Open the “Raster Calculator” tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Raster Calculator).
 - b. In the expression box, write a statement that adds “ccopen” (step I.C.3) and “hisev” (step I.C.2), and then assigns “1” to pixels when $\text{ccopen} + \text{hisev} > 0$ and “0” when $\text{ccopen} + \text{hisev} = 0$ using the “Con” function. The final expression will be of the form “Con((“workspace/hisev.tif” + “workspace/ccopen.tif”) > 0, 1, 0)” (see example screenshot below).

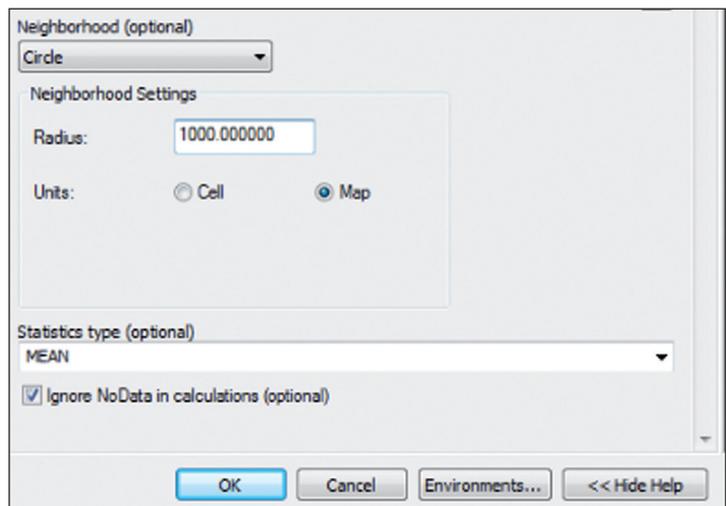


Screenshot of a conditional statement in the Raster calculation tool.

- c. Name the output raster “BrnOpn.tif” and set its location to your INPUTS folder. Click OK.

**4.3 White-Headed Woodpecker
Instructions for Burned Forests
(continued)**

5. Apply the “Focal Statistics” to “BrnOpn.tif” (step I.C.4) and further process with “Raster Calculator” to generate layers describing percent area burned or open.
 - a. Open the Focal Statistics tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
 - b. Designate “BrnOpn.tif” as the “Input Raster”.
 - c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Mean”. Name the resulting layer “locbrnopn_prp.tif”.
 - d. Run the Focal Statistics tool again (Repeat steps I.C.5.a–b), this time setting the neighborhood to “circular”, size to radius = 1000, and units = “Map”. Set Statistics type = “Mean” and select “Ignore NoData in calculations” (see screenshot below). Name the resulting layer “landbrnopn_prp.tif”.



Dialog box for neighborhood and statistics type.

- e. For each layer generated in the last step (“locbrnopn_prp.tif” and “landbrnopn_prp.tif”), apply the Raster Calculator tool again (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Raster Calculator) to rescale to percentages; that is, multiply “locbrnopn_prp.tif” and “landbrnopn_prp.tif” by 100. Designate the INPUTS folder as the output location and name the output files “locbrnopn_premask.tif” and “landbrnopn_premask.tif”, respectively.
6. Clip percent area (burned or open) layers to the fire perimeter to produce final input layers. Open TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask. Successively designate layers generated in the previous step (I.C.5) (“locbrnopn_premask.tif” and “landbrnopn_premask.tif”) as Input layers and burn_bndy.shp as the mask. Designate the INPUTS folder as the output

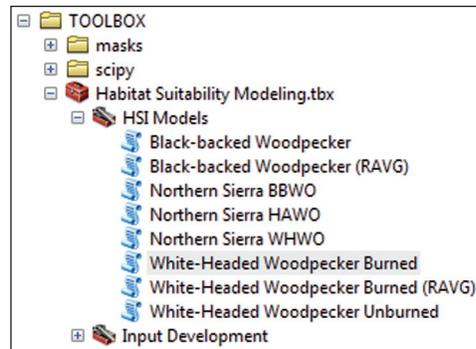
**4.3 White-Headed Woodpecker
Instructions for Burned Forests
(continued)**

location and name the output files “locbnopr.tif” and “landbnopr.tif”. For “landbnopr.tif”, set the snapping layer (Under “Environments... → Processing Extent → Snap Raster” at the bottom of the “Extract by Mask” window) to “locbnopr.tif” to ensure both layers are snapped together.

7. To remain organized and ensure input layers can be easily found in the future, delete all intermediate layers (hisev.tif, ccopen.tif, BrnOpn.tif, locbnopr_prp.tif, landbnopr_prp.tif, locbnopr_premask.tif, and landbnopr_premask.tif) or move them to another appropriate location (e.g., a subfolder named “intermediates” in your INPUTS folder in your workspace).

II. Run model application tool:

- A. From ArcCatalog, navigate to “TOOLBOX → Habitat Suitability Modeling.tbx → HSI Models” and open the “White-headed Woodpecker Burned” tool.

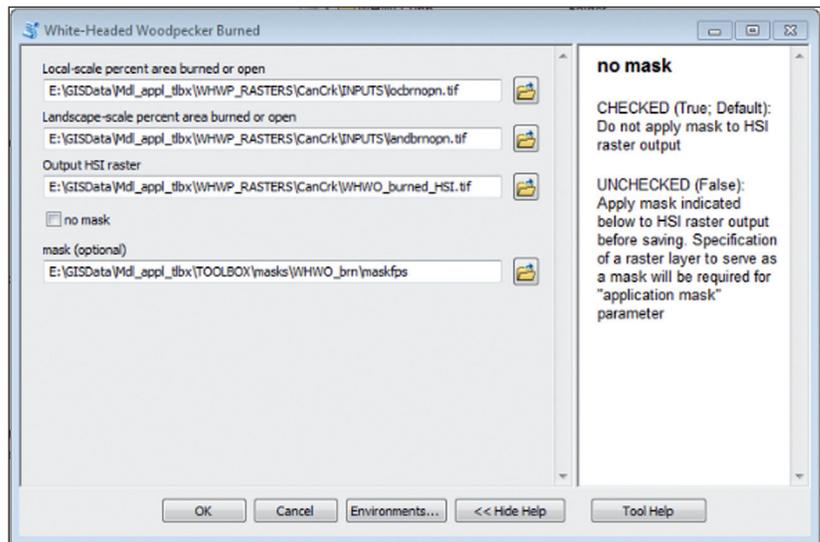


Screenshot of the filepath for the tools for HSI models.

- B. For “Local-scale percent area burned or open” and “Landscape-scale percent area burned or open”, use “locbnopr.tif” and “landbnopr.tif” input rasters, respectively (see steps I.A–C). You can either navigate to the INPUTS folder from outside the tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer.
- C. For “Output HSI raster”, designate an appropriate location and filename for the output raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, such as “WHWO_burned_HSI.tif”. Again, you can specify alternate file formats for rasters, but we recommend “.img” or “.tif” because these allow longer filenames than the default ArcGrid format (which leaves off any filename extension).
- D. Select masking option. You must either check the “no mask” box or provide a raster layer to serve as a mask for the final HSI output layer. If neither is done, the tool will produce an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → WHWO_brn → maskfps. This

4.3 White-Headed Woodpecker Instructions for Burned Forests (continued)

mask includes all areas characterized as dry conifer forest with 10 percent or more ponderosa-dominated forest within a 1-km-radius neighborhood and a slope of 40 percent or less. The mask covers only areas where GNN data are available (Washington, Oregon, and northern California). Alternatively, you may provide a comparable mask that covers your project area or check the “no mask” box, bearing in mind limitations to model applicability described earlier (see 3.2 White-headed Woodpecker Burned Forest Model Applicability). With a mask selected, the input window for this tool will resemble the screenshot below.



Dialog box for the masking option for the white-head woodpecker HSI model.

- E. Click on OK to run the model. A series of progress bars will flash. If necessary, close the “Results” window once “succeeded” is displayed. To view the ensemble model output, navigate to the output file (e.g., “WHWO_burned_HSI.tif”) and select the preview pane tab.

4.4 Northern Sierra Instructions

We provide three model application tools (one per woodpecker species) for northern Sierra Nevada forests. Outputs generated by these tools are 30-m-resolution raster layer with HSI values ranging from 0 to 1 (i.e., least to most suitable for nesting). As for other tools, we recommend using “.tif” or “.img” extensions for output layers for flexibility in filename length (the ArcGrid format leaves off any filename extension). The study area must have been burned by sufficiently large wildfires (>1,000 acres) for the necessary data to be retrievable.

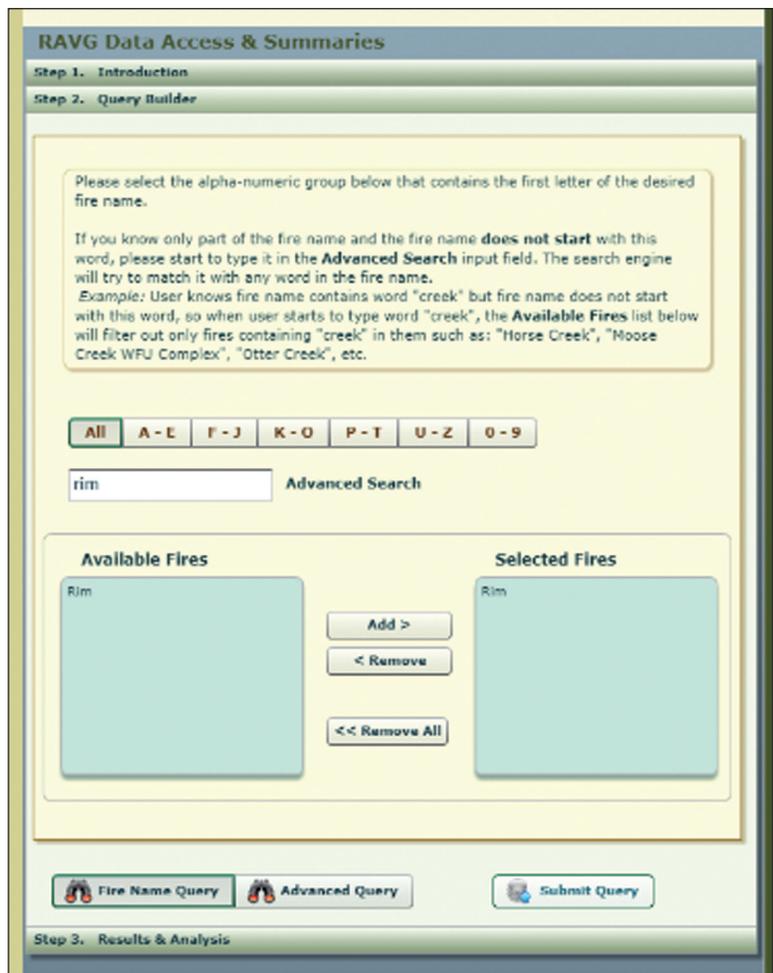
- I. Retrieve and compile environmental data layers. In this step you will retrieve remotely sensed data from Forest Service websites and input them into the Input Generation Tool to compile the variables listed in table 2.4.2. None of the files you download will need to be altered from

4.4 Northern Sierra Instructions
(continued)

their downloaded form. Pathnames for data files used in these tools cannot have spaces, so when saving the environmental data layers to your workstation, ensure that no parent folders in the file pathnames have spaces. For example, “C:\GIS\Data\Northern Sierra\rdnbr_cc.tif” is an invalid pathname. Change the name of the “Northern Sierra” folder, for example to “NorthernSierra” or “Northern_Sierra”.

A. Retrieve burn severity data:

1. Go to the Forest Service Post-Fire Vegetation Conditions website <https://www.fs.fed.us/postfirevegcondition/index.shtml> and enter the necessary information for your fire in the query builder. In this example, we are looking for the 2013 Rim Fire in California. If a window like the one below is not visible in your web browser at the web page in the link above, ensure that Adobe Flash Player is enabled in your web browser, then refresh the web page.



Screenshot of Step 2, Query Builder, window in RAVG Data Access and Summaries.

4.4 Northern Sierra Instructions
(continued)

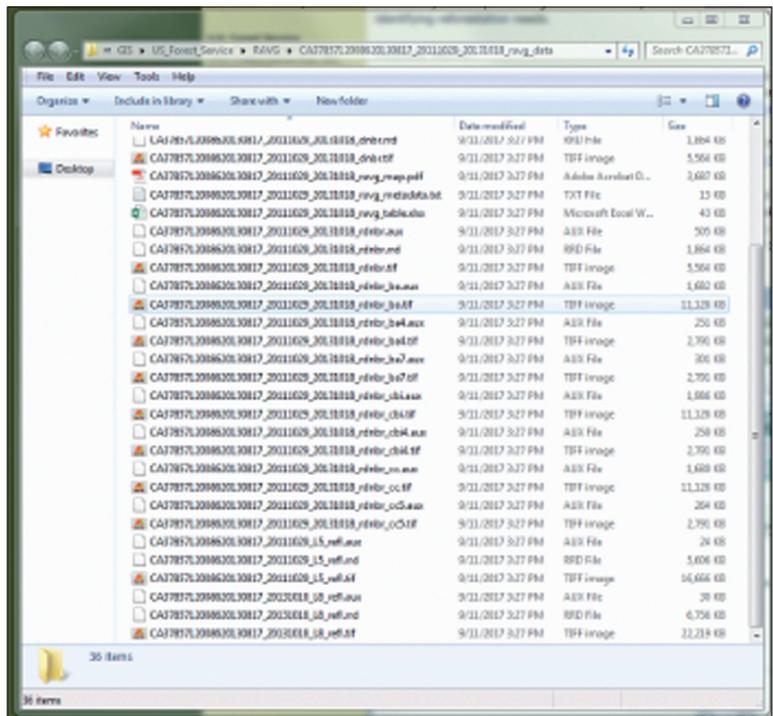
- Click on the compressed file icon under the Download Data column to download the GIS data packet for your fire, then unzip the contents into your GIS workspace.



Screenshot of Step 3, Results and Analysis, window in RAVG Data Access and Summaries.

- See the metadata document in the extracted file folder for explanation of the files associated with your download. In general, the fire perimeter polygon shapefile will end in "... burn_bndy..." and the burn severity raster will end in "_cc_alb.tif" or "_cc.tif" (hereafter, "fire perimeter" and "burn severity" layers, respectively).

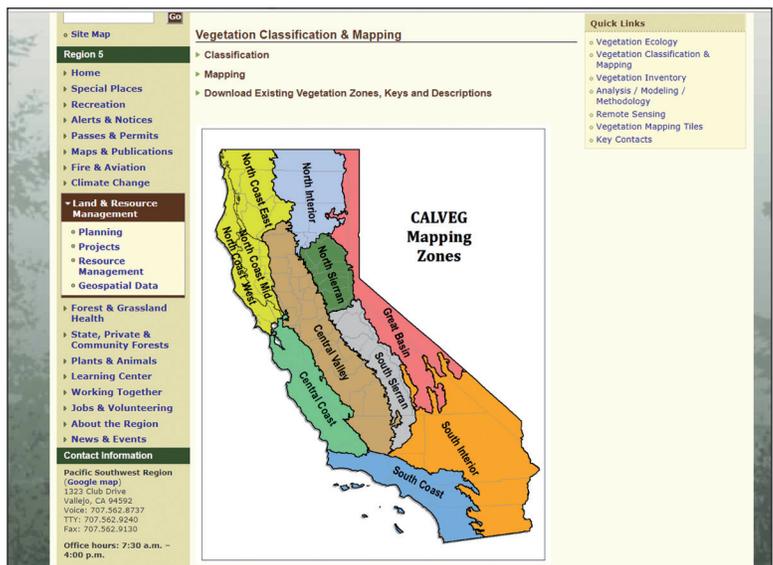
4.4 Northern Sierra Instructions
(continued)



Screenshot of directory for RAVG data files.

B. Retrieve prefire forest structure data:

1. Navigate to the Region 5 Vegetation Classification and Mapping web page <https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192>. Identify the Zone containing your fire of interest using the CALVEG Mapping Zones map on the web page. If your fire of interest is near the border of a Zone, you may also need vegetation data from an adjacent Zone to get complete coverage of the fire perimeter and a 1-km buffer area outside the perimeter. Once you have identified your Zone(s), click on “Download Existing Vegetation Zones, Keys and Descriptions”.



Screenshot of the CALVEG Mapping Zones Map at the Region 5 Vegetation Classification and Mapping website.

4.4 Northern Sierra Instructions (continued)

2. A table will appear below. Click on the Zone containing your fire of interest under the Spatial Data column of the table. If your fire of interest is near the border of a Zone, you may also need to download data for adjacent Zone(s) to get complete coverage of the fire perimeter and a 1-km buffer area outside the perimeter. Unzip the file and place the geodatabase into your GIS workspace.

purposes, it is wise to select a smaller area of interest and break apart features using tools such as the "Multipart To Singlepart" tool in ArcGIS. Reference to this program does not serve as an endorsement by the USDA Forest Service for a specific product.

Citing Geospatial Data

Spatial Data	Keys, Descriptions
Zone 1, North Coast - West	Keys Descriptions
Zone 1, North Coast - Mid	Keys Descriptions
Zone 1, North Coast - East	Keys Descriptions
Zone 2, North Interior	Keys Descriptions
Zone 3, North Sierra	Keys Descriptions
Zone 4, South Sierra	Keys Descriptions
Zone 5, Central Valley	Keys Descriptions
Zone 6, Central Coast	Keys Descriptions
Zone 7, South Coast	Keys Descriptions
Zone 8, South Interior	Keys Descriptions
Zone 9, Great Basin	Keys Descriptions

Our mission is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations.

Screenshot of the table of spatial datasets available by CALVEG Mapping Zone.

3. On the FSGeodata Clearinghouse web page, there is a “Search by keyword” option above the table of feature classes. Type “Existing Vegetation” into the “Search by keyword” text box and click the “go” button.

USDA United States Department of Agriculture Forest Service

FSGeodata Clearinghouse

Enterprise Data

Downloadable Data

- Blots (23)
- Boundaries (43)
- Environment (30)
- Geoscientific Information (8)
- Imagery & Basemaps (43)
- Inland Waters (13)
- Planning Cadastre (14)
- Structure (1)
- Transportation (4)

Data Extract Tool

Map Services

Maps

- FSTopo
- Standard Map Products
- Other Map Products

Raster Data

- Caribbean Island Land

Download National Datasets

Data collected and managed by Forest Service programs is available in a map service and two downloadable file formats – in a shape file and an ESRI file geodatabase. Metadata is available that describes the content, source, and currency of the data. You can filter the list by the topic categories in the menu at the left to help you find information you are interested in. You can view the feature classes in a single dataset by clicking on the name of the parent dataset at the bottom of the abstract.

More FS map services are available in ArcGIS Online

Topic Category Descriptions

Search by keyword: Existing Vegetation go

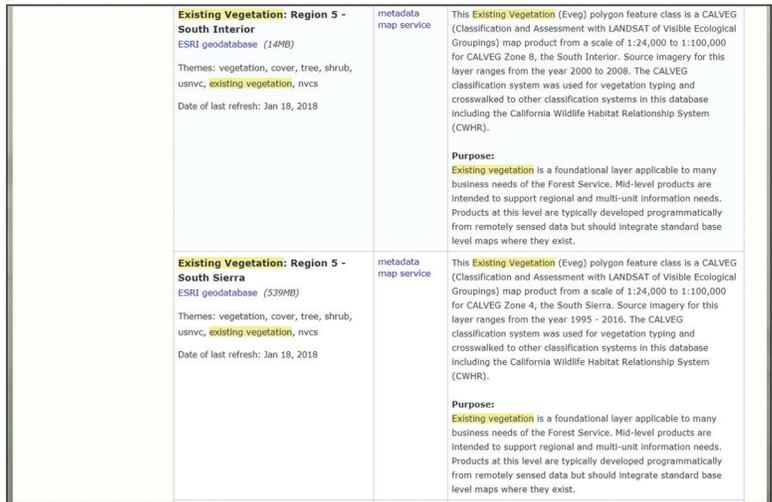
Feature Classes	metadata map service	Abstract
Activity Silviculture Timber Stand Improvement ESRI geodatabase (176MB) shape file (319MB) Date of last refresh: Apr 23, 2018		The SILVTSI (Silviculture Timber Stand Improvement) feature class represents activities associated with the following performance measure: Forest Vegetation Improved (Release, Weeding, and Cleaning, Precommercial Thinning, Pruning and Fertilization). The Activities data set portrays the areas where activities are accomplished... [see more]

parent dataset: Activities

Screenshot of the “Search by keyword” option at the FSGeodata Clearinghouse “Download National Datasets” web page.

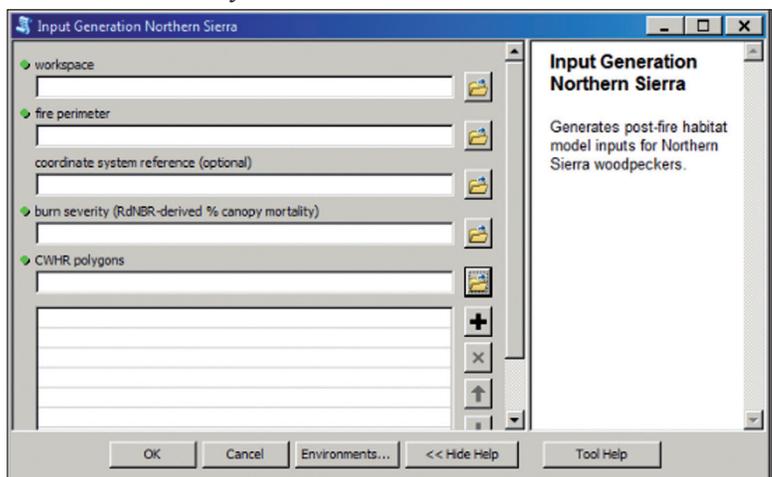
4.4 Northern Sierra Instructions
(continued)

4. Scroll down to your Zone of interest. In our example, we are looking for the “South Sierra” Zone in Region 5. Once you have found your Zone, click the “ESRI geodatabase” hyperlink below the Zone name to download the Zone data. Unzip the file and place the geodatabase into your GIS workspace.



Screenshot of descriptions of and links for Existing Vegetation geodatabases for two Region 5 Zones.

- C. Now you will compile the input variables needed to apply any of the habitat models for Northern Sierra woodpeckers (tables 2.4.2, 2.4.5) using the associated “Input Generation Northern Sierra” tool. The following subtasks are best performed entirely from ArcCatalog. **Unlike for other toolsets, the input generation tool for Northern Sierra woodpeckers does not require access to data layers on the T drive and therefore can be operated in any environment after retrieval of raw data as described in steps I.A and I.B.**
 1. From ArcCatalog, navigate to “TOOLBOX → Habitat Suitability Modeling.tbx → Input Development” and open the “Input Generation Northern Sierra” tool by double-clicking it. This folder is located at “T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX” on Citrix or the “TOOLBOX” folder extracted to your local workstation.



Screenshot of the dialog box for the “Input Generation Northern Sierra” tool.

4.4 Northern Sierra Instructions (continued)

2. Identify or create a folder where you want the layers generated from this tool to be stored. Under “workspace”, navigate to this folder. Then click “Add”. Alternatively, you can drag and drop the desired folder to this window from ArcCatalog.
3. For “fire perimeter”, navigate to the fire perimeter shapefile downloaded along with RAVG data. You can either navigate from outside the tool interface and drag and drop the perimeter shapefile into the “Fire Perimeter” box from ArcCatalog, or navigate from within the tool and click “Add”.
4. If you desire the output file to be in a different coordinate system from RAVG data (i.e., the fire perimeter shapefile), provide a spatial layer (shapefile or raster) that represents the desired coordinate system (drag and drop, or navigate from within the tool). Otherwise, leave blank.
5. For “burn severity”, use the % canopy mortality layer downloaded with RAVG data (step I.A; drag and drop, or navigate from within the tool). The filename for this layer may vary but should include “cc” (e.g., “_cc.img”, “_cc.tif”, or “_cc_alb.tif”) and not “cc5”. You may need to review metadata for downloaded layers (click on the “Description” tab when previewing in ArcCatalog) to identify the right layer. The values in the % canopy mortality layer are derived from the relativized delta-normalized burn ratio (RdNBR) and should range from 0 to 100. If no such layer exists, you can contact the Region 5 Remote Sensing Laboratory for an appropriate file.
6. For “CWHR polygons”, provide the Existing Vegetation polygon file(s) retrieved in step I.B (drag and drop, or navigate from within the tool). The attribute table for each polygon file should contain “CWHR_DENSITY” and “CWHR_SIZE” fields, from which input layers are derived. You can verify existence of these fields by previewing the attribute table for each polygon file in ArcCatalog (go to “Preview” tab at the top, select “Table” in the drop-down menu at the bottom, and scroll to the right; see screenshot below).

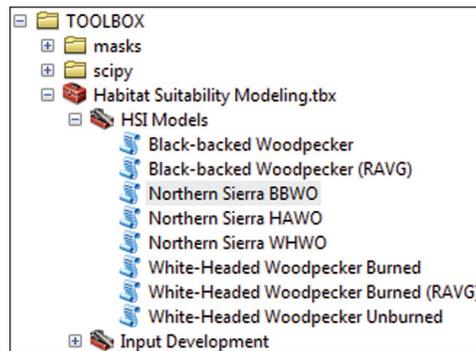
4.4 Northern Sierra Instructions
(continued)

Contents		Preview	Description				
CWHR_LIFFFORM	CWHR_TYPE	CWHR_SIZE	CWHR_DENSITY	SOURCE_DATE	CON_CFA	HDW_CFA	SHB_CFA
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			7/29/2007			
Non and Sparsely V	Urban			7/29/2007			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban			8/16/1999			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Non and Sparsely V	Urban		Not Determined / N	7/10/2009			
Herbaceous	Urban		Not Determined / N	7/10/2009			
Herbaceous	Pasture		Not Determined / N	7/10/2009			
Non and Sparsely V	Barren		Not Determined / N	7/10/2009			
Non and Sparsely V	Barren		Not Determined / N	7/10/2009			
Herbaceous	Annual Grassl		Not Determined / N	7/10/2009			
Herbaceous	Wet Meadow		Not Determined / N	7/10/2009			
Herbaceous	Perennial Gras		Not Determined / N	7/10/2009			
Conifer forest/wood	Sierran Mixed	11.0 - 23.9° D	25.0 - 39.9%	7/10/2009	20 - 29.9 p		2
Conifer forest/wood	Sierran Mixed	11.0 - 23.9° D	25.0 - 39.9%	7/10/2009	20 - 29.9 p		2
Conifer forest/wood	Sierran Mixed	11.0 - 23.9° D	40.0 - 59.9%	7/10/2009	40 - 49.9 p		4
Conifer forest/wood	Sierran Mixed	11.0 - 23.9° D	25.0 - 39.9%	7/10/2009	30 - 39.9 p		3
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			8/29/2004			
Non and Sparsely V	Urban			8/29/2004			

Screenshot of preview of details for Existing Vegetation polygon files.

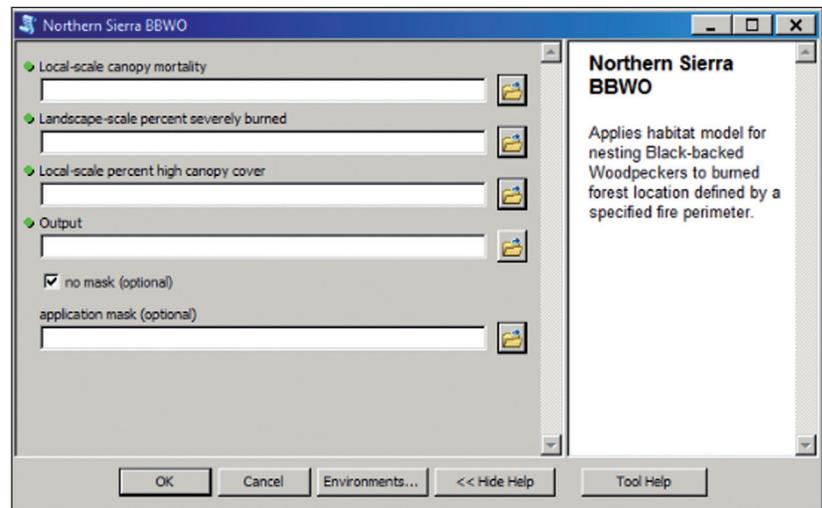
7. Click OK. All outputs will be stored under “predictors” in your workspace. Open this folder and verify presence of the following layers: “locccmort.tif”, “landccmort.tif”, “loccc.tif”, “landcc.tif”, “loctsize.tif”.
 8. *Optional*—The “_scratch” directory generated in your workspace when you implemented this tool can be deleted upon successful completion.
- II. Run any or all model application tools as desired. Now you will use the layers in the “predictors” file as inputs for the species-specific habitat suitability models for Northern Sierra woodpeckers. The following tasks are best performed entirely from ArcCatalog.
- A. From ArcCatalog, navigate to “TOOLBOX → Habitat Suitability Modeling.tbx”, open the “HSI models” toolbox, and then open the desired tool named “Northern Sierra...”, for example, “Northern Sierra BBWO”, by double-clicking it.

4.4 Northern Sierra Instructions
(continued)



Screenshot of the filepath for the tools for HSI models.

- B. For the variables listed in table 2.4.2 (abbreviations: LocCCmort, LandCCmort, LocCC, LandCC, and LocTrSize), use “locccmort.tif”, “landccmort.tif”, “loccc.tif”, “landcc.tif”, “loctrsize.tif”, respectively (generated in step I.C). You can either navigate to the “predictors” folder in ArcCatalog and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer. A subset of two or three of these input layers will be required for any one tool.



Screenshot of dialog box for black-backed woodpecker in burned forest in the northern Sierra Nevada.

- C. For the “Output” parameter, designate an appropriate location and filename for the output HSI raster. Click the button with the folder icon to the right, locate your workspace or any other desired location, and create a meaningful name, such as “HSI_BBWO.tif”. Again, we recommend “.img” or “.tif” file extensions to allow longer filenames (the ArcGrid format leaves off any filename extension).
- D. Select masking options. You must either check the “no mask” box or provide a raster layer to serve as a mask for the final HSI output layer. If neither is done, the tool will produce an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask

**4.4 Northern Sierra Instructions
(continued)**

(TOOLBOX → masks → NSierra → mask) whose rationale was described earlier in 3.4 Applicability of Northern Sierra Models . If this mask includes the entire study area (i.e., study area contains no NODATA pixels), you may check the “no mask” box and proceed with tool implementation. On the other hand, if large portions of the study area are excluded, the safest course would be to specify the suggested mask or an equivalent layer relevant to your project area.

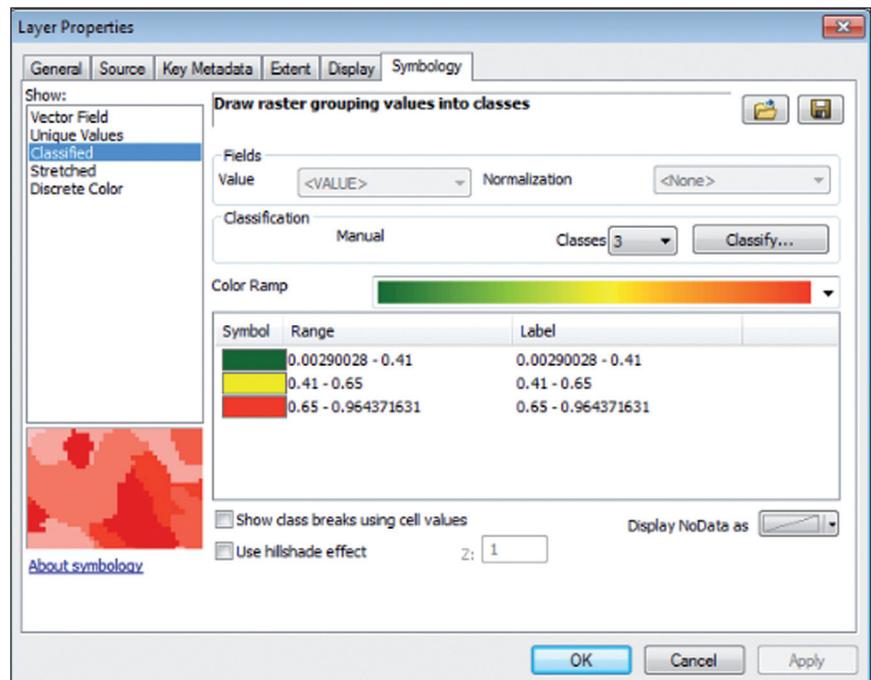
- E. Click on OK to run the model. A series of progress bars will flash. If necessary, close the “Results” window once “succeeded” is displayed. To view the ensemble model output, navigate to the output file (e.g., “HSI_BBWO.tif”), and select the preview pane tab.

5. Guidelines for Application and Interpretation of Habitat Suitability Indices

We provide both general and model-specific guidelines for displaying and applying habitat suitability index (HSI) maps to support forest planning. In general, we anticipate managers' need to display model predictions as suitability categories (e.g., low, moderate, and high suitability habitat). We therefore provide guidelines for defining and interpreting such categories.

In general, HSI maps depicting suitability categories can be displayed in ArcMap by following these steps:

1. In ArcMap, open either a new map document or an existing one containing relevant layers for project planning.
2. Open the "Catalog" window (look for  button).
3. From the "Catalog" window, navigate to the output HSI map layer generated from the model application tool (e.g., "BBWO_..._HSI_ensemble_output.tif", "HSI_HAWO.tif"), and drag and drop this layer into the ArcMap table of contents window (left-hand side of screen).
4. In ArcMap Table of Contents, right-click on the HSI output layer and go to Properties → Symbology. Select the "Classified" option in the menu on the left.



Screenshot of dialog box for Layer Properties.

From this window, select the number of categories desired, the HSI thresholds that define desired categories (click on the "Classify" button on the right), and the color scheme for mapping. We provide guidance for defining categories for particular models later in this section.

We anticipate three basic questions for forest managers with woodpecker habitat conservation objectives:

1. Where is suitable nesting habitat within the project area?
2. Where and how could management activities positively or negatively impact habitat?
3. How much suitable habitat is needed for population persistence?

To help address these questions, we relate HSIs with apparent or hatched nest densities observed at locations where models were developed. We use the relationship between HSIs and nest densities to inform suitability categories and their interpretation. Hatched nests are highly detectable with our survey methods (Russell et al. 2009), so we related hatched nest densities with HSIs where possible. At locations where hatching status had not been consistently recorded, we related apparent nest densities with HSIs. Apparent nest densities are subject to negative detection bias, but we expect this bias to be sufficiently independent of habitat for apparent densities to accurately reflect HSI-related variation and differences among suitability classes.

We generated 95-percent confidence intervals for apparent or hatched nest densities within suitability categories using nonparametric bootstrapping (Efron and Tibshirani 1986) with transects (Northern Sierra and white-headed woodpecker unburned forest models) or 600-m cells (black-backed and white-headed woodpecker burned-forest models) as sampling units. We caution that density estimates may not fully account for regional variation in population density or time since disturbance. Nevertheless, they indicate differences in nest densities among low, moderate, and high suitability habitat at sampled locations within 5 years following wildfire. In addition, we work through a hypothetical example of model application to inform postfire management strategies at the Canyon Creek Fire in the Malheur National Forest (Appendix B).

HSI models provided here describe the relative suitability of sites for nesting, and therefore cannot be used in isolation to inform how much habitat to conserve (question 3). To address this question, managers must consider population ecology and management objectives along with the distribution of modeled habitat. Relating HSIs with nest densities can help inform applications with particular population targets. Ideally, we would relate additional population parameters, such as abundance, fitness, and population viability, with habitat to develop meaningful management objectives. Such data are often unavailable and prohibitively costly to collect for most woodpecker populations.

We therefore suggest a comparative approach for forest planning. We can compare the amount of highly or moderately-to-highly suitable habitat retained among alternative management scenarios, relative to what was present historically across landscapes of interest. The aim of management objectives founded on a comparative approach is to maintain levels of habitat associated with persistent populations in other areas or time periods. Continued testing and refinement of models with newly acquired independent data will improve model predictive performance, which will concomitantly improve the information provided by this approach.

5.1 Guidelines for Postfire Habitat Models

We expect application of postfire habitat models primarily to inform management plans needing to accommodate both resource extraction (i.e., salvage logging) and woodpecker habitat conservation. To support such application, we identify suitability categories based on HSI relationships with hatched-nest densities (where available) or apparent nest densities (where hatching status was uncertain) in burned forests where models were developed (see also Latif et al. 2013, in preparation; Campos et al., in preparation). In all cases, observed nest densities increased from low to moderate and from moderate to high suitability classes (tables 5.1.1–3, figs. 5.1.1–3). Our observations suggest some variation among study locations (table 5.1.1). Nevertheless, nest densities consistently increased with increasing predicted suitability. Reserves set aside for habitat conservation should therefore proportionately favor areas classified as high over moderate and moderate over low suitability.

Table 5.1.1—Observed nest densities (per 1,000 ac) at locations habitat suitability models were developed for nesting black-backed woodpeckers. Low, moderate, and high suitability classes correspond with ensemble model predictions of 0–2, 3–5, and 6–8, respectively. Percent nests = the expected value given even sampling across categories. Area surveyed represents the extent surveyed each year multiplied by study duration at each location. 95% confidence limits (error bars) were bootstrapped using 600 m cells as sampling units (n = 67, 83, and 176 for Star Gulch, Tripod, and Toolbox locations, respectively). **Note: Values in this table are for HSIs based on MTBS (extended assessment) burn severity. For equivalent RAVG-based (immediate assessment) HSIs, refer to values in table A1.**

Fire location Quantity	Habitat suitability (HSI) class		
	Low	Moderate	High
Star Gulch (1994 Idaho)^a			
Density	0.22 (0, 0.56)	2.07 (0.32, 4.51)	3.92 (2.55, 5.35)
Percent nests	4 (0, 10)	33 (7, 54)	63 (45, 89)
Area surveyed (acres)	22,214.2	7,153.6	17,011.9
Tripod (2006 Washington)^a			
Density	0 (0, 0)	1.96 (0, 4.72)	9.86 (4.3, 16.1)
Percent nests	0 (0, 0)	17 (0, 43)	83 (57, 100)
Area surveyed (acres)	12,570.2	2,519.9	3,756.6
Toolbox (2002 Oregon)^a			
Density	1.28 (0.41, 2.26)	5.92 (3.41, 8.84)	11.03 (8.38, 13.93)
Percent nests	7 (2, 12)	32 (21, 44)	61 (49, 73)
Area surveyed (acres)	11,586.0	7,930.4	15,893.5
All three fires^b			
Density	0.43 (0.16, 0.75)	3.57 (2.18, 5.17)	7.71 (6.25, 9.33)

^a To inform potential densities within suitability classes, we suggest referencing densities associated with locations listed here that are most similar in environmental conditions to the project area of interest. Percent ponderosa pine and median percent slope are 64 percent and 47 percent at Star Gulch, 55 percent and 37 percent at Tripod, and 82 percent and 14 percent at Toolbox (for these and additional relevant data, see Hollenbeck et al. 2013).

^b Values represented by red circles and error bars in figure 5.1.1.

**5.1 Guidelines for Postfire
Habitat Models (continued)**

Table 5.1.2—Density of hatched nests (per 1000 ac) in suitability classes defined by HSI thresholds (0.34, 0.6) for white-headed woodpeckers in burned forest. Models were developed with data from Toolbox and Canyon Creek wildfire locations (Oregon). 95% CLs (in parentheses) were generated with non-parametric bootstrapping. Values for “percent nests” are the expected percent of hatched nests assuming equal area sampling across suitability classes. Area surveyed was calculated as the proportion of sites representing the surveyed area in each suitability class multiplied by the total area surveyed at each location. **Note: Values in this table are for a HSI model based on MTBS (extended assessment) burn severity. For the equivalent RAVG-based (immediate assessment) model, refer to values in table A2.**

Location Quantity	Habitat suitability (HSI) class		
	Low	Moderate	High
Toolbox (2002)			
Density	0.28 (0.06, 0.54)	1.52 (0.9, 2.2)	3.97 (1.93, 6.22)
Percent nests	5 (1, 10)	26 (16, 43)	69 (50, 80)
Area surveyed (acres)	17,592.3	15,765.1	3,780.7
Canyon Creek (2015)			
Density	0.66 (0.23, 1.2)	3.11 (1.99, 4.3)	6.12 (2.71, 10.11)
Percent nests	7 (2, 14)	31 (19, 50)	62 (41, 76)
Area surveyed (acres)	12,114.4	8,673.8	1,633.4
Both fires^a			
Density	0.44 (0.21, 0.71)	2.09 (1.49, 2.7)	4.68 (2.91, 6.68)

^a Values represented by red circles and error bars in figure 5.1.2.

We recommend managers consider several other factors along with modeled HSIs when planning management of recently burned forests. Studies in Idaho found negative effects of salvage logging on nest density and nest survival for several woodpecker species (Saab et al. 2007). Bark-drilling species, including black-backed and hairy woodpecker, favor and may require nest sites surrounded by relatively high snag densities for foraging (Dudley et al. 2012). Other species, such as white-headed woodpecker, may forage more in nearby green forest (Wightman et al. 2010). Forest conditions within 0.6 mile of the nest site therefore inform modeled HSIs, and so to conservatively maintain the HSI of a given patch, logging should be restricted within 0.6 mile of that patch. Conserving areas within 0.6 mile of potential nesting habitat will ensure that associated foraging habitat is maintained even if surrounding areas are lower in suitability for nesting.

Removal of roadside hazard trees can severely impact burned forest landscapes, especially in areas of high road density. If road closings are not feasible, habitat reserves should be located in areas with minimal road densities, and model applications should account for areas affected by roadside tree removal (e.g., by discounting prefire canopy cover input values within affected areas). Although topographic slope does little to inform

**5.1 Guidelines for Postfire
Habitat Models (continued)**

Table 5.1.3—Number of nests and observed nest densities where habitat suitability models were developed for nesting woodpeckers in the Northern Sierra Nevada Mountains by suitability class. Habitat suitability index (HSI) bins define suitability classes. All surveys were conducted within 5 years following wildfire. Expected percent nest values assume observed densities and equal area surveyed in each suitability categories. Density and percent nest values in parentheses are 95 percent CLs generated by transect-level boot-strapping (n = 45 transects replicated 5000 times).

Species	Summary quantity	Values by habitat suitability (HSI) class		
		Low	Moderate	High
Black-backed woodpecker	HSI bins	0–0.41	0.41–0.65	0.65–1
	No. nests	8	17	29
	Area surveyed (acres)	5,714.3	1,976.7	1,193.4
	Density (nests per 1,000 acres)	1.4 (0.5, 2.4)	8.6 (4.3, 13.8)	24.3 (9.4, 40.8)
	Expected % nests	4 (2, 9)	25 (14, 45)	71 (49, 83)
Hairy woodpecker	HSI bins	0–0.51	0.51–0.7	0.7–1
	No. nests	18	45	27
	Area surveyed (acres)	5,294.1	2,678.6	857.1
	Density (nests per 1,000 acres)	3.4 (1.6, 5.3)	16.8 (11.8, 23.1)	31.5 (17.3, 52)
	Expected % nests	6 (3, 10)	33 (23, 47)	61 (45, 72)
White-headed woodpecker	HSI bins	0–0.49	0.49–0.75	0.75–1
	No. nests	16	26	30
	Area surveyed (acres)	5,925.9	2,148.8	859.6
	Density (nests per 1,000 acres)	2.7 (1.4, 4.2)	12.1 (7.2, 18.6)	34.9 (17.2, 53.2)
	Expected % nests	5 (3, 10)	24 (16, 39)	70 (53, 80)

HSI models here, woodpeckers tend to favor relatively gentle slopes at some locations (Hollenbeck et al. 2011; Latif et al. 2016). Consequently, we recommend habitat reserves that include gentle slopes as available within project areas. Finally, HSI models strictly inform nesting densities, so managers may need to consider additional information on other fitness components such as nest survival as is available. In particular, nest survival for black-backed woodpecker in the Inland Northwest and Rocky Mountains can decrease with increasing proximity to unburned edge, possibly reflecting nest predator refugia provided by unburned forest (Saab et al. 2011).

Disturbance-associated woodpeckers are mobile and populations persist largely through colonization of newly burned forests mediated by dispersal (Dixon and Saab 2000; Siegel et al. 2015). Given the importance of dispersal across locations for maintaining populations, habitat targets

5.1 Guidelines for Postfire
Habitat Models (continued)

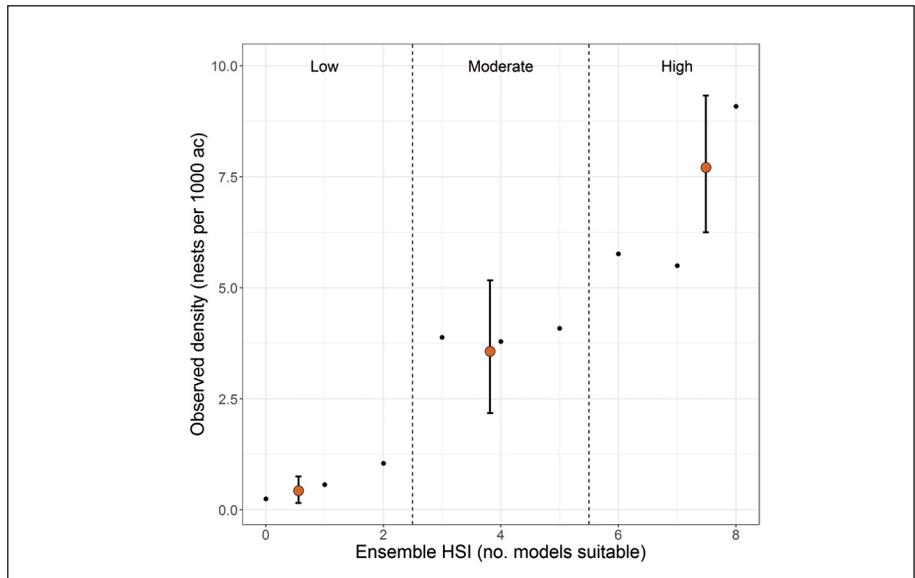


Figure 5.1.1—Observed nest densities related with ensemble HSI (i.e., the number of models classifying a given site as suitable) for black-backed woodpeckers in the Inland Northwest. Small black dots are values for individual HSI levels. Large red dots represent observed densities averaged (mean) across locations (Star Gulch [Idaho], Toolbox [Oregon], and Tripod [Washington]) within suitability categories (low, moderate, and high) and are plotted at mean HSI values. Error bars represent 95-percent confidence intervals, which were bootstrapped by using 600-m cells as sampling units ($n = 326$ across all three locations). **Note: Values in this figure are for HSIs based on MTBS (extended assessment) burn severity. For equivalent RAVG-based (immediate assessment) HSIs, refer to figure A1.**

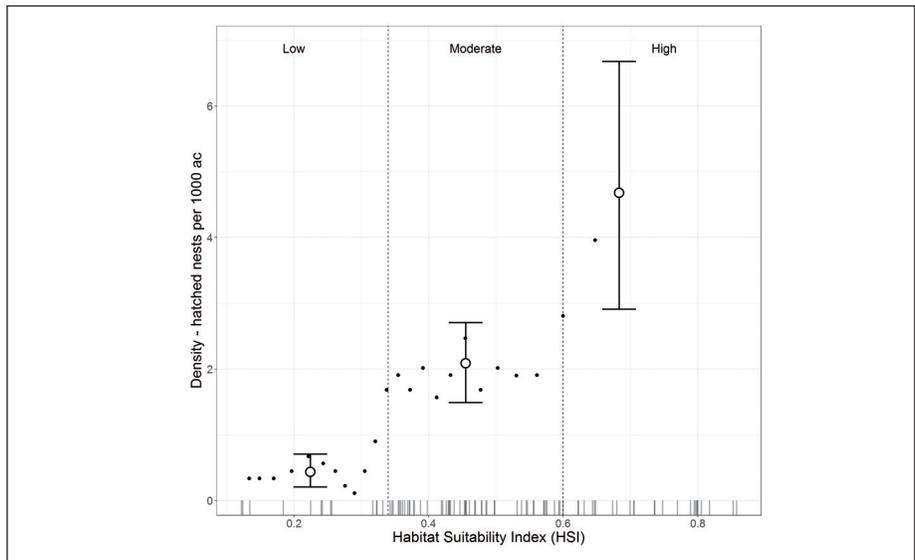


Figure 5.1.2—Densities of hatched nests for white-headed woodpeckers along an HSI gradient in burned forest. Low, moderate, and high suitability classes are differentiated by two HSI thresholds, one that maximizes the sum of sensitivity and specificity (maxSSS) and the other placed at a natural break in densities for equal-area moving-window bins in this figure (small dots) and the distribution of nest site HSIs (rug bars). Large circles and error bars are density estimates and bootstrapped 95-percent confidence intervals for habitat suitability classes, respectively. **Note: Values in this figure are for an HSI model based on MTBS (extended assessment) burn severity. For the equivalent RAVG-based (immediate assessment) model, refer to figure A2.**

5.1 Guidelines for Postfire
Habitat Models (continued)

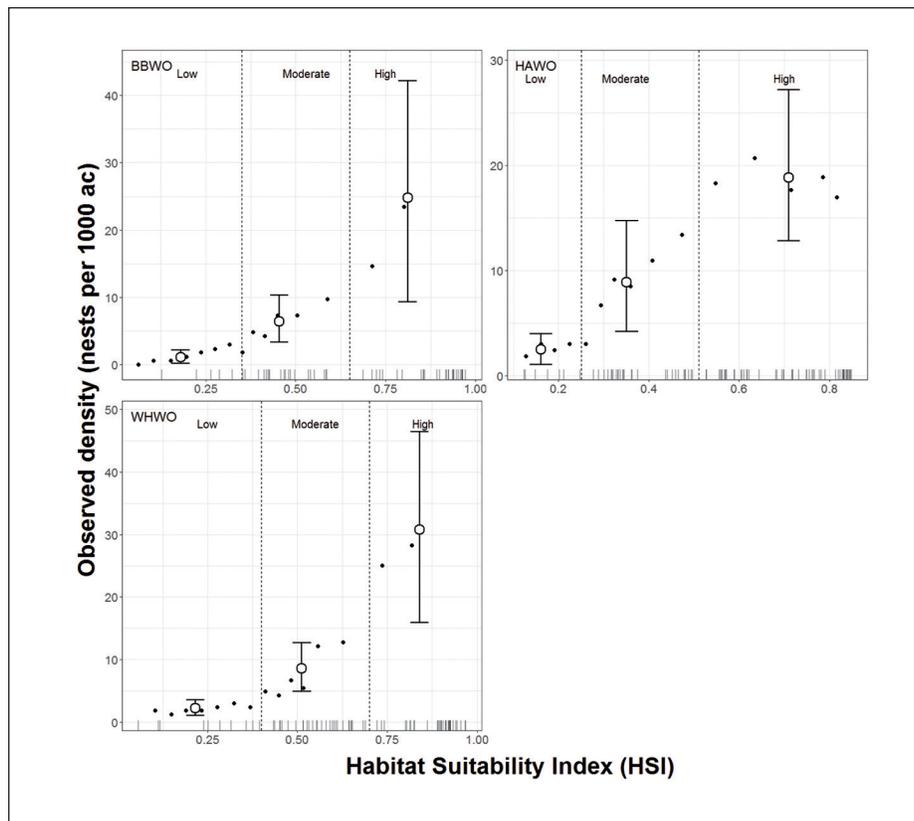


Figure 5.1.3—Observed nest densities (not corrected for detectability) related with HSI values for woodpeckers in the northern Sierra Nevada. Species are black-backed woodpecker (BBWO), hairy woodpecker (HAWO), and white-headed woodpecker (WHWO). Small open dots are values for equal-area moving-window bins, and large closed dots are values for suggested suitability categories. Error bars represent 95-percent confidence intervals generated by transect-level bootstrapping ($n = 45$ transects replicated 5,000 times). Rug plot shows HSI values for nest locations. The low-to-moderate HSI threshold maximizes the sum of sensitivity (proportion of nests classified as moderate) and specificity (proportion of landscape classified as low) (maxSSS).

at any one location should be placed in a landscape context. Thus, we recommend analyzing habitat dynamics and comparing the implications of alternate management scenarios for habitat suitability across landscapes large enough to include multiple neighboring locations (e.g., entire national forests) to inform conservation objectives for any one wildfire location. In conjunction with tools presented here, development of tools that streamline analysis of landscape-scale habitat dynamics was partially funded and is ongoing (National Fire Plan Funded Proposal FY16-FY18; Saab, Latif, and Haas FRF23516). Summaries of observed nesting densities (tables 5.1.1–3) provide further context for comparing alternate management scenarios with historically derived benchmarks; bear in mind these caveats:

1. We expect habitat models to be most applicable in forests proposed for tree harvest. Woodpeckers are likely to make some use of selectively logged forests with potentially similar reproductive success (Forristal

5.1 Guidelines for Postfire Habitat Models (continued)

2009; Saab et al. 2007, 2011). Further study may allow precise estimation of population densities with particular treatments and prefire conditions, which could inform refinement of salvage logging plans to reflect nuanced population responses.

2. Ensemble predictions for black-backed woodpecker reflect not only relative habitat suitability but also modeling uncertainty. Specifically, the moderate suitability classification indicates areas where models disagree and suitability is therefore less certain (Latif et al. 2013). Additionally, we are least confident in nest density estimates for moderate suitability areas because locations where models were developed contained relatively limited moderate suitability habitat. In contrast, model disagreement and the extent of moderate suitability habitat tend to be higher at locations with environmental conditions that deviate from where models were developed (Latif et al. 2013). Thus, we have less confidence in the predictive value of ensemble predictions in areas with proportionately extensive moderate suitability habitat (HSI = 3–5). For such project areas, monitoring the effects of management treatments and evaluation (and possible refinement) of model predictions with independent data (ideally nest locations) would be needed.
3. HSIs most explicitly describe habitat suitability for nesting but also implicitly contain information on surrounding foraging habitat within 0.6-mile-radius neighborhoods. Other studies explicitly quantify foraging habitat, home range size, and relationships between the two (Dudley and Saab 2007; Dudley et al. 2012; Tingley et al. 2014). Remotely sensed data available for most wildfire locations (i.e., burn severity, prefire canopy cover) typically lack the resolution for applying published models that quantify foraging habitat suitability. For locations with fine-scale data quantifying snag densities and distributions (e.g., field measurements or LiDAR), home range size and foraging habitat data could improve and clarify predictions of population density (e.g., Tingley et al. 2016).

5.2 Guidelines for White-headed Woodpecker in Unburned Forests

We expect HSIs for nesting white-headed woodpecker in unburned forests to primarily inform large-scale forest restoration, such as restoration projects funded by the Collaborative Forest Landscape Restoration Program (CFLRP) (<https://www.fs.fed.us/restoration/CFLRP/>). Managers can limit or defer restoration treatments (usually thinning or prescribed burning for fuels reduction) in areas characterized as high suitability and implement treatments in areas where habitat suitability is limited by a lack of canopy openings (Hollenbeck et al. 2011). Managers could also apply the HSI model to hypothetical landscapes representing projected conditions under alternative management or climate scenarios. HSI maps representing conditions in Oregon in 2002 and 2012 are posted on the T drive (T:\FS\RD\RMRS\Science\WTE\Research\RMRS-WHWO\Oregon_hsi_maps\WHWO_OR_HSI_maps.gdb). The tool for white-headed woodpecker in unburned forest supplements these data by facilitating model application to projected future scenarios or landscapes affected by disturbance relatively recently.

5.2 Guidelines for White-headed Woodpecker in Unburned Forests (continued)

We anticipate forest managers using HSI maps to identify areas where restoration could improve habitat conditions for white-headed woodpecker or to evaluate the relative benefits of alternative management strategies. To support such applications, we have identified suitability categories based on HSI relationships with observed nest densities in unburned forests of Oregon (table 5.2, fig. 5.2). Depending on specific management goals, we suggest HSI thresholds of 0.4 or 0.49 to distinguish between low, moderate, and high suitability categories. These categories are analogous to those evaluated by Latif et al. (2015), but optimized for the simplified model applied here, such that categories meaningfully differentiate observed densities across multiple national forests representing different geographic regions (table 5.2).

Table 5.2—Number of nests, area surveyed, and observed nest densities (not corrected for imperfect detection) in habitat suitability categories for white-headed woodpecker in unburned forests of Oregon. Suitability categories are low (HSI < 0.4), moderate (0.4 ≤ HSI < 0.49), and high (HSI ≥ 0.49). The model was originally developed with data from the Deschutes and Fremont-Winema National Forests, and data from the Malheur National Forest were collected following model development.

National forest	Summary quantity	Values by habitat suitability (HSI) class		
		Low	Moderate	High
Deschutes	No. nests	3	4	10
	Area surveyed (acres)	350.4	207.2	291.6
	Density (nests per 1,000 acres)	8.6	19.3	34.3
	Expected % nests	14	31	55
Fremont-Winema	No. nests	3	0	4
	Area surveyed (acres)	690.3	267.5	172
	Density (nests per 1,000 acres)	4.3	0	23.3
	Expected % nests	16	0	84
Malheur	No. nests	3	12	24
	Area surveyed (acres)	1,130.2	622.5	600.9
	Density (nests per 1,000 acres)	2.7	19.3	39.9
	Expected % nests	4	31	65
All three forests	No. nests	9	16	38
	Area surveyed (acres)	2,175.1	1,162.1	1,133.4
	Density (nests per 1,000 acres)	4.1 (1.8, 6.7)	13.8 (5.5, 23.6)	33.5 (21.7, 47.8)
	Expected % nests	8 (3, 15)	27 (12, 41)	65 (51, 79)

5.2 Guidelines for White-headed Woodpecker in Unburned Forests (continued)

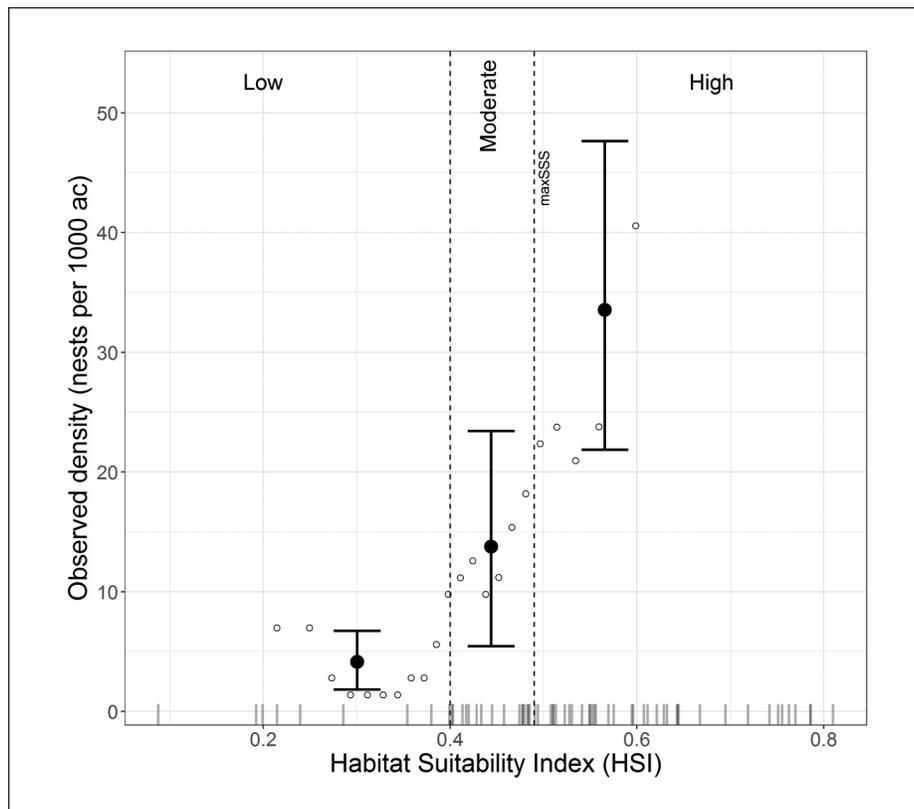


Figure 5.2—Observed nest densities related with HSI values for white-headed woodpecker in unburned forests of Oregon. Small open dots are values for equal-area moving-window bins, and large closed dots are values for suggested suitability categories. Density values are for areas within 0.2 mile of transects where survey effort was highest and evenly distributed. Error bars represent 95-percent confidence intervals generated by transect-level bootstrapping (n = 57 transects replicated 5,000 times). Rug plot shows HSI values for nest locations (n = 63). The moderate-to-high HSI threshold (0.49) maximizes the sum of sensitivity (proportion of nests classified as high) and specificity (proportion of landscape classified as low or moderate) (maxSSS).

Managers can define alternative suitability categories to accommodate particular objectives by considering how observed nest densities relate with HSIs (fig. 5.2). Managers can then plan or evaluate forest restoration by considering how treatments are likely to affect or have affected the amount and distribution of low, moderate, or high suitability habitat within project areas. Additionally, managers can further gauge the potential implications of treatments for populations by considering observed nest densities at sampled locations (table 5.2, fig. 5.2).

The HSI model presented here should be applied outside Oregon with caution, particularly in landscapes with conditions that differ substantially from those where models were developed (see Latif et al. 2015). For example, we facilitated application of this model to inform sampling design for monitoring white-headed woodpecker at the Nez Perce-Clearwater National Forest in Idaho. The model assigned extremely low HSI values to most areas because the Idaho study area was characterized by much greater

topographic relief than Oregon study areas. An alternate model fitted to available data that excluded topographic predictors (i.e., Slope and Cosine Aspect; table 2.2) appeared more useful and may be added to the GIS toolbox described here following evaluation with independent data in Idaho.

When using HSIs to inform conservation or restoration, managers need to carefully consider environmental inputs used to calculate HSIs. HSIs are calculated in part by using variables representing forest structure over a 0.6-mile-radius area (table 2.2), so management decisions need to include areas within 0.6 mile of target locations. Additionally, evaluating whether suitability at potential project areas is mainly limited by the arrangement of open- and closed-canopy forests or by the absence of ponderosa pine within 0.6 mile of these areas is necessary to inform restoration treatments. We expect restoration treatments to have greater potential to primarily improve habitat suitability in the near term by encouraging canopy mosaics, but treatments could also benefit habitat suitability in the long term if they encourage ponderosa pine dominance. To best inform their decisions, forest managers should ideally compare HSI maps generated for landscapes explicitly representing projected results of alternative management options.

We did not attempt to relate HSIs with observed nest densities. Anticipated uses of this HSI model will focus on relative differences in amount of suitable habitat under alternative scenarios rather than determining an absolute amount of habitat to conserve. Effectiveness monitoring studies of Collaborative Forest Landscape Restoration treatments are generating data for evaluating treatment effects on white-headed woodpecker nesting densities and habitat.

6. Management Implications

Despite widespread development of models intended to inform habitat management, accessibility limits their application (Guisan et al. 2013). The tools described here are designed to improve accessibility of habitat suitability models for disturbance-associated woodpeckers to assist forest management decisionmaking in western North America. Our approach consists of integrating model application tools into software commonly used for management planning (ArcGIS) and providing guidelines for interpreting HSI maps in relation to underlying species ecology.

Thus far, we have provided model application tools for woodpecker species of conservation concern in mixed conifer forests to assess various management activities. Several woodpecker species inhabit forests recently burned by wildfire, for which habitat models are powerful tools for planning postfire salvage logging activities. Additionally, in the Inland Northwest, the white-headed woodpecker specializes on ponderosa pine-dominated forests characterized by canopy mosaics, wherein habitat models for unburned forests could inform large-scale forest restoration treatments.

We will continue to develop habitat models for other woodpecker species that will broaden the application and information for science-based management decisions. For example, habitat models for Lewis's woodpecker (*Melanerpes lewis*) in burned forests would further inform salvage planning. Black-backed, white-headed, hairy, and Lewis's woodpecker use a range of habitat conditions for nesting within burned forests, such that managing for multiple woodpecker species is likely to result in conditions beneficial for a variety of other species (Saab et al. 2009, 2011). After further development and refinement of habitat suitability models for woodpeckers and other species adapted to disturbance-maintained forests, additional application tools will be incorporated into this series.

Although this series of application tools is currently geared to habitat conservation for woodpeckers nesting in dry conifer forests, we expect the approach to be broadly applicable. Additional model application tools could facilitate broader use of habitat models for a variety of species to inform management decisions and planning.

7. Troubleshooting Guide

Problem 1.—When I am attempting to retrieve RAVG burn severity data for my project area, the data retrieval window is not visible on the website as shown in the instructions (section 4.4).

Solution 1.—You may not have Adobe Flash Player installed or enabled. Search for “install or enable Adobe Flash Player” on the Internet to find instructions to install, enable, and check the status of Adobe Flash Player. If Adobe Flash Player is enabled but the online data retrieval tool remains unavailable, you can contact the RAVG program directly via email (rapid_assessment_post_fire@fs.fed.us) or through the program’s website (<https://www.fs.fed.us/postfirevegcondition/contact/index.php>).

Problem 2.—I received an error when attempting to run one of the input generation tools for black-backed or white-headed woodpecker in burned forests of the Inland Northwest (e.g., **Failed to execute (BBWOINPUTS) .**).

Solution 2.1.—If the error notification indicates that default layers on the T drive were not found, try closing and reopening the tool, and rerunning.

Solution 2.2.—The wildfire perimeter may fall outside the spatial extent where default data are available. You may need to truncate the fire perimeter shapefile to include only areas where default data are available, or develop model inputs manually (see step I.C in section 4.1 or 4.3). You can view default canopy cover and topography data at: T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\PA_RASTERS

Solution 2.3.—The extents of burn_bndy.shp and dnbr.tif files may not match. Make sure the two files are for the same fire, and check to make sure the coordinate systems are identical for both files.

Problem 3.—When attempting to operate the input generation tool for the Northern Sierras, I receive errors that resemble the following:

```
Error: "000732: <value>: Dataset <value> does not exist or is not supported."  
ExecuteError: Failed to execute. Parameters are not valid.  
ERROR 000732: Input Features: Dataset '\...' does not exist or is not supported  
Failed to execute (PolygonToRaster).
```

Solution 3.—Check the folder names and pathways for input files. Filenames and pathways should contain no spaces. In particular, the most likely reason for this error is an invalid pathname for Existing Vegetation polygons downloaded from the Region 5 website. If the file geodatabase containing the polygons is embedded within a file of the same name, you will receive this error. For example, these paths result in an error:

```
C:\GIS\vegetation\evveg\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1
```

```
C:\GIS\vegetation\Existing Veg\ExistingVegR5_SouthSierra1995_2016_v1.gdb \ExistingVegR5_SouthSierra1995_2016_v1
```

But this path is acceptable:

```
C:\GIS\vegetation\evveg\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1
```

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Appendix A: RAVG-Based Models to Support Immediate Postfire Planning

Woodpecker habitat models for burned forest in the Inland Northwest were originally developed with burn severity data available under the Monitoring Trends in Burn Severity (MTBS) program. Since 1984, the MTBS program has provided standardized and ecologically relevant data for monitoring U.S. wildfire patterns in slow-growth systems, such as forests, by contrasting prefire satellite imagery with imagery recorded 1 year postfire during the growing season (i.e., extended assessment). These data are particularly relevant for quantifying woodpecker habitat in burned forests because the timing of postfire imagery is suited to reflect the substantial tree mortality (and snag generation) during the first year after wildfire. Postfire forest planning, however, is usually started well before MTBS data become available. To support more proximate analysis needs, burn severity data based on an immediate assessment (within 45 days following wildfire containment) are also available for wildfires on National Forest System lands through the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) process.

In recognizing the need for rapid postfire assessment, we provide alternate RAVG-derived model versions (see tables 2.1, 2.3.2). RAVG-based habitat suitability index (HSI) models are structured the same as MTBS-based models, but coefficient values quantify nesting relationships with RAVG rather than MTBS burn severity. Tools for obtaining HSI maps from RAVG-based models are operated as follows:

1. Obtain RAVG-based burn severity data following step I.A in section 4.4. Apply input development instructions (step I.A in sections 4.1 and 4.3).
2. Apply input development tools using RAVG (instead of MTBS) dNBR (steps I.B–C in sections 4.1 and 4.3).
3. Apply RAVG versions of model application tools with resulting inputs. Navigate to TOOLBOX □ Habitat Suitability Modeling.tbx □ HSI models, and open the “Black-backed Woodpecker (RAVG)” or “White-headed Woodpecker Burned (RAVG)” tool. Then follow instructions in step III, section 4.1 or step II, section 4.3, respectively, to operate these tools.

To support application of RAVG-derived HSI maps where needed, we related RAVG HSIs with nest densities and compared MTBS versus RAVG HSIs. For both species, nest densities were sufficiently related with RAVG-based HSIs to inform management (tables A.1, A.2; figs. A.1, A.2). Considering these relationships, we modified HSI thresholds for RAVG-based black-backed woodpecker HSI models for classifying low, moderate, and high suitability habitat (table A1, fig. A1). For white-headed

woodpeckers, we recommend the same thresholds for RAVG HSI models as those identified for MTBS models (table A.2, fig. A.2). We compared MTBS to RAVG HSIs at three relatively large 2015 wildfires in Oregon and Washington (fig. A.3) that burned extensively across forest types and conditions where models were applicable (i.e., areas included in application masks). RAVG HSIs and suitability classifications were strongly correlated with MTBS versions for both species at all three locations (table A.3). Consequently, RAVG and MTBS HSI models identified similar areas as suitable (e.g., fig. A.4).

Consistent with our expectations given the ecological relevance of MTBS burn severity, nest densities related more closely with MTBS than RAVG HSIs (compare tables A.1, A.2 and figures A.1, A.2 with tables 5.1.1, 5.1.2 and figures 5.1.1, 5.1.2, respectively). We therefore recommend using MTBS-based models when possible for black-backed and white-headed woodpecker in the Inland Northwest, but offer RAVG-based alternatives to support planning needs following wildfire before MTBS data become available.

Table A.1—Observed nest densities (per 1,000 ac) at model development locations for nesting black-backed woodpeckers. Low, moderate, and high suitability classes correspond with RAVG-based ensemble model predictions of 0–2, 3–6, and 7–8, respectively. Percent nests = the expected value given even sampling across categories. Area surveyed represents the extent surveyed each year multiplied by study duration at each location. 95 percent confidence limits were bootstrapped using 600 m cells as sampling units (n = 67, 83, and 176 for Star Gulch, Tripod, and Toolbox locations, respectively).

Fire location Quantity	Habitat suitability (HSI) class		
	Low	Moderate	High
Star Gulch (1994 Idaho)			
Density	0.22 (0, 0.56)	2.07 (0.32, 4.51)	3.92 (2.55, 5.35)
Percent nests	4 (0, 10)	33 (7, 54)	63 (45, 89)
Area surveyed (acres)	15,803	14,114	16,463
Tripod (2006 Washington)			
Density	0 (0, 0)	1.96 (0, 4.72)	9.86 (4.3, 16.1)
Percent nests	0 (0, 0)	17 (0, 43)	83 (57, 100)
Area surveyed (ha)	4,637	1,354	1,643
Toolbox (2002 Oregon)			
Density	1.28 (0.41, 2.26)	5.92 (3.41, 8.84)	11.03 (8.38, 13.93)
Percent nests	7 (2, 12)	32 (21, 44)	61 (49, 73)
Area surveyed (acres)	10,569	9,122	15,719
All three fires^a			
Density	0.31 (0.06, 0.66)	3.17 (2.06, 4.43)	7.63 (6.09, 9.24)

^a Values represented by red circles and error bars in figure A.1.

Table A.2—Density of hatched nests (per 1,000 ac) in suitability classes defined by alternative RAVG-based HSI model thresholds (0.34, 0.6) for white-headed woodpeckers in burned forest. Models were developed at Toolbox and Canyon Creek wildfire locations (Oregon). 95 percent confidence intervals (in parentheses) were generated with non-parametric bootstrapping. Values for “percent nests” are the expected percent of hatched nests assuming equal area sampling across suitability classes. Area surveyed was calculated as the proportion of sites representing the surveyed area in each suitability class multiplied by the total area surveyed at each location.

Location	Habitat suitability (HSI) class		
	Low	Moderate	High
Toolbox			
Density	0.31 (0.1, 0.57)	1.24 (0.66, 1.85)	4.43 (2.57, 6.58)
Percent nests	5 (2, 10)	21 (11, 33)	74 (60, 84)
Area surveyed (acres)	19,319	12,857	4,962
Canyon Creek			
Density	0.8 (0.36, 1.34)	3.05 (1.84, 4.3)	8.41 (4.4, 13.27)
Percent nests	7 (3, 12)	25 (14, 40)	69 (51, 81)
Area surveyed (acres)	13,774	7,221	1,427
Both fires^a			
Density	0.51 (0.28, 0.77)	1.91 (1.32, 2.55)	5.33 (3.57, 7.25)

^a Values represented by red circles and error bars in figure A.2.

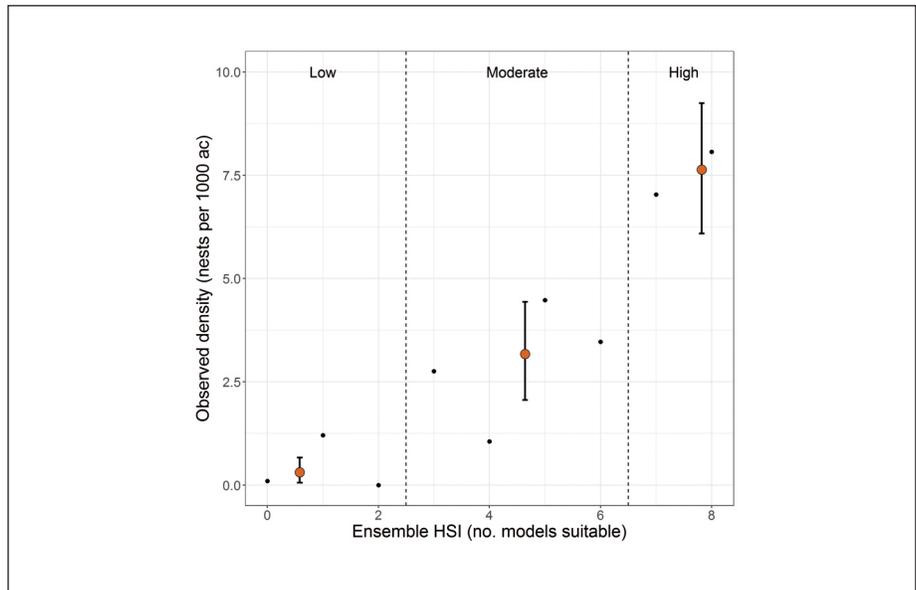


Figure A.1—Observed nest densities related with RAVG-based ensemble HSI (i.e., the number of models classifying a given site as suitable) for black-backed woodpeckers in the Inland Northwest. Small black dots are values for individual HSI levels. Large red dots represent observed densities averaged (mean) across locations (Star Gulch [Idaho], Toolbox [Oregon], and Tripod [Washington]) within suitability categories (low, moderate, and high) and are plotted at mean HSI values. Error bars represent 95-percent confidence intervals, which were bootstrapped by using 600-m cells as sampling units ($n = 326$ across all three locations).

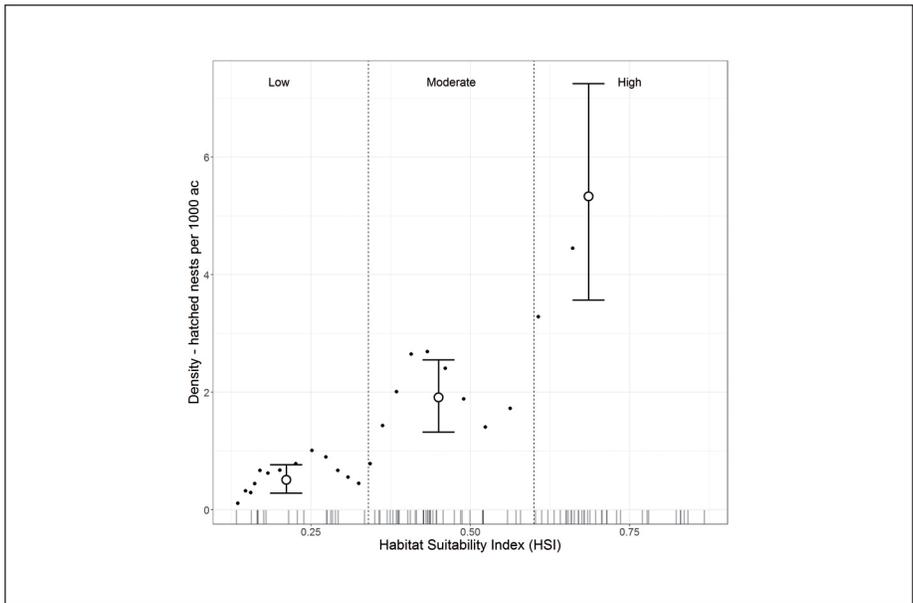


Figure A.2—Densities of hatched nests for white-headed woodpeckers along an alternate RAVG-based HSI gradient in burned forest. Low, moderate, and high suitability classes are differentiated by two HSI thresholds, one that maximizes the sum of sensitivity and specificity (maxSSS) and the other placed at a natural break in densities for equal-area moving-window bins in this figure (small dots) and the distribution of nest site HSIs (rug bars). Large circles and error bars are density estimates and bootstrapped 95-percent confidence intervals for habitat suitability classes, respectively.

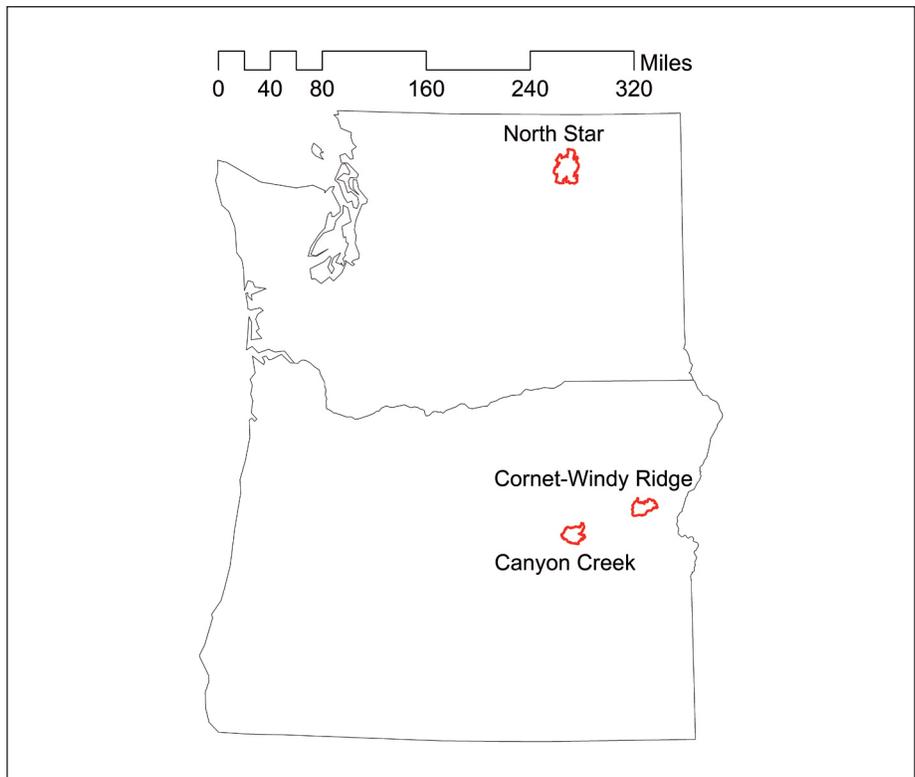


Figure A.3—Wildfires in 2015 in Oregon (Cornet-Windy Ridge, Canyon Creek) and Washington (North Star) used to compare MTBS- to RAVG-based HSIs for black-backed and white-headed woodpeckers.

Table A.3—Correspondence between original (MTBS-based) and alternative (RAVG-based) HSI models at three 2015 wildfires in Washington (North Star) and Oregon (Canyon Creek, Cornet-Windy Ridge). Correlation coefficients (Pearson’s *r*) relate continuous HSI values for 30-m pixels. The percent of pixels classified the same (low, moderate, or high suitability) using recommended MTBS- versus RAVG-based HSI thresholds are also reported.

Location	Pearson’s <i>r</i>		% Consistently classified	
	BBWO	WHWO	BBWO	WHWO
North Star	0.689	0.576	62	70
Canyon Creek	0.852	0.814	74	81
Cornet-Windy Ridge	0.762	0.716	69	74
All	0.741	0.700	66	75

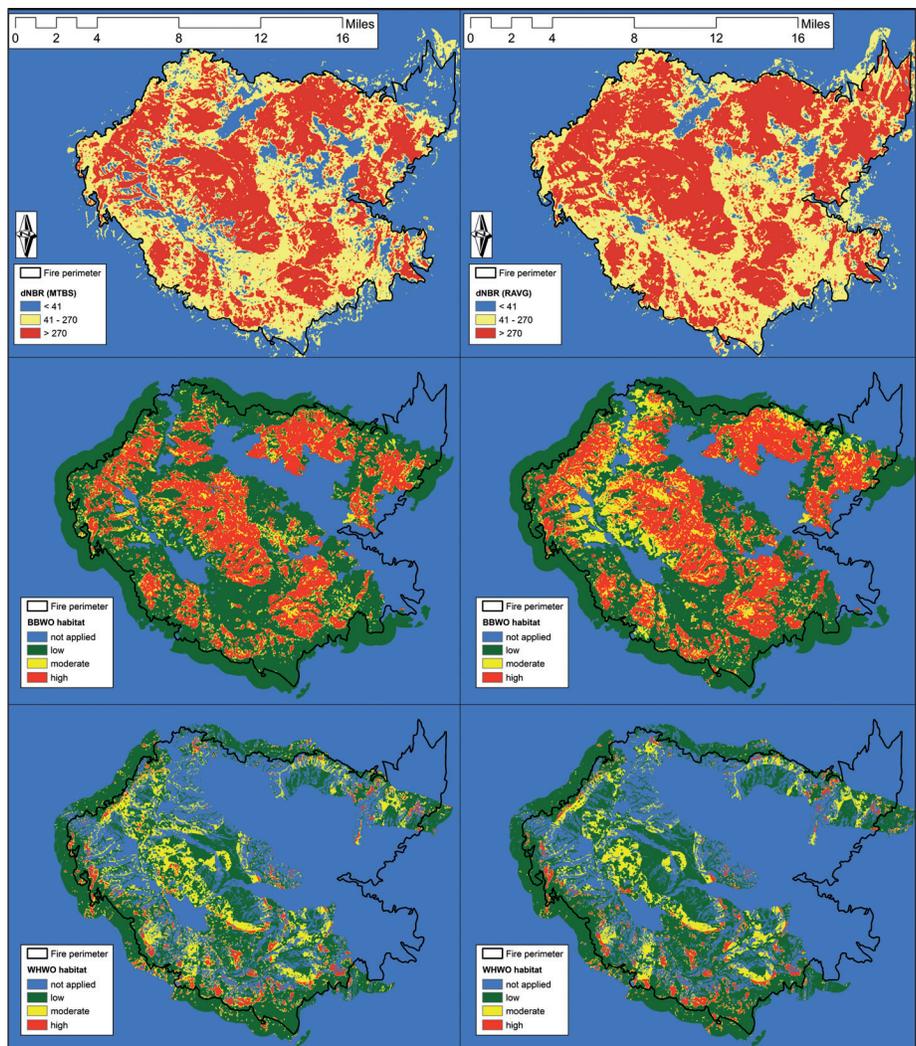


Figure A.4—Burn severity (top row) and HSI maps (bottom two rows) for black-backed (BBWO) and white-headed woodpecker (WHWO) at the Canyon Creek Fire (Oregon, 2015). Versions derived from MTBS versus RAVG are compared. HSI maps are masked to exclude areas outside the range of conditions where models were developed.

Appendix B: Demonstration of Model Application for Postfire Planning

We demonstrate the use of woodpecker habitat suitability index (HSI) models to inform postfire management using the Canyon Creek Fire (Oregon, 2015) as a case study. We consider a hypothetical scenario wherein managers have identified a series of six potential management units with opportunity for salvage logging (fig. B.1). The units considered were actual management units identified during the postfire planning process at Canyon Creek, and treatment units are the areas within management units where salvage logging was possible and implemented after slope, accessibility, and economic viability were considered. Thus, these units are realistic, but we constructed a simplified decision scenario purely to demonstrate how HSI models could inform postfire planning.

We assume a minimum sale area of 700 acres for economic desirability for salvage logging given contemporaneous market conditions. For this example, we considered a postfire management plan that allowed a maximum of 50 breeding pairs to be impacted by logging (i.e., occur within logged areas) without compromising conservation targets. In theory, these targets would be developed from a regional assessment of current population status. For simplicity's sake, we focus this scenario on one species, the black-backed

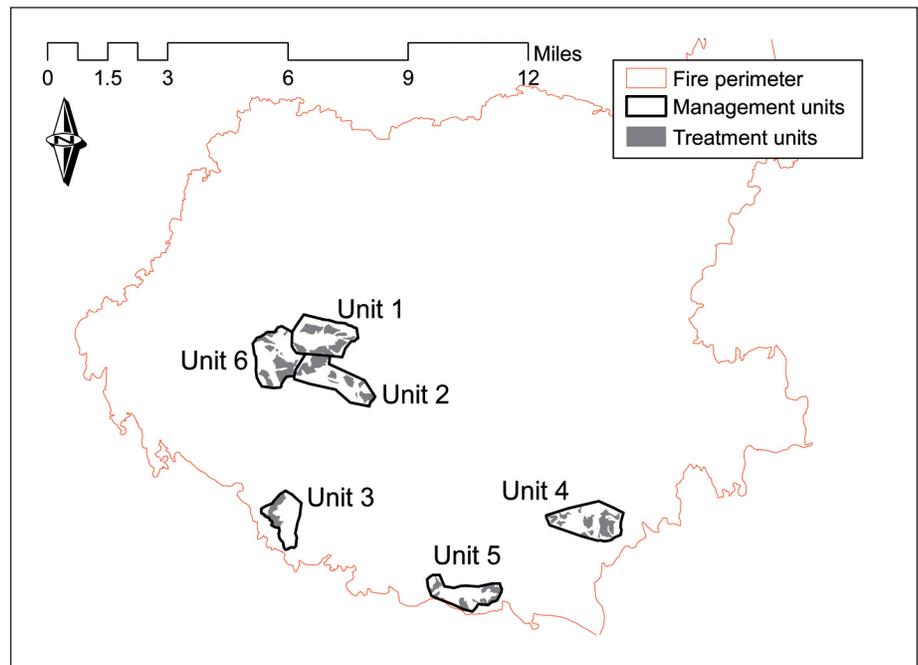


Figure B.1—Potential units considered in a hypothetical postfire management scenario for the Canyon Creek Fire (Oregon, 2015). Scenario options entail salvage logging on different combinations of management units. Treatment units are the areas within management units with logging opportunity.

woodpecker, with clearly documented negative relationships with logging (Saab et al. 2007). We consider potential effects on nesting and foraging within 0.6 mile of treated areas. We used HSI models based on Monitoring Trends in Burn Severity (MTBS) data to inform planning in this scenario, but the principles demonstrated are also relevant to model application based on Rapid Assessment of Vegetation Condition after Wildfire (RAVG) data. The HSI map relevant to this scenario is shown in figure A4 (middle row, left column), and nest density relationships with modeled suitability are in table 5.1.1 and figure 5.1.1.

Scenario options where four of six management units were included in the logging sale unit met our hypothetical economic benchmark of 700 acres treated. Of these, the upper 95-percent confidence limit for potentially affected nest numbers fell below our maximum allowable number of 50 nests in treated areas for seven options (table B.1). Assuming timber volume (and consequent economic desirability) for a given sale is related to the area treated, scenarios G and F appear most desirable. Of these, the number of nesting pairs whose foraging or nesting habitat could be affected (i.e., the 0.6-mile-radius footprint for treatment areas), was smaller for option G. Thus, option G was most desirable to meet the multiple objectives and criteria defined in our hypothetical scenario.

Our hypothetical planning scenario ignores several likely realities for managers engaged in postfire forest planning. We focused only on one woodpecker species, whereas multiple species could be of concern, including those not necessarily represented in our toolset (e.g., Lewis’s woodpecker). We considered economic viability of salvage logging units

Table B.1—Alternative options consisting of different combinations of management units selected for postfire salvage logging at the Canyon Creek Fire (Oregon, 2015). Unit numbers correspond with those in figure B1. Black-backed woodpecker (BBWO) habitat is the sum of moderate and high suitability areas, and potential nests (and 95 percent boot-strapped confidence limits) were estimated assuming similar densities to those observed at HSI model development locations (see fig. 5.1.1). When calculating potential nest numbers, densities were multiplied by 5 to reflect assumed viability of BBWO habitat for 5 years following wildfire and development of HSI models within this timeframe. Values for “treated” represent the total area actually logged. Values for “affected” represent the area within 1-km of logging, within which nesting pairs could experience reduced foraging opportunities due to logging.

Option	Units treated	Area (acres)		BBWO habitat (acres)		Number of potential BBWO nests	
		treated	affected	treated	affected	treated	affected
A	3, 4, 5, 6	721	11,020	649	4,685	32 (23, 42)	256 (168, 355)
B	2, 3, 4, 5	722	11,132	598	5,149	31 (22, 40)	281 (189, 385)
C	2, 3, 5, 6	734	10,129	582	4,437	28 (20, 37)	239 (158, 331)
D	1, 3, 5, 6	751	9,550	647	4,509	32 (23, 42)	243 (163, 333)
E	1, 2, 3, 5	752	9,576	596	4,736	30 (22, 40)	256 (173, 348)
F	2, 3, 4, 6	809	10,238	657	5,075	32 (23, 43)	269 (182, 367)
G	1, 2, 3, 6	839	8,188	655	4,396	32 (23, 43)	230 (157, 312)

in terms of the potential area treated, whereas managers probably would instead quantify timber volume, which may not correlate perfectly with area treatable. We ignored roadside hazard tree removal, which was extensive at the Canyon Creek Fire. With the high prioritization of human safety, roadside treatments may be non-negotiable, in which case assessments of impacts to woodpeckers should account for hazard tree removal. With all these considerations, postfire forest planning will be substantially more complicated than depicted in our example. Nevertheless, this example demonstrates how to apply HSI maps and related nest densities during the planning process.

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