SPECIES ACCOUNT FOR WILLIAMSON'S SAPSUCKER
HABITAT MODELS 2020

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This current project was completed by Les Gyug of Okanagan Wildlife Consulting and by Julien St-Amand as contractors to the Okanagan Nation Alliance with funding from the Habitat Conservation Trust Fund.

Common Name: Williamson's Sapsucker
Scientific Name: *Sphyrapicus thyroideus*
Provincial Species Code: B-WISA
American Ornithological Society 4-letter Code: WISA
Status: Provincial Listing: Blue (B.C. Conservation Data Centre 2018).
Global G5; Provincial S3B for species
COSEWIC Assessment: Endangered (2005, re-confirmed in 2017);
SARA: Schedule 1
Identified Wildlife under FRPA in B.C. as of 2004.

This account brings together three Williamson's Sapsucker (WISA) habitat modeling exercises at three different scales.

1. **Bioclimatic Envelopes:** Habitat selection at province-wide and breeding range-wide scales.

2. **Area of Occupancy Habitat Suitability:** model based on primarily on nest locations, breeding densities within census areas and relative abundance within the provincial Areas of Occupancy (AO). Habitat selection at the 500-1000 km^2 level (AO-size).

3. **Foraging Habitat** model based on telemetry data (St-Amand 2017). Selection within breeding territories (<1 km^2).

Projects 1 and 3 are new to this account. Project 2 was originally done 2009-2010 supported by FLNRORD and CWS, and updated in 2018 supported by FLNRORD.

The intent of this project was to identify potential WISA nest tree enhancement sites where foraging habitat may be suitable, but nest tree availability limiting.

TABLE OF CONTENTS

List of Figures 3
List of Tables 3
List of Equations 3
List of Acronyms 4
Rationale 5
Bioclimatic Envelopes 6
WISA Area of Occupancy habitat modeling 11
Ratings 13
Summary of 2008-2018 Nest Habitat Model 14
Foraging Habitat Model 17
Generalized Linear Mixed Models 17
Methods 17
Modeling 18
Evaluation 19
Multiple Regression Modeling 19
Data Preparation 19
Variable Selection 21
Regression 25
Application 27
Limitations 29
Verification 31
Combined Habitat Model 33
Rationale 33
Application 34
Results and Discussion 35
Potential Enhancement Sites 36
Habitat Capability 36
Data Products 37
References 38
Appendix 1. WISA Suitability Maps 39
Appendix 2. Sequential Application of Factors to Model Nesting Suitability 2018 41
Appendix 3. Re-analysis of 2006-2008 data used in habitat modeling of Drever et al. (2015) ... 48

List of Figures

Figure 1. WISA 95% Bioclimatic Envelope in B.C. based on WISA detections (n = 5449). Top: Southern B.C.; Bottom: WISA West and Okanagan-Boundary AOs as mapped in 2007. 7
Figure 2. Top: Lw distribution in B.C. Bottom: Py distribution in B.C. 8
Figure 3. 95% and 60% bioclimatic envelope kernels occupied by Williamson's Sapsucker over its entire breeding range compared to "available" defined as all of B.C. and all of the U.S. west of the 100th meridian. 9
Figure 4. WISA breeding range (Gyug et al 2012) showing overlap with eBird WISA detections (to 2014) and Breeding Bird Survey (BBS) routes detecting WISA, and Forest land cover (top). 10
Figure 5. Project Area for 2018 WISA habitat modeling update. 12
Figure 6. VRI Height by 5-cm classes regressed against mean Quadratic Mean Diameter (QMD) for those classes. 22
Figure 7. Exploration of VRI stand variables to use in modeling for 14 nesting territories. Used vs available selection ratio for QMD, Height and Tree Density. 23
Figure 8. Regression of selection ratio (used/available) against Lw% in VRI Rank 1 layer. 24
Figure 9. Regression of QMD vs VRI stand density for telemetry sample polygons with density >0. 26
Figure 10. % of all WISA detections by foraging selection score class (Use/Available) extrapolated to Okanagan-Boundary WISA AO (top) and West WISA AO (bottom). 28
Figure 11. Regression of plot-derived tree densities against VRI-estimated tree densities for VRI polygons with ≥10 tree count plots per polygon (n = 66). 30
Figure 12. Distances of WISA nest trees within harvested cutblocks and in openings from forest, grouped by retained tree densities in the cutblocks or openings. 34

List of Tables

Table 1. Habitat capability and suitability using the 6-Class Rating Scheme of RISC (1998), and density equivalents for Williamson's Sapsucker based on census areas >100 ha in size. 13
Table 2. Nest Habitat Suitability Model March 2018 for Williamson's Sapsucker contiguous AO in the Okanagan-Boundary region. 15
Table 3. Nest Habitat Suitability Model March 2018 for Williamson's Sapsucker contiguous AO in the West Region. 16
Table 4. Correlation of VRI stand variables within the 95%-detection-containing radius around each nest or territory on a polygon-by-polygon basis across all samples. 22
Table 5. Best foraging habitat subset model selection for the Okanagan using AIC. 25
Table 6. Foraging Habitat Suitability ratings by selection score from model based on VRI Density of stems/ha >17.5-cm dbh and on distribution of WISA detections by density. 29
Table 7. Summary of areas of WISA nesting habitat suitability model (2018) and foraging habitat model (2020) based on telemetry data. 31

List of Equations

Eqn 1 Okanagan predicted selection ratio from VRI tree (>17.5-cm dbh) density 26
Eqn 2 West predicted selection ratio from VRI tree (>17.5-cm dbh) density 27

List of Acronyms

Throughout this report, tree species are referred to by the two-letter codes used in VRI:

Ac	Black Cottonwood
At	Trembling Aspen
Bl	Subalpine Fir
Cw	Western Red-Cedar
Ew	Water Birch
Fd	Douglas-fir
Lw	Western Larch
Pl	Lodgepole Pine
Py	Ponderosa Pine
Sx	Spruce (white, Engelmann and/or hybrids of the two)

Other acronyms used:

AIC	Akaike's Information Criterion (and AICc for small samples)
AO	Area of Occupancy
CWS	Canadian Wildlife Service
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GIS	Geographic Information Systems
GLMM	Generalized Linear Mixed Modeling
MAP	Mean Annual Precipitation
MAT	Mean Annual Temperature
PCA	Principal Component Analysis
QMD	Quadratic Mean Diameter (in this case for trees >17.5-cm dbh only)
SD	Standard Deviation
ST	Seed tree, usually referring to Seed tree Cuts, i.e., clearcuts with scattered sparse trees remaining (usually at densities of 1-20/ha).
T_ave01	Average January Temperature (from ClimateBC)
USGS	United States Geological Survey
VRI	Vegetation Resources Inventory
WISA	Williamson's Sapsucker

Rationale

1. **Bioclimatic Envelopes**: The purpose of this broad-scale modeling was to provide insight into some of the possible climatic, physical and/or biological (mainly tree distribution) factors affecting WISA breeding range location, and particularly how these might affect local WISA habitat models. During analysis of foraging habitat, breeding territory selection appeared to be taking place at a wider scale than just the territory. In addition, surveys in the past few years have found WISA breeding in apparently suitable habitat outside but near the AOs, indicating that the original AO boundaries were drawn with too limited information. Bioclimatic attributes were not available in GIS formats in 2006/07 when the AO boundaries were originally drawn.

   The Bioclimatic Envelope models were not fully explored because they were only used to highlight variables that may affect habitat selection at finer scales. However, further use of the Bioclimatic Envelope to revise the AO boundaries is anticipated in the future. The same principles might also be used to predict climate change effects on WISA (e.g. Wilsey et al. 2019, who predicted WISA could lose 75% of current and potential future habitat due to climate change). However, that was beyond the scope of this project, and would be complicated by WISA's reliance upon nest trees that may be centuries old, making for a time lag in habitat change that is likely to be much slower than currently predicted climatic changes.

2. **Nest Habitat Suitability**: Previous habitat modeling had been completed based on 2008 conditions (Gyug 2009, Gyug 2010a, Gyug 2010b; collectively referred to as the 2008 modeling), which was used to delineate Critical Habitat (Environment Canada 2014). The models in the West and Okanagan-Boundary AOs have been tested and found to be reliable. The West AO and most of the Okanagan-Boundary AO has been updated to 2016 (Gyug 2018). Modeling was based primarily on nest locations, but also on breeding density in census areas, and on relative abundance. So, even though based primarily on nest tree stands, the models to some degree also take into account other habitat preferences because nesting can only occur where foraging habitat is also suitable. This model operates at the scale of the AO, and is (or should be) a model that shows nest territory selection within the AO.

3. **Foraging Habitat**: The purpose of this modeling in 2020 was specifically to identify sites where nest tree enhancements could be applied, i.e., make existing trees more suitable for nesting. Ideal sites would be where WISA foraging habitat may be suitable, but where suitable nest trees may be scarce. The WISA foraging habitat model was based on radio-telemetry data collected by St-Amand (2017) within individual WISA breeding territories. In effect, this model examines habitat selection, i.e., use in relation to available habitat within a breeding territory once the territory has been selected. This new model was then combined with the Nest Habitat model to identify areas where foraging may be suitable, but nesting conditions not as suitable.

A summary of the Nest Habitat model above is provided here for completeness, but the reader will need to reference the original species accounts for details of model development. Here we concentrate on developing the Foraging Habitat model, and the incorporation of that model into the updated 2018 nest habitat model.

Bioclimatic Envelopes

Project Area and Scale:

The project started with the B.C. provincial range of WISA, but then expanded to the global breeding range of WISA, i.e., North America west of the 100th meridian.

Approximate 1:500,000 scale, i.e., based on GIS layers with 600-m pixels.

Map Products Used:

1) ClimateWNA (Wang et al. 2012) and ClimateBC v. 6.20 (Wang et al. 2016) (Mean Annual Precipitation (MAP), Mean Annual Temperature (MAT), as well as seasonal or monthly normals)
2) WISA Range (developed from eBird data for Gyug et al. 2012)
3) eBird May-June-July WISA observation locations (up to 2014)
4) USGS Land Cover GIS Data Download (URL https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/land-cover-data-download?qt-science_center_objects=0#qt-science_center_objects)
5) Tree species ranges (Digital Representations of Tree Species Range Maps from "Atlas of United States Trees" by Elbert L. Little, Jr. (and other publications)). Deprecated web material from USGS archived (as of July 2020) at URL https://web.archive.org/web/20170127093428/https://gec.cr.usgs.gov/data/little/

Model Development

The B.C. bioclimatic envelope was developed by attaching Mean Annual Precipitation (MAP), and Mean Annual Temperature (MAT) (1981-2010 normals) to each WISA detection (N = 5449) in the current FLNRORD/CWS WISA database. Then we determined the levels of each variable that included 98%, 95% and 90% of WISA detections around the mean. The same exercise was done just for nest trees, including each nest tree only once even if used in multiple years (n = 461), with the same results. These levels were applied to the 600-m pixel MAP and MAT grids from ClimateBC in ArcView. In the first iteration, much of the central interior, where WISA does not occur, was included. Several monthly mean temperatures were examined, and the best fit to remove the central interior from the envelope was average January temperature (T_ave01).

In B.C., the bioclimatic envelope that contained 95% of WISA detections was defined by the three individual variables that each contained 98% of WISA detections: MAP (344-676 mm), MAT (3.6-6.7° C) and average January temperature (-7.0 to -3.1° C) (Figure 1). Since WISA are not present in B.C. in January, the effect of including the January temperature is almost certainly on tree distribution rather than on WISA physiological limits. The WISA 95% bioclimatic envelope is very similar to the distribution of Py in B.C. (Figure 2). It is not similar to the distribution of Lw in B.C. (Figure 2). Lw appears to be an opportunistically used nest tree species wherever it occurs within or adjacent to Py, i.e., probably because it has a similar frequent fire regime in those areas that provide for more veteran Lw than elsewhere in the range of Lw in B.C., where Lw will tend to be in even-aged stands.. Geographic projection (no B.C. Albers). The Areas of Occupancy might be refined in the future based on local and more parsimonious versions of this bioclimatic envelope.

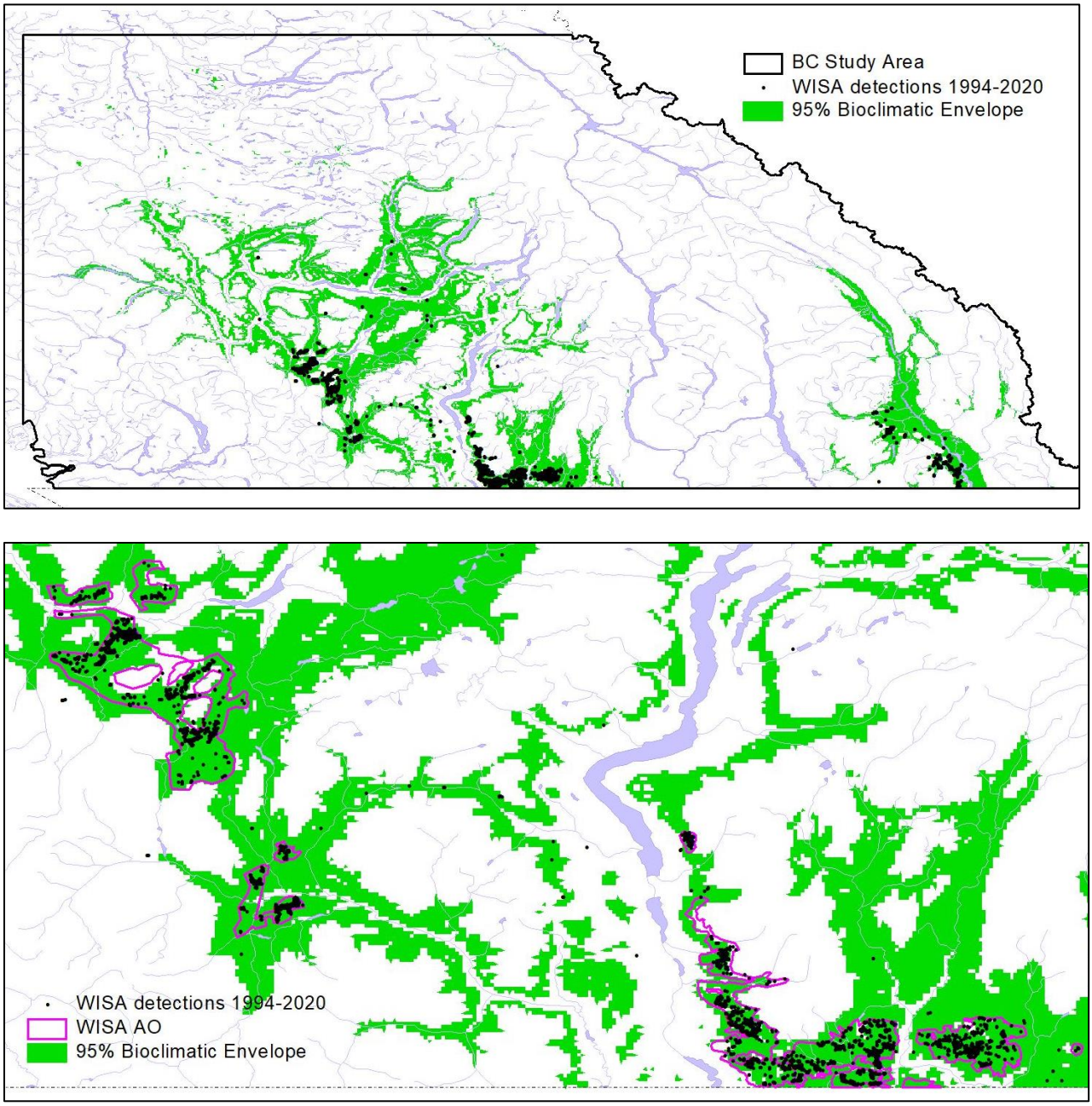


Figure 1. WISA 95% Bioclimatic Envelope in B.C. based on WISA detections (n = 5449). Top: Southern B.C.; Bottom: WISA West and Okanagan-Boundary AOs as mapped in 2007. Map projection is geographic (Lat and Long squares of decimal degrees).

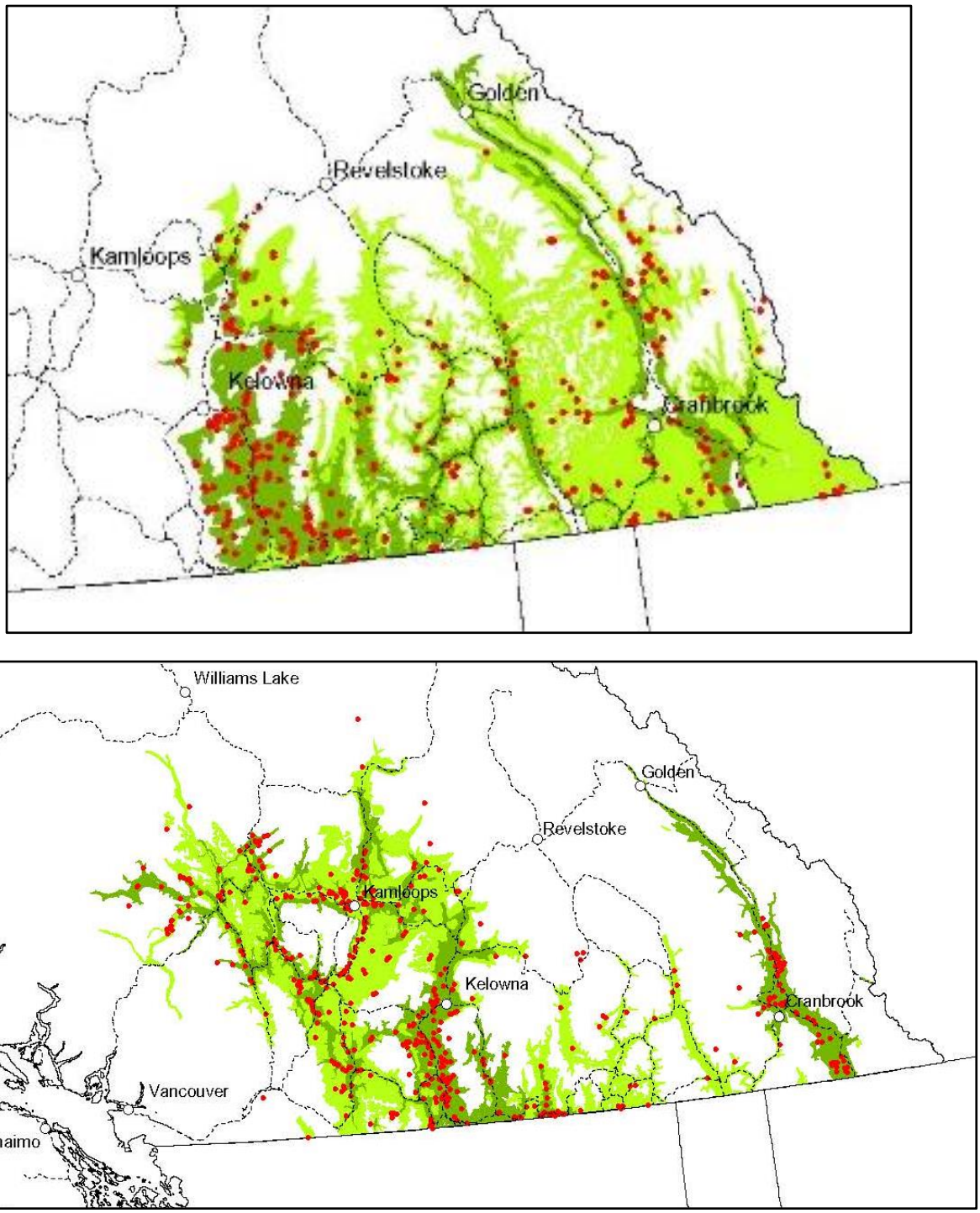


Figure 2. Top: Lw distribution in B.C. >2% areal cover (dark green), <2% areal cover light green. Bottom: Py >1% areal over (dark green) <1% areal cover (light green). Note that WISA 95% bioclimatic envelope (see Figure 1) most closely matches the distribution of Py in B.C. (excepting the West Kootenay).

The bioclimatic envelope method was extended to the entire breeding range including the U.S. (but not northern Mexico where they are known to breed in a few isolated locations) based only on MAP and MAT (Figure 3). This was not represented on a map because the 95% kernel (Figure 3) was not a simple rectangle, and therefore the boundaries of the kernel were not easily transferred to existing data products.

The bioclimatic envelope in B.C. (red dots in Figure 3) represents only a small fraction of the entire WISA breeding range bioclimatic envelope; BC is near the periphery of the Bioclimatic Envelope as defined by MAP and MAT. The large amount of U.S. available (grey) dots to lower right in graph are mostly sagebrush and desert. MAP above 1500 mm are generally coastal wet forests. The large amount of BC available (orange dots) to lower left of graph are northern forests, i.e., cold and relatively dry.

As for B.C., tree species distributions were also examined in relation to WISA breeding range. WISA breed in most of the forests of western U.S. excepting the wet forests of the west coast and interior (i.e., the Idaho panhandle). Elsewhere, the WISA breeding distribution, again, most closely matches the distribution of Py, with some high elevation exceptions. In parts of the breeding range where Py is absent in Colorado, Wyoming and Utah, Fd occurs, and nesting is mostly in At. The range of Lw in the U.S. is entirely within the range of Fd, and within that portion of WISA breeding range (Idaho and Montana) WISA is most abundant (based on eBird sightings) in the same portions where Lw overlaps with Py, just as in B.C.

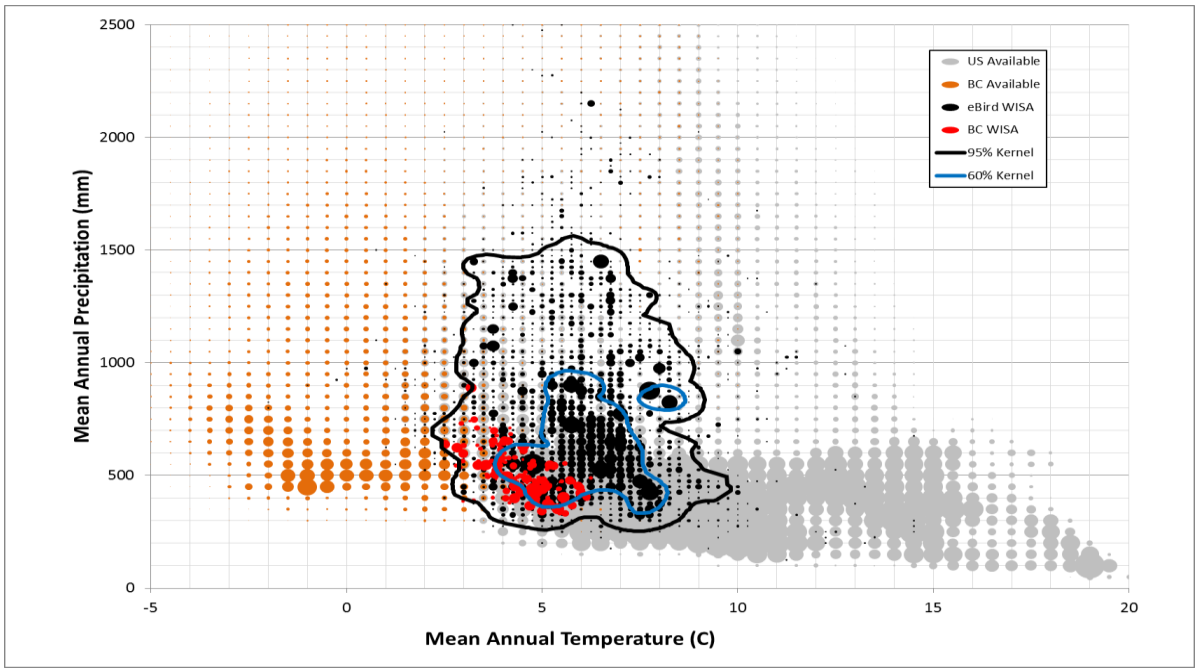
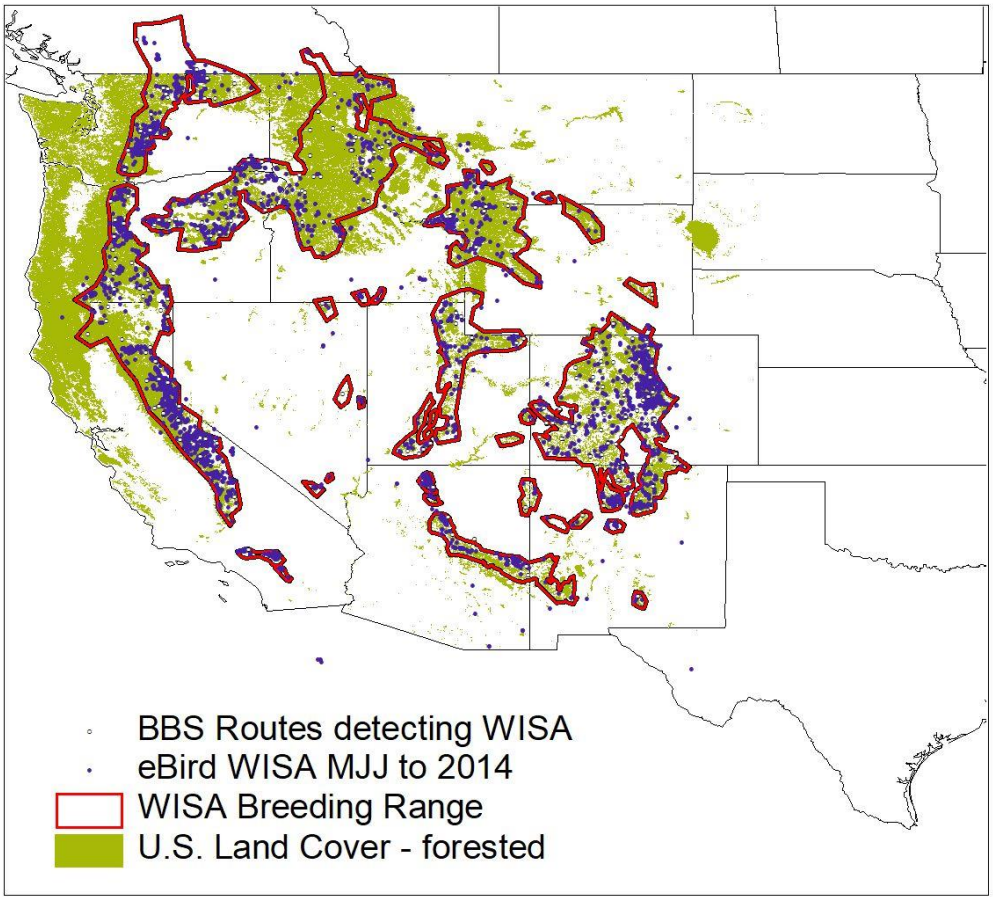


Figure 3. 95% and 60% bioclimatic envelope kernels occupied by Williamson's Sapsucker over its entire breeding range compared to "available" defined as all of B.C. and all of the U.S. west of the 100th meridian. Size of dots represent relative availability or WISA abundance at that particular intersection of MAP and MAT. Base Williamson's Sapsucker location data was current in 2014 from eBird (https://ebird.org) for the U.S. and local inventory database for Canada. Climate long-term normal data from ClimateNA (Wang et al. 2016).



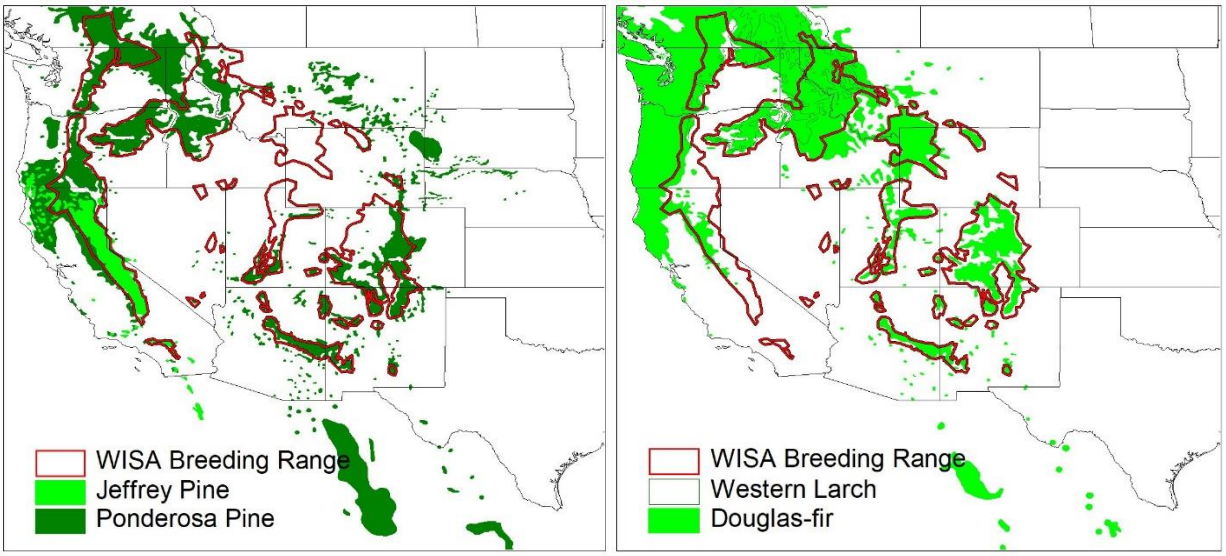


Figure 4. WISA breeding range (Gyug et al 2012) showing overlap with eBird WISA detections (to 2014) and Breeding Bird Survey (BBS) routes detecting WISA, and Forest land cover (top). Selected tree species distributions (bottom figures). Jeffrey Pine is closely related to Ponderosa Pine and replaces it in parts of the Sierra Nevada of California.

WISA Area of Occupancy habitat modeling

Project Area:

Williamson's Sapsucker (WISA) contiguous Area of Occupancy (AO) on the west side of Okanagan Lake within the Cascade Forest District (742.5 km^2; Figure 5).

WISA contiguous AO on the east side of Okanagan Lake within the Okanagan-Shuswap and Arrow-Boundary Forest Districts (521.6 km^2; Figure 5).

Biogeoclimatic Variants (Version 11, 2018): Listed from low elevation to high elevation

West: BGxw1, PPxh1, PPxh2, IDFxh1, IDFxh2, IDFdk1, IDFdk2, MSxk2
Okanagan-Boundary: IDFxh1, IDFxh4, IDFdm1, ICHmk1, MSdm1

Project Map Scale: 1:20,000 (accuracy typically ±20 m)

Map Products Used:

Base Map was Vegetation Resource Inventory (VRI) geodatabase with projected date of January 1, 2016 downloaded from Data BC (https://data.gov.bc.ca/). Complete descriptions of the VRI mapping and its precursors (used in the 2008 modeling) were provided in Gyug (2018). Some additional VRI interpretations in 2020 are outlined within the modeling text.

VRI was designed to be reliable at the regional scale, and required local interpretation to make it reliable for WISA habitat modeling at the polygon scale. In 2008 and 2018, considerable additional polygon-by-polygon interpretation was described in previous reports. No additional polygon-by-polygon interpretation was done in 2020 except to verify conditions within the telemetry analysis. Further caveats about fine-scale interpretation of VRI are discussed within the modeling text.

Digital Elevation Models used in 2008/2018 are described in previous reports.

Imagery Products Used:

- Digital orthophotos (1-m pixel) were available for 1990-1995 (Black and white) and for 2004-2005 (colour) as used in the 2008 habitat mapping.
- Imagery used for this update included 1.5-m pixel SPOT6/7 dating to 2015-2018, as well as publicly available (Google Earth and Bing) aerial photos (generally 1-m pixel) of varying dates from 2012 to 2018.
- Landsat 8 (15-m pixel) and Sentinel 2 (10-m pixel) imagery was used in 2017 to bring the mapping up to date.
- In 2008, additional stereo aerial photo interpretation was done from paper versions of 1992-2004 colour or black-and-white aerial photos with nominal scales of 1:15,000 to 1:30,000 to verify vegetation attributes, and particularly to identify veteran trees and aspen stands, but this rather intensive process was not repeated in further updates.

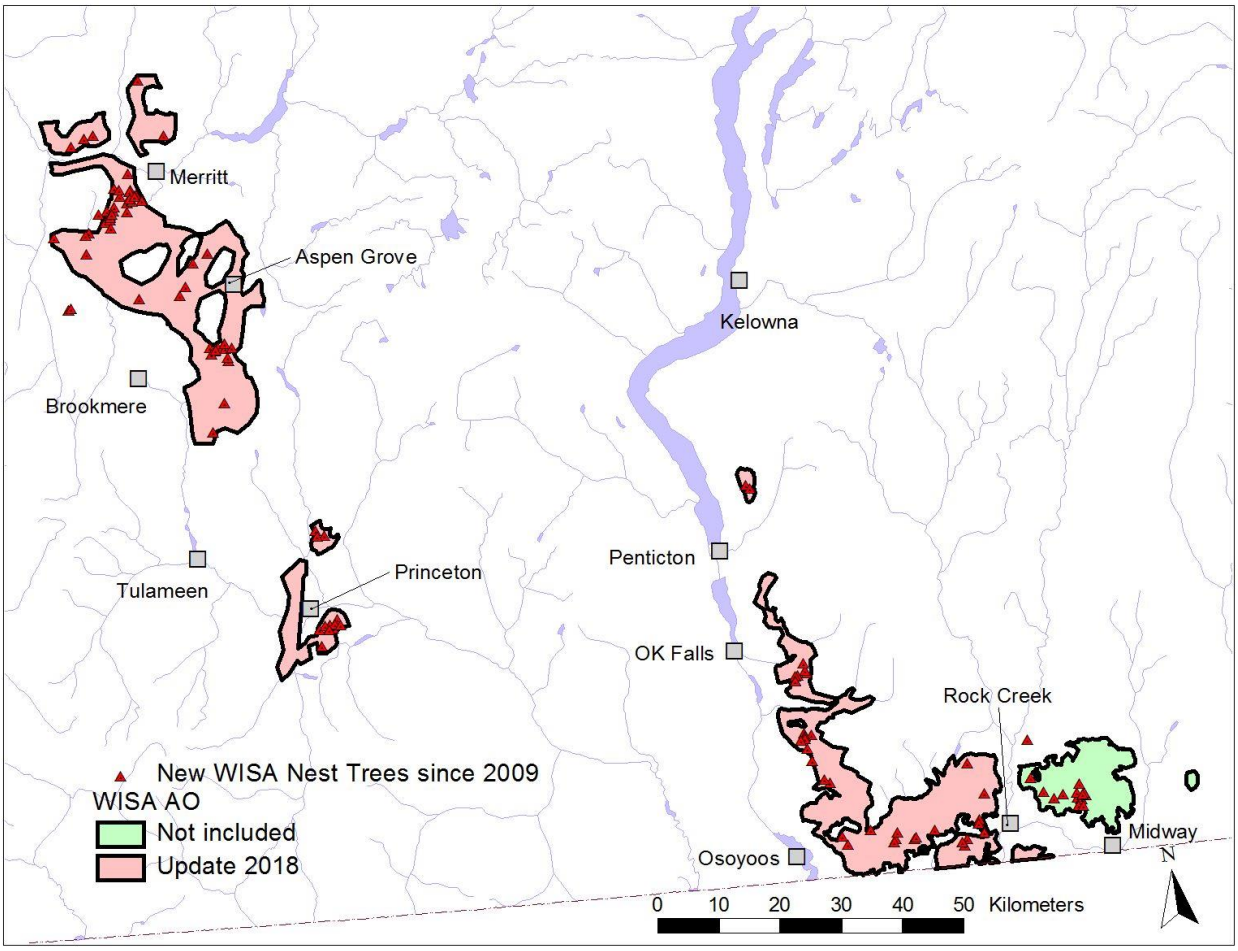


Figure 5. Project Area for 2018 WISA habitat modeling update. New nests found within project area from 2010 to 2016 (n = 102) shown. Figure from Gyug (2018).

Ratings

This model employs the 6-Class rating scheme (Table 1) recommended in the RISC standards manual (RISC 1999). For other modeling in the West, possible Moderately High (2) areas have been grouped with the Moderate (3) as they could not be reliably separated. Nil habitats have been defined as permanently non-treed habitats that would be impossible for WISA to colonize.

The WISA model profiles only nesting habitats. WISA is a central-place forager when they are feeding the young at the nest so breeding and foraging habitats must occur within close proximity as previously outlined. Breeding (nesting) occurs during the spring (usually April – early July) but WISA can be present on sites from March to September, with observed earliest date being February 28, and latest date October 21.

Table 1. Habitat capability and suitability using the 6-Class Rating Scheme of RISC (1999), and density equivalents for Williamson's Sapsucker based on census areas >100 ha in size (Gyug, unpublished data).

Percent of Provincial Benchmark	Rating	Numerical Code	Letter Code	Density (Nests or Breeding Pairs/km^2)
76-100%	High	1	H	2.3 - 3.1
51-75%	Moderately High	2	MH	1.6 - 2.3
26-50%	Moderate	3	M	0.8 - 1.6
6-25%	Low	4	L	0.2 - 0.8
1-5%	Very Low	5	VL	0.0 - 0.2
0%	Nil / Unsuitable	6	N	0

Provincial Benchmark

Density of 3.1 active nests/breeding pairs per km^2 east of Okanagan Falls (Gyug et al. 2007).
Ecosection: South Okanogan Basin/North Okanagan Highlands (SOB/NOH)
Biogeoclimatic Zone: IDFdm1 bordering on the IDFxh1 at Schoonover Mt.,
IDFdm1 at Lehman Springs,
IDFdm1 bordering on MSdm1 at Naramata.

Benchmark Habitat Description:

The forest stands at three sites (Okanagan Falls, Lehman Springs and Naramata) contained 20-40 very large (≥60 cm dbh) western larch and Douglas-fir/ha within stands of 200-300 trees >17.5-cm dbh/ha, or 130-250 trees >22.5-cm dbh. The relatively high density of very large trees was the most characteristic property of these stands. Densities of smaller trees were variable depending on local conditions and extent of Douglas-fir ingrowth since the most recent low-intensity fires. Western larch made up 30-55% of the trees >22.5-cm dbh in these stands, and 35-80% of the trees >57.5-cm dbh. The benchmark stands at OK Falls and Lehman Springs had estimated Layer 1 ages of >200 years in the FC attribute database and of 192 years at Naramata, and estimated Layer 1 tree heights of 30-44 m. Site indices for Layer 1 were all >15.8. Slopes at each of these sites were gentle to moderate (<25%).

Summary of 2008-2018 Nest Habitat Model

The habitat modeling of Drever et al. (2015) was not used for the 2008 nest habitat modeling because a) it was not available in 2008, and b) while the same statistical modeling approach was briefly attempted, there were too many caveats to the modeling and the mathematical models were found to have too little applicability to real world situations to be useful. However, that is not to say that there would not be some utility in re-examining the approach (see Appendix 3).

Ratings Assumptions and methods– VRI Stand Attribute Models

1. These models only apply within the regional contiguous Areas of Occupancy.
2. Only the IDF and PP zones have any suitability for WISA in the West Region.
3. In the West Elevations below 600 m and above 1400 m will be considered to have no suitability.
4. This model was derived from nest locations and is therefore nest stand model.
5. Non-Productive Polygons were treated as follows:
    a. Lake, Meadow, Alpine, Alpine Forest, Clearing, Cultivated field, Glacier, Ice, Gravel Bar, River, Claybank and Urban were assigned Nil/Unsuitable (6).
    b. In the West Region, Swamps and Rock were also considered Nil (6). Swamps were handled separately in the Okanagan-Boundary (see adjustments)
    c. Open Range assigned Very Low (5) but Nil (6) if truly non-treed.
    d. Non-Productive forest or Brush, Rock and Non-Productive Burn were treated as for forested polygons from their stand attributes, or otherwise assigned Very Low (VL) (5) if there were no forest attributes.
6. Any forested polygons or potentially forested polygons not otherwise assigned to M or L using Tables 2 or 3 were assigned VL (5).
7. Stand suitability was estimated first by stand attributes as per Tables 3 and 4, and then
    a. Other adjustments were made for slope and aspect, and
    b. Other adjustments were made for particular situations there were not handled well by the initial suitability classification in the top part of the tables.
8. The actual protocol for applying the factors in Tables 2 and 3 sequentially to the VRI and other attributes determined from prior FC and from imagery assessments are detailed in Appendix 1.

Table 2. Nest Habitat Suitability Model March 2018 for Williamson's Sapsucker contiguous AO in the Okanagan-Boundary region.

WISA Habitat Suitability for Okanagan-Boundary contiguous AO						
Input Variables	**High (H) (1)**	**Moderately High (M) (2)**	**Moderate (M) (3)**	**Low (L) (4)**	**Very Low (5)**	**Nil (6)**
Rank 1 Layer Projected Age	>190 years	>190 years	>120		Any other forested, potentially forested or non-productive polygons; OR, Rock and Swamp polygons as per adjustments below	All other non-forest polygons
Rank 1 Layer Projected Ht	>29.0 m					
Rank 1 Layer Site Index	>15.0					
Rank 1 Layer Crown Closure	>30%	>20%				
Crown Closure ≥15.0 m ht			>20%			
Age of oldest layer	>190 years	>190 years	>125 years	>80 years		
Tree Species	Fd or Lw leading, contains Fd and Lw	Fd or Lw leading, contains Lw	Fd or Lw present	Fd or Lw present		
Cw %.	<10%	<10%	<10%	<10%		
Sum of Pl and Bl %	<30%	<30%	<30%	<60%		
Sum of Fd and Lw %				>40%		
Boundary: % Fd of all layers ≥15.0 m ht	10-90	10-90	10-90	Fd <100%		
Okanagan: Sum of Fd and Lw % of either L1 or L2 , or if Lw present in L1R0 (veteran) layer				>40%		

Adjustments:		
Reduce H or M 1 level if	Slope >30%	Do not reduce
Upgrade from VL to L if	1. Forested polygon (>10% Crn Clos ≥15 m ht) and Lw present at >1/ha and Lw age >125 yr	
	2. Forested polygon (>10% Crn Clos ≥15 m ht) contains Fd or Lw, contains At >4% of stand, age >55 yr, and Pl <55% of stand	
	3. NP but age>125, on south or gentle slope, contains Lw, Crn Clos >10%	
Upgrade from VL to L if slope <30% and	4. Lw or At vets present in ST cut (>2 ST/ha) up to 150 m from adjacent H/M/L with >30% Crn Clos ≥15 m ht). Up to 200 m if surrounded on all sides by forested stands (NOT USED 2018)	
	5. Mature At patches >1 ha and adjacent to Fd/Lw forest, i.e., not Pl/Se	
	6. Fire-origin (60-100 yr), old high-graded stands, or old light partially cut stands (1960s-1980s) if:	
	a. Lw vets scattered throughout at >0.5/ha, or	
	b. Upgrade the portions of the stand with clumps of vets	
	7. if Ep/Ew and Lw occur in Layer 1, stand is not NP, slope <30%, Crown closure >25% and >10 m tall, and >50 years old	
	8. Any other forested stands containing vets >0.5/ha but that had been assigned VL	
Upgrade from VL to L if slope >30% and if	9. Lw vets present at >1/ha, if adjacent to H/M/L, and if polygon size >1 ha	
OR, R, NP polygons	10. assign as Nil if no mature trees	
	11. if partly treed, e.g., edges or within an arm of an irregularly shaped polygon, then remain VL	
	12. if NP polygons had been rated M or L, reduce to VL if crown closure <10%	
	13. Small swamps (<1 ha) ringed by At, Ac or tall shrubs remain VL, larger Swamps reduced to Unsuitable	
	14. 20-m buffer inside large OR and SWAMP polygons adjacent to H, M or L may be rated L if boundaries not mapped precisely, i.e., OR or Swamp contains mature trees (**Not used in 2018**)	
Downgrade to VL if	15a. Clearcuts with no mature trees, i.e., not really ST cuts 15b. ST Cuts, partial cuts or high grading but no vets and no mature At detectable	
	16. ST cuts, even if ST Lw vets, if surrounding stands were VL or young Pl stands (**Not used in 2018**)	
	18. 5% crown closure but >15 m ht, and not adjacent to intact forest stands –usually at lower edges of AO adjacent to open Py slopes (**Not used in 2018**)	

Table 3. Nest Habitat Suitability Model March 2018 for Williamson's Sapsucker contiguous AO in the West Region (west of Okanagan Lake).

WISA Habitat Suitability for Western contiguous AO						
Input Variables	**Moderate (M) (3)**	**Moderate (M) (3)**	**Low (L) (4)***		**Very Low (5)**	**Nil (6)**
Elevation and Slope	600 -1400 m, slope <45%					<600 m, >1400 m, >45% slope
Oldest Layer Age	≥100	≥180	≥180	≥58 years	Any other forested, potentially forested or non-productive polygons; OR polygons (if partially treed)	All other non-forest polygons
Oldest Layer Ht	≥20.0	≥19.0	≥18.0	≥14.0		
Site Index	≥10.0	≥11.0	≥10.0	≥11.0		
Crown Closure ≥15.0 m ht	≥20% but variable	≥20%	≥1%	≥15%		
Tree Species	≥20% by volume dead unsalvaged MPB-killed Py	Py present	Py present	At present, Either Fd and/or Py in this or adjacent polygon		
Pl % composition of Layer 1 or 2	Pl absent	≤30%	≤50%	≤30%		
Adjustments:						
Reduce to Low if:	600-800 m					
	1200-1400 m					
Reduce one level if:	Slope >25%					
Upgrade from VL to L only if:	1. veteran Py present based on photo examination or 1996-98 FC mapping indicated trees >180 years (projected to current) 2. OR if mature At patches present, based on photo examination 3. Meets 1 or 2 but NOT in polygons with Slope >25% and north aspect 4. AND Meets (1 or 2) and 3 AND either 4a. in a forested stand ≥88 years old containing Fd or Py but ≤30% Pl 4b. in a ST Cut or Partial Cut					

Foraging Habitat Model

Generalized Linear Mixed Models

Objective was to create a predictive model using VRI data and telemetry observation of foraging WISA at four sites near Oliver, Okanagan Falls, Princeton and Merritt, in 2014-2015 (St-Amand 2017, St-Amand et al 2018).

We based the foraging models on all foraging observations of breeding birds within 900 m of their nest (estimated distance for 99% of foraging trips; see St-Amand 2017). Foraging observations were mostly collected during incubation and the nestling stage; however, but some were up to 3 weeks before laying and 2 weeks after nesting. Non-breeders were excluded because they did not have a nest location, thus weighting observations using the distance from the nest would not have been possible. Observations of flycatching were omitted from the analysis because of their small sample size.

Methods

We used Principal Component Analysis (PCA) on a database of features of 1761 trees to characterize the potential foraging habitat in VRI polygons in the Okanagan and Western region separately, with data collected during the telemetry study. The goal was to pre-select VRI variables that are more likely to represent the different aspects of WISA habitat, because there were too many potential VRI variables to include in the models.

The tree features were spatially joined to the VRI polygons in ArcGIS. All tree feature variables were transformed to proportions, except for tree dbh and tree height which we averaged. The tree features considered were derived from the results of the telemetry study (St-Amand 2017, St-Amand et al. 2018, Table 1). We only considered polygons that contained >5 measured trees.

We used a standardized Pearson correlation matrix with confidence intervals. We considered the number of Principal Components (PC) necessary to represent all field variables or account for > 0.80 of the total variation in the PCA. The characterization of Principal Components was based on variables that had a significant correlation (confidence interval did not overlap with zero). Variables with correlations of > 0.85 were considered heavy influencers for the Principal Component.

We considered all numeric VRI variables that may be correlated with WISA foraging selection from the VRI geospatial database. We used a Pearson correlation matrix with the same criteria as for the field-PCA correlation matrix to identify VRI variables that are more likely to represent WISA foraging habitat.

We used Generalized Linear Mixed-Models (GLMM) to model the selection of VRI polygons for WISA foraging. To represent the zeros in the binomial GLMM, we simulated 50,850 random points <900 m from the nest, proportionally with the number of real foraging observations (average of 2,211 random points per bird). We used bird ID as the random effect to account for individual variation in habitat selection.

We assigned weights to foraging observations in the models to consider foraging distance, assuming that birds travel long distances from their nest to reach foraging patches of higher quality (weight = foraging distance/max foraging distance). Variables were standarized (mean = 0, SD = 1).

We created sets of models that were more likely to predict the selection of VRI polygons for general foraging, gleaning, sap feeding and pecking in the Okanagan and Western regions, and with the regions combined (4 foraging X 3 regions = 12 model sets). We included the quadratic term of each variable in the model selection process. We randomly created sets of 25-75 models depending on sample size and the number of variables in each model set. We present the top model based on AICc scores for each model set. The PCA and models were executed in R and the spatial simulation of random points in QGIS. Model parameters were placed in separate Excel files.

Modeling

We retained three PC in each region; however, we did not use the third PC because of conflicting correlations with proportion of blistering trees and the proportion of very large Douglas-Fir trees. In the Okanagan region, PC1 was negatively correlated with mean dbh, mean height, proportions of large trees, proportions of large and very large Douglas-fir trees, proportions of blistering trees, and proportions of Douglas-fir and hybrid spruce (PC1 = non-habitat). PC2 was positively correlated with proportions of dead trees, mean height and proportions of blistering trees, and negatively correlated with proportions of large Douglas-fir and proportions of Douglas-fir and hybrid spruce (PC2 = snags). PC3 was positively correlated with proportions of very large Douglas-fir trees, but negatively correlated with proportions of blistering trees (PC3 = veteran trees).

In the Western region, PC1 was negatively correlated with proportions of large Douglas-fir trees, proportions of blistering trees, mean height, and proportions of Douglas-fir and hybrid spruce; PC1 was also positively correlated with proportions of dead trees and mean dbh (PC1 = large snags). PC2 was positively correlated with mean dbh and height, and proportions of large trees (PC2 = mature stand). PC3 was negatively correlated with proportions of very large trees and positively correlated with proportions of large trees and proportions of blistering trees (PC3 = no veteran trees).

We included 30 VRI variables in the pre-selection process, only retaining those below a collinearity threshold ($r < 0.80$) for final model selection. In the Okanagan, we identified ten variables that were correlated with PC1 (non-habitat) and two variables that were correlated with PC2 (snags). Of these 12 variables, we retained five for final model selection: FINAL_SUIT, FD_L2_PCT, MAX_HT, FD_TOT_PCT and TOT_VOL (Nest habitat suitability as mapped in 2018, % Fd in Layer 2, maximum height (m) of any layer, % Fd sum of Rank 1 layer and layer 2, and total volume (m^3/ha) of all layers). In the Western region, we identified four variables that were correlated with PC1 (large snags) and two variables that were correlated with PC2 (mature stand). Of these six variables, we retained three: MAX_SI, STEMHAR1 and TOT_VOL (Site Index, theoretical height in meters of 50-year old trees), Rank 1 layer stems/ha >17.5-cm dbh, and total volume of lives standing trees (m^3/ha) of all layers in a given polygon). The variables related to stand age, time since cut, crown closure and Lw % (for the Okanagan only) were not included in the final modeling.

Evaluation

The most parsimonious foraging habitat models, i.e., those with ΔAICc ≤2.0, developed from the breeding territories were examined. First, hypothetical values of z-scores ranging from -2 to +2 (which should contain 95% of the distribution) were input and varied for each variable to see how the models behaved. This included attempts to maximize and minimize the model output, and to see how individual variables affected the output when others were held constant at various levels.

The models were not found to behave in a predictable fashion, i.e., in ways that made sense biologically if reapplied to WISA territories. For example, the top model that combined foraging in both regions was based on Site Index, Stems/ha in Rank 1 layer, Total volume, Maximum Ht, and Fd % (and its square). When all variables except one were averaged, i.e., set to 0, then no positive z-scores could be generated using any reasonable z-value (from -3 to +5) of any single variable. The only way to achieve a positive score was to minimize Site Index, stems/ha, and volume, maximize Fd% in Layer 2 and height, and then set Fd with a z-score of 0.4. Biologically, this means best foraging habitat is poor growing sites with low tree density and volume, but tall trees with Fd present in more than one layer.

Next, the combined foraging models were examined for fit to the WISA AO VRI (for the regions combined, and then for West and Okanagan). First the z-scores for the variables over the entire WISA AO VRI were calculated using averages and standard deviations weighted by polygon size. When the models were applied, none of the models gave any positive scores to any poygons, i.e., it appeared that all habitats were not preferred. Just looking at some of the relative values, VRI polygons with no information (i.e., all variables in the model had no values such as hayfields and lakes) had higher scores than Fd forest, i.e., the results did not make biological sense. Looking at the combination of values that resulted in positive preference (see previous paragraph), no such polygons were found to exist. The models' hypothetical results could not translate into actual results.

Given the relatively poor performance of the GLMM models when applied to the VRI data in the WISA AO, these GLMM models were not further used in this modeling. A re-assessment of the telemetry data was undertaken to attempt to find patterns of variables that might be related to foraging habitat use and make further modeling possible.

Multiple Regression Modeling

Data Preparation

We determined the radius around each nest that contained 95% of telemetry detections and considered the portions of VRI polygons within that radius to be "available". The first group was for nests for which telemetry locations were available during the nestling period (Group 1; n = 14). If both male and female had been radio-tagged at one nest, the detections were grouped as one. All WISA telemetry detections were used except for post-nesting movements consistently or significantly outside the nestling-period radius. All WISA telemetry detections, not just foraging locations, were included because the results were virtually identical to when only foraging locations were considered. Many of those telemetry locations were not considered foraging because, even though located fairly accurately, the bird's activity could not actually be seen. For radio-tagged WISA with no nest or where the nest failed very early

(Group 1; n = 5), a "territory center" was estimated either based on geometric mean of all detections or on the attempted nest site. The two groups were considered separately and only grouped when there were no significant differences. Mean 95% radius for Groups 1 and 2 were 342 m (SD 122 m) (= 36.7 ha) and 491 m (SD 223 m) (= 75.7 ha) respectively.

Available VRI polygons were weighted by area such that the polygon areas within each nest radius summed to 1. Use of VRI polygons was estimated by the number of telemetry detections within each polygon, with triple weighting for each detection >225 m from a nest. This distance was chosen based on rounding of the distance from the nest (mean = 281 m, min 153 m, max 274 m, n = 5 nests) of sites of consistently-used foraging habitat for which WISA would have to fly around or over cutblocks or non-habitat. While those were distances from the nest, St-Amand (2017) reported the maximum "single-tree" or non-habitat they would regularly cross over to get to foraging habitat was 160 m.

The sum of all detections for a given bird or pair were divided by the total of weighted detections so that use for any given nest summed to 1. For each polygon at each nest, if the ratio of used to available was >1, that was considered selection for, and if the ratio was <1, that was considered selection against. This nest-by-nest method revealed a large amount of variability between nests, and more particularly, a very unbalanced study design because not every level of every variable of interest was available within every nest radius. Patterns of habitat preferences only became clear when the available areas and the used areas were summed by variables of interest across available samples, and then the selection ratio (use/available) estimated.

VRI variables were assessed using two methods: considering selection ratio (used/available) for each nest as a single sample, and secondly summing the used and available weights for a given variable across all nests and then considering the selection ratio (used/available) of the summed sample.

Breeding territories were often not circular around the nest, so we also estimated the boundaries of kernels containing 95% of detections for each nest or territory, again excluding only any significant post-nesting movements. This was not used for used vs available analysis, but only to estimate the amount of foraging habitat each pair may require to breed. Mean 95% kernel size for Groups 1 and 2 respectively were 34.2 ha (SD 17.6 ha, n =14) and 87.3 ha (SD 52.7 ha, n = 3 with >30 detections). The sizes of the 95% kernels were similar to the sizes of the 95% radius around the nest (see above).

VRI variables considered for modeling were simplified from the many possible VRI variables. VRI aerial photo interpretation for each polygon yields measured tree height, and estimated crown closure and species percentages by stand layer. Most other variables are secondary estimates. Stand ages may be relatively reliable for even-aged stands where date of stand origin is known (whether from timber cutting or wildfire), but stand ages are very complex in the WISA AOs because most stands had been partially logged or high-graded sometime between about 1910 and 1970 with few retained records of such cutting. The resulting stands used by WISA are usually complex layers of trees of many ages and heights that are often not accurately reflected in VRI.

We used the VRI estimates of Quadratic Mean Diameter ("QMD", for trees >17.5-cm dbh) as a measure of tree size, and Stems/ha as a measure of tree density. Basal Area is a function of these two variables, and Volume is a function of Basal Area and Height, so we used the first principle variables (QMD and

Height), rather than the further derived variables. VRI gives these estimates separately by layer, but includes trees >12.5-cm dbh in the Layer 1 stems/ha. To put density on the same footing as QMD, i.e. only considering trees >17.5-cm dbh, the Layer 1 density of trees >17.5-cm dbh was back-estimated from Basal Area and QMD. For all layers in a given polygon, Basal Area>17.5 and Stems/ha >17.5 were summed, and then used to calculate QMD >17.5 of the stand considering all layers.

Variable Selection

Among the stand variables that were available, we examined each for suitability for inclusion in any possible modeling and for collinearity. These included Crown Closure for layers >15-m height, Age (years), QMD, Height and Density (Table 4).

Age was the maximum age for any layer in the polygon. In the telemetry sample, only four of the 309 polygons had a veteran layer (Layer 1 but taller than Rank 1 layer). While many veterans were present, they were included as part of the Rank 1 layer. While this lack of a separate veteran layer might significantly impact development of a model for nest tree choice, the impact on a foraging habitat model was probably not as significant. For the Rank 1 layer, often two ages were given representing a complex set of possible ages within a single layer. In that case, the older of the two ages was used. Similarly, sometimes two heights were given for a single layer, in which case the taller of the two heights was used.

Density was highly correlated only with Crown Closure (r = 0.66, Table 4) so Density was used instead of Crown Closure. Density can be measured and verified in field plots while Crown Closure is difficult to estimate consistently. Density had also been used as the primary variable in previous analyses (e.g., Gyug et al. 2010), and in the management recommendations of the WISA Best Management Practices. Crown Closure was also correlated with Age, QMD and Height, so was not a good variable to include in modeling.

The other three variables (Age, QMD and Height) were all positively intercorrelated. Age and QMD had a complex relationship. QMD increased with age (almost linearly, but with the increase in QMD slowing with advancing age) but QMD also increased, or at least was highly variable, within a group of stands that were mapped in VRI as about 100 years old. VRI-assigned stand age therefore is not a particularly good variable for application to a model because a) it does not appear to be used entirely consistently, and b) ages seem to be very difficult to apply to many of these multi-layered and previously-partially-cut stands. Therefore, Age was not used in the modeling.

Both QMD and Height were considered as variables, although because of collinearity, complications would arise if included in the same regression. For average stands in the telemetry sample, Height topped out between 30 and 35 m as QMD continued to increase, so the relationship between the two was only linear up to about QMD = 40 (Figure 6).

Table 4. Correlation of VRI stand variables within the 95%-detection-containing radius around each nest or territory on a polygon-by-polygon basis across all samples (n = 308 polygons, not weighted by area). Lw% correlation is just for Okanagan region (n = 161 polygons).

	Density	Crown Closure	Age	QMD	Height	Pl%
Density	1					
Crown Closure	0.66	1				
Age	0.30	0.64	1			
QMD	0.22	0.54	0.76	1		
Height	0.40	0.73	0.87	0.89	1	
Pl%	0.33	0.06	-0.11	-0.10	-0.13	
Lw%	0.08	0.31	0.17	0.14	-0.14	-0.08

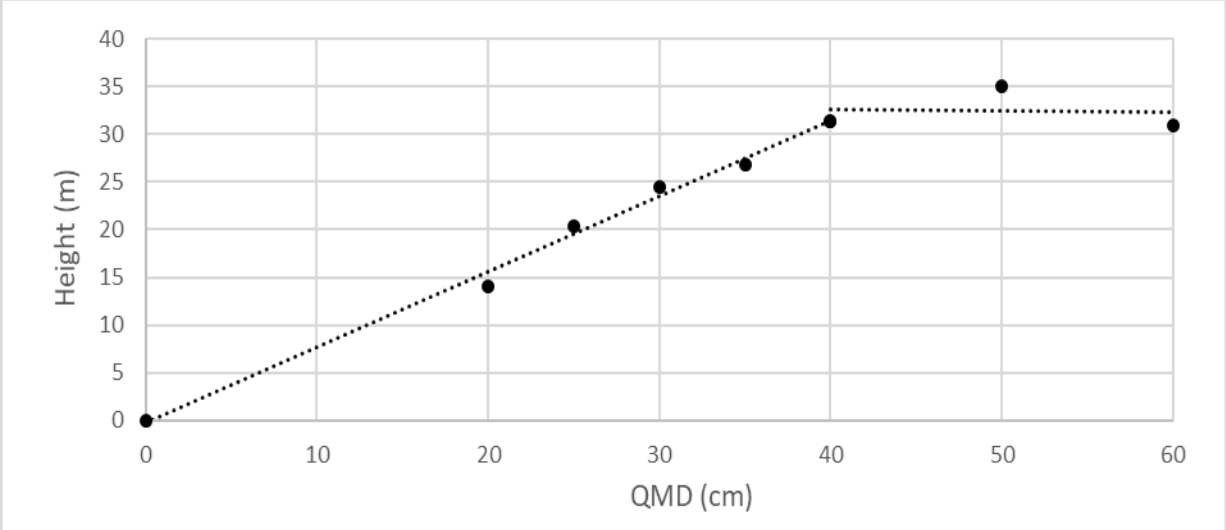


Figure 6. VRI Height by 5-cm classes regressed against mean Quadratic Mean Diameter (QMD) for those classes. The lines fit to the points graphically represent a very good linear fit up to QMD = 40 cm (r = 0.996), and then a flat line (no significant slope, r = 0.08) at larger QMDs.

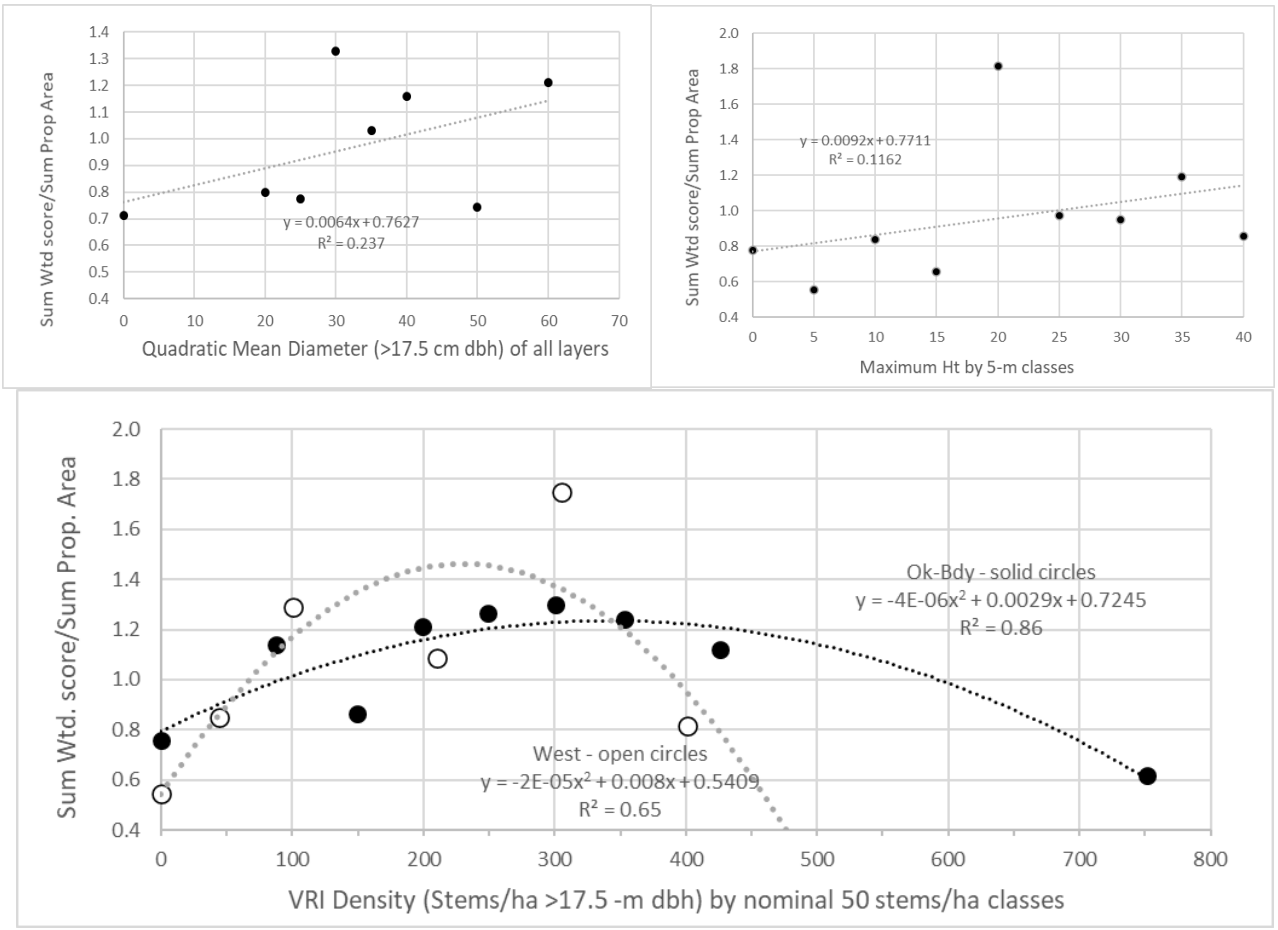


Figure 7. Exploration of VRI stand variables to use in modeling for 14 nesting territories. Used vs available selection ratio from telemetry data using the summed use/summed available for each class of x-axis variable, including QMD, Height and Tree Density. Density initially based on rounded 50-stems/ha classes later grouped to keep proportion of total area available similar for each class. Observed average densities were used on the x-axis for each nominal tree density class.

Examining the telemetry sample areas, selection of foraging habitat by WISA increased with increasing QMD and Height (Figure 7) becoming generally positive for heights ≥20 m and QMD ≥30-cm dbh. Correlation of QMD ($r = 0.49$, $p = 0.22$) was slightly better than for Height ($r = 0.34$) and appeared to be more consistently above selection ratio of 1.0 for QMDs ≥30 cm dbh.

Selection of foraging habitat by density differed between the two regions (Figure 7). In the Okanagan-Boundary, the fitted line was positive for densities between 100 and 600 stems/ha, and negative for densities above and below that range. Very few high-density stands were available in the telemetry sample so stands with densities >475 stems/ha were grouped as one (average 750 stems/ha), i.e., WISA appear to select breeding territories that do not contain many such stands, and no such stands in the West (maximum was 505 stems/ha). In the West, selection was positive between 75 and 350 stems/ha, and negative for densities above and below that. The same regional trends of tree densities (lower in the West compared to the Okanagan) and WISA response to tree densities noted here were also noted in WISA distribution at the AO level (Drever et al. 2015, see Appendix 3 of this report). Lower tree

densities in the West may have been because elevations used by WISA were lower in the West, and lower elevations may tend to have lower tree densities in dry areas of the southern interior of B.C., although there may be other causes. The fitted functions should not be extrapolated above the densities available (450 stems/ha in the West, 750 stems/ha in the Okanagan-Boundary) because the predicted selection will plunge quickly at higher densities.

For tree species, correlation of the used/available selection ratio was only high for Lw% (just for the Okanagan; r = 0.83, p = 0.003) for the 14 nest territories (Figure 8). Selection ratio was above 1.0 for Lw% ≥40%. Lw% was not correlated with any of the other stand variables, nor with Pl% (Table 4). Correlation with Pl% was negative (as expected based on St-Amand 2017) but r was low (0.27, p = 0.49). Pl% only applied to the Okanagan because maximum Pl% in any polygon in the telemetry sample was only 22% in the West, and Pl was only present in 3% of the VRI polygons.

Correlation of selection with other tree species percentages were low and not significant. There was no correlation with Fd% (for regions combined or for the West (r <0.001, r = 0.14 respectively), even though that is their primary foraging tree (St-Amand 2017). It appeared the territories that WISA select virtually all contain high amounts of Fd so that presence of Fd is simply a given in the telemetry dataset, i.e., in the territories that WISA select for nesting, both within the AO, and characterizing the AO as a whole (see Bioclimatic Envelope section).

There was no correlation of selection with Py% (for the West, r <0.001). Fd% was correlated with Pl% (r = 0.60) because as one increased the other necessarily decreased, which as above, only really applied to the Okanagan region. Fd% was also correlated with Lw% (r = 0.28, p <0.001). In the West region, Fd% was not significantly correlated with Py% (r = 0.098, p = 0.24).

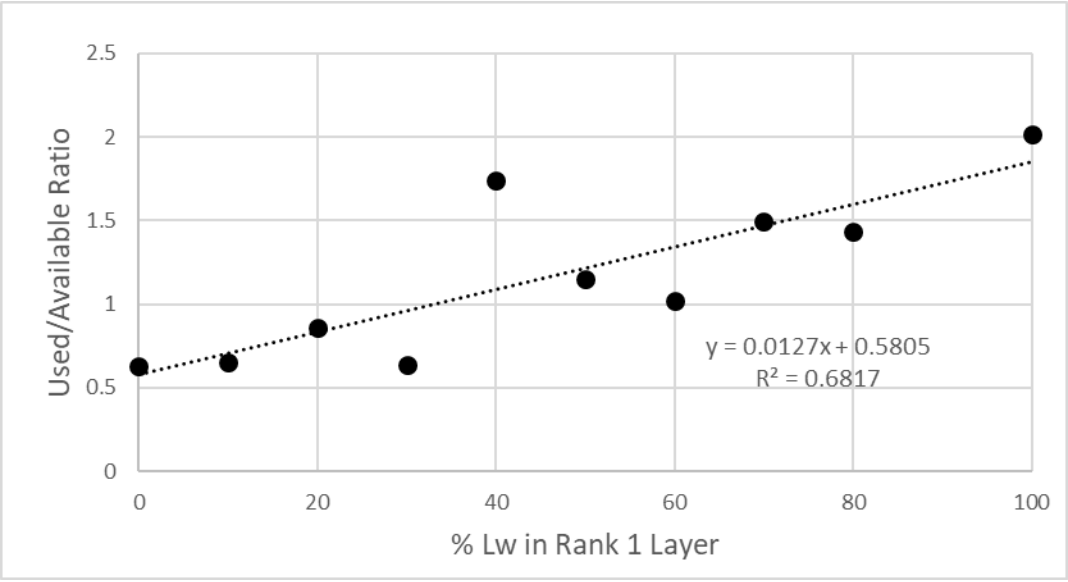


Figure 8. Regression of selection ratio (used/available) against Lw% in VRI Rank 1 layer. No polygons were available in the Lw 90% class.

Table 5. Best foraging habitat subset model selection for the Okanagan using AIC. Models with ΔAIC ≤2.0 may be considered as alternatives to the top model.

Model Terms*	df	AIC	ΔAIC	Likeli-hood*
Lw%	1	55.544	0.00	1.000
Lw% + Density + Density^2	3	56.576	1.03	1.675
Lw% + Density	2	57.147	1.60	2.229
Lw% + Density + Density^2 + Density^3 (Full Model)	4	58.575	3.03	4.552
Density + Density^2	2	59.393	3.85	6.853
Density + Density^2 + Density^3	3	61.393	5.85	18.629
Density	1	63.064	7.52	42.953

* **L**ikelihood that top model will be better than model$_i$.

*Variable Importance (standardized sum of Akaike weights of subsets considered): Lw% 0.91, Density 0.60, Density^2 0.41, Density^3 0.11.

Regression

Three variables were initially entered into multiple linear regression: QMD, Density (and its square and cube) and Lw% (for the Okanagan only). Each of the variables were grouped as in Figures 6 to 8, and then summed across all nesting territories. Wherever Density was 0, Lw% was also zeroed because the Lw% would only apply to trees smaller than 17.5-cm dbh which were not considered part of either the Density or QMD variables. For example, polygons with 20-cm dbh QMD, 200 stems/ha, and 30% Lw would be summed for weighted use (where each nest territory = 1, total of all sums = 14) and then summed for weighted availability across all nests territories (again where each nest territory = 1, total of all sums = 14). Then selection for that set of polygons estimated as summed use/summed available. Classes were either combined or dropped from the analysis when the proportion of a given class for a given analysis was <0.5% of the entire sample (and therefore with a high probability of no use recorded).

QMD had virtually no effect on the multiple regression (statistics not presented). Upon closer inspection, QMD was correlated with stand density (squared function, r = -0.88) with denser stands being made up of smaller trees on average. However, this correlation only became clear when the polygons with zero density were removed from the correlation (Figure 9). Therefore, QMD was not suitable as a variable to enter into a multiple regression with density.

For the Okanagan, AIC was used to select and evaluate the best subset model against the full model (Table 5). The most likely and parsimonious model was based only on Lw%. However, a number of other subsets had ΔAIC <2, so were possible alternatives. Based on the significant regression of the selection ratio on Density, and that Density has field-observable effects on WISA foraging behaviour (St-Amand 2017, Gyug unpublished data), the second model in Table 5 was selected.

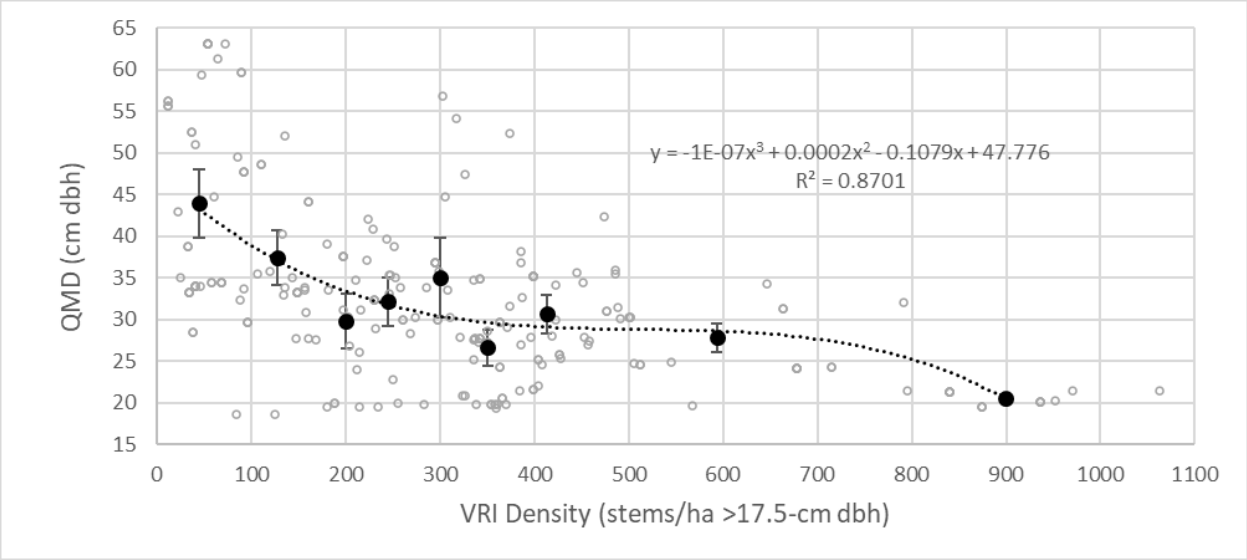


Figure 9. Regression of QMD vs VRI stand density for telemetry sample polygons with density >0 using nominal 50 stems/ha classes that were grouped as required to retain sample size. Error bars are ± 2 SE. Individual polygon data points (n = 233) shown as open grey dots. The curve fitted to individual polygons was almost identical to curve fitted from density class averages.

The Lw% effect on the foraging selection ratio was highly significant in the Okanagan. Density had a much lower effect on the predicted selection ratio than did Lw%, and the predictive power of Density was overwhelmed by Lw%. For instance, given 1 stem/ha, the selection ratio becomes positive when Lw% is >43%. This should not be the actual case because the foraging selection ratio should never truly be positive for a density of 1 stem/ha. However, this is what the model using Lw% and based on the telemetry data would predict. In other words, this particular regression model did not appear to produce a useful result. There was only one polygon with a stem density between 1 and 88 in the Okanagan nest telemetry sample (1.4% of sampled area), so the result cannot be confirmed with VRI data alone. We do not recommend that Lw% be added to the Okanagan model without further verification or testing of the actual usefulness of that factor. The Okanagan model therefore defaulted to one based on density and its square.

For the Okanagan, regression statistics were: $R^2 = 0.66$, $F_{2,6} = 5.84$, $p = 0.04$. The final regression equation was:

(**Eq^n 1**) **Selection Ratio = 0.813488 + 0.00263410 Density – 3.89413E-06 Density^2**

The rating has a lower end minimum value of 0.81 where there is no VRI density (i.e., the intercept), and a maximum value of 1.2589 at densities of 335-341 stems/ha. The rating has an upper end minimum value of 0.60 at 750 stems/ha. Density can only be validly entered into the regression equation over the range examined, i.e., up to 750 stems/ha. Above that density, the squared factor will make any predicted selection ratio very low. For entry into the model, any densities above 750 stems/ha were reduced to 750 to be validly entered into the equation. While it may seem odd for a species that relies on trees, that the predicted selection ratio is lower at very high tree densities than when there are no

trees (VRI density = 0), this is a limitation of using VRI as discussed later. In fact, many of the VRI polygons that had no density estimated, actually had some trees.

For the West, the same model was used, i.e., density and its square, to predict selection even though the regression was not significant. Regression statistics were $R^2 = 0.22$, $F_{2,5} = 0.71$, $p = 0.53$. The final regression equation was:

(**Eq^n 2**) **Selection Ratio = 0.335042 + 0.0117296 Density – 2.3197E-05 Density^2**

The rating has a lower end minimum value of 0.335 where there is no VRI density (i.e., the intercept), and a maximum value of 1.818 at densities of 250-256 stems/ha. The rating has an upper end minimum value of 0.916 at 450 stems/ha. Density can only be validly entered into the regression equation over the practical range examined, i.e., up to 450 stems/ha (not including the single very small polygon with 503 stems/ha). Above that density, the squared factor will make any predicted selection ratio very low. For entry into the model, any densities above 450 stems/ha were reduced to 450 to be validly entered into the equation.

Application

We attached the foraging selection scores to the existing WISA database to rank relative regression model output. All densities >750 stems/ha were changed to 750 stems/ha for the Okanagan, and >450 stems/ha changed to 450 stems/ha for the West as the upper limit of the input data for this model regression equation.

A high proportion of WISA detections in both regions were in polygons with no VRI density (Figure 10, 0.800 class for Okanagan-Boundary, 0.600 class for West). A higher proportion of WISA detections in the Okanagan-Boundary were in the maximum selection score class compared to the West. The distribution of selection scores in the West were spread out more evenly than in the Okanagan-Boundary.

These were based on all detections (excepting telemetry detections, which were not part of the WISA database) from many different projects with unknown possible detection biases. To examine for possible biases in the dataset, the relative proportions by broad VRI density class were compared to the 2014 patch and road monitoring, which was conducted at unbiased pre-set locations (Gyug 2014). The proportion of WISA detections in polygons with no VRI density did not differ between 2014 (n = 297) and all other detections (n = 3985) (Chi-square test, p = 0.48). In the Okanagan, the proportion of WISA detections in polygons with VRI density >600 stems/ha did not differ between 2014 (n = 128) and all other detections (n = 2089) (Chi-square test, p = 0.32). Therefore, the entire set of WISA detections were considered in setting the foraging ratings.

Foraging model ratings were based on a modified 6-class rating system of selections score classes that contained given percentages of the WISA detections relative to the maximum (Table 6), but not including those detections found in VRI polygons with no density. The percentages given in Table 6 are from RISC (1999) and were only able to be approximately met by this particular dataset.

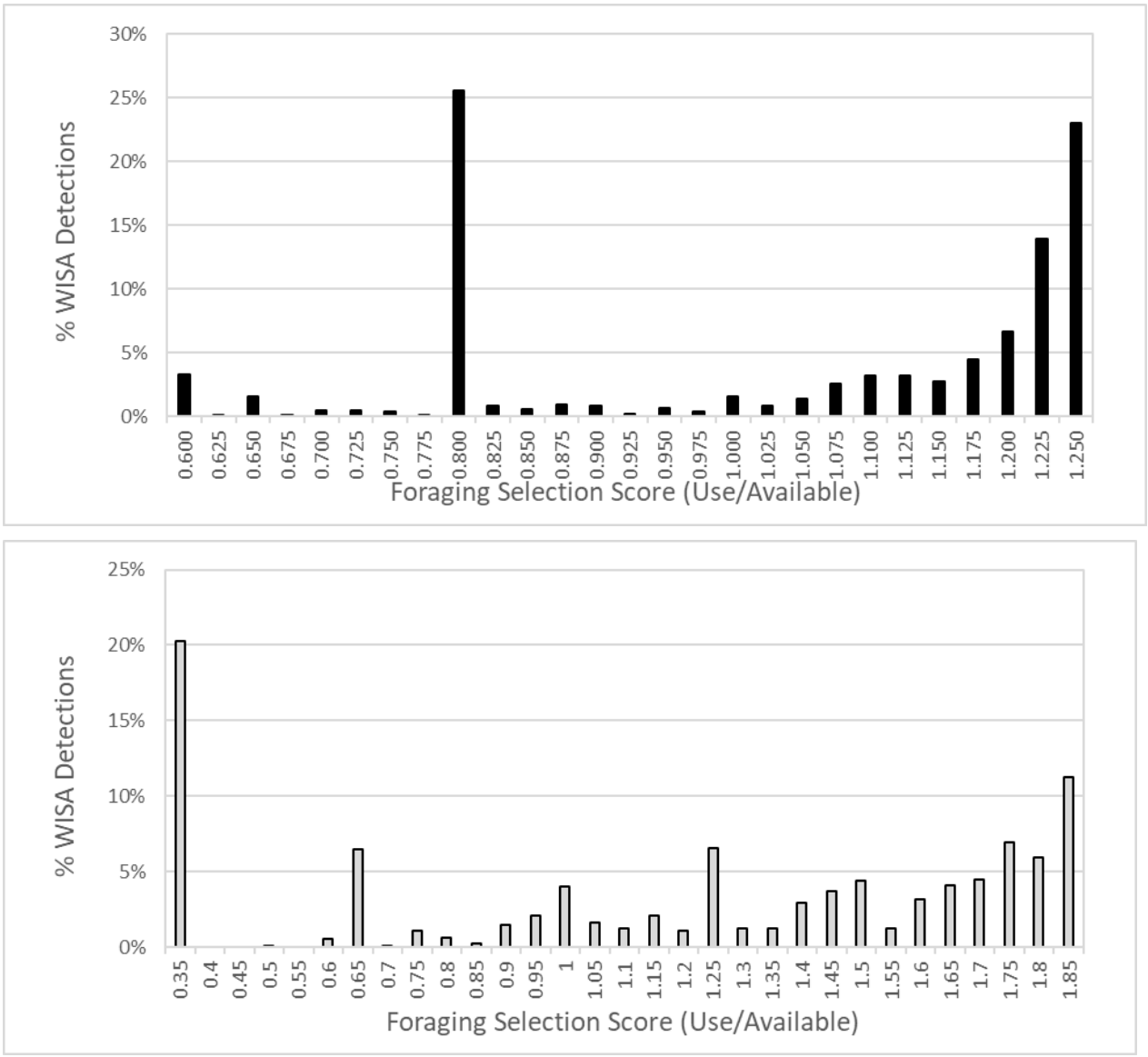


Figure 10. % of all WISA detections by foraging selection score class (Use/Available) extrapolated to Okanagan-Boundary WISA AO (top) and West WISA AO (bottom).

Table 6. Foraging Habitat Suitability ratings by selection score from model based on VRI Density of stems/ha >17.5-cm dbh and on distribution of WISA detections by density.

Rating Class	% of WISA detections	VRI Tree Density Range	Foraging Selection Score values	As applied to Combined Model
Okanagan-Boundary				
High (1)	76-100	291-386	>1.250	Useful habitat
Moderate (2 & 3)	26-75	121-290, 387-555	1.075 – 1.250	
Low (4)	6-25	10-120, 556-741	0.625 – 1.074	Not as useful
Very Low (5)	1-5	1-9, >741	<0.625	Not useful habitat
Nil (6)	0	Zero	Non-forest (0.813)	
West				
High (1)	76-100	182-325	>1.700	Useful habitat
Moderate (2 & 3)	26-75	77-181, 326-427	1.111 – 1.700	
Low (4)	6-25	27-76, 428-479	0.630 – 1.110	Not as useful
Very Low (5)	1-5	1-26, >479	<0.630	Not useful habitat
Nil (6)	0	Zero	Non-forest (0.335)	

Limitations

We verified the VRI estimates of tree density using densities from tree count plots (n = 2983 fixed radius plots from 2006-2020). Regression of plot-estimated density of stems >17.5-cm dbh against VRI-estimated density revealed a significant difference in the two estimates (Figure 11). VRI stems/ha underestimates plot tree density when plot density is <146 stems/ha, and overestimates when plot density is >146 stems/ha. The regression equations were very similar whether individual plots were used (n = 2983), only polygons with at least 4 plots per polygon used (n = 272), or only polygons with at least 10 plots per polygon (n = 66, a shown in Figure 11). While the 90% confidence interval of the regression is fairly tight, the 90% prediction interval, i.e., what can be expected in a single actual VRI polygon, is quite wide.

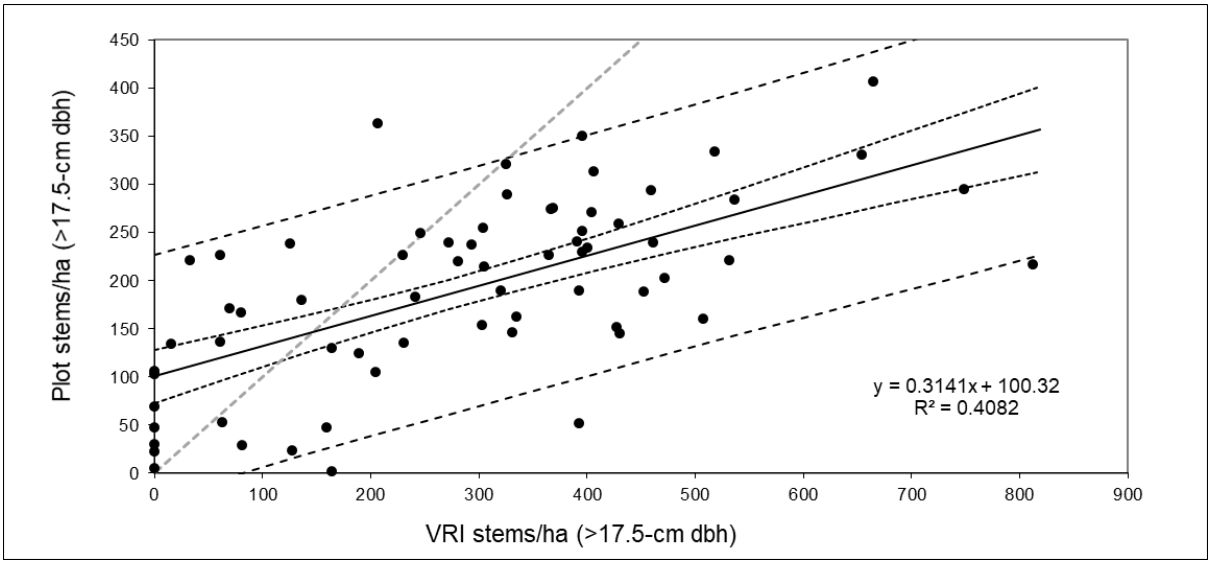


Figure 11. Regression of plot-derived tree densities against VRI-estimated tree densities for VRI polygons with ≥10 tree count plots per polygon (n = 66). 90% confidence interval (fine dashed line) and 90% prediction interval (coarse dashed line) of regression shown. Grey-dashed line is the 1:1 ratio that would be expected if VRI stems/ha accurately predicted Plot stems/ha. Note that, on average, VRI underestimated plot tree density when VRI density was below 146 trees/ha, and overestimated plot density when VRI density was above 146 trees/ha.

To provide examples, for VRI density of 50 stems/ha, observed plot tree density is predicted to be 116 trees/ha; similarly, VRI 200 stems/ha → Plot 163 stems/ha; VRI 400 stems/ha → Plot 226 stems/ha; and VRI 600 stems/ha → Plot 288 stems/ha. At this point we do not know which method is more accurate. However, this apparent discrepancy does mean that VRI densities should not be applied directly to management decisions where tree densities are involved until this can be resolved. We correlated Basal Area and QMD of the VRI polygons with Basal Area and QMD estimated from the tree count plots, and found the same discrepancy (VRI tended to overestimate Basal Area and QMD at high values, and underestimate at low values compared to plot estimates).

The ratings were based on the assumption that polygons with no trees would not be suitable for foraging, i.e., would be non-habitat. However, in many cutblocks where some trees have been retained, the VRI had simply been "emptied" with no recognition of the actual density of trees retained. This problem was common, and led to the polygon-by-polygon assessments of actual tree density in the original 2008 nest habitat modeling. This will be a severe limitation of this modeling because there were a number of telemetry locations in cutblocks with no "VRI trees", but which in fact contained trees, and which were used by WISA. It was not possible within this project in 2020 to correct all these polygons. Field assessment will be required to verify actual stand conditions before management decisions are made for any site. Those stand conditions will include presence and percentages of Fd, Lw, Pl and Py. Even though these are not within the foraging model equation, Fd is a required and preferred foraging tree, with mid-size to larger trees preferred (St-Amand 2017), Lw tended to be preferred in foraging polygons (see Model Development section), and Pl was not useful as a foraging tree (St-Amand 2017).

Table 7. Summary of areas of WISA nesting habitat suitability model (2018) and foraging habitat model (2020) based on telemetry data. Foraging habitat was used to modify potential usefulness of nesting habitat for the combined result.

Suitability Class	Okanagan-Boundary			West		
	Nesting	Foraging	Combined*	Nesting	Foraging	Combined*
1	9.6	85.0	7.0	-	209.2	-
2	24.0	186.4	16.8	-	220.5	-
3	60.3		46.8	60.2		42.2
4	179.6	86.9	157.5	272.9	36.3	240.2
5	211.6	58.9	256.8	337.1	73.4	387.6
6	36.5	104.3	36.5	72.3	203.0	72.3
Totals	**521.6**	**521.6**	**521.3**	**742.5**	**742.5**	**742.3**

*Totals of the Combined Model are not identical to the original shapefiles because of rounding when VRI polygons were converted to 20-m pixel grid, and then the pixels re-converted back to polygons

Verification

The rating scores were attached to the VRI polygons for the AO and the areas of each foraging suitability class for each region tabulated (Table 7, see maps in Appendix 1). Overall there appeared to be far more suitable foraging habitat available than suitable nest habitat.

We first examined the amount of Moderate and High suitability foraging habitat were found in the 95% radius and the 95% kernel of each of the 14 nests with telemetry data. Mean area within the 95% radius was 40.9 ha (SD 26.9 ha). Mean amount of High and Moderate suitability foraging habitat was 71% (SD 18%) of the 95% radius. Mean area of High and Moderate suitability foraging habitat within the 95% radius was 25.3 ha (SD 19.7 ha). [Note that 25.3/40.9 is 62%, not 71%, however, because the 95% radius was different for each nest, and area is a squared factor of the radius, the percentages will not be directly comparable.] Looking at the 95% kernel, the mean area of High and Moderate suitability foraging habitat within it was similar (22.6 ha, SD 17.1 ha) to the 95% radius. On average, the 95% kernel was 92% of the size of the 95% radius (range 50% to 137%).

To verify the foraging model, we examined other WISA nests to see if the same amounts of Moderate and High suitability foraging habitat were available to each of the other nests not used to build the model. Criteria for including these nests were: 1) within the AO, 2) not within the 95% radius of any of the telemetry samples, , 3) >500 m from the edge of the AO (because the VRI modeling stopped right at the edge of the AO), 4) the 2018 VRI was applicable, i.e., there had been no major habitat modifications (e.g., timber harvest or wildfire) since the nest was active, and 5) at least 500 m from each other. For nests within 500 m of each other, one was randomly selected. This left 159 nests in the verification sample; 87 in the Okanagan-Boundary and 72 in the West.

We examined the amount of Moderate and High suitability foraging habitat first in relation to the mean 95% radius around a nest (342 m; 36.745 ha), and then to the mean 95% radius plus 1 SD (122 m) (464 m, 67.637 ha). If the distribution was normal, the expectation for the verification sample would be half of the samples would be above the mean, and that 68% of the samples would be within 1 SD of the mean, leaving 16% >1 SD below the mean (and 16% >1 SD above the mean). One SD (18%) below the mean (71%) was 53% of the mean 342-m radius area, or 19.5 ha.

In the verification sample, 92 of nests (58%) were at the mean expected level of 25.5 ha Moderate and High suitability foraging habitat, i.e. slightly more than expected. 63 nests (40%) were below the expected 53% level of 19.5 ha, which was more than twice the number expected. Of these 63 nests, 36 were in the Okanagan-Boundary (41% of verification nests), and 27 in the West (38% of verification nests). These regional proportions were fairly similar, therefore regional differences were not likely contributing to the higher than expected number >1 SD below the mean area.

The radius around each nest was expanded to 464 m to see how many nests then contained the average expected level of 25.3 ha (which we considered the average apparently required amount of foraging habitat), and then the average minus 1 SD (in terms of %, 19.5 ha). In the 464-m radius, 132 (83%) of the nests contained >25.3 ha of Moderate and High foraging habitat. Thirteen nests (8.2%) contained <19.5 ha, i.e., were not within 1 SD of the apparently required amount, even in an expanded area.

We examined the setting of each of the 13 nests not having 19.5 ha foraging habitat within 464-m radius to see why the foraging suitability model may not have fit. The nests were evenly split between the Okanagan-Boundary (n = 6) and West (n = 7) regions, so regional differences in the model were not likely. The setting of these nests were:

1. Within At groves, with mixed conifers or with long distances to coniferous stands (n = 5),
2. Within or adjacent to dense young stands (n = 3)
3. At the edge of ST Cut and dense stands (n = 2)
4. Nest in WTP within ST Cut that had been emptied in VRI but had 36-67 trees/ha (n = 1)
5. In Partial Cut for which attributes had been zeroed in VRI but was still treed (n = 1)
6. Nesting in MPB-salvaged ranchland (n = 1)

We did not alter the model to find a way to fit these nests because there will almost always be some nests where WISA make use of what may appear to be lower suitability foraging habitat. Some of these will be because of limits to VRI accuracy, but others, it appeared that WISA simply had to travel further than usual to meet foraging needs.

For management implications of these analyses were that potential WISA breeding territories should contain (on average) >25.3 ha suitable foraging habitat within 342 m radius (36.7 ha). However, for a small proportion of the population, containing only 19.5 ha within a 464-m radius (67.6 ha) might be acceptable. However, the lower of the two boundaries (19.5 ha in 500-m radius) cannot be the norm – if it was, habitat would be degraded because most WISA would not be likely to establish breeding territories there

Combined Habitat Model

Rationale

Foraging suitability was used in two ways to modify the nest habitat model. First a given amount of foraging habitat was required within a given area, without which the usefulness of nesting habitat is degraded. The derivation of these areas have been given in the previous section (see Verification). To summarize, around any given pixel (i.e., any given point in the AO), at least 19.5 ha foraging habitat (mean – 1SD) is required within a 340-m radius for nesting habitat to be useful, i.e. for it to retain its suitability,, or failing to meet that goal, at least 19.5 ha within a 460-m radius (mean + 1 SD).

Besides amount of foraging habitat within a given distance of a nest, the spatial configuration was also important. We examined the distance that WISA will move to foraging habitat from a nest. The FLNRORD/CWS WISA database contained 446 known nest trees found between 1994 and 2019, 118 (26.5%) of which were in seed tree cuts, partial cuts or other habitats where there were fewer than 200 trees/ha (termed "forest" for this analysis). When these nest trees were in sites with very scarce trees, typically <20 trees/ha, WISA could easily be seen commuting on almost every foraging trip out from the nest into nearby forested habitat to gather food for nestlings. St-Amand (2017) observed that WISA will not cross open spaces of >160 m, so that figure serves as a maximum that suitable nest habitat can occur from suitable foraging habitat.

Here, we analyzed distance from forest that WISA have been observed nesting to attempt to estimate the distance from foraging habitat that WISA can tolerate and still support successful nesting. In GIS, we examined every WISA nest found outside of forests, measured the distance of nest to forest, and estimated the number of trees/ha in the nest polygon in three broad classes (<50/ha, 50-100/ha, 100-200/ha) based on plot data, field visual estimates (Gyug, unpublished data), or orthophoto interpretation. VRI estimates of tree densities in these sites were found to be unreliable because they were often zeroed, and even when a density was given, it did not necessarily appear to match the available plot data (see previous discussion on VRI limitations).

For WISA nesting in VRI polygons with <50 trees/ha (n = 29 nests, 6.5% of known nest trees), mean distance from forest was 55 m (SD 27 m), and maximum was 125 m (Figure 12). As the density of trees increased, so did the distance that WISA nested from a forest. For nest polygons with 50-100 trees/ha (n = 35, 7.9% of known nest trees), mean distance from forest was 102 m (SD 57 m) and maximum was 240 m. For nesting polygons with 100-200 trees/ha (n = 54 nests, 12.1% of known nest trees), mean distance from forest was 126 m (SD 116 m) and maximum was 577 m.

As tree densities increased, WISA appeared to be able to forage within the nesting polygon, and could therefore afford to nest further from forest. However, in the more open of these blocks (50-100/ha), WISA appeared to spend time in the denser parts of the blocks, where tree densities may have been >100 trees/ha (Gyug, unpublished observations). Given the maximum distance of 577 m, it is apparent that at least some of the polygons with 100-200 trees/ha could be used as foraging habitat without WISA needing to commute to nearby forest.

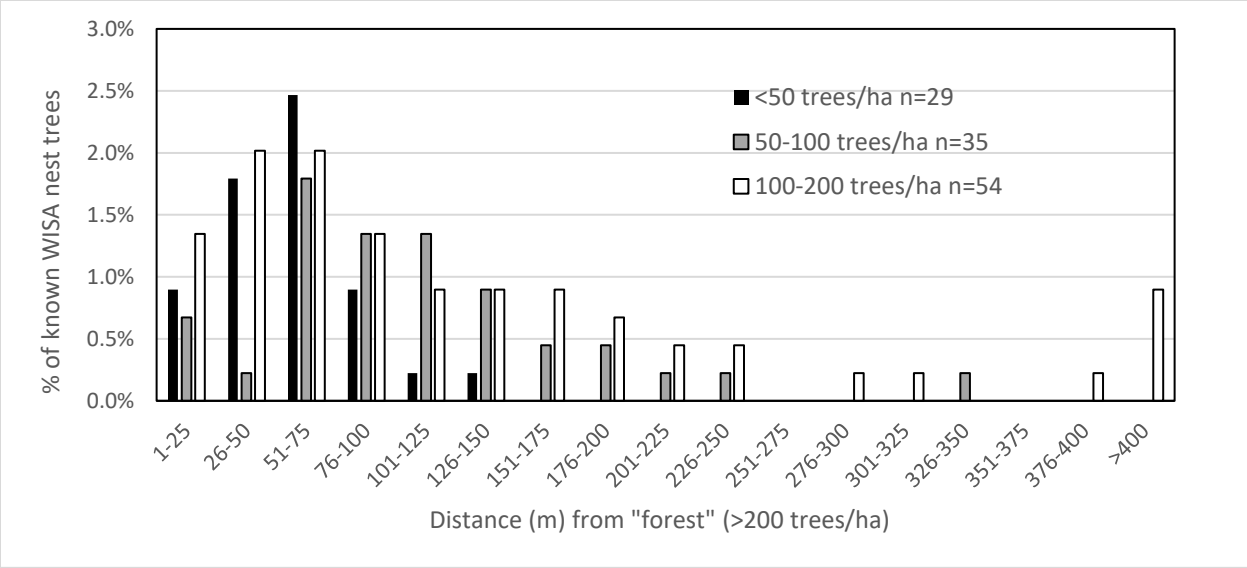


Figure 12. Distances of WISA nest trees within harvested cutblocks and openings grouped by 50-m distance class from forest (defined as stands with >200 trees/ha) and grouped by retained tree densities in the cutblocks or openings.

Application

The Nest habitat model shapefile made of adjusted or intact VRI polygons was converted to a grid with pixel size of 20 m. The foraging model was only used to adjust the nesting model by downgrading the nesting suitability where foraging suitability was insufficient (on average) to support successful breeding territories as per the ratings (Table 6). Since the nesting model already considered tree species presence and/or percentage, the foraging model based only on density was not hampered in this particular application by its simplicity.

Algorithms for combining the nest model and foraging model were done at three scales: 80 m, 340 m (mean 95% nest territory radius) and 460-m (radius of mean 95% nest territory area + 1 SD by area) as follows:

1. For open sites, e.g. seed tree cuts and open range, the 80-m scale (mean nest distance from forest where <50 trees/ha plus 1 SD) was used to adjust individual pixels as follows:
    a. All open sites such as Seedtree cuts had been modeled in 2008-2018 as maximum Low nesting suitability.
    b. In the combined model, Low suitability pixels only retained as Low if within 80 m of foraging habitat.
    c. Low nesting suitability adjusted down to Very Low combined suitability if >80 m from High, Moderate or Low foraging habitat if VRI tree density <100/ha.
    d. Using moving average, 80-m radius around any given Low pixel of low tree density must have at least 1 pixel of High, Moderate or Low foraging suitability in the 60-m neighbourhood to retain its Low suitability.

2. For any site with Low or better nest habitat suitability, the 340 m scale was used to reduce individual pixels of any nesting suitability if adequate High and Moderate suitability foraging habitat was unavailable.
    a. Using moving average, the 340-m radius around any given pixel must have ≥19.5 ha (53% of 340-m radius circle) High or Moderate foraging suitability (0.53 as mean of 340-m circular neighbourhood analysis).
    b. High, Moderate and Low nesting suitability pixels reduced in combined suitability if <45% High and Moderate foraging suitability available within 340 m by
        i. 2 levels for High and Moderately High,
        ii. 1 level for Moderate and Low,
3. Any site reduced in step 2, was reconsidered at the 460-m scale.
    a. If the 460-m neighbourhood around a pixel contained ≥19.5 ha High or Moderate foraging suitability (i.e., 0.29 as mean of 460-m circular neighbourhood analysis),
        i. then the rating, if reduced in Step 2 to Very Low, was re-raised to Low.
    b. If the 460-m neighbourhood around a pixel contained <19.5 ha High or Moderate foraging suitability (i.e., 0.29 as mean of 460-m circular neighbourhood analysis),
        i. then the rating, if reduced in Step 2 to Low, will be further reduced to Very Low.
4. Otherwise, no change.

Results and Discussion

For Moderate and better suitability nesting habitat, the final combined habitat suitability was reduced to 70-78% of the original nest model because of lack of sufficient or suitable foraging habitat (Table 7). Low suitability habitat decreased to 88% of the original; the losses resulting from downgrading of some Low suitability habitat, but some gains coming from Moderate or better habitat that was downgraded to Low. Very Low combined habitat suitability increased in area by 21% in the Okanagan-Boundary region, and 15% in the West when the foraging model was combined with the original 2018 nest model. This meant that 21% and 15% respectively in the Okanagan-Boundary and West of the assumed or modeled nesting habitat was essentially unavailable because of a lack of suitable foraging habitat.

Examining the results, some sites with apparently suitable tree densities were actually very young sites (e.g., 27 years old) in which some trees were just starting to be counted as >17.5-cm dbh. These therefore appeared to have suitable tree densities for WISA in the model, but in actuality, the very thick and dense understorey trees that were only slightly <17.5-cm dbh precluded such a site from being truly suitable foraging habitat. Therefore, age must be considered in model application. VRI polygons are not likely to be suitable if VRI-estimated age is <100 years old, or <58 years old for At.

Since the foraging model is based only on tree density, it will require assessment of tree species present to be applied usefully. Presence of Fd was almost a given in the telemetry sample from which the foraging model was developed, so the modeling did not discriminate well using that factor. Therefore, in terms of both GIS and field verification, sites must have Fd to be useful. In the Okanagan, Lw was also a very important factor in the modeling, even more so than density, at least within the range of densities WISA typically use extensively. In the 2008 modeling, presence of Lw in the VRI was found to be fairly reliable, even if the Lw% in a given VRI polygon may not have been as reliable.

Potential Enhancement Sites

Potential nest tree enhancement sites were only considered in the West region as part of this Habitat Conservation Trust Fund/Okanagan Nation Alliance project. The locations of sites for enhancement were detailed separately because any potential sites needed to be field verified for WISA potential, and for suitable trees for enhancement, after which forest licensees and others will need to be consulted.

When applying the combined model to choose enhancement sites, the three factor mentioned in the previous section will need to be considered, i.e., stand age and Fd presence. The presence of At will also be crucial as that is the primary nest tree in the West. At presence was checked in all polygons in 2008 using stereo aerial photo interpretation and Landsat enhanced to show deciduous component. The modeled polygon attributes were adjusted as necessary to show presence of At even if the VRI did not show its presence.

Site choice will also need to consider the Bioclimatic Envelope, in particular avoiding areas that should probably be excluded from the AO whenever AO boundaries are next revised. It may also be possible to extend consideration of enhancement site choice to some locations that are currently outside the AO but still within the Bioclimatic Envelope. However, there would be no WISA habitat modeling at such a site as the modeling was limited to the AO. Should such a site outside the AO be considered for enhancement, the model algorithms could be applied to that locality to determine how the suitability would be modeled.

Habitat Capability

These models were only for current suitability, not capability, i.e. for potential suitability. Almost any potentially forested polygon in the AO is capable of becoming suitable WISA nesting and/or foraging habitat if suitable nest trees can be developed from within the stand, and suitable foraging conditions exist. A capability model could be developed using the same WISA data and VRI based on tree potential, i.e., primarily based on Site Index. On forested sites (i.e., where Site Index >0), mean Site Index for Class 1 nest suitability habitat was 17.0 (S.D. 2.0, minimum 14.0, n = 163 polygons), and for Classes 2-5 the mean Site Index ranged from 13.5 to 15.0, with standard deviations in the range of 2.6-3.4 (between 478 and 7153 polygons for each class). Except for Class 1 habitat, all other habitats had similar ranges of Site Index.

For long-term management, site capability needs to be considered because many stands currently with Very Low suitability could become suitable. Under current management, these stands are not considered for tree retention and long-term (decades to centuries) nest tree recruitment. However, without taking these stands into consideration, the long-term prognosis will be for continued habitat loss, as new veterans will not be recruited into many potentially suitable stands.

Data Products

BC Bioclimatic envelope (2020)

mapmatgeo - 600-m pixel grid in geographic projection containing MAP, MAT, T_ave01 and WISA envelopes at 95%, 90% and 75%

mapmat_wisa_alb – shapefile of the above grid in BC Albers projection

wisa_map_mat_set_geo.xlsx - Excel file of WISA observations with MAP, MAT, T_ave01 attached

Nest Habitat Model (2018)

wisa_suit_20180326 – Shapefile from VRI polygon base 01/01/2016 adjusted with boundary and attribute changes to January-March 2018. This shapefile contains VRI fields, modeling adjustment fields based on photo review, WISA key factor and adjustment fields, and the final 2018 suitability rating.

see Gyug 2018 for full list; the file above was the only one used for the current project

Foraging Habitat Model and Combined Model (2020)

wisa_vri - 20-m pixel grid of WISA AO with cells identified by Value field which joins to Object_Id field of wisa_suit_20180326. The VRI fields pertinent to foraging model and the foraging selection score and Foraging Model suitability class have been attached.

comb_suit_ – 20-m pixel grid of WISA AO with nesting, foraging and combined suitability classes

wisa_vri_combined_suitability_2020-07-24 – shapefile set, BC Albers, contains relevant VRI fields, and Object_ID field for joining to wisa_suit_20180326 if required. Contains 2018 suitability field, foraging suitability field, combined suitability field, as well as the 3 steps used to combine the 2018 and foraging suitability classes. File has been converted from 20-m pixel grid back to polygons, so the polygon boundaries do not exactly match the 2018 VRI polygon boundaries

wisa_telemetry_95pct_nest_radius – polygon shapefile set of radius around nests containing 95% of telemetry observations (excepting significant post-nesting movements). BC Albers.

wisa_tele_95pct_kernels – polygon shapefile set of 95% kernels using telemetry detections (excepting significant post-nesting movements). BC Albers.

wisa_foraging_telem_2020_analysis 2020-07-23_final.xlsx - Excel data for analyses

Total size of all these files was >200 MB (uncompressed).

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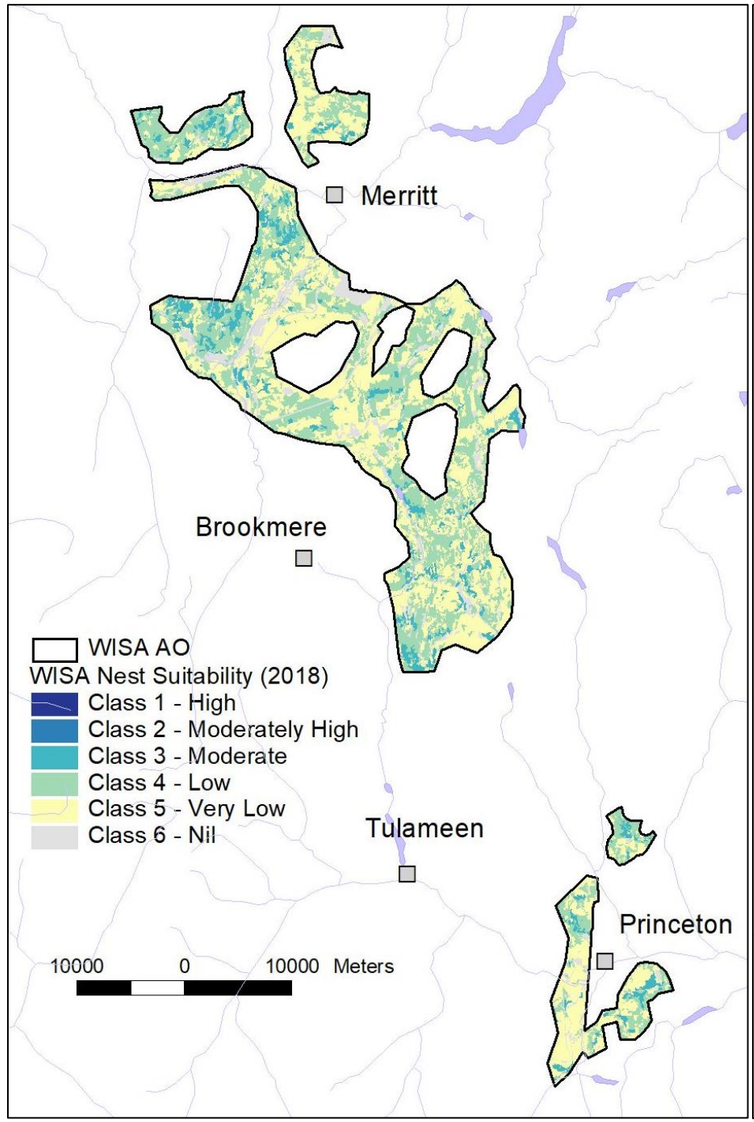
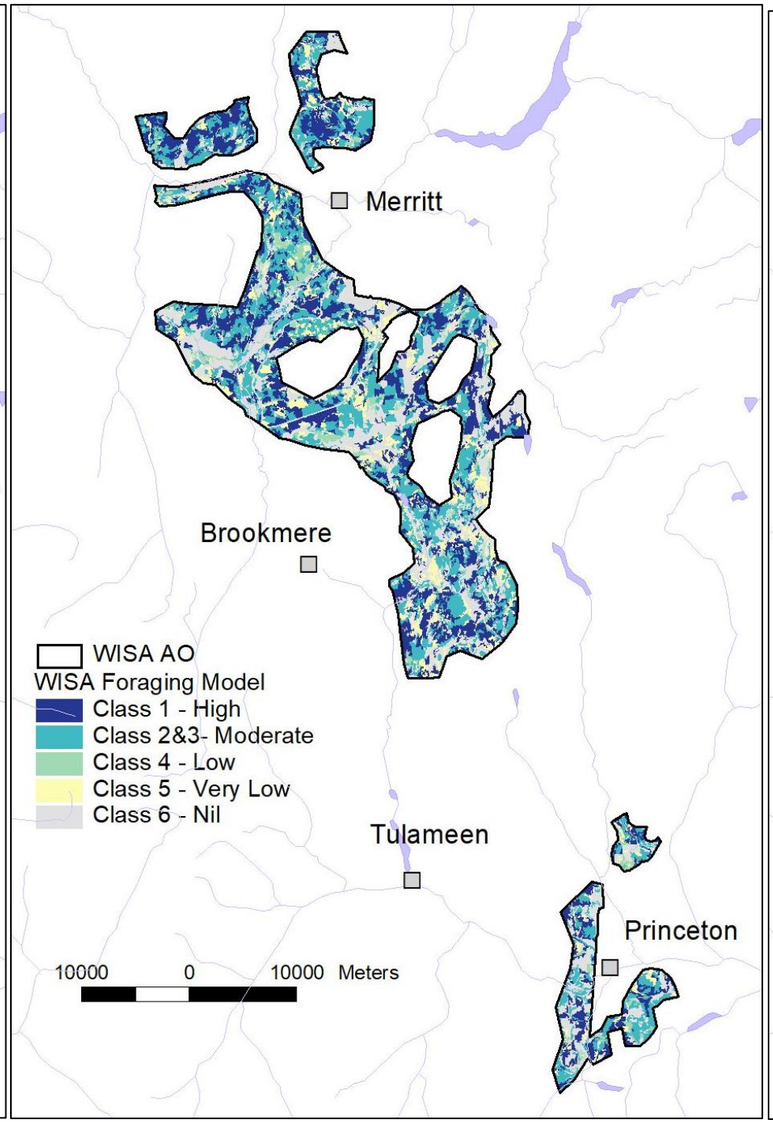
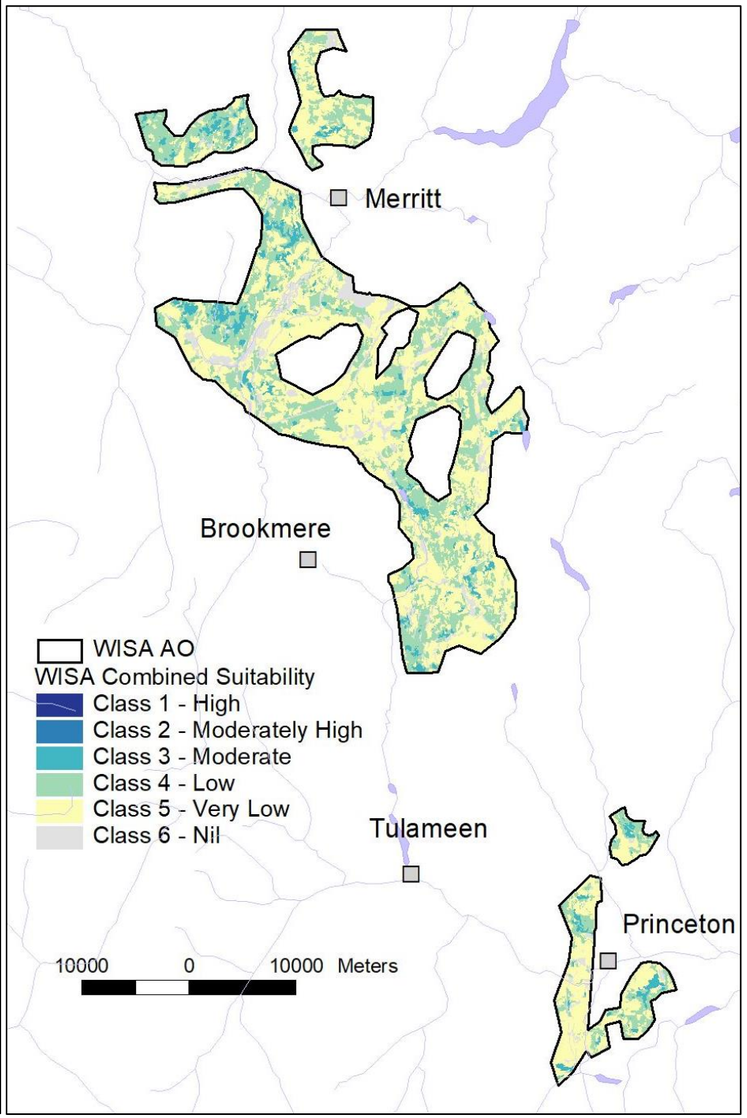
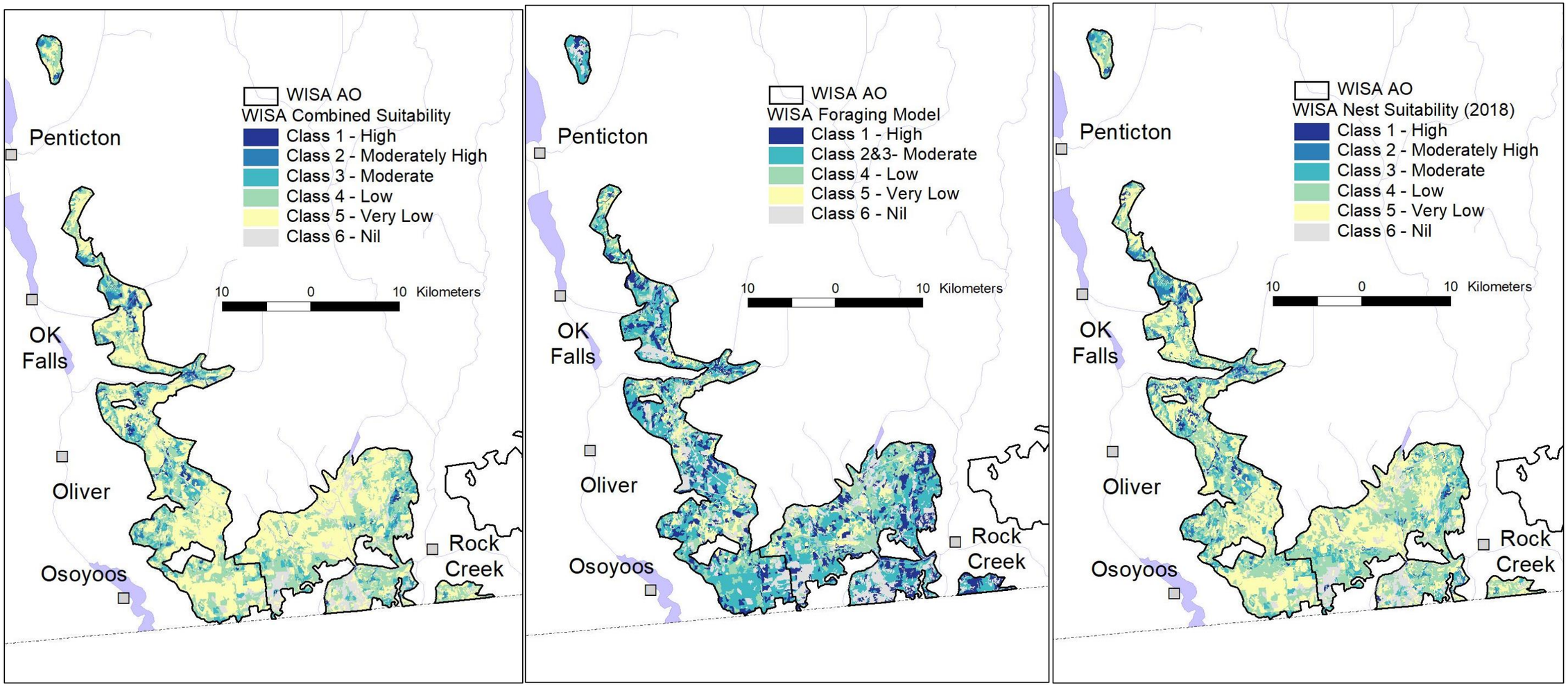
Appendix 1. WISA Suitability Maps **Map 1:** West Region; Nest (2018), Foraging and Combined Suitability Models.







Map 2. Williamson's Sapsucker 2018 nest habitat suitability model update east of Okanagan Lake.



Appendix 2. Sequential Application of Factors to Model Nesting Suitability 2018

This is divided into two sections. In the first section are outlined the steps to make the VRI suitable for WISA habitat modeling. In the second section are the steps to apply the habitat models of Tables 2 and 3 to the VRI once it has been made suitable for modeling.

The steps below have been used in Excel file **wisa_vri_base2018_forattr_20180323.xlsx (see Gyug 2018)**

Section 1: Making VRI suitable for WISA habitat modeling.

In essence, I:

- updated the VRI layer to 2018 (from 01/01/2016),
- split polygons where necessary with new harvested areas and burns,
- assessed all areas harvested after 2008 as Clearcuts, ST Cuts or Partial Cuts, and then for any such polygons harvested or burned, changed any of the VRI attributes used in the key to match the current state including:
    - For Clearcuts, all attributes set to 0 and Crown Closure to 0%
    - For ST Cuts, keep maximum age and species, set CC to 1%
    - For PartCuts, keep maximum age and species, set CC to 15% (because that is <20% of the key, meaning always Low, not Moderate)
    - For sites with no current 1.5-m pixel imagery or better, and if state was unknown, add a "?" to indicate the actual level of cut will have to be assigned later.

In more detail:

- The most recent provincial VRI geodatabase polygons and tables were downloaded from Data BC. In this case, the latest was Projected Date of 01/01/2016. However, it did not contain many cutblocks from 2015 and some from 2014, some from even earlier, and did not contain anything cut after 2015.
- All VRI layers were required. The polygons of interest intersecting the WISA AO were selected by location and saved as a shapefile because I intended to use ArcView 3.2 for at least part of the process. As it turned out there were there were corruptions introduced somewhere in the process that continually crashed crashed ArcView 3.2, and could only be identified and fixed in ArcGIS 10.1. The VRI shapefile manipulations were carried out in ArcGIS 10.1 while ArcView 3.2 was only used for dissolving small polygons, slivers and overlaps, and joining the text layer files to the shapefile. In the future, I would conduct the entire process in the ESRI geodatabase format from beginning to end.
- This polygon shapefile contained the polygon info but no tree species info. The tree species info was in a separate gdb table.
- The records from the gdb tables that matched the Feature ID of the above shapefile were found by attaching the shapefile (temporarily) to the table. Those records were selected and saved as a separate table.

- I determined how many layers each polygon had, and which layer was Rank 1 (the highest volume layer). I manipulated the .txt file to make a separate .txt file for each layer including:
    - Rank 1 layer, and
    - then for any polygons that had separate Layers 1, 2, 3, 4 and Dead.
- If there was only one layer for a polygon, it was the Rank 1 layer. Non-forest polygons would not have any Layers. About 2000 of 12000 polygons had >1 layer. About 200 also had Layers 3 and 4, but these were all under 15 m ht, so not crucial to the WISA model. About 2500 had a Dead layer, which was populated as Pl 100%, but in fact many of these polygons only contained many Py.
- For polygons with dead layer, I estimated the % dead from the % dead of the total Rank 1 live and dead volume estimates.
- The VRI appears to have NOT been updated since the original (early 1990s?) mapping on the extensive private ranch land holdings in the Merritt TSA, nor on private lands in the Boundary. Given the high amount of MPB salvage on private lands, the actual status of each polygon had to be determined by examining each against the aerial photos from 1995, 2004 and 2015. The VRI had been more currently updated for the Okanagan TSA and included new VRI for private lands as well.
- To be able to attach the .txt file with the layers to the shapefile, I renamed the field headings to 10 characters so that they can be used in the dbf file created when attached to the shapefile. These were only attached in a much later step.
- I obtained the latest Consolidated Cutblock (includes blocks sensed by satellite imagery as well, as some blocks appear never to have an approved CP, or are just missed by the system), the Harvest, the Forest Tenure Cutblock Polygon (approved CPs, not necessarily cut yet), and the fire polygon layers. There was only one fire from summer 2017 that was not in the VRI and that impacted the project area near Princeton. I also obtained the fire severity shapefile for that fire.
- ±1-m pixel orthophotos were available from:
    - 1994-1995 (black-and-white)
    - 2004-2005 (colour, excellent quality)
    - 2012-2016 (Google Earth, Bing, FLNRO licenced SPOT6/7)
- The 2008 modeling was based on primarily on the 2008 VRI, the 2004-2005 orthophotos, and paper-copy stereo colour aerial photos of different vintages (going as far back as 1990).
- Landsat 8 15-m pixel and Sentinel 2 10-m pixel imagery were used to assess status of cutblocks up to March 11, 2018, for the West, January 31, 2018, for the north part of the Okanagan, and March 13, 2018, for the south part of the Okanagan and the Boundary. Additional snow-free Landsat 8 images from 2017 (July to October) were used as required to assist interpretation of recent cutblock status.

- Cutblocks on public land that were not already in the 01/01/2016 VRI layer were identified from the orthophotos, or from the Landsat 8 imagery. These were cut into the VRI layer using the Forest Tenure Cutblock layer, or done manually where there was no cutblock polygon.
- Any forest clearing on private land was entered manually by reshaping polygons into the cleared and uncleared portions.
- Any VRI polygons that were split in this process were labeled and then the current state was estimated as:
    - Clearcut (<2 trees/ha),
    - ST Cut (2-50 trees/ha)
    - Partial Cut >50 trees/ha.
    - Estimates of tree densities were very approximate and not necessarily reliable.
    - Where no high-resolution imagery was available, and I had no personal knowledge of the site after harvest, the current condition was estimated and marked as an estimate with a "?" to be verified later.
- Where the FLNRO VRI update was last done, cutblocks were cut in but often contained Wildlife Tree Patches or uncut portions. Where these were large enough to be visible on orthoimagery, those sections were split and the forest attributes were retained for those sections. These manual fixes are not 100% as I am sure many WTPs were missed as it would have been too time consuming to fix them all. Where the cutblocks that had been cut in between 2008 and 2016 included the WTPs (if >1 ha, and as time permitted) in the block area, these were made into separate polygons and given back their forest attributes.
- Manually fixed areas included a 1000-ha cutblock north of Patchett Road, Midday Creek area in the Merritt TSA, where the entire cutblock polygon outline had been cut into the VRI, and the resulting polygon emptied of forest attributes. However, the actual cutting only took place over about 2/3 of the area, and many places had remaining intact forest. The 2008 VRI polygons were cut back into this area, the 2009 suitability rating re-applied, and then the actual cutover areas traced manually over the polygons, and the suitability rating modified for just the cutover areas.
- The VRI polygons were clipped to the WISA contiguous AO shapefile in the project area. The block of the AO north and east of Midway, most of which was TFL 8 was not included in this update because TFL 8 VRI is not available in the provincial VRI. The VRI also contained many boundary/edge matching issues adjacent to TFL 8, so that this block should be done all in one effort, rather than piecemeal. The VRI portion of this project began in March, when time was too limited to include this particular area.
- Where intersections of polygons or clipping to the AO boundary created sliver or tiny polygons of <0.1 ha, these were dissolved back into their parent polygons.
- I created a Slope, Elevation and Aspect layer in 2008 for the modeling. This layer was re-created by dissolving the 2008 WISA suitability model shapefiles as I no longer had the original shapefiles (only the raster grids) on which these had been based. This shapefile required extensive cleaning as the original shapefiles were based on VRI in which mapsheets had been

stitched together, with many sliver gaps at map boundaries. The 2016 VRI is clean and free of map-edge gaps, so this problem will not be re-created in the updated WISA model shapefile.

- The VRI shapefile was unioned with the Slope-Elevation-Aspect shapefile. Any resulting sliver and small polygons of <0.1 ha were dissolved into adjacent polygons.
- I had made many adjustments to the VRI attributes and polygons in 2008 where forest attributes or species were actually present based on colour stereo aerial photo examination but were not present in the VRI. Examples were veteran trees, At presence, trees within Open Range polygons, and retained ST or more dense tree retention within "clearcuts". There was no way to join these spatially (even millimeters rounding difference in the polygon boundaries prevents spatial matching) or by any common field, or by the centroids, so these were rejoined manually polygon by polygon, which took 3 days. This included splitting polygons where polygons had been split in 2008, or attaching the adjustment attributes to the entire polygon where the polygons remained almost unchanged.
- The forest layer tables (L1R0, R1, L2, L3, L4, Dead) were attached to the altered VRI polygon layer. The projected date was changed to 01/01/2018 with all ages updated to match this new date. Other forest attributes (e.g. height, BA) were not updated.
- VRI no longer uses the Non-Forest descriptors used in the old Forest Cover Mapping (e.g. L for Lake, OR for Open Range). These codes were used in the 2008 WISA modeling. Where newly interpreted VRI had blanks for these codes in non-forest polygons, I interpreted what the code would have been so that some areas (truly non-treed) could be assigned Unsuitable, and that potentially treed SWAMP or OR could be identified and assessed for presence of mature trees and WISA suitability. Most of these assessments were already done in 2008, and the 2008 polygon attributes copied into the new VRI.
- New fields were created to hold attributes used in the WISA habitat modeling. These included Maximum Age of any layer within a polygon, maximum R1 age and height (since each polygon and within each layer may have two ages or heights), presence of Fd, Lw, Py, At, Ew/Ep, Cw, Pl, Bl, and the percent cover of each in R1 layer.
- Crown Closure (CC) had to be adjusted for any polygons harvested or burned since the VRI of 01/01/2016, or that had not been updated in previous VRIs (see next bullet). For Clearcuts, CC set to 0%, for ST Cuts CC set to 1%, and for Partial Cuts, CC set to 15%, which was arbitrary rather than assessed for each polygon. A field was created called "CC_GT15Fnl" to hold this adjusted info and the original VRI CC_GT15 not changed.
- Very little effort appears to have been made in the FLNRO VRI update to deal with private land changes after the original interpretations in the early 1990s. This required extensive manual updating using orthophotos and satellite imagery with current forest attributes estimated for the key factors required in WISA modeling.
- Often cutblocks or partially cut areas were added during the FLNRO VRI update, and the tree attributes changed, but the veteran tree attributes disappeared in the process. Where these were ST Cuts or Partial Cuts, polygons had to be checked individually vs older FC or VRI mapping to determine the age of the stand before harvest, and the likely age of at least some of the

leave trees. Where these were veteran trees (>125, >180, or >190 years depending on the circumstances) these were noted as a ratings adjustment to be applied to the polygon later. GIS layers of Forest Cover were available from ~1998, and VRI from 2008.

Section 2: Applying the WISA habitat modeling to the adjusted VRI.

Okanagan-Boundary

Sequential Criteria for Keys. Each Key Factor has its own field in the Excel file named file sequentially as "KeyFctr_01", "KeyFctr_02" etc. as per the bullets below.

The coded values assigned are in brackets. If no criteria fit, then coded value was set to 0 (default).

1. NP Codes, all but OR, R, S, NSR, NP, NPBU, NPBR (1)
2. NP Codes OR, R, S (1)
3. R1 Age >190 (1), >120 (2)
4. R1 Ht >29.0
5. SI of any layer >15.0
6. R1 CC >30% (1), >20% (2)
7. CC >15 m ht >20% (1)
8. Age of oldest Layer >190 (1), >125 (2), >80 (3)
9. Fd/Lw (assigned codes in order from a to b)
    a. Fd or Lw leading, Fd and Lw present (1),
    b. Fd or Lw present (2),
10. Cw <10% (1)
11. Sum Pl + Bl <30% (1), <60% (2)
12. Sum Fd and Lw% of R1 >40% (1)
13. % Fd of all layers >14.9 m ht 10-90% (1), Fd 91-99% 2
14. Sum of Fd+Lw % >40% of either R1, L2, or just present in L1R0 (1)

Assign First Stage Suitability if not already 5 or 6 (Keys 1 and 2). These Assignments are listed in the Excel file as fields FSuit156, First_Suit3, etc.

FSuit156: Suit 6 if 1 =1, Suit 5 if 2 =1, and Suit 1 if 3, 4, 5, 9, 10, 11 all=1, and for Bdy, 13 = 1

First_Suit2 = 2 if 3 = 1, 6 = 2, 8 = 1, 9 = 1, 10 = 1, 11 = 1, and for Bdy 13 = 1

First_Suit3 =3 if 3 = 1 or 2, 7 =1, 8 = 1 or 2, 9 = 1 or 2, 10 = 1, 11 = 1, and for Bdy 13 =1

First_Suit 4 =4 if 8 =1, 2, or 3, 9 = 1, 2 or 3, 10 =1, 11 = 1 or 2, 12 = 1, for Bdy 13 = 1 or 2, for Okanagan 14 = 1.

First_Suit = whichever of the above first applies, and Suit 5 for any polygons not yet classified

Second Stage Suitability

15. Slope >30%, and Suit 1 to 4, Reduce 1 level (add 1 to Suit).

Third Stage Suitability Adjustments were done individually for each polygon as per numbered bullets in lower half of Table 4. These included fields corrected from 2008 (field CORREC2009 as adjusted from stereo aerial photos) and NEWFCINFO (new adjustments from orthos, satellites and attributes).

To get Final Suitability, a final check of polygons was made against imagery and ages.

This included an additional adjustment factor as a check on veteran age using old FC. If Age >190 (1996-2003 projected to 2018), then upgrade VL to L (if not already downgraded) and if Fd or Lw present, and sum Pl+Bl <60%.

West

Sequential Criteria for Keys. Each Key Factor has its own field in the Excel file named file sequentially as "KeyFctr_01", "KeyFctr_02" etc. as per the bullets below.

The coded values assigned are in brackets. If no criteria fit, then coded value was set to 0 (default).

1. NP Codes, all but OR, NSR, NP, NPBU (1); <600 m or >1400 m (1)
2. NP Code OR (1)

Assign First Stage Suitability if not already 5 or 6 (Keys 1 and 2)

FSuit156: Suit 6 if Field 1 =1; Suit 5 if Field 2 =1

First_Suit2 = 3 if Max Age ≥100; Max Height ≥20.0; Max SI ≥10.0; CC_GT15 ≥16%, Py present, unsalvaged MPB-killed pine ≥20% volume dead.

First_Suit3 = 3 if Max Age ≥180; Max Height ≥19.0; Max SI ≥11.0; CC_GT15 ≥20%, Py present.

First_Suit4 = 4 if Max Age ≥180; Max Height ≥18.0; Max SI ≥10.0; CC_GT15 ≥1%, Py present.

FS4At-FdPy = 4 if Fd or Py in polygon: Max Age ≥58; Max Height ≥14.0; Maximum SI ≥11.0; CC_GT15 ≥12%, At present and either Fd and/or Py in same or adjacent polygon

FSuit_4At = 4 if no Fd or Py in polygon: Max Age ≥58; Max Height ≥14.0; Maximum SI ≥11.0; CC_GT15 ≥12%. In the 2010 modeling I included whether Fd and/or Py were present in an adjacent polygon which resulted in a 4, otherwise 5. I did not do this foraging adjacency adjustment in 2018 yet, and am waiting until a foraging model can be overlaid. However, this was kept in its own field so that it can be identified easily for foraging adjacency consideration later.

First_Suit = whichever of the above first applies, and Suit 5 for any polygons not yet classified.

Second Stage Suitability

15. If Suit 2 or 3, Reduce to Low if 600-800 m or 1200-1400 m

Within Second Stage final calculation: Reduce one level if slope >25%

Third Stage Suitability Adjustments

Upgrade from 5 to 4 if:

1. vet Py (1) based on manual corrections of 2008, or max age >180.
2. mature At present (1), "At" when At in stand attributes or "A" when I added At based on photo interpretation adjustments.
3. NOT Slope >25 % and North Aspect (1)
4. In a forested stand ≥88 years old containing Fd or Py but ≤30% Pl (1)

Either 1 or 2 must be 1, both 3 and 4 must be 1.

5. Potential adjacency and distance factors 5 and 6 of semi-treed sites to forests were used in 2008 but not used in 2018 where this would be added later when a foraging model is overlaid. Based on corrections made in 2008, In a potentially forested stand <150 m from stands ≥88 years old, and containing Fd and/or Py, but ≤30% Pl (Stands not split by distance from forest, so only applies to whole polygons- splitting by buffer will wait until foraging analysis model developed and applied).

Additional factor using old FC (1997). If Age >190 (projected to 2018), then consider if VL should be upgraded to L if not already downgraded or clearcut, and if Py present.

Appendix 3. Re-analysis of 2006-2008 data used in habitat modeling of Drever et al. (2015).

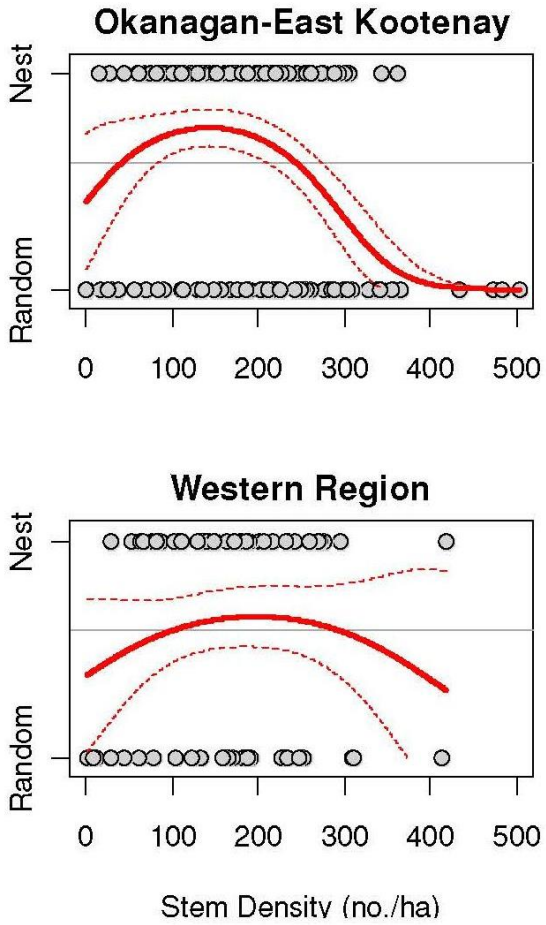


Fig. 6 (of Drever et al. 2009 manuscript). Effects of tree stem density on the probability of a site containing a Williamson's sapsucker nest in two regions of interior British Columbia, 2006-2008. Points indicated observed values and lines depict predicted values and 95% prediction intervals. Horizontal line depicts proportion of points that were nests (i.e., the baseline probability of response variable having a value of 1).

Notes:

This figure was shown here to illustrate that the Density-foraging habitat relationship found in this 2020 habitat modeling was also found in previous modeling for nest-habitat selection.

Densities in the above figure based on tree plot counts of stems >17.5-cm dbh, not VRI, so stem density will not exactly match Figure 7 of this report (see Figure 11 of this report for quantification of discrepancy between VRI and plot-based stem densities). Stem densities from plots will tend to be lower than VRI stem densities for stem densities >150/ha.

This figure was not included in the final 2015 Drever et al. publication, which only contained density graphs for several individual tree species and for Crown Closure of layers >15m tall, which can be considered a surrogate for density (although we used density in this foraging model, see pg. 21). The Crown Closure graph of Drever et al. (2015) showed the same trends as above, i.e., positive for crown closures between about 12% and 42%, and negative for crown closures above and below that range.

The top equations for WISA habitat (Nest vs Non-use) modeling from Drever et al. (2015) and the manuscript of Drever et al. (2009) (which used the same 2008 random (non-use) data and 2006-2008 nest data) were:

Model and Terms	Coefficient	SE	z-score (p)
Okanagan-Boundary-East Kootenay			
"Field 225" Drever et al. (2015)			
Density of large live lodgepole pine trees (DBH 17.5–57.4 cm)	-0.018	0.009	-2.02 (0.04)
Density of large live hybrid spruce trees (DBH 17.5–57.4 cm)	0.078	0.028	2.76 (0.006)
Quadratic term of above variable	-0.001	<0.001	-1.90(0.06)
Density of very large western larch (DBH >57.4 cm)	0.340	0.144	2.36 (0.02)
Density of very large snags (DBH >57.4 cm)	0.896	0.355	2.53 (0.01)
Quadratic term of above variable	-0.126	0.063	-2.00 (0.05)
Density of very large stumps (DBH >57.4 cm)	0.156	0.061	2.56 (0.01)
Quadratic term of above variable	-0.004	0.002	-2.24 (0.03)
Volume of logs (LED >22.4 cm)	-0.061	0.014	-4.24 (<0.001)
Model 12 "Field Ecological Requirements" Drever et al. (2009)			**(t-score)**
Density of live trees Trembling Aspen (DBH >37.5)	-0.096	0.119	-0.81
Density of large live trees Douglas-fir (DBH 17.5-57.4)	-0.005	0.003	-1.82
Density of other sap trees (DBH >17.5)	-0.008	0.003	**-2.84**
Density of very large snags (DBH >57.5)	0.274	0.193	1.42
Volume of logs (LED >22.5)	-0.040	0.011	**-3.75**
Density of very large Larch (DBH >57.5)	0.196	0.093	**2.11**
Density of very large Ponderosa pine (DBH >57.5)	-0.193	0.317	-0.61
West			
"GIS 800" Drever et al. (2015)			**z-score (p)**
Percent non-forest vegetated area (800 m)	0.260	0.089	2.94 (0.003)
Quadratic term of above variable	-0.006	0.002	-2.91 (0.004)
Percent ponderosa pine 80–119 yrs (800 m)	0.100	0.045	2.20 (0.03)
Percent ponderosa pine >120 yrs (800 m)	-0.237	0.123	-1.92 (0.06)
Quadratic term of above variable	0.009	0.005	1.94 (0.05)
Model 8 "Stand Composition" Drever et al. (2009)			**(t-score)**
Density of live trees Trembling Aspen (DBH >17.5)	0.070	0.026	**2.64**
Density of live trees Douglas-fir (DBH >17.5)	-0.0003	0.004	-0.06
Density of live trees Western Larch (DBH >17.5)	-0.005	0.003	-1.49
Density of live trees Lodgepole Pine (DBH >17.5)	-0.044	0.029	-1.53
Density of live trees Ponderosa Pine (DBH >17.5)	0.024	0.009	**2.57**
Density of live trees spruce and subalpine fir (DBH >17.5)	-0.016	0.019	-0.87

Neither of the models attempted to look at best subsets; the modeling only compared among several models (12 in Drever et al. 2009, 3 in Drever et al. 2015). I strongly suspect that if we were to examine best subsets of the top models that much simpler models would be the best fit. Note that the intercepts of each model were not given, therefore the equations could not be applied to actual data and the intercepts had to be determined from the base data (GIS 800 Intercept = -1.3964 SD 0.7507, p = 0.063. Ok-Bdy-Ek Field 225 intercept = 0.16658, SE 0.473 p = 0.72.

I re-examined the GIS800 model of Drever et al. (2015) applying nests found vs no WISA found using data collected after 2008. Since we did not collect field data for nests or random unused points found after 2008, we had no additional data for verifying the field models. For the West GIS800 model, the AUC for the published calibration dataset was 0.831 but the AUC for the validation dataset was much lower at 0.679 (see Figure below). The AUC of 0.679 in the Validation data set (n = 58 WISA nests, 621 CPB sites with no WISA) was lower than 9 of the 12 models tested in Drever et al. (2009), and lower than each of the three models considered in Drever et al. (2015). I suspect small sample size (n = 40 WISA nests, 28 unused sites) hampered the development of the West model and led to overfitting, which was apparently not transferable to the wider area.

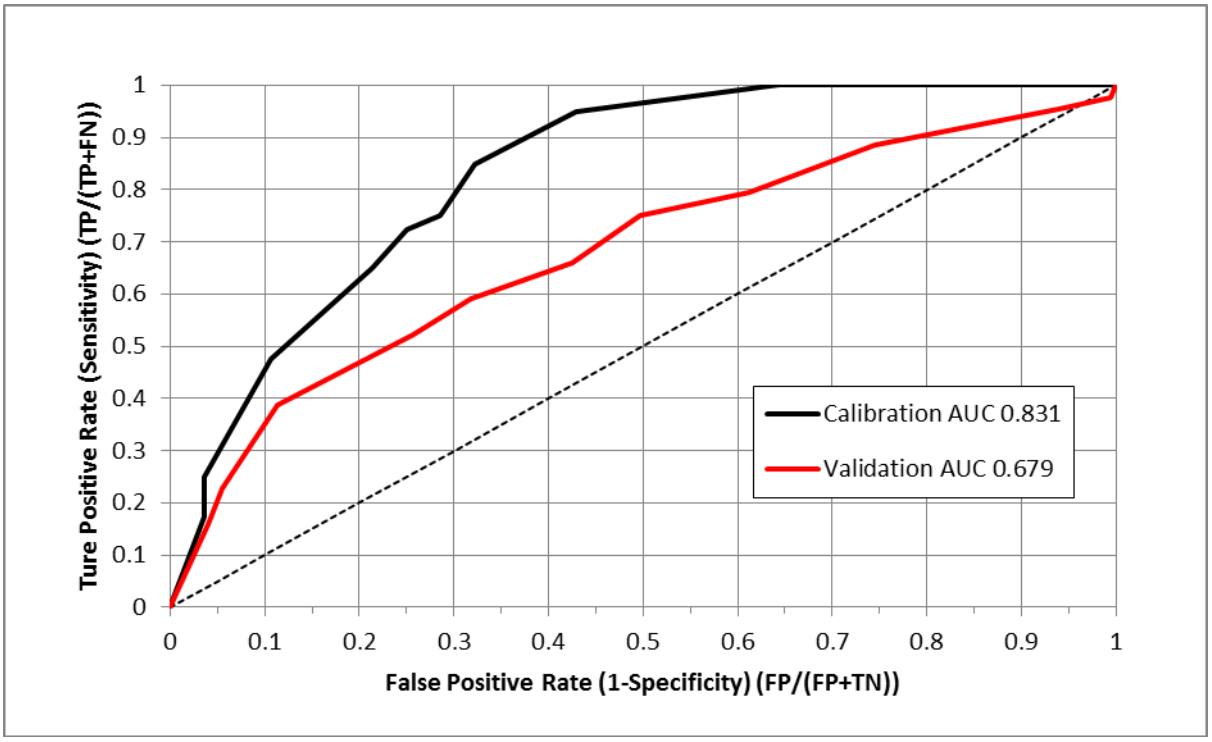


Figure 1 of Appendix 3. Resource Operating Curve for Calibration (2006-2008) and Validation (2012) datasets for GIS800 model applied to West AO by Drever et al. (2015). Dashed line is Area under the Curve (AUC) = 0.5. i.e., no different from perfectly random model.

Looking at the best subset of the GIS800 model that had 5 model terms (plus the intercept), the full model was not the best subset. Eight possible subsets had ΔAIC <2.0 which used combinations of many of all five possible variables. Looking at model averaging variable importance weights, the top variable was Py 80–119 yrs % in 800 m area, followed by Non-forest area (weight 0.76 relative to top variable) and Non-forest area^2 (weight 0.65 relative to top variable). Older Py% in area was not as important (weight 0.47 relative to top variable) and older Py%^{2} was less important (weight 0.43 relative to top variable). I believe that including the arbitrary age classes (i.e. without a firm biological basis for WISA) using the Rank 1 layer of VRI lead to a profusion of largely unwarranted variables in the modeling exercise. I think those age classes should have been simplified to just presence/absence in a given VRI

polygon, and then % in a given area, and that age would be better handled by size (QMD or Height), as in the analyses for the foraging model of this report.

I re-examined the 2006-2008 West data at the 800-m scale simplifying the tree species to just presence/absence in the Rank 1 layer for each polygon. I used a full model of 10 variables including density of live trees by 5 species, and % by tree species in Rank 1 layer of VRI polygons within 800 m. The top model had only two terms: Density of Live At trees (>17.5-cm dbh) (+ve correlation), and % Py by area in the 800-m radius (-ve correlation). Using model averaging, these were the only two co-equally important variables; other variables were irrelevant. Therefore, VRI nest habitat modeling in the West might be simplified to just two variables, although I suspect that the negative correlation with %Py was related to the positive correlation with Non-forest, and a spurious result of overfitting. I suspect that the correlation was actually with tree density as WISA in that data set tended to occur at the interface of forest and non-forest where there was abundant aspen and where tree densities were suitable, rather than in complete non-forest (i.e. non-habitat) or in very dense coniferous forest.

I re-examined the "Field 225" model for the Okanagan-Boundary-East Kootenay of Drever et al. (2015) to see if there were any best subsets that might simplify the model. Using $QAIC_c$ (because of small sample size relative to number of parameters, and overdispersion, i.e., high Chi^2 relative to number of parameters in full model), the best subset had only 3 model variables: log volume, density of Pl and density of very large Lw. However, 15 other subsets had $\Delta QAIC_c$ <2.0, indicating there were many possible best fit subsets, but none with >4 variables in the subset model. Using model averaging, the most important variable was log volume, and the top other 4 variables were density of very large Lw (weight 0.71 relative to top variable), density of spruce (weight 0.56), density of very large snags (weight 0.51) and density of Pl (weight 0.43). There did not appear to be a single unequivocal best habitat model equation. In addition, the correlation with log volume was negative, i.e., this was not related to "increased log volume = more carpenter ants = better WISA foraging habitat". High log volumes were instead associated with increasing density and elevation (Gyug, unpublished analyses), both which were correlated with lower WISA habitat suitability.

I attempted to look at log volume as an explanatory variable at the census area level because initial analyses of log volume in census areas indicated log volume was positively correlated with WISA density in places where WISA actually occurred (Gyug, unpublished analyses), in contrast to what was found at the AO level (see preceding paragraph). However, additional habitat plots (Gyug, unpublished data) in the census areas of 2012, showed the apparently significant positive correlation between log volume and WISA density in 2006-2008 (r^2 = 0.48, p = 0.03, n = 9 census areas) was no longer apparent in 2012 (r^2 = 0.038, p = 0.59, n=10). (As an aside, the census area analyses indicated that density of trees and snags >57.5 cm dbh were correlated with WISA density). As in the West, it appears that some of the variables included in the Drever et al. (2015) analysis of field data may have been spurious inferences based on overfitting a small data set, or on surrogate variables (e.g. log volume), rather than biologically meaningful variables. The results of the 2015 modeling may therefore not be generally applicable to WISA habitat selection.

I feel that further exploratory multivariate analyses of stand variables that affect WISA habitat suitability and density are warranted, but would require additional collection of data for verification of any models,

i.e., consider all the data collected to this point as exploratory as it has been analyzed separately three different times already with three different results. That extra data collection and analyses were not part of this project.