

FORAGING HABITAT OF PILEATED WOODPECKERS IN RELATION TO A  
MANAGED LANDSCAPE ON THE HOOPA VALLEY RESERVATION,  
NORTHWESTERN CALIFORNIA

By

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## ABSTRACT

### FORAGING HABITAT OF PILEATED WOODPECKERS IN RELATION TO A MANAGED LANDSCAPE ON THE HOOPA VALLEY RESERVATION, NORTHWESTERN CALIFORNIA

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The Pileated woodpecker (*Dryocopus pileatus*) is associated with older forest stages—larger diameter trees and snags for roosting, nesting and foraging, but they also use managed forests. The Hoopa Reservation is approximately 37,000 ha of mostly forested area with an array of seral stages. The Hoopa Tribe manages timber, and explicitly provides habitat for woodpeckers according to the Tribe’s Forest Management Plan (FMP). No formal study has assessed woodpecker habitat at Hoopa, and habitat has not been well described in this region. I captured eleven woodpeckers and outfitted them with transmitters between 2009 and 2014, and I used resource selection functions to examine foraging habitat selection. I compared used and available habitat, buffered with median telemetry error for all woodpeckers, then applied logistic regression to fit models to habitat covariates. Woodpeckers selected habitat near creeks, in areas with comparatively dense vegetation in the layers 1-8 m (ground) and >32-72 m (upper canopy). The birds also showed some selection of old growth and avoidance of the stem exclusion seral stages. Home ranges averaged 213 ha (138-324 ha), which is smaller than most home ranges previously reported. Results of this study help inform the Tribe’s current timber management practices and future updates to the FMP, and I suggest that

current timber practices are generally favorable for pileated woodpecker habitat. I recommend special attention be paid to the recruitment of snags via reintroduction of fire on the landscape to promote snag initiation, as well as diversification of managed forest stands that are a legacy of BIA management through habitat improvement.

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## INTRODUCTION

The Hoopa Valley Tribe (hereafter, the Tribe) claimed sovereignty from the U.S government in 1989 (Hoopa Valley Tribal Council 1994). Since that time the Tribe has formally been in charge of managing tribal resources. Accordingly, the Tribe instituted its first Forest Management Plan (FMP) in 1994, which became the governing document of forest practices on the Hoopa Valley Reservation (HVR). Because the Tribe relies on timber for revenue, and the reservation land base is held in federal trust with the United States government, the FMP describes the Tribe's objectives and intent, as well as the formal consultation process with the government for habitat mitigations (Hoopa Valley Tribal Council 2010). These consultations occur during updates to the FMP approximately every 10 years. Within the FMP, the Tribe explicitly obliges to manage for federally listed species, as well as species that are deemed culturally important.

Pileated woodpeckers (*Dryocopus pileatus*) are culturally important to the Hupa people. An intricate relationship exists wherein the woodpecker is an icon both traditionally and contemporarily. As woodpeckers are used in ceremonies with imperative themes as world renewal and warding off sickness, woodpeckers adorn the prayer items of these ceremonies and in the process are thought to be immortalized "to dance forever" (David Hostler, personal comm. 2018). Jordan (2012) described the relationship as a reciprocity between the Hupa and woodpecker. Therefore, the FMP names pileated woodpeckers as a culturally important species, and it contains provisions

intended to maintain habitat following forest harvest to ensure the persistence of pileated woodpeckers on the landscape.

Pileated woodpeckers occur across an expansive range using a variety of habitats (Bull and Jackson 1995), demonstrating plasticity in terms of tree species use (Flemming et al. 1999). However, they uniformly need habitat elements indicative of mid to late successional forest, such as large diameter, dead and dying or decadent trees (Mellen et al. 1992, Flemming et al. 1999, Aubry and Raley 2002a, Hartwig et al. 2004), and downed logs (Bull and Holthausen 1993, Torgersen and Bull 1995), all of which are considered forest structure (Franklin et al. 2002).

Bonar (2001) found selection for older forests, but determined that other forests were also used. Mellen et al. (1992) contended that old growth is not necessary to support pileated woodpeckers in Western Oregon, as over half of their study area was devoid of the old growth age habitat class of forest, although woodpeckers selected mature old growth habitat more often. More recently, Bull and Jackson (2011) categorized pileated woodpecker habitat as mature forest, and young forest with large snags. Thus, pileated woodpeckers may be adversely impacted by forest management that reduces structure (Bull and Meslow 1988, Franklin et al. 2002). However, in well-managed forests, the structural diversity necessary for pileated woodpeckers can be maintained with single tree or groups of trees, considered habitat patches, and retained within harvest units (Bull 1987). The Tribe removes only a few snags during harvest operations for safety purposes during site preparation including burning for regeneration (Hoopa Valley Tribal Council

2010). Snag retention maintains the spatial integrity of snags of various sizes on the landscape that resembles the patchy distribution in unmanaged forests (Bull et al. 1987).

Raley and Aubry (2006) advised that forest management strategies aimed to provide foraging habitat for pileated woodpeckers should take into consideration regional differences in their ecological relations. Habitat selection differs considerably between the coastal forests of Washington (Raley and Aubry 2006) and the inland forests of northeastern Oregon (Bull and Holthausen 1993), perhaps reflecting differences in the presence and abundance of available prey (Aubry and Raley 2002a). Swallow et al. (1988) described substantial differences between snags used for foraging and for resting. Mellen et al. (1992) credited the dissimilarity of forest characteristics to account for the variation in home range sizes across study areas. Similarly, Raley and Aubry (2006) acknowledged that foraging preference changed regionally, but interpreted a failure to recognize local selection for tree species in their study to mean that tree characteristics, rather than species, guided foraging selection. They suggested that large, decadent trees provided a more suitable climate for arthropod species. Presumably, foraging habitat is guided by the abundance of prey, predominately consisting of carpenter ants (*Camponotus* spp., Beckwith and Bull 1985, Bull et al. 1992, Raley and Aubry 2006), but also beetles and fruit to a lesser degree (Shroeder 1983). While there is no way for woodpeckers to actually know how many arthropods are deep within the foraging substrate, their selection of territory is most likely driven by structural cues that indicate the quality of habitat.

Variations of foraging are recognized seasonally and regionally due to weather, and prey availability (Conner 1981, Aubry and Raley 2002). In Alberta, surrounding habitat did not influence pileated woodpeckers exploitation of all available substrates regardless of successional forest stage in Bonar's (2001) observations. There are reported differences in foraging use between studies where downed wood is a widely used substrate in northeastern Oregon, but rarely used in western Washington (Bull 1987, Aubry and Raley 2002). Pileated woodpeckers in Virginia increased excavation considerably, as opposed to pecking, in the winter. Depending on the region, and the availability of large tree's and the decadence of those trees to house prey, pileated woodpeckers seem to readily make needed adjustments to exploit the habitat of the region in which they reside. Pileated woodpeckers are strong excavators and can bore into healthy trees to exploit prey (Conner 1981), but tend to use trees with rot to conserve energy (Bull et al. 1992), so these differences may describe the adjustments made when circumstances are not ideal.

Since pileated woodpeckers forage diurnally (Bull and Jackson 1995) and a great deal of their daytime activity is spent foraging, diurnal tracking of pileated woodpeckers is useful to assess foraging habitat. Nearly half (42%) of Bull and Holthausen's (1993) observations of pileated woodpeckers were foraging; however, in some instances observer disturbance may have caused the birds to cease foraging activity and resting activity to be observed instead. Tomasevic and Marzluff (2018) reported slightly less time budget allocated to foraging (29%). Bonar (2001) found pileated woodpeckers to

spend most of their time foraging (86%) year round. Foraging, therefore, likely accounts for half or more of their diurnal activity.

The managed forest habitats currently on the HVR are a legacy of past forest management practices, those that occurred before and after the implementation of the FMP. The result is a heterogeneous mix of multiple forest-age classes (i.e., seral stages) and various amounts of retained standing dead wood (snags), downed wood, and tall residual trees (Franklin et al. 2002). This study is designed to examine how pileated woodpeckers are using the present landscape at the home range scale, and reflect on the management strategy set forth by the Tribe. The Tribe considered pileated woodpecker habitat in developing the FMP, but no study has scrutinized the efficacy of the existing management, and while pileated woodpeckers have been studied in Oregon, Washington and Canada, no intensive studies of pileated woodpeckers in California have been published. Therefore, tribal management has relied on the findings of pileated woodpecker habitat selection from elsewhere. Differences in vegetation prompt a need for pileated woodpeckers to be studied in the mixed conifer hardwood vegetation of Northwestern California.

While the Tribe addressed needs for nesting and roosting in the FMP, the foraging requirements for pileated woodpeckers, in terms of managed forest patches, remain unknown. Due to the cultural importance of woodpeckers and paucity of regional information on the foraging habitat requirements for pileated woodpeckers, specifically within a montane hardwood habitat type, it is important for the Tribe to develop a better understanding of foraging requirements of this species in this region.

I examined pileated woodpecker habitat on HVR, using previous research to hypothesize how seral stages and habitat features resulting from past management may affect current habitat selection. In Missouri, Renken and Wiggers (1993) reported positive correlations between pileated woodpeckers and both snag and large tree densities, and a negative correlation with pole stands. Flemming et al. (1999) found that pileated woodpeckers foraged on larger, more decayed trees than were randomly available within the same stands in contiguous and fragmented forests. In Ontario, Bush et al. (2009) suggested pileated woodpeckers preferred forest types that contained large trees and snags because they were used disproportionately for foraging. Lemaître and Villard (2005) found the best predictor of foraging substrate use was tree dbh, greater diameter yielding greater probability of use.

In northeastern Oregon, Bull and Holthausen (1993) found that smaller home ranges, assumed to be high in quality, contained comparatively high percentages of area in stands characterized as old-growth, and with greater than or equal to 60% canopy closure. While Bonar (2001) suggested that territory size was a function of sufficient foraging substrates and predator avoidance by way of canopy cover. Renken and Wiggers (1989) posited that home range sizes should increase according to the sparseness of suitable foraging substrate. Large trees and snags are the relic features of old-growth forests and may provide greater foraging opportunities for pileated woodpeckers (Aurbry and Raley 2006); whereas forest stands lacking in relic structure that serve as residual habitat after a disturbance event, and canopy cover, potentially influencing vulnerability to avian predation tend to be little used (Mellen 1992, Bull et al. 2007). Lemaître and



Villard (2005) concurred with Flemming et al. (1999), in their supposition that pileated woodpeckers behaved differently when preferred mature forest was not available, consequently relying on deciduous hardwoods in response to forest fragmentation.

Bush et al. (2010) conducted a foraging study in Ontario, Canada, concluding that although pileated woodpeckers may not be old growth obligates, they favor mature forests with moderately dense canopy closure. While it is logical that pileated woodpeckers choose old growth habitat when available, and that relic features on the landscape can provide sustenance for foraging, roosting and nesting in the absence of contiguous old growth (Bull and Holthausen, 1993; McClelland and McClelland, 1999), perhaps woodpeckers are influenced more by old growth patches themselves than any particular structural feature.

Vertical structural complexity, typical of mature and old growth forests (Franklin and Van Pelt 2004), may also be an important habitat component (Kamnyev 2013). Aubry and Raley (2002a) recognized partitioned placement of nests and roosts with regard to the forest canopy. Bull et al. (1996) found that nearly all nests were in forested areas with two canopy levels, characteristic of the vertical diversification of mature forests (Franklin et al. 2002). In addition to nesting and roosting sites having some relationship to canopy levels, foraging occurs at a variety of vertical layers of the forest, and vertical vegetation diversity could affect foraging habitat selection (Bull and Holthausen 1993). In addition, dense upper canopies could provide some safety from aerial predators such as red-tailed hawks (*Buteo jamaicensis*), accipiters (Accipitridae spp.), and barred owls *Strix varia* (Bull et al. 1992, Bonar 2001, Weins et al. 2013), and a

relatively open mid-canopy level could aid in flight for relatively large-winged forest species (Aubry and Raley 2002a, Bull et al. 2011) like pileated woodpeckers.

In the managed landscape of HVR, where the canopy cover is naturally high, and an abundance of structure is interspersed throughout variously aged patches of forest with uneven snag and tree retention, pileated woodpeckers should exhibit clear selection of habitats within their home ranges (i.e., third order habitat selection, Johnson 1980). I sought to understand whether pileated woodpeckers were associated with particular developmental stages of the forest, and if they were avoiding forest stages resulting from current or past management. Subsequently, if particular stages were important, does proximity to patches of these seral stages also influence where woodpeckers forage, or do the density of residual features such as snags and tall trees (i.e. foraging substrate; McClelland 1979) affect foraging habitat selection? Likewise, how does the forest cover and vegetation structure affect the use of habitats for foraging?

Based on the rationale provided by theoretical foraging theory (Pyke 1984), the previous empirical work on foraging woodpeckers reviewed above, and the history of and current habitat distribution on HVR, I hypothesized that seral stage, structure, and remnant features would predict foraging locations of pileated woodpeckers within their home ranges at HVR. Specifically, I expected: 1) use of old-growth habitat should be used disproportionate more relative to its availability; 2) remnant features such as snags and tall trees would be important predictors of habitat use, but that distance to old growth may combine with or be overwhelmed by these features; 3) canopy density and height would predict pileated woodpecker habitat use, with the expectation that woodpeckers

would select canopy structure that allowed movement and provided adequate cover and nesting opportunities.

### Study Area

The Hoopa Valley Reservation is 37,636 ha of mostly forested area. The residential zone on and near the valley floor and recent harvests are considered unforested areas of the HRV. The Tribe's FMP and forest has been Smartwood certified by the Forest Stewardship Council since 1995. It is the only Smartwood certified old-growth forest in North America and has been subject to annual audits and undergone recertification every five years to maintain certification. The terrain on the HVR is rugged, often with slopes averaging greater than 40%. Elevation ranges from 100 m to 1075 m. Mean maximum annual temperature is 20.8° C; mean minimum temperature is 6.7° C and annual mean precipitation 148.4 cm (Western Regional Climate Center). Most of the HVR exists in montane hardwood forest (Mayer and Laudenslayer 1988), with the dominant tree species being Douglas fir (*Pseudotsuga menziesii*), tan oak and Pacific madrone (*Arbutus menziesii*). Shrub species that dominate the understory on the reservation are evergreen huckleberry (*Vaccinium ovatum*) and salal (*Gaultheria shallon*). California black oak (*Quercus kelloggii*) and Oregon white oak (*Quercus garryana*), and riparian habitats with red alder (*Alnus rubra*), white alder (*Alnus rhombifolia*) and big leaf maple (*Acer macrophyllum*) are also prevalent throughout the reservation.

The amount of structure, defined as trees, snags and logs in a variety of groupings left post harvest (Franklin et al. 2002) delineates the harvest type. Under current management, primary timber harvest types are modified clearcut, shelter wood, and group shelterwood. Modified clearcut retains the least structure, and group shelterwood retains the most. Shelterwood is a regeneration type harvest with green tree and snag retention to varying degrees. Group shelterwood retains groups of trees in habitat islands. Shelterwood trees and groups are to remain on the landscape, never to be harvested. Currently 53% of the HVR is in intensive cut status, 27% in no-cut status, 15% in urban, and 5% other.

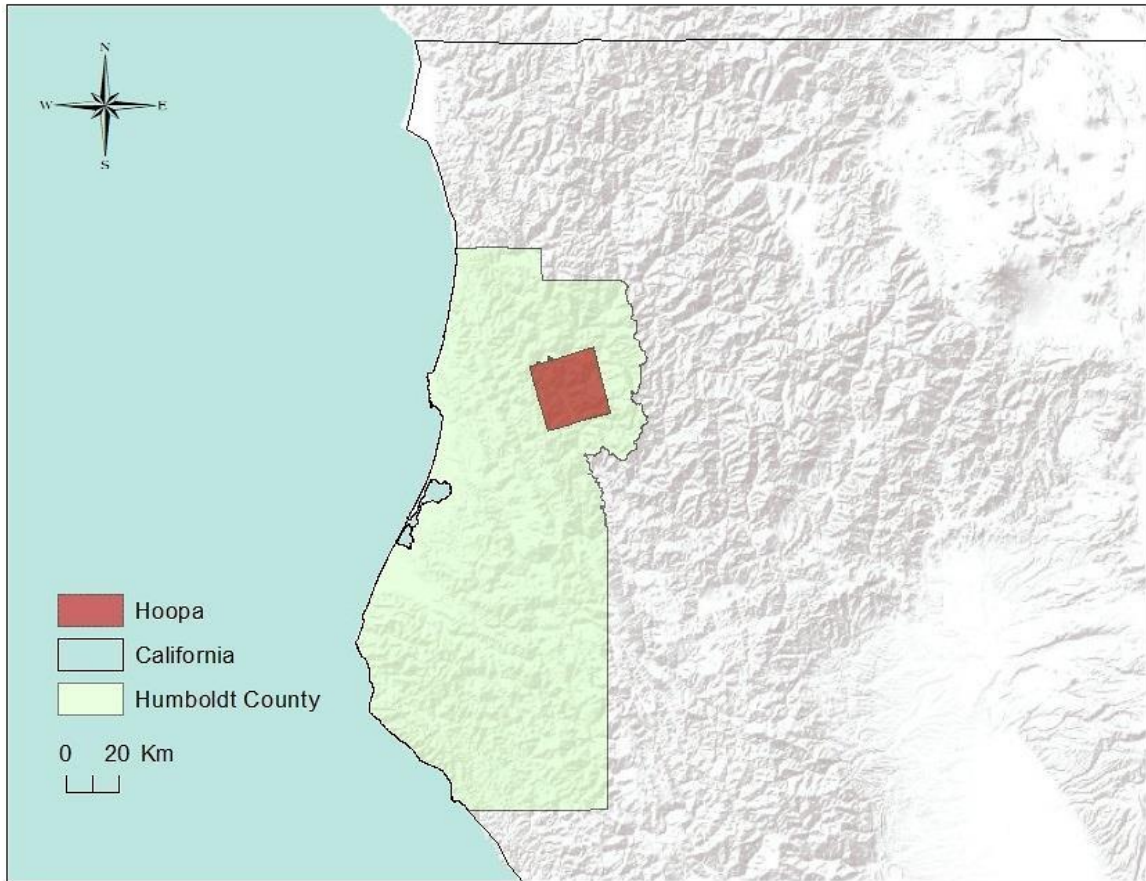


Figure 1. Hoopa Valley Reservation (in red) is located within California approximately 140 km of the Oregon border and 480 km N of San Francisco.

## MATERIALS AND METHODS

To assess habitat selection on the reservation, I captured and outfitted 11 pileated woodpeckers with 10 g radio transmitter backpacks (Holohil, RI-2B). I targeted areas where pileated woodpecker pairs were formerly identified from a 2006 reservation-wide woodpecker occupancy study (Hoopa Tribe 2006). Capturing pileated woodpeckers proved difficult because the birds rarely descended low enough to get caught in nets (see Results).

I elicited a response with a digital caller (Wildlife Technologies, MA-15) or with an MP3 player and used a variety of recorded pileated woodpecker calls. I captured woodpeckers with a 6 m x 2.5 m mistnet (Avinet, 60 mm mesh), in some cases using two nets stacked vertically on 5 m metal poles and affixed with guy lines. I also used hand-carved pileated woodpecker decoy attached to a nearby tree. The decoy was fitted with a hinge and screwed to a tree, while also attached to monofilament that was pulled by a remote observer to mimic pecking movements. I visited targeted areas prior to capture to qualify the location as potential capture sites and to determine the best approach to set up the operation. I typically set up mistnets the prior afternoon and deployed first thing in the morning. Occasionally, a second attempt was made at a nearby location, but at a far enough distance that the same woodpeckers would not be disturbed (at least 1 km).

I had an experienced bird extractor as an assistant to safely remove the woodpeckers from the net. Usually this took less than 5 min. Transmitters were attached with Teflon tubing, which was intended to lie smoothly against the feathers and secure

the back pack harness closely to the bird (Raley and Aubry 2002a). This was a lengthy process, and if there was time, we took photos of the open wings and collected wing chord measurements. Initial work ups averaged 50 min from in the net to release. With practice and after simplifying the process, handling time was reduced to 40 min, but longer than the goal of < 30 minutes. Every pileated woodpecker flew well with the backpack attached at release.

I used triangulation, close distance biangulation, and walk-ins for visual sightings to determine pileated woodpecker relocations. I collected data in all months of the year, though telemetry work was concentrated in the warmer months. I attempted to gather relocation data 2-3 times per week in the summer months, but when they proved difficult, such as when the signal disappeared altogether, and in non-summer months, I aimed for weekly relocations (see Results for details). I dealt with position error in the field by streamlining the telemetry process to capture an independent observation by obtaining points and recording information swiftly. Specifically, I developed a system to reduce time during the radio telemetry process by attaching the compass and gps unit to my person, and writing most information in the notebook before exiting the vehicle for an azimuth. Often the next bearing location was a 10 min drive, so I made sure that driving between telemetry points was where most time was spent. I began to recognize good vantage points for obtaining a signal, and stopped wasting time on stops that continually caused the radio signal to deflect. I approached the woodpecker as closely as feasible, without causing the bird to move, to obtain acceptable points. I attempted to obtain triangulation angles greater than 25 degrees, and no angles less than 20 degrees were

used. When the bearings indicated that the woodpecker flew to a new location before I obtained three azimuths, I started over with a new set of azimuths.

After field tracking, I assessed position error with the program Location of a Signal (LOAS, 4.0.3.8; Ecological Software Solutions, LLC, Florida, USA). LOAS provided an error ellipse for each relocation point, which shifted each relocation point to the centroid of the error ellipse. I discarded relocation points with ellipses that were unreasonably large, such as those covering the area of the entire home range. These rare instances (< 10% of ellipses) occurred for various reasons (bird movement, signal bounce, human error, but mostly long distances to the bird), and I assumed their distribution was independent enough of habitat so as to not bias the habitat distribution of remaining ellipses. I imported corrected relocation points into ArcMap 10.2.2. (ESRI, ArcGIS) and created a shapefile, which I then read into the program RStudio (1.0.153) for home range analysis. Two woodpeckers had considerably greater numbers of relocations, based on a technician who collected telemetry data more frequently than the other birds. For analysis, I randomly removed relocation points within those respective home ranges, so that the numbers were similar to the other relocation samples (see Results). I used the `adehabitatHR` package for R (Calenge 2006) for 100% Kernel Density Estimates (KDE) of the final home range size. I chose the Least Squares Cross Validation approach to find an appropriate smoothing parameter (Gitzen and Millsbaugh 2003). I also calculated 100% Minimum Convex Polygons (MCPs).

I used a Design III sample design (i.e., individual use vs. individual availability; Thomas and Taylor 2006), and a Resource Selection Function (RSF; i.e., application of



logistic regression, Manly et al. 2002) to compare habitat use and availability at the 3<sup>rd</sup> order of habitat selection (i.e., selection of habitat within home range; Johnson 1980). I conducted RSFs with individual bird identify as a random effect with the package lme4 (Northrup et al. 2013, Gillies 2006, Bates et al. 2015). The study area was the entire reservation (Figure 1). Habitat selection analyses focused on habitat predictors available from HVR's extensive GIS coverage including LiDAR data.

To estimate a RSF (Manly et al. 2002), I used a 38 m buffer around each used location, and treated the available locations in the same fashion to compare used and available buffers. To do this, I generated 3 random points for every used location within each bird's MCP, rather than within a fixed kernel home range estimate, because MCPs may more accurately represent available area than fixed kernel methods (Gillies et al. 2006, Kauhala and Auttila 2009). To account for location error, I calculated the median error of retained ellipses (from LOAS, see above) to be 38 m and used that distance to buffer every relocation and random point (i.e., circle with a 38 m radius), and then extracted the predictor variables where they intersected the buffers and clipped the predictor variables using the gDifference function in RStudio, allowing me to retain the various GIS layers that made my predictor variables within each buffer. Relocation buffered points constituted "used" and random buffered points constituted "available" habitat.

Forest seral stage variables (Table 1) were derived from a GIS coverage that combines both Light Detection and Ranging (LiDAR; Hoopa Tribal Forestry 2014) and multispectral data into a single polygon coverage. I classified 7 seral stages from an

original 24 forest classification categories that I subsequently collapsed into: early seral with residual structure (RS), early seral with no structure/pole stand (PS), mature seral (MS), old growth (OG), stem exclusion (SX), Open (OP) and True Oak woodland (TOW). TOW was underrepresented in the used buffers, so I further collapsed that class into the OP seral.

For each used and available buffered point, I calculated the proportion of the buffer comprised of each strata and included these values as predictor variables. I also included predictors of remnant features: snag density and tall tree density, as large trees and snags are deemed to be important habitat components in other regions (Flemming et al. 1999, Savignac et al. 2000, Aubrey and Raley 2002). I identified snags in the LIDAR tree data using a combination of the LIDAR data with multispectral data (Hoopa Tribal Forestry 2014). The spectral data identified deadwood while the LiDAR data represented the heights to arrive at “dead wood above 10 meters and slender,” which I assumed were snags. I considered the number of LiDAR identified snags per 38 m buffer to be an index of snag density (SND). Residual tall trees were also detected by LiDAR, and any tree over 45 m in height was considered a tall tree (TT). As with snag density, tall trees within each buffer comprised the tall trees predictor variable. Proximity to habitat features may also influence the selection of habitat within a

birds home range, so I included distance to old growth (DOG, in m), based on the abundant evidence that pileated woodpeckers favor old growth. I included distance to creeks (DCR, in m) based on the fact that streamside habitats are protected from harvest and managed for old seral wildlife habitat zones on HVR, but were unclassified by LiDAR-based analysis (Hoopa Valley Tribal Council 2010). They tend to be of an older seral stage, but multispectral data failed to classify the unique deciduous component within creeks, so I included distance to creeks as a predictor variable. Distance variables were calculated from each point location (i.e., the center of each used and available buffer). I log transformed all seral stage and distance predictors to normalize the data. Finally, I included indices of the vertical vegetation structure profile based on the evidence and hypotheses that canopy cover and forest structure are important for foraging and flying pileated woodpeckers. Vertical vegetation density predictors were comprised of LiDAR data of vertical canopy density indices at various height increments. The data were created such that 8 LiDAR points per m<sup>2</sup> created a density of returns to describe surfaces or terrains (Hoopa Tribe 2014). Originally, there were 10 categories at consecutive canopy heights by increments of 8 starting at 1 m and ending at 72m. I collapsed those into 4 predictors to reduce the pool of predictor variables, and I chose them based on strata deemed relevant to pileated woodpeckers in this study area and to minimize correlations with the other habitat variables: 1-8, 8-24, 24-32 and 32-72 m.

Table 1. Description of 6 categories of forest seral stage on HVR used in habitat selection analysis.

Predictor	Seral	Detailed description of seral
OG	Old growth	Unharvested timber stands averaging 60-95% total canopy density across all stands. Includes multiple canopy layers with the majority of the density occurring from 24 to 48 m with 10% or more occurring at 40 m and above.
MS	Mature seral	Harvested and Unharvested timber stands with total canopy densities averaging 85-100% across all stands. Includes multiple canopy heights with majority of density occurring from 16 to 32 m with residual structure from 32 to 72 m. These stands often are the result of early timber harvest from the 1950's and early 60's where residual structure remain and resembles a mid to late successional forest
RS	Early seral with residual structure	Harvested timber stands averaging 20-95% canopy density across all stands. Sometimes includes multiple canopy layers from 1 to 72 m. Always includes at least 5% canopy density at 24 m and above.
SX	Stem exclusion	Harvested timber stands averaging 85-100% canopy density across all stands with the majority of canopy density occurring between 16 to 32 m. Harvests that occurred during the BIA era of management resulted in large swaths of clearcut stands that are now regenerating as young den stands lacking residual structure and these stands have no canopy density above 32 m.
PS	Early seral with no residual structure (pole stand)	Harvested timber stands averaging 20-95% canopy density across all stands with the majority of canopy density occurring between 8 to 24 m and lacking structure above 32 m.
OP	Open	Open areas of natural prairie, chaparral or disturbed areas impacted by fire or timber harvest with total canopy density < 40% and average density ranging from 2 to 29% with the majority of canopy density occurring between 8 to 24 m.

Once I tabulated all potential predictor variables for each used and available buffer, I constructed a correlation matrix, and identified pairwise correlations with Pearson's  $r$ . If two or more predictors had a correlation coefficient exceeding 0.6, I did not use them in the same model, after Hebblewhite and Merrill (2008) who screened for collinearity using a 0.5 threshold value. That resulted in an extra model structure to prevent the amount of old growth within a buffer (OG) and distance to old growth (DOG) from appearing together in a model. Other correlated variables were the density of tall tree (TT) and OG. Therefore I made an additional model structure to include TT and SND. I also checked the variance inflation factor (VIF) for every model, using the rule of thumb threshold value of 10. Models with a  $VIF \geq 10$  were removed from the model structure.

With 14 predictor variables that could reasonably be hypothesized to co-occur in a model, I chose to use a tiered modeling process to reduce the number of candidate models. I structured four sets of *a priori* candidate models to examine pileated woodpecker foraging habitat selection starting with forest seral stage, followed by distances to key resources (DOG and DCR), then densities of remnant structures (SND and TT), and finally vertical vegetation densities at four strata (Table 2). For each model set, I evaluated top models using AICc due to a small sample size (Burnham et al. 2011). I then selected the top variable(s) for each tiered model set to assemble a final candidate set (while avoiding models containing correlated variables). I evaluated the top model in this final set following Boyce et al. (2002) and Johnson et al. (2006). Specifically, I calculated the predicted probability of use for each used and available location, then

divided these scores into 10 equal bins. I then calculated mean prediction probabilities for each bin as well as the proportion of used locations for each bin. I used the Pearson's correlation coefficient to evaluate the relationship between the predicted probabilities and the proportion of used locations, with a strongly predictive model yielding a coefficient near one and a poor model having a coefficient closer to zero. Linear regression was used to find if the slope of the resulting line was significantly different from zero and to yield the  $R^2$  value (Johnson et al. 2006).

Table 2. Tiered approach to model selection. Leading models from four candidate models sets (A-D) were then combined into a final model set (see Table 8 in Results) while avoiding combinations of variables that were strongly correlated.

A. Seral stage	B. Key resources	C. Remnant structures	D. Vegetation density in vertical strata
pres ~ SX + OG + RS + PS + MS + OP	pres ~ DCR + DOG	pres ~ SND + TT	pres ~ 1to8 + 8to24 + 24to32 + 32to72
pres ~ SX + OG + RS + PS + MS	pres ~ DCR	pres ~ SND	pres ~ 1to8 + 32to72
pres ~ SX + OG + RS	pres ~ DOG	pres ~ TT	pres ~ 1to8
pres ~ SX + OG + MS	pres ~ 1	pres ~ 1	pres ~ 1
pres ~ SX + MS			
pres ~ SX + RS			
pres ~ SX + OG			
pres ~ OG+MS			
pres ~ OG			
pres ~ SX			
pres ~ 1			

## RESULTS

Between 2012 and 2014, I made a total of 73 capture attempts of pileated woodpeckers, and successfully captured 11 individuals (15% capture success; Table 3; capture and tagging under HSU IACUC No. 11/12.W.44-A). I excluded data from two woodpeckers from further analysis, as one died a little over a month after capture, and one transmitter failed shortly after deployment. I used the data from nine woodpeckers (7 males, 2 females) for a total of 426 relocation points. I also admitted the relocation data of one woodpecker from a pilot study in 2009 (IACUC No [number pending retrieval from CNRS]).

Table 3. Successful and unsuccessful attempts to catch pileated woodpeckers per year.

Year	Success	Fail	Total
2012	4	22	26
2013	5	20	25
2014	2	20	22
Total	11	62	73



I found the size of Minimum Convex Polygons 131-325 ha mean  $\pm$  1 SE:  $210 \pm 20.3$ ); and Kernel Density Estimates (132-413 ha;  $244 \pm 29.3$ ) to be similar, but MCPs were slightly smaller (see Appendix A for two examples). The number of relocation points per woodpecker ranged from 23 to 100 ( $47 \pm 8.7$ ; Appendix B). Relocation points occurred throughout the year, (mean locations/bird =  $39 \pm 3.6$ ) but were concentrated in warmer months, with 59% of all locations occurring between May and September (Appendix C). I randomly subsampled data sets for two woodpeckers with large number of relocations points by 50% and 35% yielding a total of 348 relocation points that were more evenly distributed among the analyzed 9 woodpeckers.

In the candidate model set examining forest seral stages, the best predictor of foraging site was the proportion of stem exclusion seral stage (SX) where the relative probability of pileated woodpecker presence decreased as stem exclusion increased in buffered used and available locations (Table 4). This variable occurred in the top four models, which were all within 2 AICc points and collectively bore 72% of the cumulative model weight. Used locations were negatively associated with this variable ( $\beta = -0.8632$  in the top model) and the 95% confidence intervals (CI = -1.719, -0.072) for the coefficient did not overlap zero (Figure 2, Appendix D). The amount of mature seral (MS), residual structure (RS) and old growth (OG) in buffered locations each also occurred once in the top four models. RS had a positive coefficient ( $\beta = 0.087$ ), but the 95% confidence intervals overlapped zero (CI = -0.585, 0.736). OG had a positive coefficient ( $\beta = 0.0435$ ) with 95% confidence intervals that overlapped zero (CI = -0.415,

0503). MS had a negative coefficient ( $\beta = -0.11466$ ), with 95% confidence intervals that overlapped zero (CI = -0.766, 0.515).

The most parsimonious model examining distances to creeks and distance to old growth included the single predictor distance to creeks with a negative coefficient ( $\beta = -0.097367$ ) although confidence intervals overlapped zero (Table 5, Appendix E, CI = -0.213, 0.018). The null model was ranked second by AICc, and a model containing both distance to creeks and distance to old growth was third and still within 2 AICc points of the top model, suggesting relatively little resolution of these variables.

The null model ranked on top in the models examining remnant structure (Table 6). However, models containing each remnant feature predictor alone, snag density and tall tree density, were also competitive, with a positive coefficient for snag density ( $\beta=0.036$ ) with 95% confidence interval that overlapped zero (CI = -0.053, 0.121) a negative coefficient for tall trees ( $\beta = -0.004$ ), and 95% confidence intervals that overlapped zero (CI = -0.017, 0.008).

Table 4. Resource selection function models of used and available buffered telemetry locations for 9 pileated woodpeckers in the Hoopa Valley Reservation, ranked by AICc and examining the influence of 6 forest seral stages: residual structure (RS), early seral with no structure/pole stand (PS), mature seral (MS), old growth (OG), stem exclusion (SX), and Open (OP). I also ran a null model (pres ~ 1) containing only a constant and a parameter for the random effect (bird ID).

Model <sup>a</sup>	K <sup>b</sup>	Log(L) <sup>c</sup>	AICc <sup>d</sup>	$\Delta$ AICc <sup>e</sup>	W <sup>f</sup>
pres ~ SX	3	-780.47	1567.00	0.00	0.34
pres ~ SX + MS	4	-780.41	1568.80	1.89	0.13
pres ~ SX + RS	4	-780.44	1568.90	1.95	0.13
pres ~ SX + OG	4	-780.45	1568.90	1.98	0.13
pres ~ 1	2	-782.77	1569.50	2.60	0.09
pres ~ OG	3	-782.36	1570.70	3.78	0.05
pres ~ SX + OG + RS	5	-780.39	1570.80	3.87	0.05
pres ~ SX + OG + MS	5	-780.40	1570.90	3.90	0.05
pres ~ OG+MS	4	-782.36	1572.70	5.79	0.02
pres ~ SX + OG + RS +PS + MS	7	-780.08	1574.20	7.29	0.01
pres ~ SX + OG + RS +PS + MS +OP	8	-779.22	1574.60	7.60	0.01

Figure 2. The modeled relative probability of woodpecker use (*pres*) of sample units (38m habitat buffers) sharply decreased as the proportion of stem exclusion (SX) forest seral stage increased in the buffers. Relative probability of use slightly increased as old growth

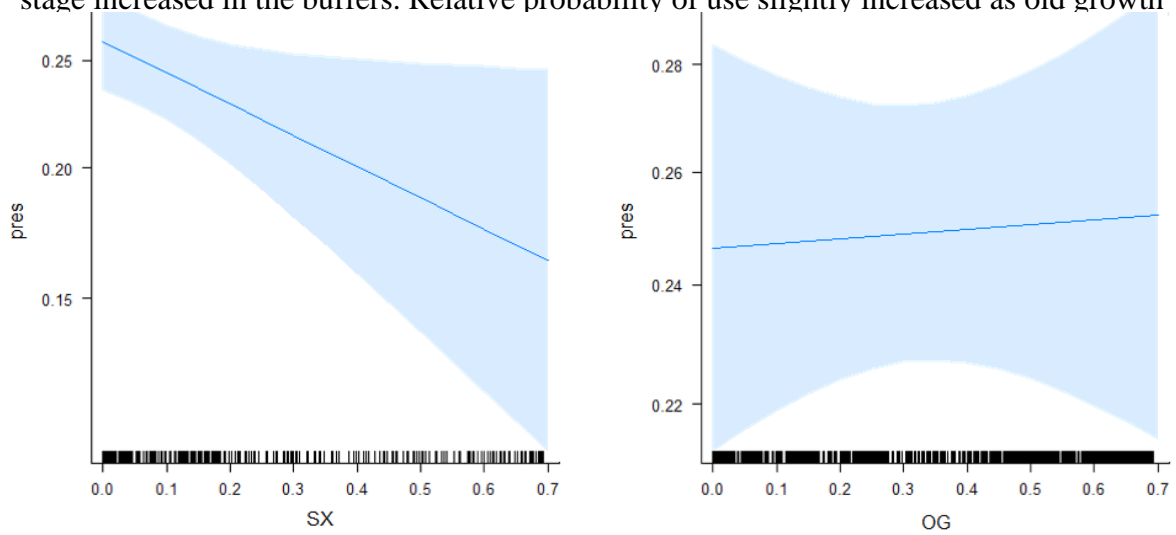


Table 5. Resource selection function models of used and random buffered telemetry locations for 9 pileated woodpeckers in the Hoopa Valley Reservation, ranked by AIC<sub>c</sub> and examining the influence of distance to creek (DCR) and distance to old growth seral stage (DOG). I also ran a null model (pres ~ 1) containing only a constant and a parameter for the random effect (bird ID).

Model <sup>a</sup>	K <sup>b</sup>	Log(L) <sup>c</sup>	AIC <sub>c</sub> <sup>d</sup>	ΔAIC <sub>c</sub> <sup>e</sup>	W <sup>f</sup>
pres ~ DCR	3	-781.39	1568.80	0.00	0.43
pres ~ 1	2	-782.77	1569.50	0.75	0.30
pres ~ DCR + DOG	4	-781.39	1570.80	2.00	0.16
pres ~ DOG	3	-782.75	1571.50	2.71	0.11

<sup>a</sup>DCR = Distance to Creeks. DOG = Distance to old growth.

<sup>b</sup>Number of parameters

<sup>c</sup>Log<sub>e</sub>(likelihood)

<sup>d</sup>Akaike's Information Criterion corrected for small sample size

<sup>e</sup>Difference between AIC<sub>c</sub> and top model AIC<sub>c</sub>

<sup>f</sup>AIC<sub>c</sub> weight

Table 6. Resource selection function models of used and random buffered telemetry locations for 9 pileated woodpeckers in the Hoopa Valley Reservation, ranked by AIC<sub>c</sub> and examining the influence of residual structures, namely the density of snags (SND) and tall trees (TT). I also ran a null model (pres ~ 1) containing only a constant and a parameter for the random effect (bird ID).

Model <sup>a</sup>	K <sup>b</sup>	Log(L) <sup>c</sup>	AIC <sub>c</sub> <sup>d</sup>	ΔAIC <sub>c</sub> <sup>e</sup>	W <sup>f</sup>
pres ~ 1	2	-782.77	1569.50	0.00	0.46
pres ~ SND	3	-782.45	1570.90	1.37	0.23
pres ~ TT	3	-782.55	1571.10	1.57	0.21
pres ~ SND + TT	4	-782.30	1572.60	3.09	0.10

<sup>a</sup>SND = Snag density. TT = tall trees.

<sup>b</sup>Number of parameters

<sup>c</sup>Log<sub>e</sub>(likelihood)

<sup>d</sup>Akaike's Information Criterion corrected for small sample size

<sup>e</sup>Difference between AIC<sub>c</sub> and top model AIC<sub>c</sub>

<sup>f</sup>AIC<sub>c</sub> weight

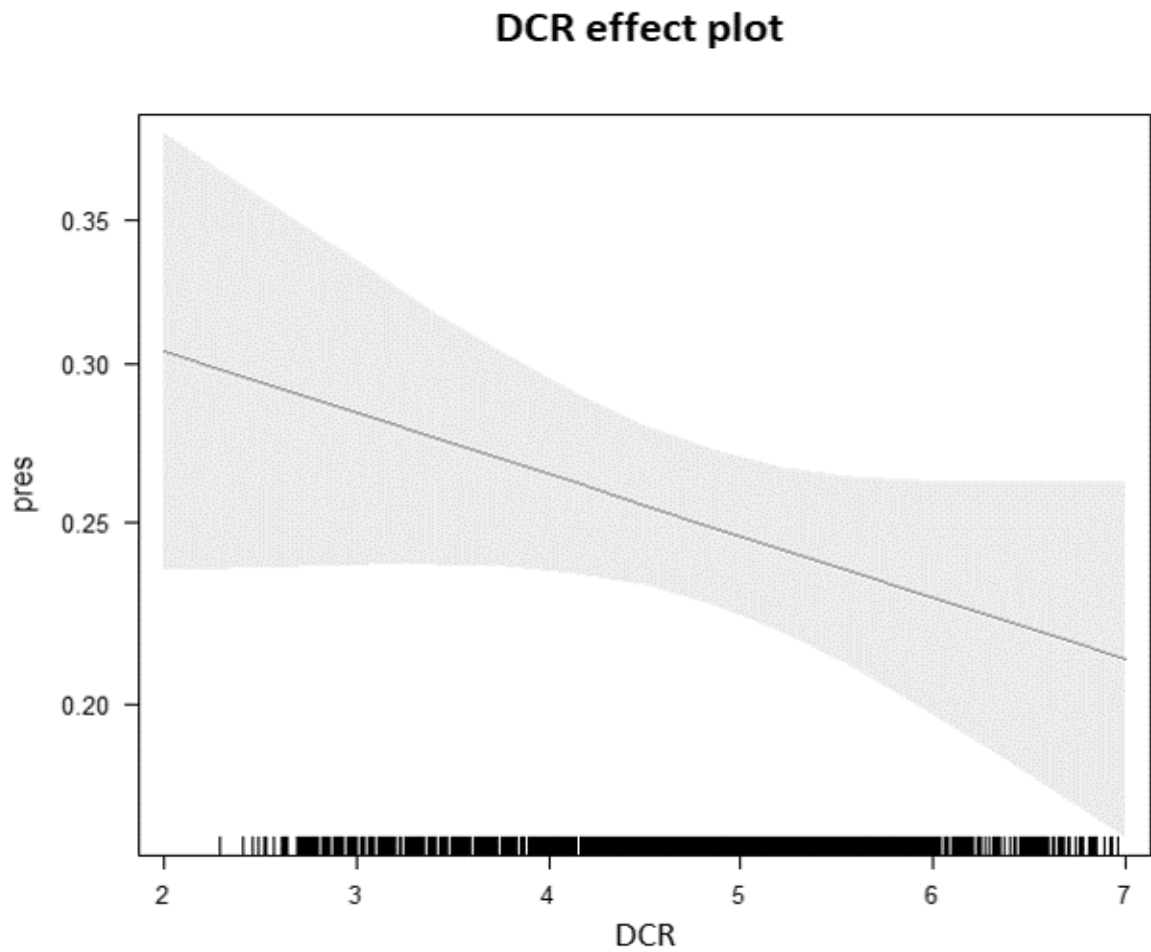


Figure 3 . Woodpeckers showed a slight selection for nearer proximity to creeks when distance to creeks (DCR) was modelled individually. The relative probability of use (pres) of sample units (38 m habitat buffers) decreased as their distance to creeks increased (DCR).

The most parsimonious model examining vertical vegetation profile densities included densities at the 1-8 m and 32-72 m layers (Table 7), both with positive effects (Figure 4); the coefficient for 1-8 m ( $\beta = 0.007$ ) was positive and 95% confidence intervals did not overlap zero (CI = 0.002, 0.013), but that for 32-72 m ( $\beta = 0.004$ ) did (CI = -0.001, 0.010; Appendix F). However, the next model was very competitive, with a model containing only vegetation density at 1-8 m that was barely distinguishable ( $\Delta\text{AIC}=0.14$ ) from the top model; together these two models bore 71% percent of the overall weight.

After pulling top and competitive variables from the previous tiers of modeling, there were 13 models in the final set of models. Of those, the top five models were within 2 AICc and collectively contained 81% of total weight for the model set (Table 8). These top five models included the vertical vegetation density variables 1-8 m and 32-72 m, the amount of stem exclusion and old growth seral stage, distance to creeks, distance to old growth, and snag density. The single top model only included vertical vegetation density 1-8 m and 32-72 m and distance to creeks, and these three variables occurred in all five top models. The effect of distance to creek was negative and the confidence interval did not overlap zero (Table 9). The effect of vegetation density 1-8 m and 32-72 m were both positive, and their confidence intervals did not overlap zero and slightly overlapped zero, respectively (Table 9). Using the “bin-method” to assess model fit (see Methods), the fit of the top model was relatively strong, with a significantly positive correlation between the proportion of sample units that were used and the mean predicted probability of use



among 10 bins of sample units, and the confidence interval for the slope included 1.0 ( $F = 11.99$ ,  $R^2 = 0.60$ ,  $P = 0.006$ , slope = 0.957; Figure 5, Table 7)

Table 7. Reporting of the values for  $R^2$ , Adj  $R^2$ , AICc, residual SE and overall F of the bin method” of RSF model evaluation, showing that the top 5 models were a good fit to the data.

Model	$R^2$	Adj $R^2$	AICc	Residual SE	Overall F
pres~DCR+1to8+32to72	0.60	0.55	-28.09	0.04	11.99
pres~DCR+1to8+32to72+SX	0.48	0.41	-26.12	0.04	7.32
pres~DCR+SNDD+1to8+32to72	0.41	0.33	-24.61	0.05	5.50
pres~DCR+1to8+32to72+OG	0.64	0.59	-32.79	0.03	14.12
pres~DCR+1to8+32to72+DOG	0.60	0.55	-31.68	0.03	11.79

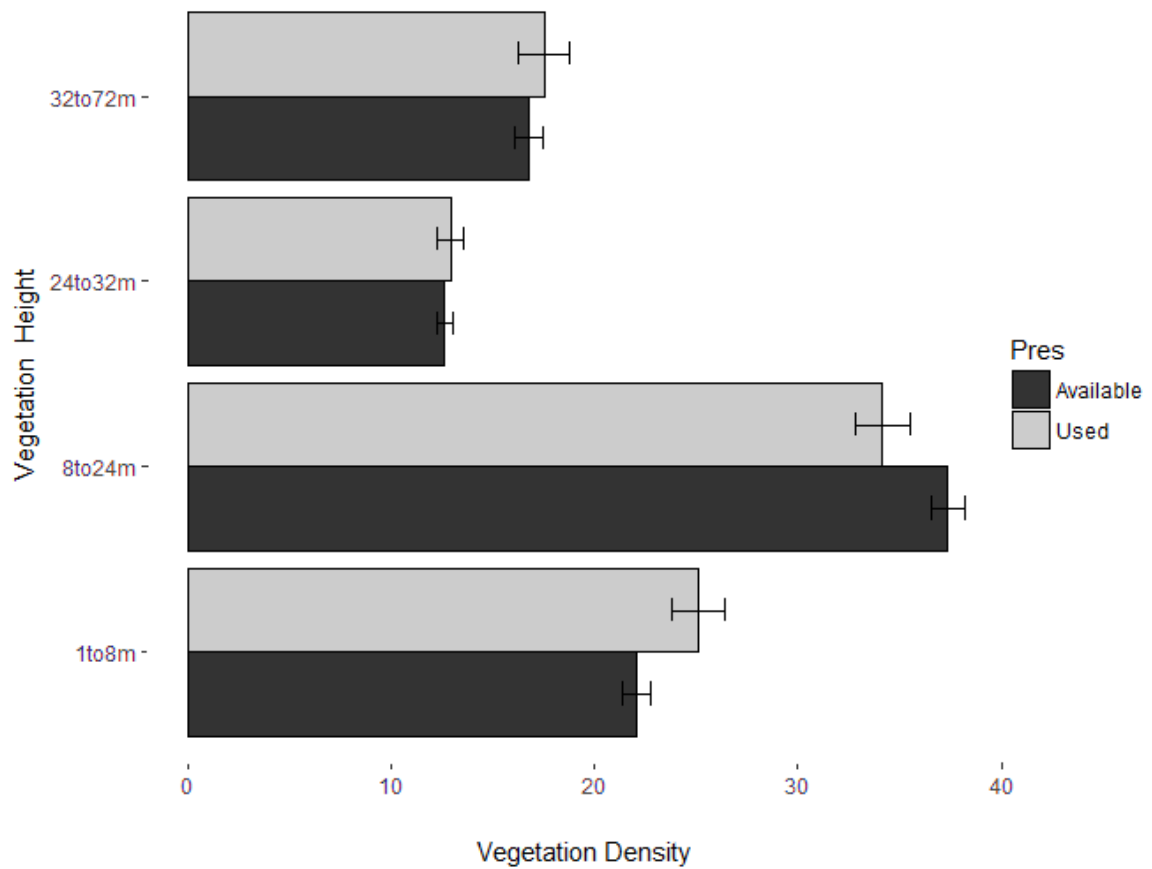


Figure 4. Mean ( $\pm 1$  SE) index of vegetation density at used and available locations as revealed by LiDAR at various vegetation heights and indicative of developmental stages of a managed forest. 1-8 m represents the ground level and 32-72 m represents the uppermost canopy.

Table 8. Resource selection function models of used and random buffered telemetry locations for 9 pileated woodpeckers in the Hoopa Valley Reservation, ranked by AICc and examining the influence of LiDAR estimated of vegetation density in four vertical profile categories, 1-8 m, 8-24 m, 24-32 m, and 32-72 m. I also ran a null model (pres ~ 1) containing only a constant and a parameter for the random effect (bird ID).

Model <sup>a</sup>	K <sup>b</sup>	Log(L) <sup>c</sup>	AICc <sup>d</sup>	ΔAICc <sup>e</sup>	W <sup>f</sup>
pres ~ 1to8 + 32to72	4	-779.49	1567.00	0.00	0.37
pres ~ 1to8	3	-780.57	1567.10	0.14	0.34
pres ~ 1to8 + 8to24 + 24to32 + 32to72	6	-778.11	1568.30	1.28	0.19
pres ~ 1	2	-782.77	1569.50	2.54	0.10

<sup>a</sup>1to8 = Vegetation density at 1-8 m. 32to72 = vegetation density at 32-72 m. 8to24 = vegetation density at 8-24 m.

<sup>b</sup>Number of parameters

<sup>c</sup>Log<sub>e</sub>(likelihood)

<sup>d</sup>Akaike's Information Criterion corrected for small sample size

<sup>e</sup>Difference between AIC<sub>c</sub> and top model AIC<sub>c</sub>

<sup>f</sup>AIC<sub>c</sub> weight

Table 9. Models Ranked by AICc examining variables from the most parsimonious models of all subsequent models for 9 pileated woodpeckers on the Hoopa Valley Reservation. All models included a random effect for pileated woodpecker ID.

Model	K <sup>a</sup>	Log(L) <sup>b</sup>	AICc <sup>c</sup>	ΔAICc <sup>d</sup>	W <sup>e</sup>
pres ~ DCR + 1to8 + 32to72	5	-776.74	1563.50	0.00	0.25
pres ~ DCR + SX + 1to8 + 32to72	6	-775.81	1563.70	0.17	0.23
pres ~ DCR + 1to8 + 32to72 + SND	6	-776.27	1564.60	1.07	0.15
pres ~ DCR + OG + 1to8 + 32to72	6	-776.62	1565.30	1.78	0.10
pres ~ DCR + SX + 1to8 + 32to72 + DOG	7	-775.74	1565.60	2.05	0.09
pres ~ 1to8 + 32to72 + SND	5	-779.29	1568.60	5.11	0.02
pres ~ 1	2	-782.77	1569.50	6.03	0.01
pres ~ DCR + SND	4	-780.77	1569.60	6.05	0.01
pres ~ DCR + MS + OG + SX	6	-778.89	1569.80	6.32	0.01
pres ~ MS + OG + SX + 1to8 + 32to72	7	-778.39	1570.90	7.35	0.01
pres ~ DCR + MS + OG + SX + SND	7	-778.43	1570.90	7.41	0.01
pres ~ MS + OG + SX + SND	6	-780.16	1572.40	8.86	0.00

<sup>a</sup>Number of parameters

<sup>b</sup>Log<sub>e</sub>(likelihood)

<sup>c</sup>Akaike's Information Criterion corrected for small sample size

<sup>d</sup>Difference between AIC<sub>c</sub> and top model AIC<sub>c</sub> <sup>a</sup>Number of parameters

<sup>b</sup>Log<sub>e</sub>(likelihood)

<sup>c</sup>Akaike's Information Criterion corrected for small sample size

<sup>d</sup>Difference between AIC<sub>c</sub> and top model AIC<sub>c</sub>

<sup>e</sup>AIC<sub>c</sub> weight

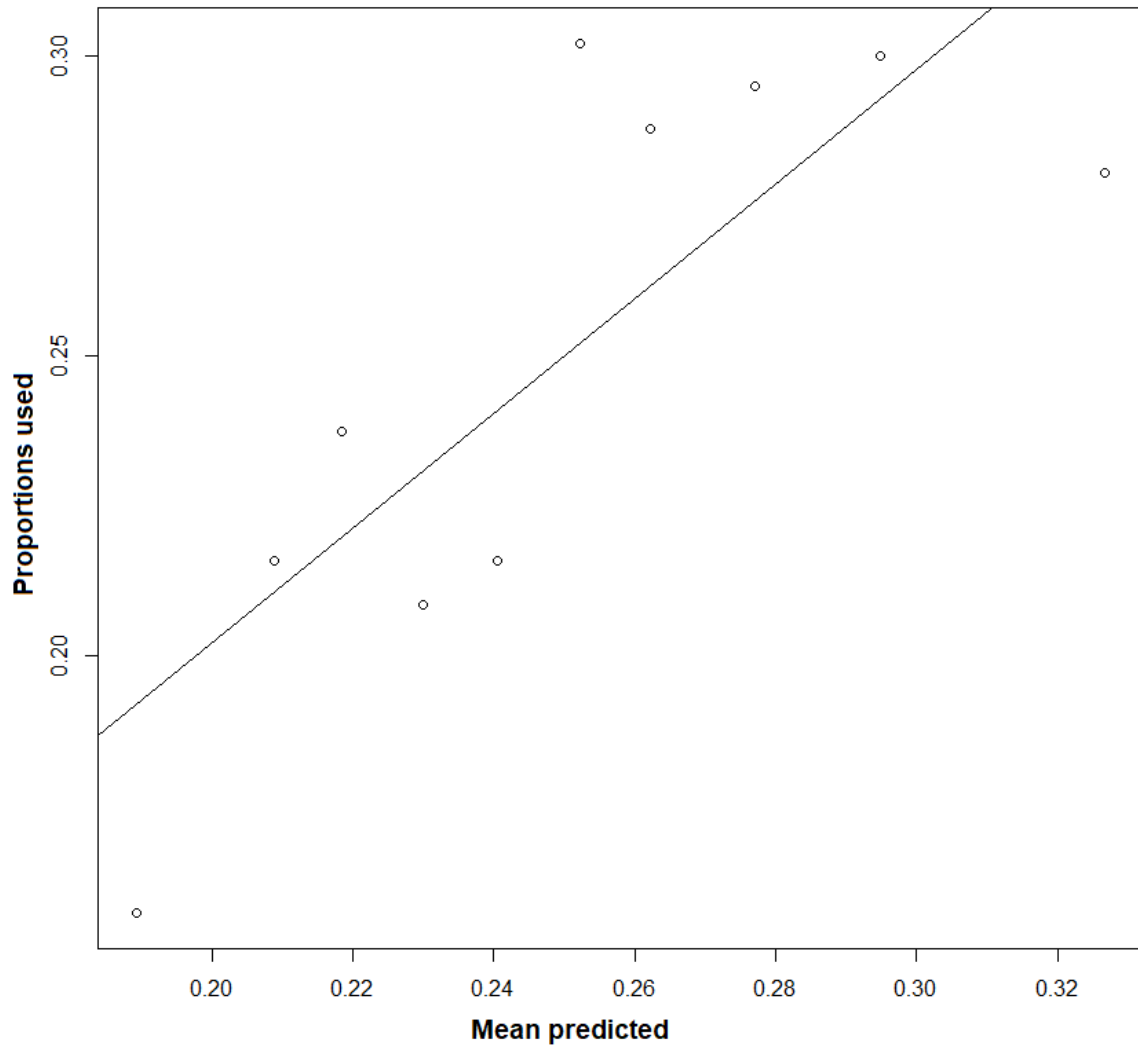


Figure 5. The results of a linear regression comparing of the proportion of used sample units values and the mean of predicted values within 10 bins of sample units.

Table 10. Coefficients, standard errors and confidence intervals from the top model of the model structure comprised of the most parsimonious predictors of all preceding model sets. Bolded font indicates coefficients whose 95% confidence intervals did not overlap zero.

<b>pres~DCR+1to8+32to72</b>				
Covariate <sup>a</sup>	Coefficient	SE	95% CI LL	95% CC UL
<b>Intercept</b>	<b>-0.702</b>	<b>0.295</b>	<b>-1.285</b>	<b>-0.127</b>
<b>DCR</b>	<b>-0.144</b>	<b>0.061</b>	<b>-0.263</b>	<b>-0.024</b>
<b>1to8m</b>	<b>0.009</b>	<b>0.003</b>	<b>0.001</b>	<b>0.013</b>
32to72m	0.005	0.003	-0.001	0.011

<sup>a</sup>DCR = Euclidean distance to creeks, 1to8 = vegetation density vertical from 1 to 8 meters, 32to72 = vegetation density vertical from 32 to 72 m. Bolded rows signify confidence intervals not overlapping zero.

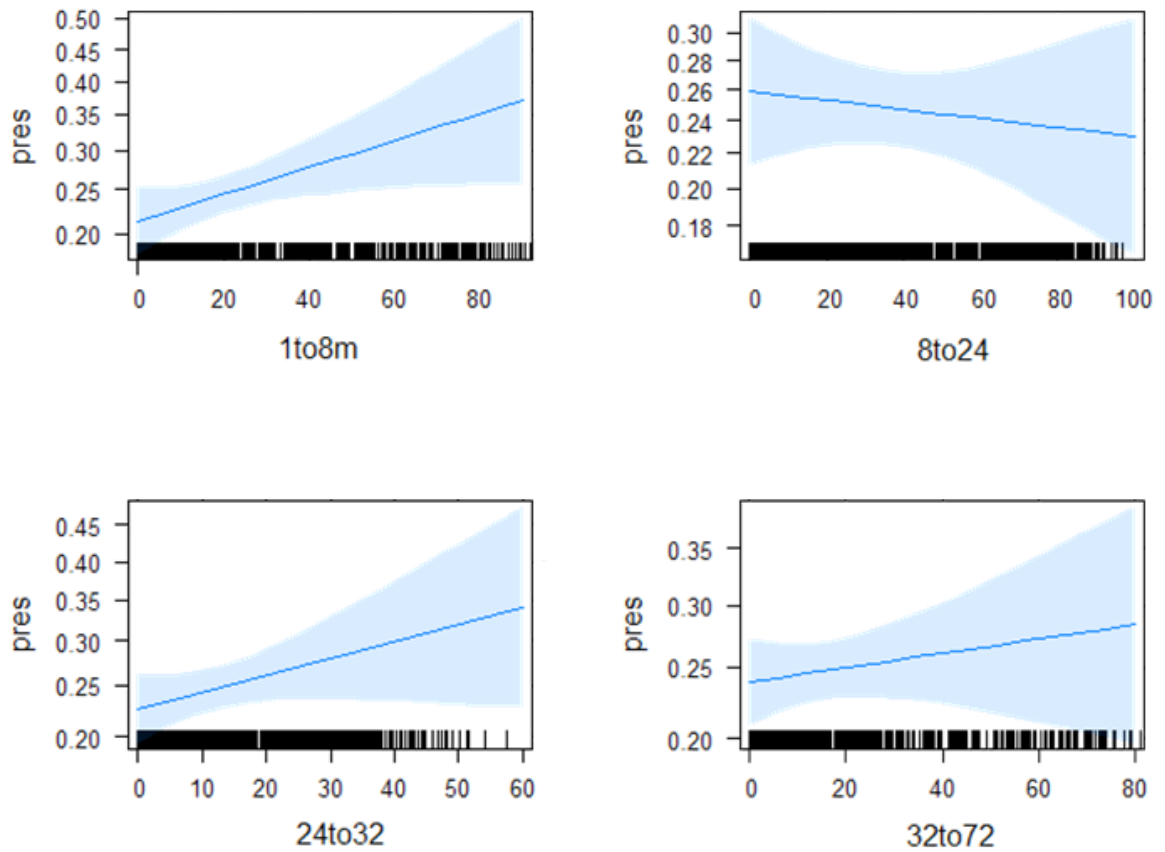


Figure 6. Relative probability of use (pres) of sample units (38 m habitat buffers) increased as the vegetation density at 1-8, 24-32 and 32-72 m increased in the buffers. Relative probability of use decreased as vegetation at 8-24 m increased in the buffers.

## DISCUSSION

Foraging theory, previous analyses of pileated woodpecker habitat selection, and the unique history and habitat heterogeneity on the HVR led me to hypothesize that seral stage, structure, and remnant features would strongly predict pileated woodpecker foraging habitat selection on the reservation. In particular, based on the birds' documented affinity for old-growth characteristics (Mellen et al. 1992, Bull and Holthausen 1993, McClelland and McClelland 1999, Bull et al. 2011), snags (Bull and Holthausen 1993, Bull et al. 2007), and open sub-canopies for ease of flight movement for slow flying crow-sized bird (Bull et al. 2011, Raley and Aubry 2006), I expected to see that telemetry points, representing foraging events, would be positively associated with the amount of old-growth habitat, the density of tall trees, and tall canopy cover, whereas used sites were nearer old-growth habitat and had less cover at intermediate canopy heights. I found some support for these expectations, although other factors proved at least as important, especially a negative association with distance to creeks and the amount of stem exclusion seral stage.

Selection for old growth habitat by foraging pileated woodpeckers in my study area was present, but not as strong as expected based on previous research. Used locations were positively associated with amount of old-growth habitat, and negatively associated with distance to old growth (Table 5, Figure 2). These appeared in the fourth and fifth most competitive models overall (Table 6), but confidence intervals for the coefficients for both parameters overlapped zero, suggesting only modest strength of



evidence. Since habitat characteristics associated with old growth forests that have proven to be important for pileated woodpeckers in other regions are represented by large trees in height and girth, in other areas those features may be more important than in my study area because the Douglas fir trees that predominate within the HVR are naturally large, even at younger forest stages. Correspondingly, canopy is naturally dense as well. Bonar (2001) and Mellen et al. (1992) reported a weak selection for the old growth age class. Most of the forest at Hoopa is represented by canopy cover >60%. Perhaps the lack of strong selection of the old growth habitat in my study indicates an abundance of resources for pileated woodpeckers on HVR. McClelland (1979) believed that the minimum amount of forest required to support pileated woodpeckers depends partly on food availability. Interestingly, I also found that home range size for the birds I monitored (MCPs ranged from 131-325 ha), was smaller than reported by other studies, which is consistent with the notion that HVR may provide comparatively high quality habitat. For example, previously reported home range sizes were 407 ha in Eastern Oregon, 478 ha in western Oregon, 863 ha in Western Washington (Bull and Jackson 1995), which were all considerably larger than the home ranges in my study (mean of 210 ha). Lemaître and Villard (2005) reported the mean home range size in published studies to be 360 ha.

Likewise, pileated woodpeckers showed modest selection for snags in my study. Snag density appeared in the third most parsimonious model, but confidence intervals overlapped zero (Table 5;  $\beta=0.045$ , CI = -0.047, 0.134). Yet, the confidence interval around modeled probability of use dramatically widened above 5 snags per 38 m radius buffer. Ten is the maximum number of snags in the 38m buffer I recorded, and there were

relatively few buffers with >5 snags. Perhaps a higher density of snags in my study area would have yielded stronger statistical relationships. Raley and Aubry (2006) noted foraging sites with a greater density of large snags, considering both diameter and height. Savignac (2000), however, demonstrated selection for small and large snags. Because woodpeckers in their study area did not exploit downed wood, indicating inconsistency with other studies (Bull and Holthausen 1993), they assumed an abundance of snags provided enough foraging to circumvent reliance upon that resource. Shroeder (1983) Maximum suitability for pileated woodpeckers across their range can be met when 0.17 or more large snags occur per 0.4 ha. Extrapolating 4-5 snags per 38m plot to ha, it seems that an abundance of snags would cause that resource to not be strongly selected in my study.

On HVR, forest canopies can be very tall (30+ m), and pileated woodpeckers showed positive selection (Table 8, Figure 6) for the areas with high indices of vegetation density in the tallest categories (32-72m). The tallest trees on HVR are approximately that height. According to the most recent continuous forest inventory data collected on the HVR(Hoopa Tribal Forestry, unpublished data), trees at 69 m are within the 100<sup>th</sup> percentile for height. According to Bull (1987), ideal habitat for pileated woodpeckers in eastern Oregon included two canopy heights with the uppermost located at 30 m. Upper canopy in that forest would be the midstory canopy at Hoopa. This variable occurred in all of the top five models, and confidence intervals did not overlap zero in all but one model. Dense vegetation in mid-range heights and subcanopies can inhibit flying movements for relatively large-winged forest species (Aubry and Raley 2002a, Bull et al.

2011), My results are largely consistent with this expectation, as these mid-range strata did not appear in any of the top models, and there was a weak negative association of used locations with vegetation density in the 8-24 m layer (Figure 6). Density of the canopy at the 32-72 m level represents both mid-story and upper canopy levels. Mid-story at that height would be tall tanoak and madrone trees. The upper-story would be composed mostly of Douglas fir. Canopy at this level could provide protection from aerial predators, most notably red-tailed hawks, accipiters (*Accipitridae* spp.), and barred owls (Bonar 2001, Weins et al. 2013).

However, my results also showed a strong positive association of used locations with vegetation density in the 1 to 8 m layer, which was an unexpected result. Confidence intervals for this predictor did not overlap zero in any of the top five models. Densities at 1-8 m represent the vegetation present at the ground and shrub or young tree levels. Typically high density of ground level vegetation is characterized by huckleberry thickets beneath other canopies. Alternate examples of dense, ground level canopy are in open, recently cut-over stands where *Ceanothus* spp. dominates the brushy ground cover. Under the Tribe's current forest management regime (Hoopa Valley Tribal Council 1994), residual structure is left on the landscape, so these seral stages may be recently cut (~15 years), and residual trees within them are used for foraging, occasionally even nesting by pileated woodpeckers (personal observation). Flemming et al. (1999) found that ground cover did not affect the probability of woodpeckers foraging low, which was the foraging mode most frequently observed in recording foraging height on tree boles. Newell (2009) pileated woodpeckers foraging within 3 m of the ground 16%, not

including use of downed woody debris. Ground predators reported for pileated woodpeckers are gray fox (*Urocyon cinereoargenteus* (martens) and weasels (*Mustela spp.*) squirrels (*Sciurus spp.*), pacific fisher (*Pekania pennanti*) (Bull and Jackson 2011). Many species of mesocarnivores overlap woodpecker home ranges on the HVR, especially pacific fisher (Rennie 2015), and the two species occasionally use the same trees. There is photo documentation (Hoopa Tribal Forestry 2007, Appendix G) of a fisher snapping at a pileated woodpecker from the fisher's den cavity that had been engineered by a pileated woodpecker, as the woodpecker foraged on the same tree (Aubry and Raley 2002b). Also, black bears (*Ursus americanus*) have been identified as potential predators of pileated woodpeckers fledglings and eggs (Conner 1977, Tozer et al. 2009). The density of bears is higher in Hoopa than reported anywhere else in the country (Mathews 2008).

The variable that most strongly predicted foraging habitat selection for pileated woodpeckers in my study was distance to creeks, which was present in all five of the top models (Table 5) and showed a strong selection for nearer proximity to creeks. (Figure 3). Pileated woodpeckers are known to drink water before roosting, and have been observed to eat snow (Hendricks 1996, Bull and Jackson 2011), suggesting woodpeckers could respond to a scarcity of water. Pileated woodpeckers also have been known to nest nearer to water, so they could be selecting for water itself (Conner 1975). The big woods bottomlands of eastern Arkansas harbor high densities of woodpeckers, and the productivity there is attributed to old growth hardwoods and possibly water stress to the trees, ultimately promoting decay and cavity development (Krementz 2010). High water

during the winter months may also apply stress to deciduous trees along creek corridors. While these direct associations with water could be operating in my study, it is also possible that the apparent effect of distance to creeks results from their riparian vegetation associated with creeks. At Hoopa, in connection with the patchy distribution of a managed landscape, creeks are characterized by contiguous swaths of late successional forest, as riparian corridors are in protected status. Within harvested stands, the majority of residual structure is held in the stream corridors. In addition, multispectral analysis failed to classify one important component of creeks, which is the deciduous substrate (pers. comm. Jimmy Campbell, Appendix H). At Hoopa, the deciduous riparian trees are primarily alders and maples, which grow and decay quickly (Fryer 2011, Fryer 2014), creating a suitable environment for carpenter ants. Erskine (2008) observed foraging evidence on several species of old, live maples, (*Acer* spp.) and confirmed the presence of wood boring insects. Also, other hardwoods located near streams may provide coarse woody debris for foraging, as fallen standing or intact dead wood can provide for arthropod habitat (Jia-bing et al. 2005, Torgersen and Bull 1995). Flemming et al. (1999) found that woodpeckers foraged more readily on deciduous substrates in a fragmented forest as compared to a more contiguous forest; Lemaître and Villard (2005) concurred that woodpeckers were highly selective of deciduous stands in a fragmented setting. Perhaps woodpeckers at Hoopa rely on the rapidly decaying deciduous substrate provided by the creeks in response to a patchy framework of the overall forest habitat given the succession of seral stages.

Pileated woodpeckers also showed strong avoidance of the stem exclusion seral stage (Figure 2). This is an interesting finding as it relates to past management. Mellen et al. (1992) observed that forest age classes <40 years old were avoided. Bonar (2001) attributed less use in young or open stands to a lack of foraging substrates. The stem exclusion seral stage has little to no canopy above 32 m. Also that seral is nearly entirely represented by large, intensive clearcuts typical of the BIA management of the HVR 40 to 80 years ago. That regime left very little residual structure on the landscape that might be used for foraging. Those stands were also often sprayed with herbicides to suppress other species of tree, such as tanoaks, from outcompeting merchantable timber. Therefore, stem exclusion stands can be stands of relatively large trees, but they often lack a dead or decadent element. The legacy of that management is still recognized in stands practically devoid of habitat not only for woodpeckers, but also insects, birds, deer and other denizens of a healthy forest. Interestingly, the foraging of black bears on Douglas fir trees appears to introduce some dead trees and improve habitat for woodpeckers in these otherwise homogenous stands (Mendia et al. in press).

Pileated woodpeckers (*Dryocopus pileatus*) are important to managed forests because they can function as “ecosystem engineers” (Sekercioglu 2006) in forested habitats. They excavate cavities in trees on a yearly basis that other animals use secondarily as nests and dens (McClelland 1979, Bull 1987, Aubry and Raley 2002). As the largest cavity excavator in western forests, the pileated woodpecker is vital to the provisioning cavities made available to other large species unable to enter the smaller cavities of other primary cavity excavators (Bonar 2000). For example, the Pacific fisher

(*Martes pennanti*), a species of special concern in California and a culturally important species to the Hupa, has been shown to use old pileated woodpecker cavities in northwestern California (J. M. Higley, Hoopa Valley Tribe, personal communication). Thus, the pileated woodpecker may function as a keystone species (Aubry and Raley 2002b) in western forests.

Pileated woodpeckers create at least one nest cavity and several roost cavities every year. Bull et al. (1992) reported that pileated woodpeckers used an average of 7 roost cavities per 10 months, so it is conceivable that that could be a low estimate. Therefore, providing adequate habitat for the nesting, roosting, and foraging of pileated woodpeckers in a managed forest is vital to ensuring recruitment of cavities for large secondary cavity nesters. Adequate habitat for roosting and nesting requires an abundance of trees that are large enough for cavities (Bull 1987, Hartwig 2004). Decadence of the individual tree is important because it requires less energy for excavating (Bull et al. 1992, Aubry and Raley 2002a). Habitat for nest and roost trees differ at times in the same study (Bull et al. 1992, Aubry and Raley 2002a). Bull et al. (1992) suggested that the roosts were in large diameter trees because increased girth allowed for pileated woodpeckers to enter and maneuver.

## Management Implications

My study shows that pileated woodpeckers favor areas near creeks, selecting for dense cover at the ground and upper canopy levels, avoiding the stem exclusion age classes indicative of pre-tribal management, and exhibiting some affinity for the old growth age class of the forest. Under Tribal management, the HVR is now on an 80 year rotation cycle. In addition to longer rotation, the forest includes stands permanently removed from harvest, and is harvested to maintain residual structure. That structure should continue to provide quality habitat for woodpeckers. Conner (1980) declared that rotation times of 80 years for eastern managed forests should be sufficient as long as suitable amounts of mature structure remain available. The FMP was last updated in 2008, and will undergo another revision in the next few years. I see no need to advocate substantial changes based on my study. However, my study does not explicitly examine the proximity or contagion of preferred habitat patches, and I would advocate further study to examine population dynamics, and forest patch isolation and size in relation to woodpecker usage, with respect to three components of habitat fragmentation, loss of the original habitat, reduction in habitat patch size, and increasing isolation of habitat patches. In addition, my study documented a very strong avoidance of stem exclusion seral stages, which are a direct legacy of old BIA forest management practices, and this suggests that active habitat improvements in those stands might improve foraging habitat for pileated woodpeckers.



Selection against greater distances from creeks may be an indication of the fragmented landscape, but that is not conclusive, as woodpeckers have long been known to use habitat nearer to open water (Hoyt 1957, Conner 1975). In addition, the current FMP calls for stream buffers applied to creeks at 61 m for class 1 streams, and 30.5 m for class 2 streams; those habitats are uncut, maintain high canopy cover, and contain deciduous hardwood substrates that are subject to water stress, and so provide decadent substrate to foraging woodpeckers.

Since woodpeckers avoided the stem exclusion age class, and showed only modest selection of the old growth age class, I conclude that current management does well in providing habitat for pileated woodpeckers. My habitat recommendations are to consider the recruitment of snags as the forest continues to change, and working to reintroduce fire to the landscape to promote snags. McClelland (1979) associated fire scars resulting from historic fire frequency to the presence of nests, offering that thick bark enabling nest trees to survive fire events and describing the close relationship that pileated woodpeckers have with these structures that are influenced by fire. Depending on intensity, fire affects fungus by destroying sound wood to provide infected substrates, or destroying fungus (Marcot 2017). Fire has been virtually absent as a management tool in the past 100 years and means for introducing heart rot fungus (sci name) may be limited for healthy trees. Shroeder (1980) proposed that pileated woodpeckers population levels could be managed at selected levels by killing trees to aggressively promote snags, or letting the natural process ensue. I recommend treating some stem exclusion stands to create canopy gaps in the forest by removing some trees, and scarring or removing tops

of some trees to promote inoculation of fungal spores (Bednarz et al. 2013) to encourage pileated woodpecker habitat.

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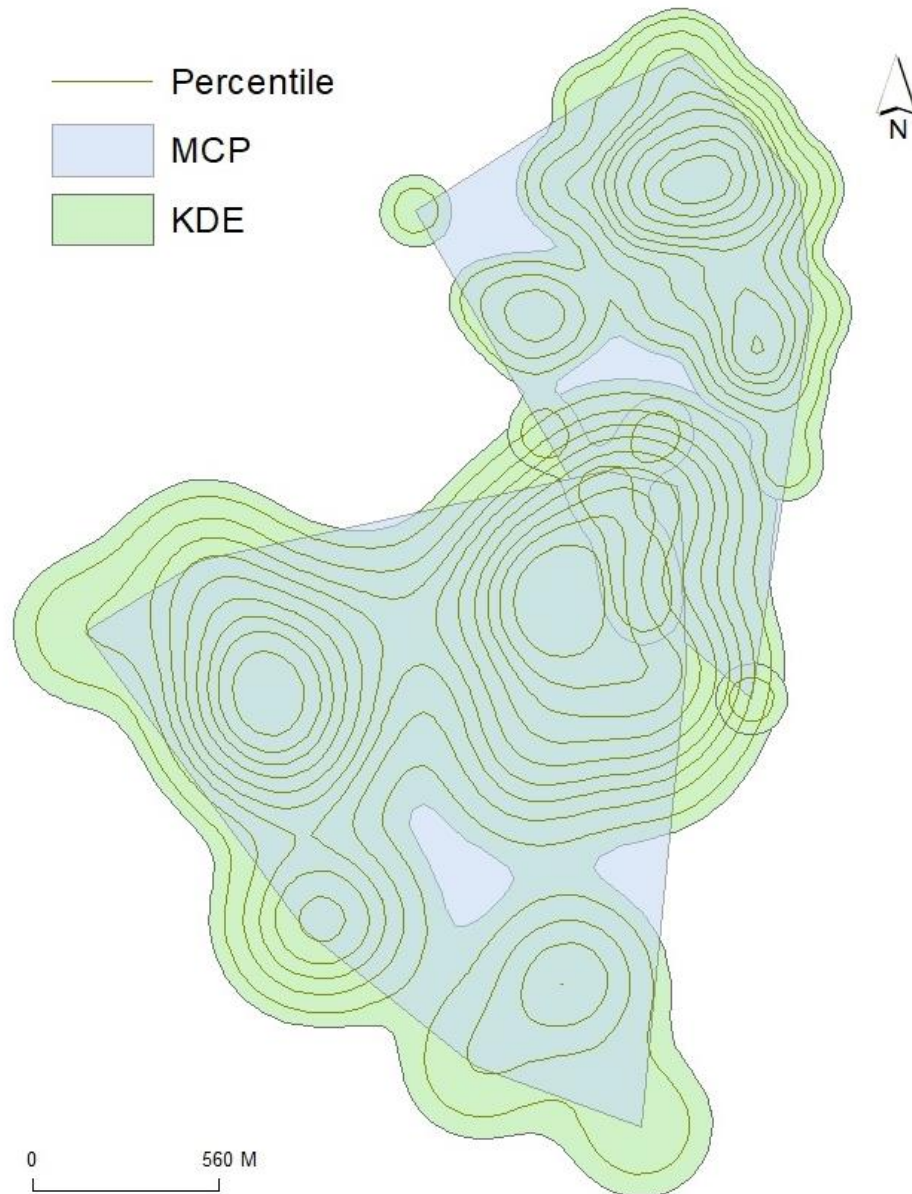


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## APPENDICES

APPENDIX A. Example of pileated woodpecker home ranges comparing minimum convex polygons and kernel density estimates

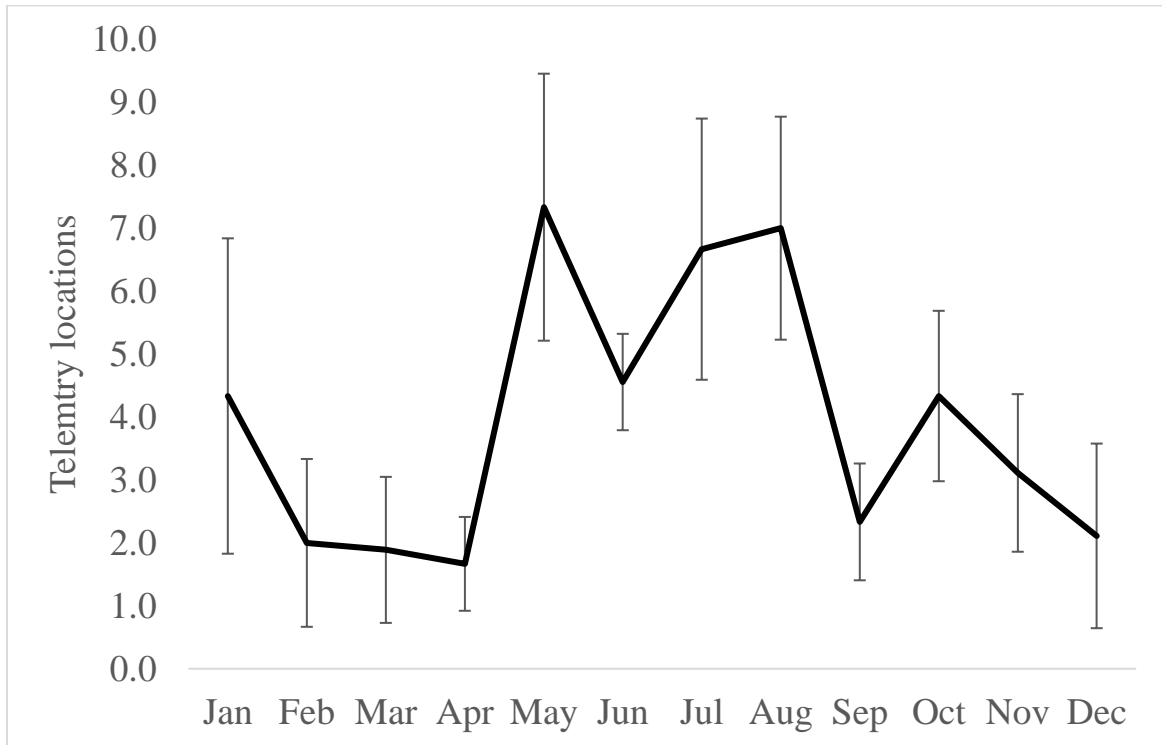


APPENDIX B. Pileated woodpeckers were tracked between 2012 and 2014, with the exception of one woodpecker included from a pilot study from 2009.

Short code <sup>a</sup>	N (relocations)	First tracked	Last tracked
MPW1001	23	5/1/2009	5/4/2010
FPW1002	27	4/29/2012	11/14/2013
MPW1003	45	5/1/2012	7/10/2013
MPW1004	36	5/3/2012	3/16/2013
MPW1005	28	5/16/2012	6/18/2013
MPW1006	100	3/16/2013	6/9/2014
MPW1009	80	8/7/2013	4/18/2014
MPW1010	39	5/15/2014	8/22/2014
FPW1011	48	5/15/2014	8/22/2014

<sup>a</sup>Shortcode = unique identifier for each animal. Females began with “F” and males with “P” and each follow in the same sequential order.

APPENDIX C. Distribution of radio telemetry locations of all tracked woodpeckers by month (mean number of locations  $\pm$  1 SE,  $n = 9$  birds used in habitat selection analyses).



APPENDIX D. Coefficients, standard errors and confidence intervals from the top logistic regression model of the model models assessing forest seral stages.

<b>pres~SX</b>				
Covariate <sup>a</sup>	Coefficient	SE	95% CILL	95% CC UL
<b>Intercept</b>	<b>-1.045</b>	<b>0.066</b>	<b>-1.176</b>	<b>-0.917</b>
<b>SX</b>	<b>-0.863</b>	<b>0.419</b>	<b>-1.719</b>	<b>-0.072</b>

<sup>a</sup>SX = stem exclusion forest age, when a closed canopy develops and the brushy understory dies back.

APPENDIX E. Coefficients, standard errors and confidence intervals from the top logistic regression model of the models assessing log-transformed distance to creeks and distance to old growth.

<b>pres~DCR</b>				
Covariate <sup>a</sup>	Coefficient	SE	95% CILL	95% CC UL
<b>Intercept</b>	<b>-0.632</b>	<b>0.286</b>	<b>-1.197</b>	<b>-0.075</b>
DCR	-0.098	0.059	-0.213	0.018

<sup>a</sup>DCR = distance to stream (log transformed).

APPENDIX F. Coefficients, standard errors and confidence intervals from the top logistic regression model assessing the predictors considered from the most parsimonious models of all preceding models.

<b>pres~1to8+32to72</b>				
Covariate <sup>a</sup>	Coefficient	SE	95% CI LL	95% CC UL
<b>Intercept</b>	<b>-1.342911</b>	<b>0.118873</b>	<b>-1.579225345</b>	<b>-1.11296832</b>
<b>1to8 m</b>	<b>0.007162</b>	<b>0.002841</b>	<b>0.001554832</b>	<b>0.01270458</b>
32to72 m	0.004408	0.002989	-0.001494626	0.01023226

<sup>a</sup> Vegetation density (based on LiDAR) at vertical canopy intervals.



APPENDIX G. Photo documentation of a pileated woodpecker landing on a tree with roost cavities occupied by a pacific fisher attending her den. The last photo of the series shows a photo of the fisher snapping at the woodpecker, causing him to flee.



Photo Credit: Rebecca Green.

APPENDIX G. Statement by Hoopa Tribal Forestry GIS specialist, Jimmy Campbell describing a peculiarity in the multispectral data.

In a conversation that I had with Jimmy Campbell, Hoopa Tribal Forestry's GIS specialist in April, 2018, he described a peculiarity of the multispectral data of riparian habitat that was not yet improved. He said there was a failure to classify riparian habitat, because the spectral signature of deciduous hardwoods along stream corridors was too similar to other hardwoods, such as madrones. Because of that, the riparian class appeared where it shouldn't: outside of the confinement of stream corridors.

APPENDIX H. Personal communication with J. Mark Higley regarding the den cavities used by female fishers provisioned by pileated woodpeckers.

In a conversation that I had with Mark Higley in 2012. He told me that 50% of the documented den cavities used by pacific fishers on HVR were excavated by pileated woodpeckers.

APPENDIX I. A poem written by D. Blake in the concluding process of thesis development.

**PIWO Ts'ehdiyah**

Your acknowledgement of me  
 Is sweet, whatever it may be.  
 When you break as laborer  
 To protect your ladylove  
 Treating me as predator,  
 I'm honored that you saw me  
 And am smitten with your protectiveness  
 Your call, distinct duress.  
 This, I imagine to be the reason,  
 Your magnificence  
 Not just pleasing,  
 Is headdress of our prayers

The many times you've spoken to me  
 Your great attendance near and far  
 Uncanny,  
 Not to be overlooked  
 Glowing Red and Ebony  
 With the light of the forest in your back ground,  
 A celestial contrast  
 Of quick departure  
 Yet steadfast  
 In nature

I've fought myself  
Not to call you mine.  
As you belong to a better time  
A period when we communicated  
As brothers  
When we fought together  
As overcomers  
Of evil and woes  
Our common foes  
You whisper this to my heart  
And I can see that you still concede  
To what was  
Anciently agreed  
Each time you grace me with your presence  
And humble me again  
Resplendent in your every essence  
I brazenly call you friend