Project Title: Modeling habitat and population responses of at-risk woodpecker species to post-fire salvage logging

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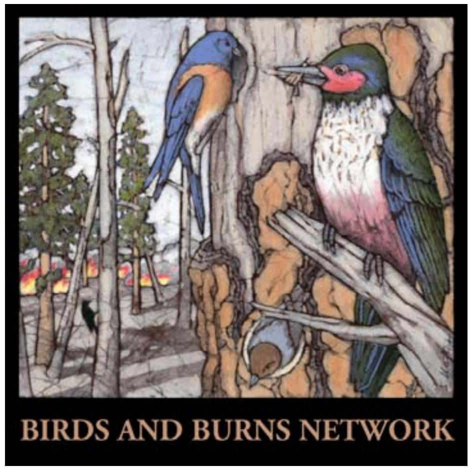

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I. Abstract
Recent legislation regarding postfire management policies (i.e. National Fire Plan [USDA 2000], Healthy Forest Initiative [White House 2004], Healthy Forest Restoration Act [USDA 2003]) focuses planning efforts on postfire salvage logging and fuels reduction projects. Harvest of burned trees (i.e. postfire salvage logging) impacts a number of wildlife species, particularly those specialized for using post-wildfire habitats. We studied the effects of post-fire salvage logging and developed habitat suitability models for nesting black-backed woodpeckers (*Picoides arcticus*), an at-risk woodpecker species strongly associated with recently burned forests. Salvage logging slightly decreased snag density and average snag diameter, whereas coarse woody debris significantly increased after logging. Nesting densities of black-backed woodpeckers were reduced in logged areas, however, nest survival appeared unaffected by salvage logging and influenced primarily by the timing of nest initiation. We identified field-collected and remotely-sensed habitat factors that consistently predicted habitat suitability for nesting black-backed woodpeckers in the Northwestern United States (Idaho, Oregon, Washington). Snag densities measured in the field, and pre-fire canopy cover and burn severity measured remotely were the variables that most consistently predicted nest occurrence of black-backed woodpeckers in burned forests. Habitat suitability models calibrated from Idaho data (Star Gulch Fire) and derived from logistic regression performed well in Washington on the Tripod Fire but performed poorly in Oregon on the Silver/Toolbox fires. Habitat suitability models calibrated from Oregon data (Silver/Toolbox Fire) and derived from Mahalanobis distance performed poorly in Washington on the Tripod Fire. Findings from this research highlight the importance of: (1) identifying areas in recently burned forests of high habitat suitability for species specialized in using post-wildfire habitats; and (2) developing design criteria for postfire salvage logging to inform management on selection of areas for timber harvest, and concurrently, selection of habitat reserves for key wildlife species.

II. Background and Purpose
Public land managers face significant challenges when attempting to implement national fire policies and concurrently meet the requirements of existing laws to maintain habitats and populations of wildlife species associated with post-fire habitats. Fire creates dense stands of standing dead trees that provide habitat patches for a variety of wildlife, notably cavity-nesting birds (e.g., Saab and Powell 2005). Several species of cavity-nesting woodpeckers are designated as species at risk because they are responsive to fire and timber management activities (Saab et al. 2007). In forested regions of the western United States, controversy over post-fire management activities (particularly salvage logging), frequently results in legal conflicts (e.g., USDA 2004). Litigation over salvage logging often reflects the challenges faced by land mangers when attempting to legally demonstrate that habitat and populations are maintained for species of concern (i.e. management indicator and sensitive species). Standardized guidelines for conservation of postfire landscapes are not available. Currently, a wide variety of approaches are used for managing burned forests and they depend on land ownership and discretion of individual managers (Lindenmayer et al. 2006). Public land agencies need to develop and implement consistent design criteria for post-fire management on federal lands that will maintain habitats and populations of species at risk, notably cavity-nesting birds. Although some information is available to assess the impacts of post-fire salvage logging on habitats of fire-associated and dead-wood dependent vertebrates, little information exists on how logging activities affect populations of woodpeckers (McIver and Starr 2001, Saab et al. 2005). This paucity of information contributes to the uncertainty involved when developing post-fire management plans. Currently, managers cannot reliably evaluate expected responses by fire-associated wildlife across burned forests because we lack models linking wildlife populations to multi-scale forest conditions after post-fire salvage logging treatments. This project was developed in response to a 2006 announcement for proposals (Task 4 of AFP 2006-3) on "effects of post-fire management activities". The focus of our project has been to evaluate the effects and effectiveness of post-fire management activities, namely salvage logging, on habitats and populations of at-risk woodpecker species dependent on burned forests. Our goals have

been on identifying factors that contribute to suitable habitat for wildlife species specialized in using recently burned forests, and concurrently reduce fuels through salvage logging. The specific objectives of this project were to:

1. Develop regression models to assess the relative influence of post-fire salvage logging on nest survival and productivity of at-risk woodpecker species using dry forest habitats.
2. Quantify the predictive ability of woodpecker nest occurrence models (habitat suitability models) developed from data collected in Idaho by using observations in Oregon.
3. Quantify fuels reduction after post-fire salvage logging to assess the effects on wildlife habitat.
4. Develop guidelines regarding the use of remotely-sensed pre-fire vegetation conditions and post-fire burn severity to predict habitat suitability of burned forests (e.g., patch area and configuration of snag habitats) for woodpeckers.

III. Study Description and Location

Nest Searching and Monitoring

Nest surveys and monitoring of Black-backed Woodpeckers were conducted in three recently burned forests dominated by ponderosa pine (*Pinus ponderosa*) in Idaho, Oregon, and Washington within 10 years of the wildfire (Figure 1). Nest cavities were located by using systematic searching along belt transects (0.4 x 1.0 km) through the study areas (Dudley and Saab 2003). In Oregon and Washington nest searching was conducted from April-June and in Idaho from May-July, corresponding to the slightly later nesting season in Idaho. Nests were monitored every 3-4 days either visually or using an electronic camera mounted to a telescoping pole (TreeTop II; Sandpiper Technologies, Inc.). The area surveyed annually at each location averaged about 800 ha.

Field-collected Habitat Measurements

Habitat components were measured for both nest locations and non-nest random locations within study sites on three burns in Idaho, Oregon, and Washington. In Idaho and Washington, snags were common and dense. In Oregon, snags were sparser and spread farther apart. A cross hatch design is more accurate than circular plots when the sampled vegetation is less common (Bate et al. 1999). Therefore in Idaho and Washington, sampling plots were 11.3-m radius circles, and in Oregon, plots consisted of two intersecting 20 m x 100 m rectangular plots. Each year on the Silver/Toolbox fires tree/snag and log characteristics surrounding nest trees and non-nest random trees within a plot were recorded, including tree/snag/log species, decay, diameter, and densities. We used the planar transect method described by Van Wager (1968) and Brown (1974) to determine the biomass of downed wood before and after logging operations on the Silver/Toolbox fires. We used tallies and diameters of wood pieces ≥ 7.6cm diameter at the point of intersection with sampling transects, and specific gravity values of 0.4 for sound pieces and 0.3 for rotten pieces (Brown 1970). Results were expressed in metric tons / ha. Subsequently, we used Welch's t-test for samples with unequal variances to compare before and after logging wood loads.

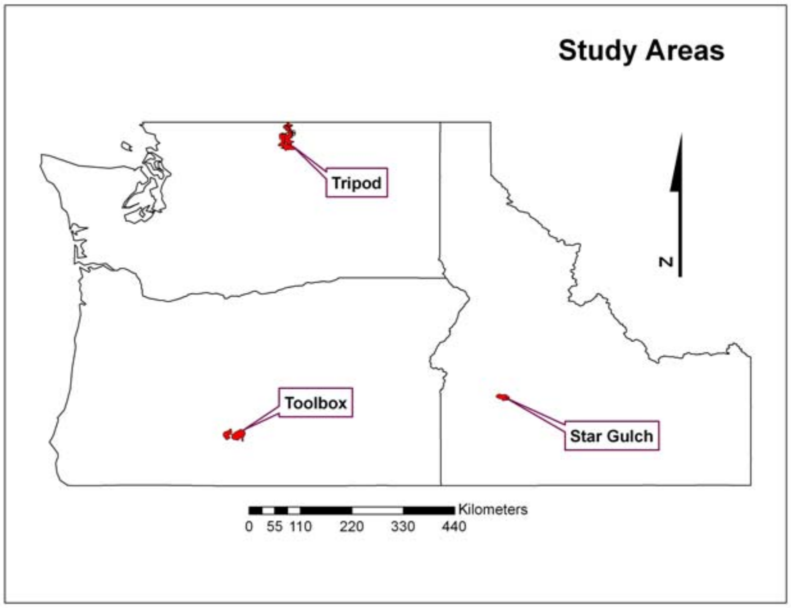

Figure 1. Wildfire study areas, including the 1994 Star Gulch Fire, the 2002 Toolbox-Silver Fires, and the 2006 Tripod Fire.

Remotely-sensed Habitat Measurements

We assigned habitat characteristics to nest locations as well as to randomly identified non-nest locations based on remotely sensed data that included: location covariates (aspect, slope, and elevation), forest stand covariates (prefire crown closure and cover type), and burn severity (methods detailed in Russell et al. 2007). Local characteristics were measured at the pixel-scale (30 m x 30 m) centered on the focal tree (nest or non-nest tree), while landscape characteristics were measured within a 1-km circular radius of focal trees. This area (340 ha) corresponded to the home-range sizes of most cavity-nesting birds that depend on snags for foraging and nesting (Saab et al. 2004). Vegetation and burn severity were derived from Landsat 7 Thematic Mapper images (Remote Sensing Applications Center, USDA Forest Service; and Gradient Nearest Neighbor [GNN], Ohmann and Gregory 2002) representing pre- and postfire conditions and cover type was assigned as ponderosa pine, mixed conifer, and other. In Oregon and Washington, local-scale pre-fire canopy cover was derived from pixel level GNN data as the mean cover associated with a rectangular 3x3-pixel window surrounding each pixel in the image to take into account errors in remote sensing classification (Booth and Oldfield 1989). Habitat patches were defined as contiguous pixels of the same cover type. Patch area was calculated as the number of contiguous patch-pixels x area of one pixel ($900m^2$), and subsequently converted to hectares. We averaged burn severity, cover type, and prefire crown closure maps using a 3x3-pixel window. Burn severity was calculated as the change in the normalized burn ratio (DNBR) between pre- and postfire conditions (Cocke et al. 2005, Key and Benson 2006).

Modeling Nest Survival

Relationships between nest survival and habitat and abiotic covariates were examined with generalized non-linear mixed models (PROC NLMIXED; SAS Institute, Inc. 2004), as described by Rotella et al. (2007). An advantage of this statistical method over traditional Mayfield estimates is the ability to include numerous covariates that may be important predictors of the survival model, such as habitat, age of nest, observer effects, or weather covariates, as well as potential random effects (Rotella et al. 2007). Biologically defensible *a priori* models hypothesizing the effects of covariates on daily nest survival (DSR) were evaluated with an information-theoretic approach (Burnham and Anderson 2002). Competing models corrected for small sample sizes were evaluated with AIC_c. Ranking ΔAIC and weight values then facilitated detection of the model or models best suited for inference (Burnham and Anderson 2002).

Modeling Habitat Suitability

We used two methods for modeling habitat suitability, a weighted logistic regression (Russell et al. 2007) and Mahalanobis distance technique (Rotenberry 2006). A weighted logistic regression allows the user to weight the response variables when the ratio of zeros (non-nest locations) to ones (nest locations) is not equal (Allison 1999; PROC Logistic [SAS Institute Inc., Cary, NC]). The partitioned Mahalanobis distance technique (Rotenberry et al. 2006) was used to estimate and map the distribution of black-backed woodpeckers using only nest site data from the Silver/Toolbox fires. Mahalanobis distance (D^2) is the squared standardized distance of a multivariate observation (environmental and/or habitat variables) from the multivariate mean of a sample or population (niche). Smaller distances indicate a greater similarity to the mean habitat for a given species and these distances can be rescaled to produce a habitat suitability index (HSI) that ranges from 0 to 1, with 1 representing a set of environment/habitat conditions equal to the species' mean (Clark et al. 1993, Rotenberry et al. 2006). Since D^2 models utilize presence-only data and are easily adapted to produce maps of suitable habitat (Rotenberry et al. 2006, Barrows et al. 2008, Preston et al. 2008), they are an attractive approach for identifying suitable habitat to guide resource management.

Logistic regression models containing remotely sensed data included 1) pixel level aspect, slope, and elevation; 2) pixel level prefire canopy cover, prefire cover type, and burn severity; and 3) landscape-level data, that is, percentages of each prefire canopy cover and cover type measured within the 1-km radius around each plot center. Candidate models for remotely sensed data included all possible combinations of covariates. All variables we chose were identified by previous research as potentially important for nest-site selection of cavity-nesting birds (e.g., Li and Martin 1991, Russell et al. 2007, Saab et al. 2009). We were interested in generating models with the best ability to discriminate between nest and non-nest locations, and we used a best-subsets modeling approach to avoid excluding models that could be potentially useful to land managers. We first assessed models using information-theoretic approaches corrected for small sample sizes (i.e., Akaike's Information Criterion corrected for small sample size [AICc]; Burnham and Anderson 2002). We evaluated best models on their ability to correctly discriminate between nest plots, where we located $\geq$1 nest during the early years after fire (1–4 yr) versus random non-nest plots.

For the Mahalanobis distance approach, we used freely available digital spatial data sets to extract or derive 1) slope; 2) local-scale pre-fire canopy cover; 3) landscape-scale pre-fire canopy cover; 4) pre-fire cover type patch area; and 5) burn severity to develop our niche model. One of the advantages of the Mahalanobis distance (D^2) approach is the ability to produce habitat suitability maps by applying the model derived from species occurrence data (calibration data) to every point (or pixel) in a target landscape using a GIS. Consequently, many variables used to build the black-backed woodpecker nest-site model were maintained or derived in a GIS environment.

Model diagnostics for Habitat Suitability

For the logistic regression models, we used receiver operating characteristic curves (ROC) to evaluate the model's ability to distinguish between ones (nests) and zeros (non-nests). We used leave-one-out cross-validation methods to evaluate the number of correctly predicted nest versus non-nest locations for the 2 top models because of our relatively small sample size (Efron and Tibshirani 1993). In leave-one-out cross-validation, predicted values for a data point are generated from models developed without using that data point. Logistic regression models were evaluated by classifying observations as nest or non-nest on the basis of threshold values or cutoff points in the range of the predicted values, which range between zero and one (Fielding and Bell 1997, Pearce and Ferrier 2000). An observation with a predicted value below some threshold value (e.g., 0.5) is classified as a non-nest, whereas an observation with a predicted value above the threshold value is classified as a nest. This evaluation can be conducted over a wide range of values and be used to generate ROC curves that evaluate the relationship between the number of true positives and the number of false positives at different thresholds (e.g., Pearce and Ferrier 2000, Gardner and Urban 2003). Area under the ROC curve (AUC) provides an index representing the model's ability to discriminate between positive and negative observations (Hanley and McNeil 1982). Swets (1988) suggested that an AUC between 0.5 and 0.7 reflects low accuracy, 0.7–0.9 reflects moderate accuracy, and $\geq$0.9 indicates excellent accuracy. When >1 model was equally plausible (i.e., within 2 ΔAICc points of the top model), we used AUC to select the model with the best discriminatory power for further evaluations.

For Mahalanobis distance (D^2k) models, we calibrated and validated our D^2k model for black-backed woodpecker nest-sites with 248 nest site observations within the Silver/Toolbox fires in central Oregon. We reserved 50 (20%) of these observations for model validation and the remaining observations were used for model calibration (development). We developed functions and scripts in R statistical software (R Development Core Team 2006) to develop, validate, and implement partitioned Mahalanobis distance models and associated habitat suitability indices (HSI) patterned after SAS (SAS Institute 2004) code published by Rotenberry et al. (2006).

IV. Key Findings

Overall

- Salvage logging slightly decreased snag density and average snag diameter, whereas coarse woody debris significantly increased after logging on the 2002 Silver/Toolbox Fire in Oregon.
- Nesting densities of black-backed woodpeckers were reduced in logged areas; however, nest survival appeared unaffected by salvage logging on the 2002 Silver/Toolbox Fire in Oregon.
- Snag densities measured in the field, and pre-fire canopy cover and burn severity measured remotely were the variables that most consistently predicted nest occurrence of black-backed woodpeckers in burned forests of Idaho, Oregon, and Washington.
- Habitat suitability models developed from remotely-sensed data and calibrated for Idaho (1994 Star Gulch Fire) performed well in Washington (2006 Tripod Fire) but performed poorly in Oregon (2002 Silver/Toolbox Fire), and models calibrated for Oregon performed poorly in Washington.
- Remotely-sensed pre-fire canopy cover, burn severity, slope, and aspect can be used to develop well-performing habitat suitability models for woodpeckers using recently burned forests.
- Habitat suitability models developed and tested in the same location performed well, whereas model performance was mixed when applied to other ponderosa pine-dominated forests.
- Development of habitat suitability models and associated maps from remotely-sensed data allows managers to rapidly select areas for both postfire timber harvest and retention of wildlife habitat in recently burned forests.

Nest Survival on Silver/Toolbox fires

A total of 210 black-backed woodpecker nests were located and monitored after the Silver/Toolbox Fires in Oregon from 2003-2006 to evaluate nest survival. Snags of lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) made up 90% of all selected nest tree species. Black-backed woodpeckers gradually switched from nesting primarily in lodgepole pine to ponderosa pine as year postfire increased (Figure 2), corresponding to the temporal changes in tree decay (and ease of excavation) after wildfire (Forristal 2009).

Variables relating salvage logging to daily survival rates received little support. Generally, treatment units had higher nest survival than control units, both before and after salvage harvest (although both had very high survival). Similarly, birds appeared to prefer control units, both before and after logging. Control units on the Silver/Toolbox fires were originally selected as reserves for nesting woodpeckers and those units were excluded from logging. Differences in snag abundance likely played an important role in shaping this difference. Indeed, pre-harvest densities of large diameter (≥23cm dbh) snags in control units averaged 101 ±10.17 SE versus 73 ±13.01 (SE) snags per ha in treatment units. Nest densities were generally higher in units containing higher snag densities, but nest survival was comparable in control and treatment units. The importance of plot-scale snag abundance in our nest-site selection models (Saab et al. 2009) and the lower nest densities (Figure 3) in treatment units suggests that birds are sensitive to salvage logging activities, an important consideration for managers attempting to conserve nesting habitat while still permitting salvage logging on burned landscapes.

Estimated daily nest survival rate (DSR) assuming constant survival (null model) was 0.9940 ± 0.2006 SE (95% CL = 0.9911, 0.9960). Exponentiating daily survival rate (DSR) by the average number of days in the full nesting period yields an overall estimate of nest success $0.9940^{40} = 0.7855$ (95% CL = 0.6996, 0.8495).

Models of DSR containing logging covariates at the plot and landscape scales were not supported, however we were unable to successfully model the effect of logging at the patch scale due to a lack of nest failures within the treatment units in the pre-logging period. However, we found that the drop in DSR from pre to post-logging periods in the logged units was double the change observed in the unlogged units over the same time frame, suggesting decreasing survival with logging.

Models of DSR containing habitat covariates at any spatial scale received little or no support from our data. The temporal effect of Julian date was the most parsimonious in explaining daily survival rate. The coefficient estimate for Julian date was negative ($\hat{\beta}_{JDate}$ = -0.051 ± 0.015 SE; 95% CL = -0.081, -0.021), indicating that later dates through the nesting season coincided with decreasing DSR. Our model results indicated that with each elapsed day, the odds of nest failure increased by 0.05. Thus, nests initiated on April 30th would have an overall nest success of 90.5% (95% CL = 84.4%, 96.7%), whereas nests initiated on May 20th and June 9th would have success rates of 76.1% (95% CL = 68.4%, 83.9%) and 47.5% (95% CL = 22.5%, 72.5%), respectively. Few nests, however, initiated during the month of June.

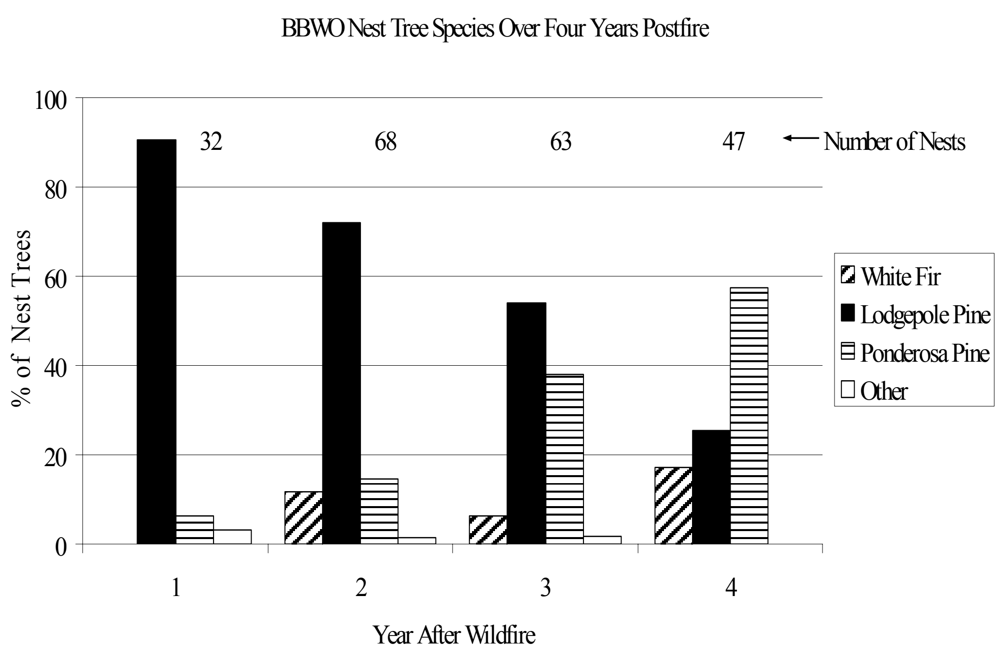

Figure 2. Black-backed woodpecker (BBWO) nest tree species by year since wildfire on the Toolbox Fire, Oregon 2003-2006. Annual nest sample sizes are indicated above each group of bars.

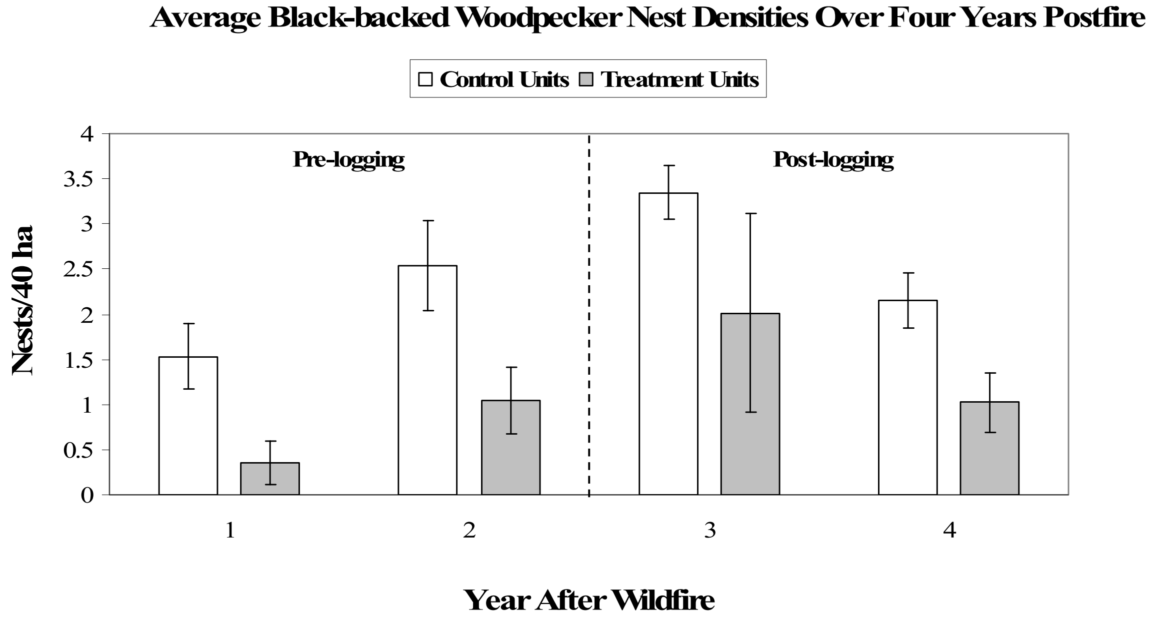

Figure 3. Black Black-backed woodpecker mean nest densities (±1 SE) by year postfire by study unit type over four years since wildfire in the Silver/Toolbox fires of south-central Oregon, 2003-2006.

Fuels Reduction on Silver/Toolbox Fires

Postfire snag densities of random plots within control units were generally higher than those in treatment units, both before and after logging on the Toolbox/Silver fires (Appendix 1). Salvage logging in treatment units slightly decreased snag density and average diameter of snags (Appendix 1), whereas coarse woody debris substantially increased after logging (Table 1). The amount of logged area around non-nest points at landscape scales increased after salvage logging; larger logged areas were associated with treatment units compared to non-nests in control units. Proportion of high snag density habitat at landscape scales decreased significantly after logging in treatment units.

Pre-harvest densities of large diameter (≥ 23cm dbh) snags in control units averaged 101 ±10.17 SE versus 73 ±13.01 (SE) snags per ha in treatment units. While salvage logging occurred in all treatment units, the severity and spatial extent of logging varied from unit to unit. "Leave" snags were marked within treatment units, but loggers were free to choose which unmarked snags they wished to harvest or ignore. For instance, most lodgepole pine was left unharvested due to its high postfire decomposition rate, smaller diameters, and low commercial value. Examination of snag densities at non-nest plots within treatment units showed only a slight reduction in snags after logging took place (Appendix 1). Thus, all post-logging units retained snag densities greater than that originally prescribed and may have still served as quality black-backed habitat. Additionally, average diameter of non-nest plot snags located in treatment units was not significantly reduced after logging (Appendix 1).

Table 1. Weight of coarse woody debris (≥ 7.6 cm diameter) before and after logging on the Silver/Toolbox fires.

	Before (n = 14)		After (n = 40)			
	Mean	**SD**	**Mean**	**SD**	**t-value**	***p***
Coarse Woody Debris (metric tons/ha)	28.28	22.52	46.03	41.24	1.98	0.052

Development of Habitat Suitability Models- Weighted Logistic Regression

Based on initial model development of nesting habitat suitability (Saab et al. 2002, Saab et al. 2004, Russell et al. 2007), we used six variables to develop the weighted logistic regression model for habitat suitability of nesting black-backed woodpeckers on the Star Gulch Fire (Table 2). The best logistic regression models all contained many of the same covariates (Table 3), so we chose a single model from this reduced pool based on the ability of the models to distinguish between nest and non-nest random locations (i.e., larger AUCs) and on the number of covariates in the model. The final chosen model (model 1, Table 4) contained habitat covariates reflecting geographic position (aspect and elevation) and local level crown closure (medium and high). Our best model indicated that black-backed woodpeckers were associated with east- and south facing slopes, lower elevations, and greater proportions of medium and high levels of canopy closure. Although burn severity was not included in the chosen model to develop habitat suitability, this variable was included among the top models (Table 3) and summary statistics indicate that nest sites were located in higher severity areas than at non-nest random locations (Table 2).

Table 2. Summary statistics measured at nests and non-nest random locations in an unlogged burn in Idaho, USA (1-4 yr post-fire), 1995 - 1998. Local level was measured at pixels surrounding focal trees (nest or random), while landscape level was measured within a 1-km radius of focal trees (nest or random).[a]

	Black-backed woodpecker nest (n = 37)		**Non-nest random location (n = 90)**	
Covariate[a]	**Mean**	**Std Error**	**Mean**	**Std Error**
Northness (aspect)	0.106	0.115	0.059	0.0714
Eastness (aspect)	0.226	0.1145	-0.009	0.0780
Slope (%)	38.803	1.947	37.586	1.501
Elevation (m)	1575.030	26.731	1666.880	20.913
Local level prefire crown closure 40-70%	0.568	0.052	0.379	0.035
Local level prefire crown closure 70-100%	0.249	0.058	0.257	0.036
Landscape level prefire crown closure 40-70%	0.430	0.011	0.403	0.010
Landscape level prefire crown closure 70-100%	0.107	0.010	0.114	0.007
ΔNBR (Burn severity)	512.486	34.788	414.585	23.572

[a] Variable explanations: Northness = cos (aspect), Eastness = sin (aspect). Local level prefire crown closure 40-70% = proportion of 3x3 pixel area classified as ponderosa pine or mixed forest with 40-70% crown closure, Local level prefire crown closure 70-100% = proportion of 3x3 pixel area classified as ponderosa pine or mixed forest with 70-100% crown closure, Landscape level prefire crown closure 40-70% = proportion within 1-km radius classified a ponderosa pine or mixed forest with 40-70% crown closure, Landscape level prefire crown closure 70-100% = proportion within 1-km radius classified a ponderosa pine or mixed forest with 70-100% crown closure, Burn severity = Delta normalized burn ratio.

Table 3. Model selection results for top models containing remotely-sensed data based on weighted logistic regression associating nest-site characteristics of black-backed

woodpeckers (*Picoides arcticus*) to non-nest random locations in the unlogged portion of the 1994 Star Gulch Burn, Idaho, USA (1-4 yr post-fire), 1995-1998.

K[a]	AIC_c[b]	ΔAIC_c	AUC[c]	Model[d]
7	230.176	0.000	0.751	Northness, Eastness, Elevation, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%
6	230.883	0.707	0.744	Eastness, Elevation, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%
8	231.509	1.333	0.750	Northness, Eastness, Elevation, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%, Burn severity
5	231.776	1.600	0.710	Elevation, Local level prefire crown closure 40-70%, Burn severity
7	232.023	1.847	0.743	Eastness, Elevation, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%, Burn severity
6	232.050	1.874	0.729	Northness, Eastness, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%
8	232.070	1.894	0.752	Northness, Eastness, Elevation, Local level prefire crown closure 40-70%, Local level prefire crown closure 70-100%, Landscape level prefire crown closure 70-100%

[a] K = no. of parameters including intercept and error term
[b] AICc = Akaike's Information Criterion corrected for small sample size
[c] AUC = area-under-the-curve statistic from receiver operating characteristic curve
[d] Model variables include: Northness = cos(aspect), Eastness = sin(aspect), Elevation = elevation in meters, Local level prefire crown closure 40-70% = proportion of 3x3 pixel area classified a ponderosa pine or mixed forest with 40-70% crown closure, Local level prefire crown closure >70% = proportion of 3x3 pixel area classified a ponderosa pine or mixed forest with >70% crown closure, Burn severity = Delta normalized burn ratio, Landscape level prefire crown closure >70% = proportion within 1-km radius classified a ponderosa pine or mixed forest with >70% crown closure.

Table 4. Parameter estimates, profile-likelihood confidence intervals, Wald chi-square statistics, and *P*-values for parameter estimates for the best model of nest versus non-nest random locations of black-backed woodpeckers (*Picoides arcticus*) in the unlogged portion of the 1994 Star Gulch, Idaho USA (1-4 yr post-fire), 1995-1998.

Model[a]	Parameter Scale	Estimate	95% Profile-likelihood CI	Wald X^2	Pr > X^{2b}
Intercept		1.4059	-2.1152, 4.9543	0.6144	0.4331
Northness	Local	-0.5151	-1.1355, 0.0716	2.8288	0.0926
Eastness	Local	0.7647	0.2400, 1.3159	7.8312	0.0051
Elevation	Local	-0.0021	-0.0043, -	3.9494	0.0469

			0.0001		
Local level prefire crown closure >40-70%	Local	2.7545	1.4317, 4.1458	16.599 7	<.0001
Local level prefire crown closure >70%	Local	2.6015	1.1182, 4.2188	10.978 1	0.0009

[a] Model variables include: Northness = cos(aspect), Eastness = sin(aspect), Elevation = elevation in meters, Local level prefire crown closure >40-70% = proportion of 3x3 pixel area classified a ponderosa pine or mixed forest with >40-70% crown closure, Local level prefire crown closure > 70% = proportion of 3x3 pixel area classified a ponderosa pine or mixed forest with >70% crown closure

[b] Probability that a particular Wald X^2 test statistic is as large as, or larger than, what has been observed under the null hypothesis.

Habitat Suitability Maps and Predictive Ability – Logistic Regression

We constructed relative suitability maps for black-backed woodpeckers based on the identified best Star Gulch logistic regression model for the Star Gulch fire (Figure 4), Toolbox Fire (Figure 5), and the Tripod Fire (Figure 6). For Star Gulch nests using a relative predicted probability cutoff value of $\geq$ 0.50, 75.7% were correctly predicted to be in suitable habitat (relative predicted probability). Similarly, 75.6% of non-nest random locations at Star Gulch were predicted to be in unsuitable habitat (relative predicted probability < 0.50). With a sample size of only 8 nests from 2008 in the Tripod burn, the model showed a lower level of agreement with 4/8 of found nests falling within predicted suitable habitat (relative predicted probability $\geq$ 0.50). However, of the remaining 4 nests, 3 fell in habitat with a predicted relative probability of occurrence of $\geq$ 0.45. With a sample size of 248 nests in the Toolbox burn, the model did not perform well with only 41% of nests (102/248) located within predicted suitable habitat (relative predicted probability $\geq$ 0.50).

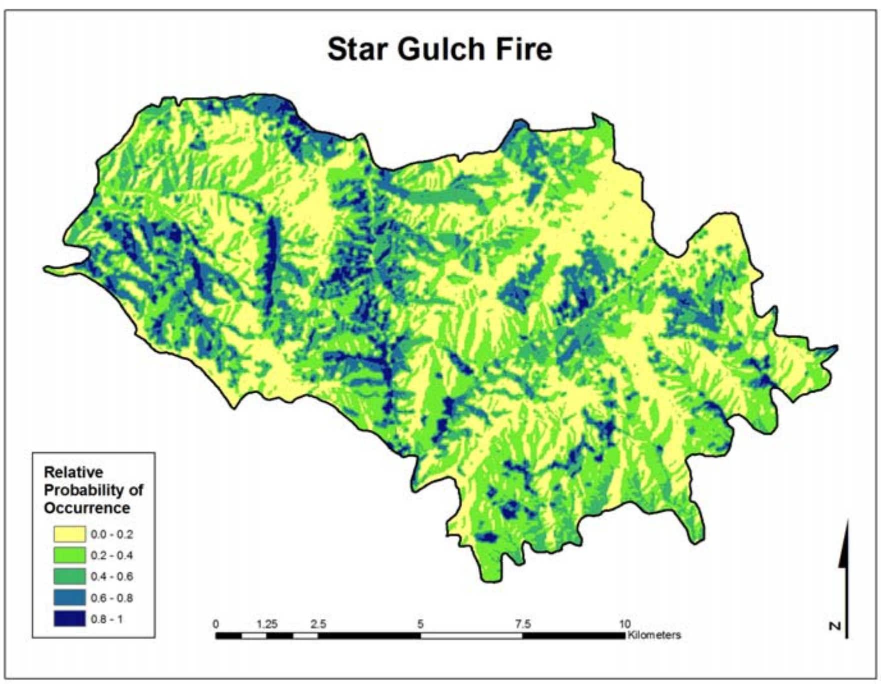

Figure 4. Habitat suitability map derived from logistic regression for black-backed woodpecker nest sites in the Star Gulch Fire in western Idaho. Darker areas indicate higher suitability.

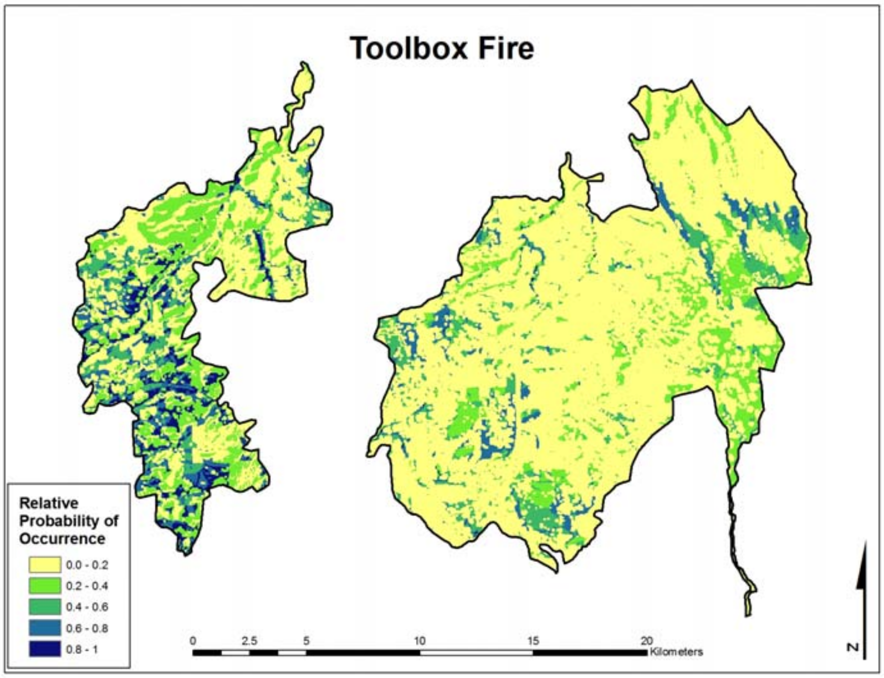

Figure 5. Habitat suitability map as applied from the Idaho-derived logistic regression model for black-backed woodpecker nest sites in the Silver/Toolbox fires in Oregon. Darker areas indicate higher suitability.

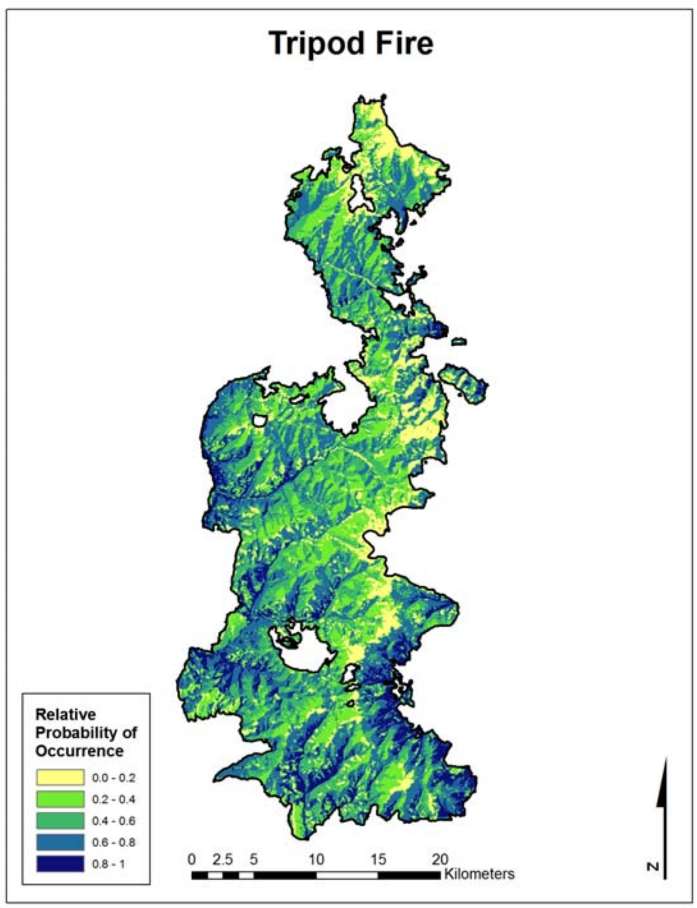

Figure 6. Habitat suitability map as applied from the Idaho-derived logistic regression model to the Tripod fire in Washington. Darker areas indicate higher suitability.

Development and Predictive Ability of Habitat Suitability Models- Mahalanobis Distance

Five variables were selected to develop the Mahalanobis model for habitat suitability of nesting black-backed woodpeckers on the Silver/Toolbox fires (Table 5). Variables were selected based on our previous research results (Russell et al. 2007, Saab et al. 2009). Nest locations had significantly higher pre-fire canopy cover and higher burn severity than the average measured over the burned landscape (Table 5). Model results indicated the greatest change between partitions 4 and 5, suggesting that partition 4 may have been a suitable threshold partition for the selected habitat model (Table 6). Figure 6 shows the median HSI for each k-partitions model. Partition 4 consistently performs best for both the calibration and validation datasets and appears to be similar in value (Calibration median HSI = 0.65, Validation median HSI = 0.68). Evaluation of the eigenvectors for partitions 1 through 4 do not suggest any dominant environmental/habitat factors since each variable has 2 evenly distributed, large magnitude eigenvector values. Consequently, we selected D2 (k=4) as our habitat model. The selected model applied to calibration data (Mean HSI = 0.57, Std.Dev = 0.34) and validation data (Mean HSI = 0.58, Std.Dev. = 0.34) performed similarly, suggesting good predictive ability at the location where the model was developed (Silver/Toolbox fires).

Table 5. Summary of nest-sites and landscape habitat variables in the Silver/Toolbox fires in Oregon during 2003-2007. Canopy cover measurements are pre-fire.

	Nest-site Locations			Landscape		
Variable	**Mean**	**SD**	**SE**	**Mean**	**SD**	**SE**
Slope (%)	11.05	8.58	0.54	10.25	12.55	0.02
Landscape-scale Canopy Cover (%)	39.84	7.53	0.48	15.47	15.49	0.03
Local-scale Canopy Cover (%)	50.40	14.31	0.91	17.15	22.00	0.04
ΔNBR	535.12	158.61	10.07	168.15	205.73	0.34
Patch Area (ha)	807.02	2072.65	131.61	1482.08	2524.09	4.14

n (nest sites) = 248; n (landscape) = 370926 pixels

Table 6. Results of PCA on correlation matrix of calibration dataset. Shaded region indicates the partitions of the selected model (*k*=4). Eigenvector values in bold are likely to be important factors in determining the limitation of nest-site locations.

Principal Component	5	4	3	2	1
Partition (*k*)	1	2	3	4	5
Eigenvalue	0.4057	0.6805	0.9700	1.0582	1.8853
Proportion of Variance	0.0812	0.1361	0.1940	0.2116	0.3771
Eigenvectors:					
Slope	0.1293	**0.7304**	**0.4724**	-0.1282	-0.4585
Canopy cover w/n 1km	-0.3376	**-0.4445**	0.2550	**-0.7119**	-0.3415
Canopy cover at the pixel	**0.6420**	**-0.4334**	-0.0056	0.2441	-0.5835
Δ NBR	**-0.6619**	0.0084	-0.2136	**0.4859**	-0.5292
Patch Area (ha)	-0.1382	-0.2847	**0.8162**	**0.4255**	0.2295

Habitat suitability maps- Mahalanobis Distance

Application of the D^2 (*k=4*) model to the Toolbox/Silver fire landscapes yielded a habitat suitability map (both fires) with mean HSI = 24.57, Std. Dev. 29.96 (Figure 7). The maximum predictive gain for this landscape was achieved with a threshold HSI = 0.33, above which 73% of known nest sites occurred in 27% of the landscape. Although the eigenvector values are difficult to interpret to assess the relative direction and effect of model variables, an assessment of the summary statistics indicates that nest sites are located in areas of higher pre-fire canopy cover and higher burn severity than the average conditions on the burned landscape (Table 5). Also, a visual inspection of the habitat suitability map suggested a negative influence of slope on high-suitability nest sites. Alternatively, it appears that relatively flat sites present more suitable nest sites.

Application of the Oregon-derived D^2 ($k=4$) model to the Tripod fire in Washington yielded a suitability map with a mean HSI = 0.32, Std dev. 3.53 (Figure 8). The map appeared to perform poorly, but needs to be assessed with field-collected validation data. Only 1% of the landscape is identified as above the management HSI threshold determined for Oregon sites (0.33). High suitability locations appeared to occur in areas containing ponderosa pine and mixed ponderosa/other-conifer habitat types.

The relatively large number of partitions in our Oregon-derived model likely makes it less suitable for application to other geographic areas (as suggested by Preston et al. 2008). D^2k models with fewer partitions tend to have more generality, thus more likely to be extensible to other landscapes, when they consist of relatively few partitions. Refinement of the black-backed woodpecker nest-site model developed in Oregon may improve its generality. This would likely involve identification and/or derivation of environmental/habitat measures that better define the limitation of nest-site niche.

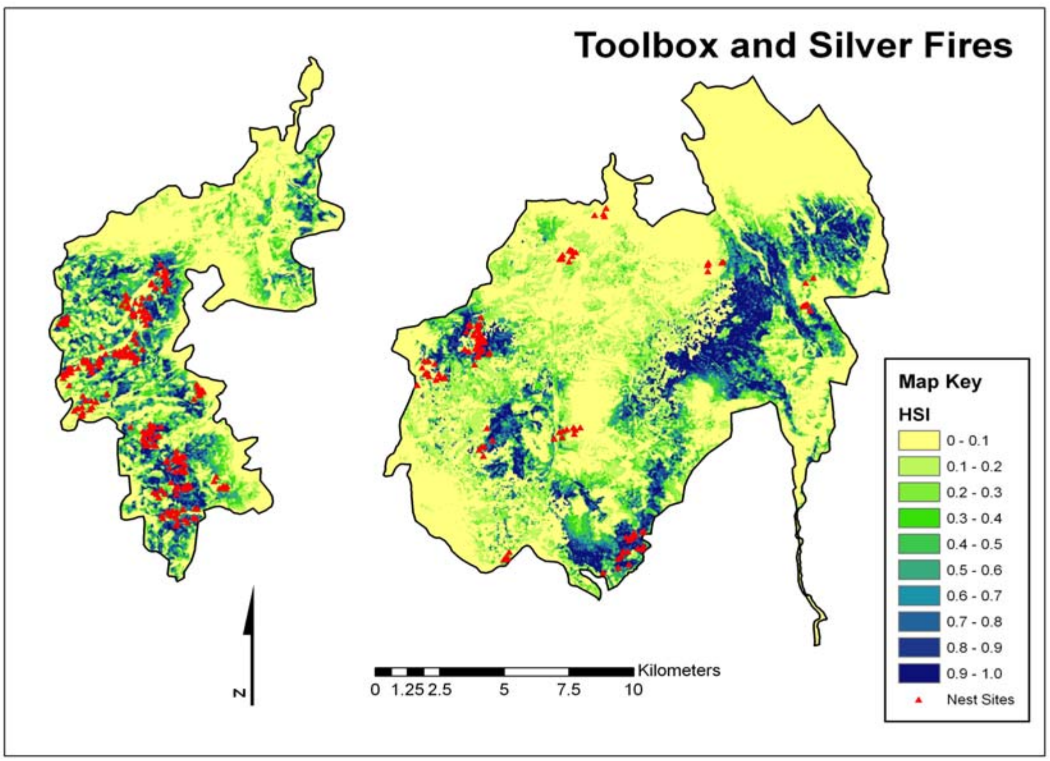

Figure 7. Habitat suitability map (developed from data in the same location) for black-backed woodpecker nest sites in the Toolbox (right) and Silver (left) fires in central Oregon. Darker areas indicate higher suitability. Red triangles indicate actual nest locations from 2003-2006.

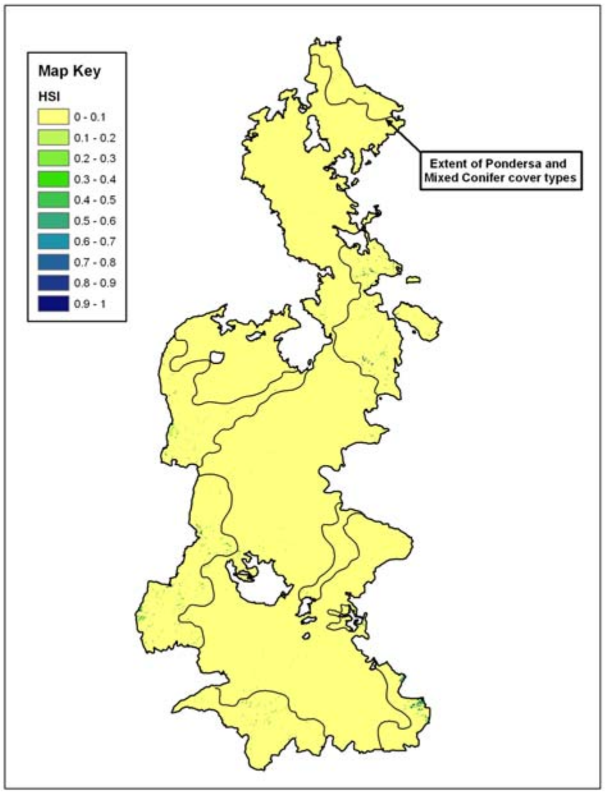

Figure 8. Habitat suitability map as applied from the Oregon-derived Mahalanobis distance model to the Tripod fire in Washington. Darker areas indicate higher nest site habitat suitability. Solid lines show the general extent of pre-fire Ponderosa pine forest types occurring in margins of fire boundary.

V. Management Implications

Overall

- Development of habitat suitability models and associated maps from remotely-sensed data allows managers to rapidly select areas for both postfire timber harvest and retention of wildlife habitat in recently burned forests.
- Habitat suitability models developed and tested in the same location performed well, whereas model performance was mixed when applied to other ponderosa pine-dominated forests.
- Habitat suitability models may not be transferable in space when topography and tree species composition differ.

Assessment of Predictive Ability of Models across Study Areas

Land managers require predictive models of woodpecker habitat in postfire landscapes to make timely decisions regarding management activities such as postfire timber harvest. Development of habitat suitability models and associated maps from remotely-sensed data allows managers to rapidly select areas for both timber harvest and retention of wildlife habitat. External validation of our habitat suitability models with data from other wildfires was necessary to evaluate the general applicability of our habitat suitability models to other forests. As anticipated, models developed and tested in the same location performed well. We had mixed results for model performance when applied to other ponderosa pine-dominated forests. Important physical and tree species differences likely played a significant role in model performance when models developed in one location were applied to different locations. The original model of habitat suitability for nesting black-backed woodpeckers was developed in Idaho on the Star Gulch Burn, where mean slope is moderate (~38%) and conifer species are almost exclusively ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*). This model appeared to perform well on the Tripod Burn, where tree species composition (ponderosa pine and Douglas-fir), topography (mean slope ~ 34%) and burn severity (> 400 Δ NBR) were similar to Star Gulch (Table 7). In contrast, the Idaho Star Gulch model performed poorly when applied to the Silver/Toolbox fire, where tree species composition was more diverse (ponderosa pine, lodgepole pine, white-fir [*Abies concolor*], and rarely Douglas-fir), and topography (low slope ~10%) and burn severity (< 200 Δ NBR) were substantially less (Table 7). Similarly, the Silver/Toolbox model performed very poorly on the Tripod Fire, where tree species composition, slope, and burn severity differed. While all study locations were predominantly ponderosa pine, these results still suggest that habitat suitability models developed in one location will not always transfer to other locations. We expect that other variables could improve model fit, however, models may not be transferable in space when topography and tree species composition differ.

Table 7. Slope and burn severity of three study areas, the 1994 Star Gulch Fire in Idaho, the 2002 Silver/Toolbox fires in Oregon, and the 2006 Tripod Fire in Washington.

Slope (%)	**Star Gulch Fire (n =90 pixels)**	**Tripod Fire (n = 787793 pixels)**	**Silver/Toolbox Fire (n = 370926 pixels)**
Mean	37.59	33.7	10.25
SE	1.501	0.02	0.02
Burn Severity (Δ NBR)			
Mean	414.585	404.35	168.15
SE	23.572	264.40	0.34

Guidelines for Developing Habitat Suitability

- Fine scale

Our field collected data revealed that Black-backed woodpeckers showed changing preferences for nest snag characteristics over time (from lodgepole to ponderosa pine), thus retaining the full range of snag species and diameters should be a component of maintaining black-backed nest habitat. This pattern is similar to our observation in Idaho where woodpeckers generally selected Douglas-fir then ponderosa pine within four years after fire (cf. Saab et al. 2009). Snag density at the plot scale (0.4 hectares) was the most important predictor of nest-site occurrence, with increasing snag numbers favoring black-backs. Our results imply that management activities severely reducing the number of large (≥23 cm dbh) snags will decrease the odds of a black-backed woodpecker nest. Preserving clumps of snags in salvage-harvested areas may attract nesting birds, as long as residual snag densities on the larger landscape provide adequate food supplies for adults and nestlings. As harvest intensity was fairly light in this study, the level of logging triggering black-backed nest avoidance (if such a threshold exists) remains unknown and requires further study.

- Broad scale

Use of remotely-sensed data in modeling habitat suitability (logistic regression and Mahalanobois distance) yielded consistent results on the importance of high pre-fire canopy cover (> 40%) and high burn severity (Δ NBR > 500) for nesting black-backed woodpeckers across study sites. These characteristics were also found as good predictors in our earlier modeling efforts (Russell et al. 2007). Patch area (defined by cover type) was also found to be a good predictor in our earlier modeling (Russell et al. 2007) but not found in the modeling reported here. The modeling efforts described in this report provided an increased number of non-nest random locations (random absence) compared with our original modeling reported in Russell et al. (2007). The increased number of random absence locations also increased the number of locations that occurred in large conifer patches that could have lead to data contamination, masking the effect of patch size (cf. Keating and Cherry 2004). Patch area can be defined in multiple ways (e.g., by cover type only, by canopy cover only, or the combination of the two) and we are still exploring how to best define patch area. Based on our radio-telemetry study of home range size on the Star Gulch Fire, Black-backed Woodpecker home ranges were approximately 72-131 ha (175-324 acres) during the period of 4 – 6 years after wildfire (Dudley and Saab 2007). Habitat within home ranges was not uniform but included patches dominated by high pre-fire crown closure and high burn severity. Therefore, we recommend a minimum burned area of 72 ha (175 acres) before evaluating the potential habitat suitability. Our step-by-step process for developing the habitat suitability models and maps is in progress. In preparation, prior to developing a habitat suitability map from remotely-sensed data, the following are needed:

1) ArcGIS, Spatial Analyst
2) Data analysis software, SAS or R.
3) pre-fire vegetation classification of cover type and canopy cover derived from Landsat ETM+.
4) Burn severity derived as Δ NBR.
5) Digital elevation model (DEM).
6) Aspect and slope calculated from DEMs.

VI. Relationship to Other Findings and Ongoing Work

- Our model results of nest site selection by Black-backed Woodpeckers (Russell et al. 2007, Saab et al. 2009) are consistent with other studies, i.e. black-backed woodpeckers select high-severity patches in areas where pre-fire canopy cover and tree density are moderate to high (Hanson and North 2008, Hutto 2008, Vierling et al. 2008). Our study is the first attempt to model nest-site selection using only remotely-sensed data.
- Our nest survival results, however, differed from those reported elsewhere. We did not find an effect of habitat or salvage logging on nest survival, although we did not evaluate the effect of burn severity on survival. Reproductive success was lower in low- and moderate-severity conditions than it was in high-severity patches of a South Dakota burn (Vierling et al. 2008). Nest density and reproductive success were also highest in high-severity areas with the highest proportions of forest that was mature prior to the fire (Nappi and Drapeau 2009).
- Nest densities of Black-backed woodpeckers in this study were reduced after partial postfire salvage logging, although they continued to nest in such areas (Saab et al. 2007, Forristal 2009, Saab et al. 2009). Importantly, salvage logging in our study areas was a partial removal of selected trees and areas were not clearcut. Other studies reported that postfire salvage logging significantly reduced occupancy of Black-backed Woodpeckers (Hutto 1995, Hutto and Gallo 2006, Hanson and North 2008, Hutto 2008). Hutto and Gallo (2006) found no Black-backed Woodpecker nests in salvage logged areas, despite above-minimum snag retention, and Hanson and North (2008) found no Black-backed Woodpeckers foraging in salvage logged areas, despite high retention of small snags and some retention of large snags.
- Ongoing work: 1) Completion of field work for the validation of habitat suitability models for Black-backed Woodpeckers on the Tripod Fire in Washington and the Toolbox Fire in Oregon; 2) development and validation of habitat suitability models for nesting white-headed woodpeckers in burned and unburned forests of Oregon, Washington, and Idaho; 3) development and testing of a monitoring protocol for the presence of sensitive woodpecker species in Idaho; 4) development and validation of habitat suitability models for nesting Lewis's woodpeckers in burned forests of Oregon and Idaho; and 5) Ecological trade-offs of different fire conditions for bird communities of ponderosa pine forests in Idaho.

VII. Future Work Needed

The ongoing research listed above reflects the research team's consideration of future work needed and work for which they could obtain immediate funding. Additional topics would include:

- Completion of black-backed woodpecker data collection in Washington and incorporation of data on nesting locations for other sensitive woodpecker species (White-headed [*Picoides albolarvatus* and Lewis's [*Melanerpes lewis*] woodpeckers in different wildfires across a range of conditions in Idaho, Oregon, and Washington (different levels of burn severity, different cover types, etc.) will improve the accuracy of the predictive models in a wide-variety of landscapes.
- Development and validation of habitat suitability models for sensitive woodpecker species in forests affected by bark beetle outbreaks because such areas are proposed for salvage logging and the predictive models will inform managers about retention areas for key wildlife.
- In addition to maintaining habitat for species of concern, land managers must also consider the economic trade-offs of reserving habitat versus allowing postfire timber harvest. Areas preferred by fire associated species such as woodpeckers (large diameter trees, in high densities), are often areas suitable for timber harvest as well. Evaluating the economic value of species is more difficult.
- Establishing target objectives for management of a particular species is often species specific. Previous studies have used "the probability of persistence of at least one breeding individual on the landscape at the end of the 100-year time horizon", "area of flying squirrel habitat at the end of a planning period of 60 years", and a population viability index where "a population is viable if its predicted size at the end of the horizon exceeds a population size target n". Because postfire landscapes are ephemeral habitat for species such as black-backed woodpecker, long-term goals of population sizes are not appropriate measures for our system. Populations of black-backed woodpeckers often peak 4-5 years postfire and then decline, however populations of Lewis's woodpeckers continue to increase after fire for at least 10 years (Saab et al. 2007). Therefore, development of dynamic models should be intended to optimize nesting pair numbers of these two woodpecker species for up to 10 years postfire.

VIII. Deliverables Crosswalk Table

Proposed	Delivered	Status
Presentations/Workshops at regional, national, and international forums	See citation database on JFSP website (currently includes 27 meeting/conference presentations)	Completed (posted on JFSP website)
Decision support software	Results submitted to DecAID, the Decayed Wood Advisor for managing snags, partially dead trees, and down wood for biodiversity in forests – decision support system http://www.fs.fed.us/r6/nr/wildlife/decaid/index.shtml	Completed
Interactive website	Results submitted and accessed via weblink in the USFS interactive website (http://www.fs.fed.us/biology/wildecology/related.html)	Completed
Management document	Work with North American Bird Conservation Initiative authors to produce a supplement to appropriate Landbird Conservation Management Strategies (BCR 9 and 10)	In progress

5 Refereed Journal Articles, 1 Master's Thesis	1) Saab, V., R. Russell, and J.G. Dudley. 2007. Nest densities of cavity-nesting birds in relation to postfire salvage logging and time since wildfire. Condor 109: 97-108. 2) Dudley, J. G. and V. A. Saab. 2007. Home range size of Black-backed Woodpeckers in burned forests of southwestern Idaho. Western North American Naturalist 67(4), 593–600. 3) Russell, R.E, V.A. Saab, and J. Dudley. 2007. Habitat suitability models for cavity-nesting birds in a postfire landscape. The Journal of Wildlife Management 71(8):2600–2611. 4) Saab, V.A., R.E. Russell, J.G. Dudley. 2009. Nest-site selection by cavity-nesting birds in relation to postfire salvage logging. Forest Ecology and Management 257: 151-159. 5) Russell, R. E., V. Saab, J. Rotella, and J. Dudley. 2009. Detection probabilities of woodpecker nests in mixed conifer forests in Oregon. Wilson Journal of Ornithology **121**:82–88. 6) Forristal, C. 2009. Influence of Postfire Salvage Logging on Black-Backed Woodpecker Nest-Site Selection and Nest Survival. M.S. thesis. Montana State University, Bozeman. 103p.	1) In print 2) In print 3) In print 4) In print 5) In print 6) Completed
Journal Article	*Saab et al.* (manuscript) Habitat suitability models for nesting woodpeckers using burned forests in Idaho, Oregon, and Washington.	In progress
General Technical Report	*Saab et al.* (manuscript) GTR "Design Criteria for Post-fire Salvage Logging to Maintain Habitats and Populations of Sensitive Woodpeckers" to Rocky Mountain Research Station	In progress
Project Website	http://www.rmrs.nau.edu/wildlife/birdsnburns/	Updated as needed

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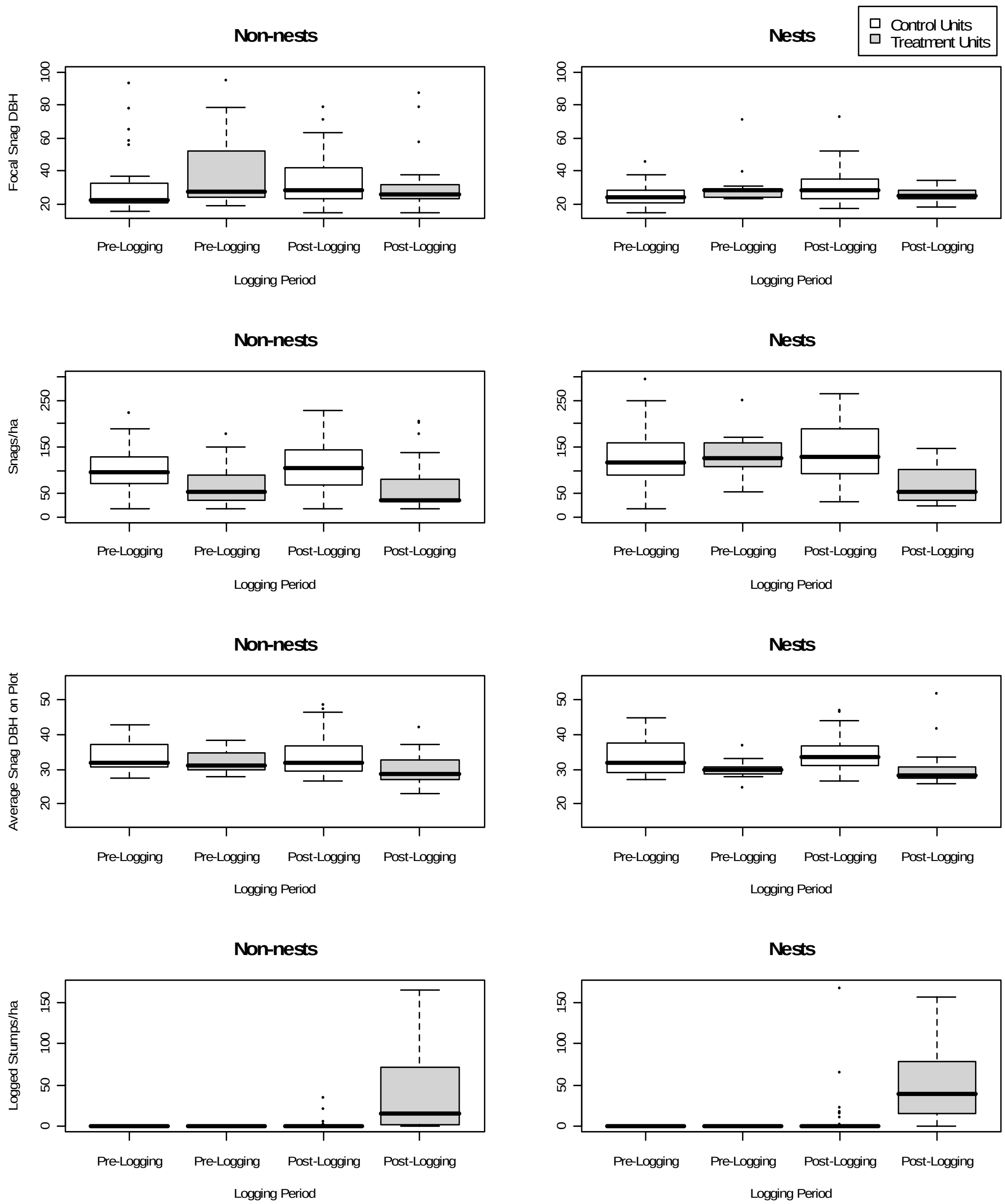

Appendix 1. Box and Whisker plots of nest/patch suite habitat variables used in nest-site selection models. Random, non-nest habitat data are in the left column of plots and nest data in the right column of plots. Within each plot, data are separated by control and treatment unit, as well as pre-logging and post-logging time periods. The upper and lower edges of each rectangle indicate the 25% and 75% quantiles, respectively. Medians are shown by a dark horizontal line within each rectangle. Whiskers indicate 1.5 times the 25% and 75% quantiles. Points shown above or below a whisker are >1.5 times the closest whisker.