Appendix 15-C

Crown Mountain Modelling Appendix: Wildlife Habitat Models

Crown Mountain Modelling Appendix: Wildlife Habitat Models

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1.1 Introduction

1.1.1 Modelling Overview

Species distribution models are increasingly being utilized to understand how landscape changes including habitat loss, fragmentation and climate change are influencing the distributions of animals (Pacifici, Reich, Dorazio & Conroy, 2016; Royle & Dorazio, 2008). Distribution models have the unique ability to visualize the potential effects of developments on wildlife species and are highly suited to assessing environmental impact (Boyce, 2006). Habitat distribution models were used to provide the spatial distributions of valued components (VCs) based on each species habitat utilization patterns across the Local Study Area (LSA). Habitat models provided quantitative measures of habitat quality, quantity and connectivity in the LSA. This facilitated a more quantitative assessment of potential effects of the proposed Crown Mountain Coking Coal Project (the Project) on wildlife species in the area. By assessing impact in terms of loss of habitat, reduced connectivity and habitat fragmentation, we were better able to assess the impact of the Project on wildlife population viability.

Three different modeling approaches were used depending on data availability. These included occupancy models, resource selection functions (RSF) and habitat suitability index models (HSI). Within this project occupancy models were created when data was adequate but subject to a detection errors (e.g., aerial surveys, ground surveys, etc.), and HSI models were used when sample sizes of species presence were too low to run a more complex model.

Resource selection functions were estimated for grizzly bears and the Columbia spotted frog. Models were estimated using a used-available study design (Manly et al., 2002). The RSF calculated a relative probability of habitat use by incorporating a combination of habitat variables relevant to the species' habitat requirements. The RSF yielded a relative probability of use map for the Project footprint, LSA and the RSA.

Occupancy models were utilised to estimate habitat suitability for the carnivore VCs including Canada lynx, American marten, American badger and wolverine; for the ungulate VCs including, moose, elk, mountain goat and bighorn sheep; for the amphibian VCs including western toad; and for the bird species VCs including olive-sided flycatcher, woodpeckers and red-winged blackbird. Occupancy models differ from RSF in that they account for imperfect detection that is associated with many observational survey methods. Failing to account for detection error can bias estimates and related inferences by under-estimating species occurrence (Mackenzie et al., 2018; Royle & Dorazio, 2008).

Habitat suitability index (HSI) models are routinely applied in conservation biology to map species occurrences by modelling key environmental variables associated with ecological niche. HSI models were developed based on an understanding of species habitat requirements gained though a thorough review of primary literature, best management practices, grey literature, first-hand knowledge and information from recourse authorities. The HSI modelling approach was taken to model the extent of suitable habitat for the following VCs: birds - American dipper, harlequin duck, mallard duck, northern goshawk, spotted sandpiper; invertebrates - Gillette's checkerspot; and mammals - at-risk bats, including little brown myotis, northern myotis, and eastern red bat as one classification.

1.1.2 Study Objectives

The goals of the Crown Mountain baseline assessment were to deliver the required measurement indicators (occurrence, distribution and habitat availability) outlined in the AIR (EAO, 2018). More specifically, the goals were to:

1) provide baseline estimates of occurrence for selected VC wildlife species.
2) model VC selected wildlife-habitat relationships at a 1 km^2 scale to determine drivers of habitat use and selection in the LSA.
3) develop a predictive distribution map for VC wildlife species based on their habitat use characteristics.

1.2 Methods

1.2.1 Model Selection

Model selection was based on model likelihood and parsimony and based on the methods outlined by Burnham & Anderson (2002). Akaike's Information Criteria (AIC) and AIC weights were the main tools used to test parsimony and select models, deviance information criteria (DIC) was also used for the Columbia spotted frog and functions similarly to AIC in model selection. AICc or AIC for small sample sizes, was used rather than AIC. AICc weights were used to determine the weight of evidence for each model and were summed for each covariate in the 95% confidence interval set. Variables with high summed model weights were considered more important in explaining species occurrence. The direction of influence of habitat covariates was determined by the sign of the β-coefficients. Covariates were considered to have strong or robust impact if their 95% confidence intervals ($\beta \pm 1.96 \times SE$) did not include zero (Burnham & Anderson, 2002). A weighted model averaging technique was used to calculate overall regression (β), occupancy (Ψ) and detection probability (p) estimates (Burnham & Anderson, 2002; Royle & Dorazio, 2008). A goodness of fit test using 10,000 bootstrap samples and a Pearson's chi-squared statistic was performed on the global model (MacKenzie & Bailey, 2004). The AICc table was trimmed to remove all models with delta AICc greater than 7, table was then trimmed again leaving only the top models whose weight summed to 95%. Variable weights were determined by summing model weights which contained the variables.

1.2.2 Occupancy Models

Occupancy models were used to assess the distribution of a number of VCs in the Project LSA (EAO, 2018). Site occupancy models were built using replicated detection/non-detection surveys to estimate a detection probability (p) and derive estimates of species occurrence (Ψ; MacKenzie et al., 2002). In addition to providing estimated probability and area of species occupancy, the models also accounted for detection errors, which are a feature of most survey data. Occupancy models were created using multivariate analyses using variables known to be associated with the model species (MacKenzie et al., 2018).

Occupancy models were developed using a mix of data sources, including transects, camera traps and aerial survey data. Construction of the occupancy matrix that defined the presence and absence of species was achieved using a 1 x 1 km grid sampling unit (e.g. Wittington et al. 2014). A single occasion using transect data (aerial and walking transects) was defined using spatial replicates, where an occasion was defined as a species-specific length of the transect, whereas temporal replicates were specified for camera trapping data. Survey data and analyses provided estimates of habitat occupancy, probability of occurrence and habitat suitability.

The following assumptions were required to interpret occupancy (Ψ) as probability (Mackenzie et al., 2018):

1) sites are closed to changes in species occupancy (no permanent colonization or vacancy by the species for the sampling duration).
2) species are not falsely identified.
3) detections are independent.
4) heterogeneity in occupancy and detection probability are modelled using covariates.

Of the above assumptions, number 3 'detections are independent' was the most likely assumption to be broken. Lack of independence causes serially correlated data which can inflate occupancy estimates and confidence intervals. However, as a multi covariate occupancy model was constructed, this decreases the chance of serial autocorrelation being an issue as the occupancy and detection of species on consecutive occasions are better accounted for. In addition, in cases where these assumptions were not fulfilled occupancy was interpreted as a function of habitat suitability and relative probability (Makenzie *et al.* 2018).

Occupancy models were run in Presence software (Hines, 2006) and within the R version of Presence, RPresence (Makenzie & Hines, 2018). Data for occupancy analyses was gained using our own camera trapping and line transect field surveys, surveys by a collaborating consultancy and by using governmental survey data including aerial surveys covering the LSA and available through online governmental portals. Data was overlain with our sampling grid within a GIS, and spatial replicates per grid square were defined and used to fill the occupancy matrix with 1 present or 0 absent.
Occupancy models were constructed using a standard procedure for multivariate models. A candidate set of variables were selected for each species and a correlation matrix constructed where any two variables with a correlation of > 0.45 were not used in the same multivariate model. Univariate analysis was first conducted independently for both the occupancy and detection side of the equation, using variables that were relevant to the species under investigation. Univariate models were ranked using AIC, highlighting the best variables to use for multivariate analyses. All occupancy covariates that emerged with a reasonable level of support (AICc<4) were retained for multivariate testing (Burnham & Anderson, 2002). We then tested multivariate models influencing species detection. Occupancy was held constant and detection covariates shown as important during univariate analyses were entered into multiple models, and AIC model selection procedures used to select the best performing detection model. Following analyses of detection, detection was held constant and the occupancy side of the equation tested using multivariate analyses and variables shown to influence occupancy during univariate analyses.

Model fit was evaluated using a Chi squared goodness of fit test with 10,000 bootstraps and c-Hat was calculated to assess overdispersion. C-Hat values of 1 were considered perfect, less than 2 were considered acceptable, and > 2 indicated overdispersion, usually due to lack of sample independence or due to unaccounted variation in occupancy.

1.2.3 Resource Selection Functions

Resource selection models were used only for grizzly bears and Columbia spotted frogs. The modeling methods and results used for the Grizzly bear were based on analyses and results previously reported in Apps and Lamb (2019), who were responsible for the grizzly bear research. The Columbia spotted frog model used a similar approach as the grizzly bear model including a used-available resource selection function design and a mixed effects model. Random effects were only used in the grizzly bear model and controlled for differences between sampling and behavior of individual GPS collared and radio-tracked animals (e.g., Gillies et al., 2006). In both models the relative probability of resource use was defined by a logistic model:

$$w(x) = \exp(\beta 0 + \beta 1 x1 + \beta 2 x2 + \cdots + \beta k\ xk + \gamma 0ij)$$

where β0 is the intercept, βk was the selection coefficient for the kth habitat characteristic and γ0ij was the random intercept for the jth individual used in the grizzly model.

Attributes of model variables were extracted from a GIS data base from used and paired-random available locations. Initially univariate associations of habitat selection were assessed to explore associations and in variable screening. For multivariate analyses, variables were selected based on ecological function to derive predictive functions that reflected relative habitat value across the study area. As the grizzly bear research was conducted by different authors, different correlation thresholds were used for grizzly models than for other species. For grizzly bears if two variables had a Pearson correlation > 0.7 they were not included in the same model. The Columbia spotted frog model used a correlation threshold of > 0.45 similar to the occupancy models.

To evaluate model performance in the grizzly bear model a k-fold cross validation was carried out (Boyce et al., 2002). For each model, habitat selection was calculated but data were withheld to use for testing. The process was repeated *5* times. Model fit was evaluated by tabulating the proportion of animal locations within 16 equal-area bins of predicted habitat probability (Boyce et al., 2002). The relationship between area-adjusted frequency values and the ordinal classification of habitat-selection probability was evaluated using Spearman rank correlation coefficients (Rs). Receiver operating characteristics (ROC) were also used, where area under the curve (AUC) was measured as a second measure of model fit. Model fit and predictive ability were used to assess confidence in the application of the predictive mapping outputs. Due to the smaller sample size in the Columbia spotted frog model, withholding data required for cross validation was not possible, however ROC curves were used to test model performance.

1.2.4 Habitat Suitability Index Models (HSI)

Habitat Suitability Index (HSI) models aim to define, for any given species, its spatial range or probability of occurrence based on important environmental variables limiting its distribution (Soberon & Peterson, 2005). These models were developed for several VCs for which occurrence data were sparse. Model implementation entailed:

1) rating the importance of environmental variables in terms of their suitability in supporting the life requisites of species.
2) evaluating the impact of other critical factors limiting or otherwise threatening species and their habitat; and,
3) integrating these overlapping values to produce a ranked model, to estimate the extent of potential habitat at varying levels of suitability.

We developed HSI models based on British Columbia's Wildlife Habitat Rating Standards, meeting or exceeding the requirements for rating habitat use (MoELP, 1999). Rating schemes were determined based on the level of knowledge available to assess the habitat requirements of species, and developed according to seasonal habitat use patterns, which varied according to the life history of each VC. Prior to developing HSI models, we conducted a thorough literature review and summarized important habitat attributes with reference to available environmental data. Models were implemented only after explicitly formulating ratings assumptions. Because HSI models were developed for species with too little data for statistical models, formal validation was not conducted. However, species occurrence data, where available, were used to qualitatively assess HSI model performance.

1.2.5 Wildlife Species Modelling

1.2.5.1 Carnivore Models

1.2.5.2 Carnivore Model Candidate Variables

A selection of variables expected to influence carnivores were derived from various digitized GIS resources. Due to the difference in ecology of grizzly bears and other carnivores, a separate set of candidate variables were derived for grizzly bears (Table 1.2-1) and other VC carnivores (Table 1.2-2).

Table -1 Habitat variables expected to influence grizzly bear habitat selection for Spring, Summer, Autumn and Winter Seasons within the Southern Canadian Rocky Mountains, 2003 – 2018. All grizzly bear variables were standardised to a 100 x 100m pixel resolution.

Habitat Variable	Source	Description
Land Cover		
EOSD_BL broad-leaf	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
EOSD_CN coniferous	Landsat-derived earth observation for sustainable forest development	Averaged across each pixel

Habitat Variable	Source	Description
	(EOSD; Wulder et al. 2008).	
EOSD_HB herbaceous	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
EOSD_RE rock & exposed	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
EOSD_WT wetland	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
EOSD_SH shrub	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
EOSD_SI snow & ice	Landsat-derived earth observation for sustainable forest development (EOSD; Wulder et al. 2008).	Averaged across each pixel
Terrain		
ELEV Elevation (m)	BC Ministry of FLNRORD CDED - Digital Elevation Model	Averaged across each pixel (m)
SLOPE Slope (%)	Derived from Elevation within ArcGIS	Averaged across each pixel (%)
COMPLX Terrain complexity index	Derived from Elevation within ArcGIS	Averaged across each pixel
CURVA Terrain curvature and soil wetness/seepage index	Derived from Elevation within ArcGIS	Averaged across each pixel
SOL_DURA Mean daily max solar duration (min), May - Oct	Derived from Elevation within ArcGIS	Averaged across each pixel
SOL_ENER Mean daily max solar insolation (KJ), May - Oct	Derived from Elevation within ArcGIS	Averaged across each pixel
Landsat 5		
BVI Mean of the bright vegetation index	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
BVI-SD Standard deviation of the BVI at specified scale	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
GVI Mean of the green vegetation index	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
GVI-SD Standard deviation of the GVI at specified scale	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel

Habitat Variable	Source	Description
WVI Mean of the wet vegetation index	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
WVI-SD Standard deviation of the WVI at specified scale	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
NDVI Mean of the normalized difference vegetation index	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
NDVI-SD Standard deviation of the NDVI at specified scale	Landsat-5 Thematic Mapper (TM) satellite imagery	Averaged across each pixel
Human Influence		
ROADS Weighted density of linear transportation features	GeoBC Atlas, Integrated Transportation Network Ministry of FLNRORD, EV CEMF AltaLIS Access - Alberta	Converted into a density raster and averaged across each pixel
URB-AG Urban, settled, & agricultural lands	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC (last modified 2019-09-05)	Averaged across each pixel
LHU-HI Localized human-use - "high" intensity	Derived from NTS blocks of CanVec data (CTI 2010).	Averaged across each pixel
LHU-LO Localized human-use - "low" intensity	Derived from NTS blocks of CanVec data (CTI 2010).	Averaged across each pixel
RESDEN Residential polygons	Derived from NTS blocks of CanVec data (CTI 2010).	Averaged across each pixel
ACCESS Index of human accessibility/remoteness	Derived from NTS blocks of CanVec data (CTI 2010).	Averaged across each pixel
Berry		
BERRY_VM Predicted berry kcal - *Vaccinium membranaceum*	Values derived from a berry distribution model	Averaged across each pixel (kcal)
BERRY_SC Predicted berry kcal - *Sheperdia canadensis*	Values derived from a berry distribution model	Averaged across each pixel (kcal)
Mines		
MINE_A Mines Active	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC	

Habitat Variable	Source	Description
MINE_R Mines Abandoned and/or Reclaimed	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC	

Table 1.2-2 Habitat variables expected to influence VC carnivores other than grizzly bears. All variables were standardised to a 25 x 25m pixel resolution.

Habitat Variable	Source	Description
Parent Material	Soil Landscapes of Canada (SLC) BC Soil Survey	Area coverage per grid cell (%)
Elevation	BC Ministry of FLNRORD CDED - Digital Elevation Model	Average value per grid cell (m)
Solar Radiation	Calculated from Elevation covariate using ArcGis 10.7, Spatial Analyst toolbox; Area Solar Radiation	Average value per grid cell (kWh/m^2). Raster calculated at 200m^2 cell size, resampled to 25m^2 for analysis.
Slope	Calculated from Elevation covariate using ArcGIS 10.7; Slope tool	Average value per grid cell (%)
Terrain Ruggedness	Calculated using vector ruggedness measure (VRM) of terrain in ArcGis 10.7 script; available from Environmental Systems Research Institute ArcScripts website	Average VRM index value per grid cell
Prey	Snowshoe Hare model	Average snowshoe hare model index value per grid cell
Grasslands, Crops, Pasture and Open Canopy Forest	Terrestrial Ecosystem Mapping (TEM) site series: GA03, Gb, Gb04, Gb20, Gg, Gg12, Xv BC & AB: Government of Canada, Agriculture & Agri-Food Canada, Annual Crop Inventory 2018	Area coverage per grid cell (%)
Agriculture	Agriculture & Agri-Food Canada, Annual Crop Inventory 2018	Area coverage per grid cell (%)
Avalanche Chutes and Alpine Areas	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM) Predictive Ecosystem Mapping (PEM)	Area coverage per grid cell (%)
Riparian Areas	BC Freshwater Atlas (Streams, Wetlands, Lakes)	Percent area coverage per grid cell of merged water features

Habitat Variable	Source	Description
	Alberta Merged Wetland Inventory, AltaLIS Hydrography	
Deciduous Forest	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Coniferous Forest	EOSD Land Cover, Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Early Seral Forest	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Mid Seral Forest	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Old and Mature Forests	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Wetlands	BC Freshwater Atlas (Wetlands) AltaLIS Hydrography - Alberta	Area coverage per grid cell (%)
Rivers	BC Freshwater Atlas (Rivers) AltaLIS Hydrography - Aberta	Area coverage per grid cell (%)
NDVI	Normalized Difference Vegetation Index. Landsat 8 OLI – July/August 2019	Average NDVI value per grid cell.

1.2.5.3 Grizzly Bear RSF Model

RSF were constructed for grizzly bears for spring, summer and autumn based on GPS collar locations from a total of 75 grizzly bears between 2003 and 2019, the winter RSF was based upon denning locations inferred based on clustering of GPS location data during the expected denning period. Models were run using a random effects logistic regression. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Beta values used in predictive maps presented in the carnivores existing conditions report (Crown Existing Conditions **Section 15.6.4**) are shown in **Table 1.2-3**. The predictive ability of models was assessed using k-fold cross validation and ROC curves (**Table 1.2-4**).

Table 1.2-3 Coefficients Predicting Grizzly Bear Habitat Selection for Spring, Summer, Autumn and Winter Seasons within the Southern Canadian Rocky Mountains, 2003 – 2018

Spring		Summer		Autumn		Winter	
Variable	β	Variable	β	Variable	β	Variable	β
L1_COMPLX	0.00052	L1_ROADS	-0.00023	L2_LHU-HI	-0.00003	L1_LHU-LO	-0.00869
L2_BERRY_VM	-0.00007	L1_URB-AG	-0.00011	L2_RESDEN	-0.00048	L1_COMPLX	-0.00174
L2_BERRY_SC	-0.00012	L1_LHU-LO	-0.00664	L2_SLOPE	-0.00812	L1_BVI	-0.01351
L2_ROADS	-0.00023	L1_WVI	-0.02959	L2_COMPLX	0.00078	L1_GVI	-0.02871
L2_URB-AG	0.00000	L2_BERRY_VM	0.00015	L2_BVI	-0.00738	L2_BERRY_VM	0.00054
L2_LHU-HI	-0.00062	L2_BERRY_SC	0.00007	L2_GVI	0.04323	L2_BERRY_SC	0.00012
L2_LHU-LO	-0.00117	L2_LHU-HI	-0.00004	L2_WVI	-0.02241	L2_ROADS	-0.00072
L2_CURVA	-0.00057	L2_SLOPE	-0.01146	L2_MINE_A	-0.00016	L2_LHU-HI	-0.10612
L2_WVI	-0.00710	L2_COMPLX	0.00043	L3_BERRY_VM	0.00005	L2_SLOPE	0.03821
L2_MINE_A	0.00000	L2_BVI	-0.00359	L3_BERRY_SC	-0.00013	L2_CURVA	0.00831
L3_SLOPE	-0.00160	L2_GVI	0.03831	L3_ROADS	-0.00001	L3_WVI	0.02272
L3_BVI	-0.00532	L2_MINE_A	-0.00009	L3_URB-AG	0.00002		
L3_GVI	0.03962	L3_CURVA	-0.00666	L3_CURVA	-0.01481		

Table 1.2-4 Predictive Efficiency of Seasonal Models of Grizzly Bear Habitat Selection across the Lower-Elk/Crowsnest/Hwy3 Study Area of the Southern Canadian Rocky Mountains, 2003-2018

Model	AUC	SE	Rs	CS
Spring	0.60	0.00	0.98	59.00
Summer	0.61	0.00	0.94	60.00
Autumn	0.55	0.00	0.97	56.50
Winter	0.77	0.06	0.95	67.60

Statistics given are the area under the receiver operating characteristic curve (AUC), Spearman-rank correlation (rs), and model classification success (CS) at cut point P = 0.5.

The AUC values reported for grizzly bears are poor but indicate some predictive value of the models. Three of the models have AUCs between 0.5 and 0.7 indicating poor discrimination capacity, whereas the denning model lies between 0.7-0.9 has a good discrimination capacity, according to AUC. However, ROC curves (AUC) are not the most suitable assessment method of RSFs, because RSFs are a continuous measure without a true 1, 0 dichotomy. The grizzly study in particular used a buffer to delineate availability (0s) and so many of the available points (0s) followed the distribution of grizzly bear used locations. As a result of the study design where unused points overlap the distribution of bears, there are less true 'unused' points which lead to lower AUC values. The poor ability of ROC curves to assess RSFs is one reason why Boyce et al (2002) created the k-fold cross validation method. Although the Boyce method has its critics, it performs a better assessment of RSF fit than do ROC curves. The Rs (Spearman's rank correlation) values for each cross-validated model indicate a good fit of the RSF and suggest the models are suitable for predictive interpretation.

1.2.5.4 Wolverine Occupancy Model

Occupancy models for wolverine were based upon data collected via a combination of baited and un-baited camera traps, as well as sign survey transects. A total of 165 sites were used in the model with a maximum of 31 observations (occasions) per site, models were run as annual models. Models were run using a single season occupancy model fit with RPresence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model χ^2=223285235.84, P value=0.01, $\hat{c}$=25.6. Models and beta values of variables correspond to those presented in the carnivores existing conditions report and are shown in **Table 1.2-5** and **Table 1.2-6.**

Table 1.2-5 Showing the Top Models Describing Wolverine Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(AHI + RU + COD)p(BAIT)	303.30	0	0.055	6	290.77
psi(PRV + RU + COD)p(BAIT)	303.33	0.02	0.054	6	290.79
psi(AHI + RU)p(BAIT)	303.43	0.12	0.051	5	293.05
psi(SCA + RU + COD + PRV)p(BAIT)	303.89	0.59	0.041	7	289.18
psi(AHI + RU + CC)p(BAIT)	303.99	0.68	0.039	6	291.46
psi(AHI + RU + OC)p(BAIT)	304.10	0.79	0.037	6	291.57
psi(AHI + RU + COO)p(BAIT)	304.13	0.82	0.036	6	291.59
psi(SCA + RU + COD + AHI)p(BAIT)	304.13	0.82	0.036	7	289.41
psi(PRV + RU + CC)p(BAIT)	304.22	0.92	0.034	6	291.69
psi(),p()	317.81	14.51		2	311.66

Table 1.2-6 Showing Beta Values and Standard Errors for Habitats Influencing Wolverine Occupancy in the LSA

Variable	Beta	SE
Average Human Influence (AHI)	-1.69	0.56
Ruggedness Max (RU)	0.78	0.35
Coniferous Dense (COD)	0.63	0.26
Minimum Distance to Primary Rivers (PRV)	0.89	0.31
Snow Cover Mean Index (SCA)	0.63	0.26
Closed Canopy (CC)	0.6	0.27
Open Canopy (OC)	-0.68	0.3
Coniferous Open (CO)	-0.68	0.3
Mean Elevation (EL)	0.89	0.35

1.2.5.5 American Badger Occupancy Model

Occupancy models for American badger were based upon data collected via a combination of baited and un-baited camera traps, as well as sign survey transects. A total of 97 sites were used in the model with a maximum of 50 observations (occasions) per site, models were run as spring /summer season models. Models were run using a single season occupancy model fit with Presence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. Beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model, χ^2 =3084243345.92, P value=0.00, $\hat{c}$ =3.32. Models and beta values of variables correspond to those presented in the carnivores existing conditions report and are shown in **Table 1.2-7** and **Table 1.2-8**.

Table 1.2-7 Showing the Top Models Describing American Badger Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(OCG),p(O)	325.85	0.00	0.46	4.00	317.42
psi(OCG, MNS, UF, DD),p(O)	326.45	0.60	0.34	7.00	311.19
psi(OCG, PREY, RDS, MNS),p(O)	327.45	1.60	0.20	7.00	312.19
psi(PREY),p(.)	337.45	11.60	0.00	3.00	331.19
psi(RDS, OCG),p(.)	338.57	12.72	0.00	4.00	330.14
psi(OCG, RDS, ELE),p(.)	347.38	21.53	0.00	5.00	336.72
psi(UF),p(O)	348.96	23.11	0.00	4.00	340.53
psi(.)p()	349.07	23.22	0.00	2.00	344.94

Table 1.2-8 Showing Beta Values and Standard Errors for Habitats Influencing American Badger Occupancy in the LSA

Variable	Beta	SE
Open Canopy Grasslands (OCG)	0.95	0.31
Prey (Prey)	10.08	2.97
Roads (RD)	-0.71	0.54
Unfavourable soils (US)	-0.33	0.38
Dominant drainage (DD)	-0.22	0.24
Mines (MNS)	-0.85	0.49

1.2.5.6 American Marten Occupancy Model

Occupancy models were based upon data collected via a combination of baited and un-baited camera traps, as well as sign survey transects. A total of 167 sites were used in the model with a maximum of 18 observations (occasions) per site, models were run as annual models. Models were run using a single season occupancy model fit with RPresence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. Beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model χ^2 =470960.58, P value=0.06, $\hat{c}$ =2.38. Models and beta values of variables correspond to those presented in the carnivores existing conditions report and are shown in **Table 1.2-9** and **Table 1.2-10**.

Table 1.2-9 Showing the Top Models Describing American Marten Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(SRA + CCA + COD)p(CT)	595.06	0	0.041	6	582.53
psi(CCA + EL)p(CT)	595.11	0.05	0.040	5	584.74
psi(SRA + CCA)p(CT)	595.25	0.20	0.037	5	584.88
psi(SRA + CCA + CC)p(CT)	595.36	0.30	0.035	6	582.84
psi(PSR + CCA)p(CT)	595.39	0.33	0.034	5	585.02
psi(SRA + CCA + PSR)p(CT)	595.49	0.43	0.033	6	582.96
psi(PSR + CCA + COD)p(CT)	595.52	0.46	0.032	6	583.00

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(SRA + CCA + COD + PSR)p(CT)	595.53	0.47	0.032	7	580.83
psi(SRA + EL + CCA)p(CT)	595.54	0.48	0.032	6	583.01
psi(.)p()	605.13	10.07		2	598.98

Table 1.2-10 Showing Beta Values and Standard Errors for Habitats Influencing American Marten Occupancy in the LSA

Variable	Beta	SE
Secondary Road Area (SRA)	-0.52	0.23
Percent Canopy Closure A (CCA)	0.67	0.22
Coniferous Dense (CD)	0.42	0.19
Elevation Mean (EL)	0.66	0.23
Closed Canopy (CC)	0.39	0.19
Minimum Distance to Primary and Secondary Rivers (PSR)	0.56	0.20
Percent Old Seral Stage (OSS)	0.4	0.22

1.2.5.7 Canada Lynx Occupancy Model

Occupancy models for Canada lynx were based upon data collected via a combination of baited and un-baited camera traps, as well as sign survey transects. A total of 179 sites were used in the model with a maximum of 52 observations (occasions) per site, models were run as annual models. Models were run using a single season occupancy model fit with RPresence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The variable weights were then multiplied by the univariate betas in order to create the final model. Beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model χ^2=11769730928, P value=0.13, $\hat{c}$=1.84. Models and beta values of variables correspond to those presented in the carnivores existing conditions report and are shown in **Table 1.2-11** and **Table 1.2-22**.

Table 1.2-11 Showing the Top Models Describing Canada Lynx Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(MHI + OML)p(SRD + BT)	1271.22	0	0.266	6	1258.73
psi(MHI + CCA + OML)p(SRD + BT)	1271.43	0.21	0.239	7	1256.78
psi(MHI + OSS + CCA + OML)p(SRD + BT)	1272.79	1.57	0.122	8	1255.94
psi(MHI + OSS + OML)p(SRD + BT)	1273.01	1.79	0.109	7	1258.35
psi(OML + PRV)p(SRD + BT)	1273.42	2.20	0.089	6	1260.93
psi(OML + OSS + PRV)p(SRD + BT)	1275.51	4.29	0.031	7	1260.85
psi(PRD + EL)p(SRD + BT)	1275.66	4.44	0.029	6	1263.18
psi(PRD + EL + OSS)p(SRD + BT)	1276.12	4.90	0.023	7	1261.46
psi(MHI + OSS + CCA)p(SRD + BT)	1276.22	5.00	0.022	7	1261.56
psi(.)p()	1303.77	32.55		2	1295.54

Table 1.2-22 Showing Beta Values and Standard Errors for Habitats Influencing Canada Lynx Occupancy in the LSA

Variable	Beta	SE
Max Human Influence (MHI)	-1.18	0.29
Percent Old and Mature at Low Elevation (OML)	-0.86	0.23
Percent Canopy Closure A (CCA)	0.95	0.3
Percent Old Seral Stage (OSS)	0.66	0.33
Minimum Distance to Primary Rivers (PRV)	1.11	0.24
Minimum Distance to Primary Road (PRD)	0.78	0.24
Mean Elevation (EL)	1.24	0.28

1.2.5.8 Ungulate Modelling

1.2.5.9 Ungulate Model Candidate Variables

A selection of variables expected to influence VC ungulates were derived from various digitized GIS resources (Table 1.2-13). All ungulate models used a threshold where variables with a Pearson's correlation >0.45 were not included in the same model.

Table 1.2-33 Habitat variables expected to influence ungulate habitat selection. All ungulate habitat variables were standardised to a 25 x 25m pixel resolution

Habitat Variable	Source	Description
Elevation	BC Ministry of FLNRORD CDED - Digital Elevation Model	Average value per grid cell (m)
Solar Radiation	Calculated from Elevation covariate using ArcGis 10.7, Spatial Analyst toolbox; Area Solar Radiation	Average value per grid cell (kWh/m^2). Raster calculated at 200m^2 cell size, resampled to 25m^2 for analysis.
Slope	Calculated from Elevation covariate using ArcGIS 10.7; Slope tool	Average value per grid cell (%)
Aspect	Calculated from Elevation covariate using ArcGIS 10.7; Aspect tool	Average value per grid cell (degrees)
Terrain Ruggedness	Calculated using vector ruggedness measure (VRM) of terrain in ArcGis 10.7 script; available from Environmental Systems Research Institute ArcScripts website	Average VRM index value per grid cell
Coniferous and Broadleaf Forests	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) EOSD Land Cover Classification	Area coverage per grid cell (%)
Canopy Closure	Vegetation Resource Inventory (VRI) Alberta Vegetation Inventory (AVI)	Area coverage per grid cell (%)
Grasslands, Crops, Pasture and Open Canopy Forest	Terrestrial Ecosystem Mapping (TEM) site series: GA03, Gb, Gb04, Gb20, Gg, Gg12, Xv BC & AB: Government of Canada, Agriculture & Agri-Food Canada, Annual Crop Inventory 2018	Area coverage per grid cell (%)
Agriculture	Earth Observation for Sustainable Development of Forests Land Cover	Area coverage per grid cell (%)
Mineral Licks	BC Wildlife Species Inventory Survey Observations – Mineral Licks	Average distance to point features per grid cell
Avalanche Chutes and Alpine Areas	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM) Predictive Ecosystem Mapping (PEM)	Area coverage per grid cell (%)
Riparian Areas	BC Freshwater Atlas (Streams, Wetlands, Lakes) Alberta Merged Wetland Inventory, AltaLIS Hydrography	Area per grid cell of merged water features
Early Seral Forest	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI),	Area coverage per grid cell (%)

Habitat Variable	Source	Description
	Terrestrial Ecosystem Mapping (TEM)	
Shrubs	Terrestrial Ecosystem Mapping (TEM), EOSD Canadian Land Cover	Area coverage per grid cell (%)
Old and Mature Forests	Vegetation Resources Inventory (VRI), Alberta Vegetation Inventory (AVI), Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Wetlands	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Area coverage per grid cell (%)
Rivers and Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Rivers and streams classified by Strahler order. AB data queried to match Strahler ordering of BC dataset. Area of buffered streams per grid cell. Buffer size scaled proportionally by Strahler order.
Annual Snowpack	NASA Terra/MODIS Snow Cover (10 year average)	Averaged snow cover index value per grid cell
Roads	GeoBC Atlas, Integrated Transportation Network Ministry of FLNRORD, EV CEMF AltaLIS Access - Alberta	Average area of buffered roads per grid cell. Buffer size scaled proportionally to road class.
Burns	BC Fire Perimeters – Historical AB Historic Wildfire Perimeters	Merged fire perimeters, all fires between 10-25 years. Area per grid cell
Cutblocks/ Logging	Harvested Areas of BC (Consolidated Cutblocks) Alberta AVI post inventory cutblocks	Area coverage per grid cell (%)
Predators	Wolf model index	Average index value per grid cell
Mining Areas	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC BC: Ministry of FLNRORD, EV CEMF BC: VRI - Forest Vegetation Composite Polygons and Rank 1 Layer. AB: Alberta Biodiversity Monitoring Institute, Human Footprint Inventory 2016	Area coverage per grid cell (%)
Built-up Areas	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC (last modified 2019-09-05) AB: Residential areas from Alberta Biodiversity Monitoring Institute, Human	Area coverage per grid cell (%)

Habitat Variable	Source	Description
	Footprint Inventory 2016 AB: Waste disposal areas, residential areas, leisure areas, liquid storage areas, buildings, ritual cultural areas from Topographic Data of Canada - CanVec Series	
Human Influence	Global Human Influence Index (1995-2004)	Average global human influence index value per grid cell

1.2.5.10 Moose Occupancy Model

Occupancy models for moose were based upon data collected via a combination of camera traps, as well as ground survey and aerial survey transects. A total of 229 sites were used in the model with a maximum of 26 observations (occasions) per site. Models were run using a single season occupancy model fit with RPresence and Presence software, for summer and winter seasons. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model for summer, χ^2= 16562577876.94, p value=0.02, $\hat{c}$=0.24 and for winter χ^2=1432671360.09, P value=0.21, $\hat{c}$=1.04. Models and beta values of variables correspond to those presented in the ungulates existing conditions report and are shown in **Table 1.2-44** and **Table 1.2-55** for summer, and **Table 1.2-66** and **Table 1.2-77** for winter.

Table 1.2-44 Showing the Top Models Describing Moose Occupancy in the LSA during Summer, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Loglikelihood
psi(EL,PRD,CML,ESF),p(A,CT)GOF	1473.29	0.00	0.31	8.00	1456.58
psi(CML,TRV,PRD,EL,ESF),p(A,CT)	1473.44	0.15	0.29	9.00	1454.54
psi(EL,PRD,CML,OF),p(A,CT)	1475.98	2.69	0.08	8.00	1459.27
psi(EL,PRD,CML,MSF),p(A,CT)	1476.01	2.72	0.08	8.00	1459.30
psi(EL,PRD,CML),p(A,CT)	1476.07	2.78	0.08	7.00	1461.52
psi(CML,TRV,PRD,EL),p(A,CT)	1476.41	3.12	0.07	8.00	1459.70
psi(CML,TRV,PRD),p(A,CT)	1477.63	4.34	0.04	7.00	1463.08
psi(EL,PRD,CML,AV),p(A,CT)	1477.93	4.64	0.03	8.00	1461.22

Model	AICc	DeltaAICc	AIC weights	Parameters	Loglikelihood
psi(EL,TRV,CML,ESF),p(A,CT)	1477.96	4.67	0.03	8.00	1461.25
psi(.)p()	1530.23	56.94	0.00	2.00	1526.17

Table 1.2-55 Showing Beta Values and Standard Errors of Variables Describing Moose Occupancy in the LSA during Summer

Variable	Beta	SE
Old Mature Forest	3.48	1.18
Early Seral Forest	-2.62	1.30
Tertiary Rivers	2.74	1.20
Secondary Roads	2.44	1.50
Wetlands	1.29	0.72
Primary Roads	2.54	1.35

Table 1.2-66 Showing the Top Models Describing Moose Occupancy in the LSA during Winter, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(AHI + PRD + SLP + ESSFdkw)p(AE + CT)	1090.88	0.00	0.20	8.00	1074.23
psi(AHI + PRD + ESSFdkw)p(AE + CT)	1091.28	0.40	0.17	7.00	1076.77
psi(ESSFdkw + PRD + SLP)p(AE + CT)	1091.82	0.94	0.13	7.00	1077.31
psi(ESSFdkw + PRD)p(AE + CT)	1092.50	1.62	0.09	6.00	1080.12
psi(ESSFdkw + PRD + MPR + SLP)p(AE + CT)	1093.25	2.37	0.06	8.00	1076.59
psi(ESSFdkw + PRD + MPR)p(AE + CT)	1093.95	3.07	0.04	7.00	1079.44
psi(ESSFdkw + PRV + MIN + SLP)p(AE + CT)	1094.27	3.39	0.04	8.00	1077.61
psi(ESSFdkw + PRV + SLP)p(AE + CT)	1094.48	3.60	0.03	7.00	1079.97
psi(ESSFdkw + PRV)p(AE + CT)	1094.49	3.61	0.03	6.00	1082.11
psi(.)p()	1108.29	17.41		2.00	1100.11

Table 1.2-77 Showing Beta Values and Standard Errors of Variables Describing Moose Occupancy in the LSA during Winter

Variable	Beta	SE
Average Human Influence (AHI)	-0.66	0.29
Minimum Distance to Primary Road (PRD)	0.53	0.21
Mean Slope	0.46	0.28
ESSFdkw	-1.60	0.61
Predator Max (MPR)	3.89	1.75
Minimum Distance to Primary Rivers (PRV)	0.51	0.24
Mines Min (MIN)	0.39	0.19

1.2.5.11 Elk Occupancy Model

Occupancy models for elk were based upon data collected via a combination of camera traps, as well as ground and aerial surveys. A total of 229 sites were used in the model with a maximum of 38 observations (occasions) per site. Models were run using a single season occupancy model fit with RPresence for summer and winter seasons. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model for summer, χ^2= 17890842.11, p value=0.40, ĉ=0.71 and for winter χ^2= 208831.2516, P value=0.003, ĉ=9.17. Models and beta values of variables correspond to those presented in the ungulates existing conditions report and are shown in **Table 1.2-88** and **Table 1.2-99** for summer, and **Table 1.2-20** and **Table 1.2-** for winter.

Table 1.2-88 Showing the Top Models Describing Elk Occupancy in the LSA during Summer, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
Psi (OMF,ESF,TRV)	286.38	0.00	0.26	7.00	271.49
Psi (OMF,ESF,PRD)	286.46	0.08	0.25	7.00	271.57
Psi (OMF,SRD,WL)	287.36	0.98	0.16	7.00	272.47

Psi (OMF,ESR,TRV,SRD)	288.11	1.73	0.11	8.00	270.96
Psi (OMF,ESF,SRD,WL)	288.11	1.87	0.10	8.00	271.10
Psi (OMF,ESF,WL)	288.25	2.48	0.08	7.00	273.97
Psi (OMF,WL,TRV)	288.86	3.72	0.04	7.00	275.21
psi(.)p()	290.10	11.32	0.00	4.00	289.39

Table 1.2-99 Showing Beta Values and Standard Errors of Variables Describing Elk Occupancy in the LSA during Summer

Variable	Beta	SE
Coniferous Dense Forest	-1.00	0.36
Open Canopy Forest and Grasslands	1.04	0.51
Coniferous Open Forest	1.16	0.72
Secondary Roads	1.41	0.93
Old and Mature Forest	-0.90	0.56

Table 1.2-20 Showing the Top Models Describing Elk Occupancy in the LSA during Winter, and a Null Model for Comparison

Model	AICc	Delta AICc	AIC weights	Parameters	Loglikelihood
psi(AHI + EL + APR + GR_PEMLE_LC)p(CT + AE)	855.29	0	0.27	8	838.63
psi(GR_PEMLE_LC + EL + APR)p(CT + AE)	856.06	0.77	0.18	7	841.55
psi(AHI + EL + APR + GR_PEMLE_LC + ESSFdk1)p(CT + AE)	856.60	1.32	0.14	9	837.78
psi(AHI + EL + GR_PEMLE_LC + ESSFdk1)p(CT + AE)	856.96	1.67	0.12	8	840.30
psi(AHI + EL + GR_PEMLE_LC)p(CT + AE)	857.35	2.06	0.10	7	842.84
psi(ESSFdk1 + EL + APR + GR_PEMLE_LC)p(CT + AE)	857.45	2.16	0.09	8	840.79
psi(APR + EL)p(CT + AE)	859.23	3.94	0.04	6	846.85
psi(ESSFdk1 + EL + GR_PEMLE_LC)p(CT + AE)	860.16	4.87	0.02	7	845.65
psi(AHI + EL + APR)p(CT + AE)	860.28	4.99	0.02	7	845.77
psi(.)p()	899.80	44.51		2	891.62

Table 1.2-21 Showing Beta Values and Standard Errors of Variables Describing Elk Occupancy in the LSA during Winter

Variable	Beta	SE

Average Human Influence (AHI)	1.02	0.36
Mean Elevation (EL)	-2.08	0.49
Predator Mean (APR)	-0.79	0.31
GR_PEMLE_LC	1.70	1.00
ESSFdk1	-1.76	0.84

1.2.5.12 Bighorn Sheep Occupancy Model

Occupancy models were based upon data collected via a combination of camera traps, as well as ground and aerial surveys. A total of 253 sites were used in the model with a maximum of 51 observations (occasions) per site, models were run as annual models. Models were run using a single season occupancy model fit with RPresence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model, χ^2=59955.18, P value=0.61, $\hat{c}$=0.68. Models and beta values of variables correspond to those presented in the ungulates existing conditions report and are shown in **Table 1.2-10** and **Table 1.2-113**.

Table 1.2-10 Showing the Top Models Describing Bighorn Sheep Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
Ψ (RU),p(SN,A)	304.88	0	0.18	5	294.64
Ψ (RU,AV),p(SN,A)	305.19	0.56	0.15	6	292.85
Ψ (RU,FG),p(SN,A)	305.3	0.75	0.14	6	292.96
Ψ (RU,MLB),p(SN,A)	305.61	1.17	0.12	6	293.27
Ψ (RU,AV,MLB),p(SN,A)	306.34	1.68	0.09	7	291.88
Ψ (RU,SRV),p(SN,A)	306.42	3.62	0.08	6	294.08
Ψ (RU,OMF),p(SN,A)	306.46	3.86	0.08	6	294.12
Ψ (ET,SR,MLB),p(SN,A)	306.49	3.87	0.08	7	292.03
Ψ (RU,OMF,MLB),p(SN,A)	306.69	3.97	0.07	7	292.23
Ψ (.),p()	342.5	37.62	0	2	334.34

Table 1.2-11 Showing Beta Values and Standard Errors of Variables Describing Bighorn Sheep Occupancy in the LSA during Winter

Variable	Beta	SE
Terrain Ruggedness	2.886	0.745
Escape Terrain	-8.768	2.492
Mineral Licks	-1.409	0.678
Solar Radiation (May)	1.159	0.559
High Elevation Grassland	0.453	0.286
Avalanche Chutes	0.394	0.334
Old Mature Forest	-0.595	0.524
Predator Occurrence	-6.765	4.215
Secondary Rivers	-0.998	0.494
Elevation	0.796	0.473

1.2.5.13 Mountain Goat Occupancy Model

Occupancy models for mountain goats were based upon data collected via a combination of camera traps, as well as ground and aerial surveys. A total of 256 sites were used in the model with a maximum of 38 observations (occasions) per site, models were run as annual models. Models were run using a single season occupancy model fit with RPresence. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model χ^2=79278.43, P value=0.72, ĉ=0.52. Models and beta values of variables correspond to those presented in the ungulates existing conditions report are shown in **Table 1.2-12** and **Table 1.2-13**.

Table 1.2-124 Showing the Top Models Describing Mountain Goat Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Loglikelihood
Psi (ET,PRV,AP),p(SN,A)	226.77	0	0.43	7	212.32
Psi (ET,OMF,PRV),p(SN,A)	227.81	1.04	0.256	7	213.36
Psi (ET,PRV,ESF),p(SN,A)	229.62	2.85	0.104	7	215.17
Psi (ET,PRV,PR),p(SN,A)	230.34	3.57	0.072	7	215.89
Psi (ET,ESF,SRV),p(SN,A)	231.11	4.34	0.049	7	216.66
Psi (ET,ESF,PR,MLB),p(SN,A)	231.15	4.38	0.048	8	214.57
Psi (.),p()	256.5	29.73	0	4	248.34

Table 1.2-135 Showing Beta Values and Standard Errors of Variables Describing Mountain Goat Occupancy in the LSA

Variable	Beta	SE
Escape Terrain	6.22	2.13
Primary Rivers	-0.80	0.29
South Aspects	0.60	0.29
Old and Mature Forest	-1.07	0.39
Early Seral Forest	-2.45	1.78
Predators	-0.65	0.30
Mineral Licks	1.32	0.51
Secondary Rivers	-0.70	0.28

1.2.5.14 Bat Modelling

1.2.5.15 At-Risk Bat Model Candidate Variables

A selection of variables expected to influence at-risk bats were derived from various digitized GIS resources (Table 1.2-26).

Table 1.2-146 Habitat Attributes Modelled for At-Risk Bat Species

Variable	Source	Description
Forest cover / structural stages	Vegetation Resource Inventory (VRI) Alberta Vegetation Inventory (AVI)	Old growth and mature forest cover ranked high suitability (3) and young forest cover ranked medium suitability (2)
Wetlands and riparian features	BC Freshwater Atlas Wetlands Alberta Merged Wetland Inventory	Water features (inc. rivers, buffered streams, lakes, and wetlands) ranked according to proximity from either high suitability (3) or medium suitability (2) roosting habitat

Variable	Source	Description
Herbaceous foraging habitat and flyways	Vegetation Resource Inventory (VRI) Alberta Vegetation Inventory (AVI)	Early seral vegetation cover (structural stages 1–3), roads, and cut blocks incorporated as foraging habitat and flyways within high and medium suitability "habitat continua"; flyway habitat values modified across an 8 km proximity gradient calculated on a decimal scale based on the proximity of roosting habitat to (wetland) foraging habitat, and the proximity of foraging (wetland) habitat to roosting habitat
Hibernacula	DEM (Terrain Ruggedness Index) Karst	Intersection of karst + areas of high terrain ruggedness (>=0.3) (raster buffered / generalized)
Open water bodies (winter)	Average winter solar radiation	Areas selected where average winter solar radiation = >0 intersected with areas where terrain curvature = <0.35
Elevation	TEM, VRI, PEM	All HSI model outputs multiplied by raster mask representing the elevational niche (<2,300 m) of little brown myotis

1.2.5.16 At-Risk Bats HSI Model

Habitat Requirements

Bats in BC use a variety of habitat types throughout the year, including roosting habitat and foraging/drinking habitat (BC MoE, 2016). Roosts (e.g., maternity roosts, day roosts, hibernacula) provide protection from predators, rest, thermal protection, and sites for social interactions with conspecifics (BC MoE, 2016; Stevens & Lofts, 1988; Nagorsen & Brigham, 1993). Roosting habitat in BC tends to be in mature and old growth forests and foraging habitat in low elevation riparian and wetland areas (Grindal, Morissette, & Brigham 1999; Vonhof & Barclay, 1996). Roosts can occur in cliff and rock complexes, caves, wildlife trees (large diameter trees with cavities and/or sloughing bark), snags, and human features including mines, tunnel, buildings, and bridges (Nagorsen et al., 1993; Holloway & Barclay, 2001). Roost selection varies by season and by time of day (BC MoE, 2016). Maternity sites (e.g., trees cavities, rock crevices) and hibernacula are the main limiting habitat features for many bat species (e.g., little brown myotis, northern myotis) within their range (COSEWIC, 2013). Many bat species use hibernacula as overwintering habitat for hibernation and winter survival (COSEWIC, 2013; Environment Canada, 2015). Hibernacula are generally in underground openings (e.g., caves, abandoned mines, wells, and tunnels), and usage of the site varies based on temperature and humidity levels (Boyles & Willis 2009; Environment Canada, 2015; BC CDC, 2015). Multiple bat species, such as the northern myotis (*Myotis septentrionalis*) and little brown myotis (*Myotis lucifugus*), may occur in the same hibernaculum but different sections (Environment Canada, 2015). Bat hibernacula are considered critical habitat, and relatively few sites have been identified in BC (Craig & Holroyd, 2013). Hibernacula are also hot spots for gene flow and information transfer, therefore their protection is critical for bats (Norquay et al., 2013).

Forest structure and heterogeneity (e.g., tree species, composition, stage age, and structure) play an important role on bat habitat use (Boyles & Aubrey, 2006; Jung et al., 2012; Luszcz & Barclay, 2016). Bat activity tends to be greater in mature and old growth forests, largely due to increased structural heterogeneity, higher suitable roosting habitat, and less clutter (Luszxz & Barclay, 2016; Swystun et al., 2007). Clutter in a forest refers to obstacles that may interfere with detections of echoes from prey, and reduces manoeuvrability and ability (Luszxz & Barclay, 2016; Norberg & Rayner, 1987). Younger (early-mid seral) forests tend to be relatively dense and homogenous in structure, which can create increased clutter for bats (Luszxz & Barclay, 2016).

Three at-risk bats are identified as VCs in this EA, including: the little brown myotis, the northern myotis, and the eastern red bat (*Lasiurus borealis*). Due to the limited information available for other at-risk bat species considered in this EA, the habitat requirements of the little brown myotis were used to develop an HSI model that was generalized for all three at-risk bat species of concern in the study area. Models were developed to describe spring / summer foraging habitat and winter hibernacula.

The little brown myotis inhabits a wide range of habitats, from dry open forests to wet riparian areas, from low elevations up to approximately 2,300 m (Klinkenberg, 2019; Burns, Frasier & Broders, 2014). They are most often associated with open habitats, such as ponds, roads, forest edges, and open canopy (0-50%) forests (Segers & Broders, 2014). Little brown myotis require wetlands and areas around water bodies (e.g., riparian areas, forests edges) for drinking and foraging (i.e., gleaning; Environment Canada, 2015). Daytime roosts are used for protection from weather and predation and are found on south- or southeast-facing slopes, as well as in old buildings, tree cavities, and snags (Segers & Broders, 2014; Stevens & Lofts, 1988; Hilty, 2020). Hibernacula are often found in underground openings, caves, tunnels, buildings, and abandoned mines, where temperatures are relatively stable (Boyles & Willis 2009; Environment Canada, 2015; BC CDC, 2015). High quality hibernacula are important for both overwinter survival and female reproduction (Norquay et al., 2013). Populations are likely limited by roost site availability rather than food (Stevens & Lofts, 1988). The little brown myotis is a medium-range flyer, which may range 5–8 km from its day-roost (BC MoE 2016).

Ratings Assumptions

Foraging habitat

There is a moderate level of knowledge of the foraging habitat requirements of the little brown myotis, justifying a 4-class HSI rating scheme. Under this rating scheme habitats were ranked as: 1) High; 2) Medium; 3) Low; and 4) unsuitable (Nil). Ratings assumptions for roosting and foraging habitat follow below:

- Roosting sites (mature and old growth forests) within close proximity to foraging habitat (water features, and early seral herbaceous and shrubland habitats), represent optimal (high suitability) thermal, security, reproductive, and foraging habitat for little brown myotis.

- Roosting sites (young forests) within close proximity to foraging habitat (water features, and early seral herbaceous and shrubland habitats), represent medium suitability thermal, security, reproductive, and foraging habitat for little brown myotis.

- The elevational niche of the little brown myotis is limited to below 2,300 m asl
- The little brown myotis may range up to 8 km from roosting sites

Wintering habitat

There is limited knowledge of the wintering habitat requirements of the little brown myotis, justifying a 2-class HSI rating scheme. Under this rating scheme habitats are ranked as: 1) Useable; and 2) Likely no value. Ratings assumptions for wintering habitat follow below:

- Areas with a high probability of karst and high terrain ruggedness represent useable wintering (living and thermal, *i.e.*, potential hibernacula) for the little brown myotis, where these areas lie within a 2 km buffer of water bodies that are potentially open (for drinking) through winter
- The elevational niche of the little brown myotis is limited to below 2,300 m asl

Model Descriptions

Spring-Summer Roosting and Foraging Habitat

To model roosting and foraging habitat for at-risk bat species, two potential "habitat continua", representing contiguous roosting habitat, flyways, and foraging habitat, were ranked and integrated into an HSI model. High suitability roosting and foraging habitat was represented by a raster incorporating old growth and mature forest cover (high suitability roosting habitat), wetlands and riparian areas (foraging habitat), and a proximity gradient covering adjacent flyways (early seral vegetation cover, clearcuts, etc.), with values calculated on a decimal scale over a range of 8 km (foraging range). Medium suitability roosting and foraging habitat was represented by a raster incorporating young forest cover (medium suitability roosting habitat), wetlands and riparian areas, and a proximity gradient covering adjacent flyways, with values calculated on a decimal scale across the same range. Proximity gradients were incorporated as reciprocal indices, where the value of roosting habitat was modified based on its proximity to foraging habitat and the value of foraging habitat was modified based on proximity to roosting habitat. When ranked and integrated these rasters represented the overlap of potential high and medium suitability "habitat continua", with habitat values ranked according to the parameters outlined in the Ratings Assumptions and in **Table 1.2-146**. The model was further modified (clipped) based on the known elevational niche of the little brown myotis. The generalized model formula for this HSI is as follows, where: ROMF = ranked old growth and mature forest cover; RYF = ranked young forest cover; RWR = ranked wetlands and riparian areas; PG = a proximity index calculated on the decimal scale across an 8 km buffer extending away from roosting areas; and E = elevational niche index.

$$\mathbf{((((ROMF + RW)PG) + ((RYF + RW)PG))/2) \times E}$$

Wintering Habitat

To model wintering habitat for at-risk bat species, we considered potential karst in areas of high terrain ruggedness as representing potential (useable) hibernacula, limited by the elevational niche of little brown bat (<2,300 m) and by proximity to water bodies predicted to be open (for drinking) through winter. Areas of low terrain curvature were selected within aspects where average winter solar radiation remained above zero to identify potential seepage sites where water might continue to flow / remaining open. We then generated a 2 km buffer around these sites, and selected all potential hibernacula falling within that range as useable habitat. A general formula for the HSI model for wintering habitat follows, where: PK = potential karst; HTRI = areas of high terrain ruggedness; E = elevational niche index; WSR = winter solar radiation index; LTC = low terrain curvature; and B = a 2 km buffer.

(PK x HTRI x E) x ((WSR x LTR)B)

Although there is some indication that bats may favour southern slopes as roosting habitat or hibernacula, we did not incorporate aspect into HSIs because of contradictory evidence of bat hibernacula found outside these idealized aspects in the study area (L. Andresen, pers. comm., 2021). Habitat attributes incorporated into the wintering HSI model for at-risk bat species are summarized in **Table 1.2-146**.

1.2.5.17 Bird Modelling

1.2.5.18 Bird Candidate Variables

A selection of variables expected to influence VC bird species were derived from various digitized GIS resources (Table 1.2-27). More species specific variables were developed for HIS models and are listed in those sections.

Table 1.2-157 Habitat Variables Expected to Influence VC Birds

Habitat Variable	Source	Description
Rivers	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygons reduced to line work; outlines buffered 25 m to represent shorelines and shallows; rasterized and ranked as high suitability habitat; raster integrated with other water features based on 4-class rating scheme; river features adopted instead of Strahler stream orders because of the more accurate contours
Wetlands and lacustrine features	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygons reduced to line work; outlines buffered 25 m to represent shorelines and shallows; rasterized and ranked as high suitability habitat; raster integrated with other water features based on 4-class rating scheme

Stony shores	BC Soil Survey Soil Landscapes of Canada (Alberta)	Areas mapped as 'Stony' OR 'Very stony' AND 'Fluvial' extracted and intersected with water feature margins; rasterized with a burn value of 1; reduction scale factor of 0.5 applied to the inverse area (this index was integrated with the unforested shoreline index to accentuate ideal habitat and penalize unsuitable habitat)
Unforested (open) shoreline habitat	Digital Elevation Model for British Columbia – CDED – 1:250,000 KBRCE (2019) disturbance dataset Human Footprint Inventory (2019)	Forested areas mapped as 'old', 'mature', or 'young' extracted and intersected with water feature margins; rasterized with a reduction scale factor of 0.5; congruent scale factor applied to inverse area (this index was integrated with the stony shores index to accentuate ideal habitat and penalize unsuitable habitat)
Potential mine contamination	Digital Elevation Model for British Columbia – CDED – 1:250,000 Human Footprint Inventory (2019) KBRCE (2019) disturbance dataset	Downstream stream segments, wetlands, and lacustrine features intersected with mine footprints; 2km mine proximity raster calculated and integrated with DEM; results normalized on decimal scale (0 to 1); model raster multiplied by resulting index to apply a penalty to downstream water features in proportion to mine proximity and water flow
Rivers	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygon rasterized and ranked as high suitability habitat (=3); integrated with other water features; rivers adopted instead of stream orders because of their more accurate contours and features such as mid-stream islets
Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Line work buffered by 20 m for fourth and fifth order streams and 15 m for first, second, and third order streams; rasters ranked as high suitability (=3) integrated with other water features
Braided channels	BC Freshwater Atlas BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Interstices of streams selected and buffered 300 m; resulting vector manually edited to remove interstices of lesser streams, retaining only the interstices of major channels; rasterized with congruent scale factor of 1; inverse area rasterized with reduction scale factor of 0.5
Vegetation cover	Alberta Vegetation Inventory (AVI)	All vegetation cover classes (structural stages 1-7) extracted and intersected

	BC Vegetation Resource Inventory (VRI)	with water features; rasterized with a congruent scale factor of 1; reduction scale factor of 0.5 applied to inverse area
Crops	Earth Observation for Sustainable Development of Forests Land Cover	Shapes of annual and perennial crops rasterized
Forest structural stage	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI)	Baseline habitat suitability rankings for northern goshawk were attributed based on forest structural stage classifications. Within the four-class rating scheme: early successional habitats (structural stages 1, 2 & 3) were ranked low in suitability; mid-successional forest habitats (structural stages 4 & 5) were ranked medium; and mature and old growth forests (structural stages 6 & 7) were ranked high.
Crown closure & Stand height	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI)	Layers representing crown closure and stand height generalized in a 4-level set of classes. These classes converted to a set of decimal factors, which were applied to modify the ranked baseline rasters representing the proportional area covered by each forest structural stage class. The general formula modifying each structural stage class is: *ranked.forest.cover x ((canopy closure + stand height) / 2)*
Subalpine fir dominance	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) BC Biogeoclimatic Zones	BC VRI queried to select areas where subalpine fir is dominant in BC; AB VRI queried to select areas where subalpine fir is dominant in AB; where AVI / VRI data were unavailable, cool aspects (azimuth: 90° to 292.5°) of the ESSF were derived from a DEM for the RSA; areas derived from each of these analyses were merged and rasterized with a reduction scale factor of 0.25 (the inverse area retaining congruent scale factor of 1) to produce this raster
Soil coarseness	BC Soil Survey Soil Landscapes of Canada (Alberta)	Fine soils mapped with 'Drainage' = 'Eolian', 'Imperfectly drained', 'Poorly drained', and 'Moderately well drained' were intersected with streams and rasterized as a reduction scale factor of 0.5; a congruent scale factor of 1 was applied to the inverse area within the RSA; the resulting soil coarseness index

			was multiplied with ranked habitats to penalize areas with fine sediments
	Unforested (open) shoreline habitat	Digital Elevation Model for British Columbia – CDED – 1:250,000 KBRCE (2019) disturbance dataset Human Footprint Inventory (2019)	Forested areas mapped as 'old', 'mature', or 'young' extracted and intersected with water feature margins; rasterized with a reduction scale factor of 0.5; congruent scale factor applied to inverse area (this index was integrated with the stony shores index to accentuate ideal habitat and penalize unsuitable habitat)

1.2.5.19 Olive-sider Flycatcher Occupancy Model

Occupancy models for olive-sided flycatcher were based upon data collected via a combination of breeding bird surveys, migratory point counts, migratory surveys, migratory transects, and regular transects. A total of 68 sites were used in the model with a maximum of 18 observations (occasions) per site, used to predict spring / summer habitat occupancy. Models were run using a single season occupancy model fit with RPresence and Presence software. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps, χ^2= 9748.05, P value=0.55, ĉ=0.00. Models and beta values of variables correspond to those presented in the birds existing conditions report and are shown in **Table 1.2-168** and **Table 1.2-179**.

Table 1.2-168 Showing the Top Models Describing Olive-Sided Flycatcher Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(CCC + ESS)p(D)	169.38	0	0.18	5	158.41
psi(ESS)p(D)	169.72	0.34	0.15	4	161.09
psi(SHR + ESS)p(D)	170.11	0.73	0.12	5	159.14
psi(CHA + ESS)p(D)	170.26	0.88	0.12	5	159.29
psi(PRV + ESS + CCC + SHR)p(D)	170.99	1.61	0.08	7	155.12
psi(PRV + ESS)p(D)	171.00	1.61	0.08	5	160.03
psi(SHR + ESS + CCC)p(D)	171.02	1.64	0.08	6	157.64
psi(PRV + ESS + SHR)p(D)	171.46	2.08	0.06	6	158.08
psi(CHA + ESS + CCC)p(D)	171.54	2.16	0.061	6	158.16

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(.)p()	180.63	11.25		2	174.25

Table 1.2-179 Showing Beta Values and Standard Errors of Variables Describing Olive-Sided Flycatcher Occupancy in the LSA

Variable	Beta	SE
Percent Canopy Closure C (CCC)	0.80	0.72
Percent Early Seral Stage (ESS)	5.12	2.85
Shrubs (SHR)	1.50	1.48
Canopy Height Mean (CHM)	0.55	0.35
Minimum Distance to Primary Rivers (PRV)	-0.75	0.44

1.2.5.20 Woodpecker Occupancy Model

Occupancy models for woodpeckers (all species grouped) were based upon data collected via a combination of breeding bird surveys, wetland surveys, migratory point counts, migratory surveys, migratory transects, and regular transects. A total of 77 sites were used in the model with a maximum of 62 observations (occasions) per site, used to predict spring / summer habitat occupancy. Models were run using a single season occupancy model fit with RPresence and Presence software. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps, χ^2=18263596636.80, P value=0.72, $\hat{c}$=0.64. Models and beta values of variables correspond to those presented in the birds existing conditions report and are shown in **Table 1.2-30** and **Table 1.2-31**.

Table 1.2-30 Showing the Top Models Describing Woodpecker Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(BU + CCC)p(M)	700.5	0	0.22	5	689.65
psi(BU + SLP + CCC)p(M)	701.62	1.12	0.13	6	688.42
psi(BU)p(M)	702.23	1.73	0.09	4	693.67

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
psi(CCC + EL)p(M)	703.29	2.79	0.06	5	692.44
psi(BU + SLP)p(M)	703.3	2.80	0.05	5	692.46
psi(COD + RUG + CCC)p(M)	703.77	3.27	0.04	6	690.57
psi(CCC + RUG + CCA)p(M)	704.16	3.66	0.04	6	690.96
psi(PSR + CCC + COD)p(M)	704.21	3.71	0.03	6	691.01
psi(COD + CCA + CCC)p(M)	704.29	3.79	0.03	6	691.09
psi(.)p()	712.76	12.26		2	706.43

Table 1.2-31 Showing Beta Values and Standard Errors of Variables Describing Woodpecker occupancy in the LSA

Variable	Beta	SE
Built Up (BU)	-1.28	0.44
Percent Canopy Closure C (CCC)	1.01	0.77
Slope Mean (SLP)	-0.77	0.34
Elevation Mean (EL)	-1.04	0.37
Coniferous Dense (COD)	-0.68	0.36
Ruggedness Mean (RUG)	-0.96	0.37
Percent Canopy Closure A (CCA)	-1.12	0.44
Minimum Distance to Primary or secondary Rivers (PSR)	-1.03	0.37

1.2.5.21 Red-Winged Blackbird Occupancy Model

Occupancy models for red-winged blackbird were based upon a combination of breeding bird surveys, wetland surveys, migratory point counts, migratory surveys, migratory transects, and regular transects. A total of 96 sites were used in the model with a maximum of 65 observations (occasions) per site, used to predict spring / summer habitat occupancy. Models were run using a single season occupancy model fit with Presence software. Model averaging was used to create the final model for prediction and based on weighted model averaging using Akaike's weights. The beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a Chi squared goodness of fit test with 10,000 bootstraps on the top model, χ^2=18671171513.80, P value=0.27, ĉ=1.08. Models and beta values of variables correspond to those presented in the birds existing conditions report and are shown in **Table 1.2-3232** and **Table 1.2-**.

Table 1.2-32 Showing the Top Models Describing Red-Winged Blackbirds Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Logliklihood
Psi (SRV), p (D, LWA)	353.89	0	0.261	5	343.22
Psi (SHR, SRV), p (D, LWA)	354.53	0.64	0.19	6	341.59
Psi (CCD, SRV), p (D, LWA)	354.82	0.93	0.165	6	341.87
Psi (CCD, SRV, SHR), p (D, LWA)	354.99	1.1	0.151	7	339.72
Psi (CCD, SHR), p (D, LWA)	355.56	1.67	0.113	6	342.62
Psi (SHR), p (D, LWA)	356.55	2.66	0.069	5	345.89
Psi (CCD), p (D, LWA)	357.15	3.26	0.051	5	346.48
psi(.),p(.)	386.40	31.41	0.00	2	382.27

Table 1.2-33 Showing Beta Values and Standard Errors of Variables Describing Red-Winged Blackbird occupancy in the LSA

Variable	Beta	SE
Percent Canopy Closure C (CCD)	0.91	0.78
Shrub cover (SHR)	0.58	0.47
Minimum Distance to Primary or Secondary Rivers (SRV)	-1.02	0.65

1.2.5.22 Northern Goshawk HSI Model

Habitat Requirements

Breeding areas represent the functional ecological unit for northern goshawk (*Accipiter gentilis atricapillus*) survival and reproduction (Stuart-Smith et al., 2012). Northern goshawks exhibit strong fidelity to these areas which they will occupy for decades if suitable conditions persist, including adequate prey availability, forest structure supporting nesting sites, and sub-canopy flyways supporting hunting (Harrower 2007; Mahon 2008; Squires & Reynolds 1997). These areas encompass not only nest trees (historic, current, and potential future) but also the surrounding plucking posts, roosts, and post fledgling areas associated with nest trees. Nests are generally placed at least 100 m from stand edges, where forests lie adjacent to non-forest, shrub-dominated or herbaceous habitats (Stuart-Smith et al., 2012). To protect northern goshawks, land managers must look beyond nest trees to apply conservation measures at the scale of the greater breeding area and annual home range. Northern goshawks require a sufficient prey base over areas as great as 8,400 ha to ensure their survival and reproductive success

(Harrower, 2007; Kenward, 1982; Mahon, 2008, 2009; Squires & Kennedy, 2006; Stephens, 2001; Tornberg & Colpaert, 2001). Management activities at smaller scales, such as buffers around individual nest trees, are considered inadequate (Stuart-Smith et al., 2012).

Ideal habitat attributes for northern goshawk are associated with mature and old growth forest stages, which feature complex, multi-storied, closed canopy structures that provide thermal cover and support nest sites and sub-canopy flyways (Stuart-Smith et al., 2012). Though these conditions are typical of mature and old growth forests, they may exist in forests of various structural stages, depending on stand composition, site history, local productivity, and stand height (Kenward 2006; Penteriani 2002; Squires & Kennedy 2006). In the East Kootenays, nesting suitability in the Ponderosa Pine (PP) BEC Zone is limited by the predominance of open forests with low canopy closure (Stuart-Smith et al., 2012). In the Engelman Spruce – Subalpine (ESSF) Zone, nesting suitability is limited by the preponderance of subalpine fir (*Abies lasiocarpa*), as these trees have canopy structures largely unsuitable for nests, narrow crowns resulting in open canopy closure, and a multi-storied stand structure that impedes sub-canopy flyways (Stuart-Smith et al., 2012).

Beyond the breeding area, northern goshawks also depend on suitable foraging habitat throughout their home range, which is essential to adult survival and rearing of young (Stuart-Smith et al., 2012). In North America, the correlation between northern goshawk home range size, habitat use, and foraging preference is poorly understood (Squires & Reynolds, 1997). Differences between breeding and winter foraging habitat, males and females, and the broad diet of northern goshawks, also challenge the characterization of suitable foraging habitat. The age of forests typically used by goshawks for foraging is generally similar to those used for nesting, though foraging may occur in a wider range of forest age classes, including early and late seral stands supporting high prey abundance (Squires & Reynolds 1997; Finn et al., 2002).

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of northern goshawk, justifying a 4-class rating scheme. Under this rating scheme, habitat suitability is ranked as: 1) high; 2) medium; 3) low; and 4) unsuitable (nil). Ratings assumptions are as follows:

- Old growth and mature forests represent optimal (high suitability) living, thermal, and reproductive habitat year-round, providing canopies are relatively closed (crown closure = 50–60%), stand height is 23–25 m, and stand age is 80–120 years. *Predictors vary depending on BEC Zone (Stuart-Smith et al., 2012).

- Early to mid-seral forest stages have limited value as foraging and security habitat throughout the year. Depending on prey availability, these environments may be accessed by goshawks in rank order of importance from mid- to early-seral stages (suitability medium to low).

- The value of early- and mid-seral environments as habitat is proportional to their distance from mature and old growth forests, limited by a range (in diameter) of ~2.8 km, corresponding to the goshawk's estimated breeding range of 2,400 ha in the RSA (Stuart-Smith et al., 2012).

- High elevation forests with a high proportion of subalpine fir are low suitability as habitat for northern goshawk.

Model Description

Northern goshawk models were constructed to represent the spring / summer season. The HSI model implemented for northern goshawk incorporated baseline habitat suitability rankings based on forest structural stage classifications, as outlined in the Ratings Assumptions and in **Table 1.2-18**. Baseline habitat suitability rankings of forest cover classes were modified by an index incorporating estimates of stand height and canopy closure, depending on the range of structural characteristics deemed suitable for northern goshawks across different biogeoclimatic zones (Stuart-Smith et al., 2012). A 2,650 m buffer was applied to all old growth and mature forest classes and used to clip early- and mid-seral habitat beyond the extent of old growth and mature forest classes, representing the area most likely to be used by nesting goshawks outside of their primary nesting and fledging habitat. A euclidean distance raster was then generated with the same maximum distance (2,650 m), spanning the decimal scale from 0 to 1, to modify the suitability of early seral habitat across that range, with values diminishing relative to the distance of pixels from old growth and mature forest classes. Finally, high elevation forests with a high proportion of subalpine fir (>50%), were rasterized with reduction scale factor of 0.25, and the inverse area weighted with a congruent scale factor of 1, to produce an index integrated into the model (multiplied with the input raster) as a penalty. A general formula for the HSI model developed for northern goshawk is as follows, where: RFC = forest cover ranked by structural stage; $CCSH_{BEC}$ = idealized stand height and canopy closure index, which varies depending on BEC zone; RES = ranked early serial habitat; BA = a proximity raster generated based on the known breeding area for northern goshawk; and SF = the subalpine fir index.

$$((RFC \times CCSH_{BEC}) + (RES \times BA)) \times SF$$

Owing to differences in the resolution of terrestrial ecosystem mapping (TEM) data available for the RSA and LSA, rasters representing each structural stage class (high, medium, low) were generated separately for these areas. In the TEM data available for the LSA, land cover classifications are ascribed to polygons based on deciles quantifying the proportional area covered by each land class on a scale of 1-10. Rasters were therefore generated for each decile, then integrated—(DEC_1 + DEC_2 + DEC_3) / 3—to produce output rasters representing the proportional area covered by each forest successional stage on a decimal scale (0-10). For the RSA, forest structural stage was represented as complete deciles (10) and incorporated as such. Rasters were then ranked by multiplying the baseline values (1-10) representing the proportional cover of each forest successional stage class by 1 (low), 2 (medium), and 3 (high). When integrated, these baseline rasters describe the habitat value of land cover on a scale of 10–30 based on the proportional coverage of each forest structural stage class, where 10 = low; 11-20 = medium, and 21–30 = high suitability.

Table 1.2-184 Habitat Attributes Modelled for Northern Goshawk

Variable	Source	Description
Northern goshawk breeding area	NA	Euclidean distance raster calculated within 2,650 m buffer of mature and old growth forests (structural stages 6 & 7)
Forest structural stage	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI)	Baseline habitat suitability rankings for northern goshawk were attributed based on forest structural stage classifications. Within the four-class rating scheme: early successional habitats (structural stages 1, 2 & 3) were ranked low in suitability; mid-successional forest habitats (structural stages 4 & 5) were ranked medium; and mature and old growth forests (structural stages 6 & 7) were ranked high.
Crown closure & Stand height	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI)	Layers representing crown closure and stand height generalized in a 4-level set of classes. These classes converted to a set of decimal factors, which were applied to modify the ranked baseline rasters representing the proportional area covered by each forest structural stage class. The general formula modifying each structural stage class is: *ranked.forest.cover x ((canopy closure + stand height) / 2)*
Subalpine fir dominance	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) BC Biogeoclimatic Zones DEM	BC VRI queried to select areas where subalpine fir is dominant in BC; AB VRI queried to select areas where subalpine fir is dominant in AB; where AVI / VRI data were unavailable, cool aspects (azimuth: 90° to 292.5°) of the ESSF were derived from a DEM for the RSA; areas derived from each of these analyses were merged and rasterized with a reduction scale factor of 0.25 (the inverse area retaining congruent scale factor of 1) to produce this raster

1.2.5.23 American Dipper HSI Model

Habitat Requirements

American dipper (*Cinclus mexicanus*) populations are limited by their dependence on the unique habitat characteristics of montane stream-side environments for foraging and nesting. Nest sites are built near swift-moving waters amongst complex rocky and organic riparian features such as cliffsides, boulders and fallen trees, above annual flood surge levels in areas inaccessible to predators (Campbell & Ryder, 2013; Kingery, 1996; Loegering & Anthony, 2006; Willson & Kingery, 2011). Dippers favour clear, unpolluted streams, often on high gradient channels constrained by steep walls, with coarse substrates supporting their prey: aquatic invertebrates, tadpoles, small fishes, and fish eggs (Campbell & Ryder, 2013; Kingery, 1996; Loegering & Anthony, 2006).

Ideal habitat attributes for American dipper include streams less than 15 m in width and 2 m in depth, flowing over coarse substrates of rock, cobble, gravel, and sand, which are known to support greater abundances of benthic invertebrates than finer substrates (Kingery, 1996; Willson et al., 2009; Willson & Kingery, 2011). Rugged, high elevation landscapes are more likely to give rise to the fast-moving waters favoured by dippers than those at lower elevations (Osborn, 1999). While American dippers have been documented nesting along silty, glacier-fed streams near Juno, Alaska, researchers speculate that their success in these areas likely depends on proximity to clear-running channels, and to their nesting and brooding before summer increases in silt content, among other strategies (Cotter, 2018).

Studies of American dipper ecology are often contradictory due to extreme environmental variability exhibited across their mountainous distributional range (Price & Bock, 1983). While some studies have found riparian forest cover and canopy closure to be positive predictors of the aquatic invertebrates preyed on by dippers (Allan et al., 2003; Hawkins et al., 1982; Loegering & Anthony, 2006), canopy closure do not always reliably predict dipper nesting habitat (Willson et al., 2009). Furthermore, although American dippers are negatively affected by freshwater pollution (e.g., Anderson et al., 2008; Wayland et al., 2007), American dipper occurrences can be weakly predicted by water quality variables (Feck & Hall, 2004). American dipper occurrences have been found to be most strongly related to aquatic invertebrate abundances; where high abundances of benthic invertebrates (e.g., coarse streambed substrates) are the most important attributes of American dipper habitat (Feck & Hall, 2004). However, water quality remains critical, as industrial pollution can cause dippers to abandon streams and contaminate invertebrate prey, resulting in contaminated eggs and reduced productivity of dipper populations (Wayland et al., 2007).

American dipper often have a greater probability of occurring in areas distant from human disturbance (e.g., roads; Loegering & Anthony, 2006). However, the support structures of bridges and dams are known to provide breeding habitat at low elevations, in association with steams with low channel gradients, good water quality, and abundant invertebrates (Campbell et al., 1997; Kingery, 1996; Osborn, 1999; Willson et al., 2009). American dippers have also been observed foraging in areas with relatively high levels of human activity (Parks Canada, 2013; Barber, 1996), and are known to use artificial nest boxes (Hawthorne, 1979; Loegering & Anthony, 2006). As American dipper are sensitive to water quality, human industrial impacts such as mines represent a negative influence on the landscape.

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of American dipper, justifying a 4-class rating scheme. Under this rating scheme habitats are ranked as: 1) high; 2) medium; 3) low; and 4) unsuitable (nil). Ratings assumptions are as follows:

- Upland second and third (Strahler) order streams represent optimal living, foraging, and reproductive habitat (high suitability) for American dipper year-round, especially where these streams flow over coarse soils and rugged terrain.

- Fourth, fifth, sixth, seventh, and eighth order streams have limited value as living, foraging, and reproductive habitat, in rank order of importance (medium to low suitability).
- First order streams are of dubious importance (ephemeral, or inaccurately mapped) and therefore ranked low in suitability.
- Streams flowing over fine sediments support lower abundances of aquatic invertebrates and are therefore less valuable as foraging habitat.
- Contamination due to mining has a detrimental impact on water quality and riparian invertebrate communities, with higher trophic level consequences for bird reproduction, thus negatively affecting American dipper breeding habitat.

Model Description

American dipper models were constructed to represent the spring / summer season. The HSI model for American dipper incorporated buffered water courses with habitat suitability rankings based on stream order (**Table 1.2-195**). A soil coarseness index was generated and applied to penalize watercourses with fine soils. A potential mine contamination index was similarly applied to penalize downstream reaches of American dipper habitat based on proximity to mine footprints. A general formula for the American dipper HSI model is as follows, where: RS = ranked stream orders; SC = soil coarseness index; and MC = potential mine contamination index.

RSO x SC x MC

Table 1.2-195 Habitat Attributes Modelled for American Dipper

Variable	Source	Description
Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Second and third order streams ranked high (3); fourth and fifth order streams ranked medium (2); and sixth, seventh, and eighth order streams ranked low (1); because of their ephemeral and/or questionable status, first order streams were also ranked low (1).

Variable	Source	Description
Soil coarseness	BC Soil Survey Soil Landscapes of Canada (Alberta)	Fine soils mapped with 'Drainage' = 'Eolian', 'Imperfectly drained', 'Poorly drained', and 'Moderately well drained' were intersected with streams and rasterized as a reduction scale factor of 0.5; a congruent scale factor of 1 was applied to the inverse area within the RSA; the resulting soil coarseness index was multiplied with ranked habitats to penalize areas with fine sediments
Potential mine contamination	Digital Elevation Model for British Columbia – CDED – 1:250,000: https://catalogue.data.gov.bc.ca/dataset/7b4fef7e-7cae-4379-97b8-62b03e9ac83d KBRCE (2019) disturbance dataset Human Footprint Inventory (2019)	Downstream stream segments intersected with mine footprints; 2 km mine proximity raster calculated and integrated with DEM; results normalized on decimal scale (0 to 1); model raster multiplied by resulting index to apply a penalty to downstream water features in proportion to mine proximity and water flow

1.2.5.24 Spotted Sandpiper HSI Model

Habitat Requirements

Spotted sandpipers (*Actitis macularius*) depend on open riparian and shoreline areas for foraging and nesting, generally occurring within 200 m of water (Burger, 2015). In BC, nesting sites can feature low woody and herbaceous ground cover, with 72 % of nest sites (n=72) found within 15 m of water (Campbell et al., 1990). However, some amount of herbaceous cover appears to be important, as it offers beneficial cover from predators (Reed et al. 2020). Small islands were also found to be favoured as nesting sites, providing similar protection (Reed et al., 2020). The spotted sandpiper diet includes a range of aquatic and terrestrial invertebrates, including midges (Diptera), mayflies (Ephemoptera), grasshoppers, crickets (Orthoptera), beetles (Coleoptera), caterpillars (Lepidoptera), worms (Annelida), mollusks (Mollusca), crustaceans (Crustacea), spiders (Araneae), and vertebrates such as small fish (Actinopterygii; Reed et al., 2020).

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of spotted sandpiper, justifying a 4-class HSI rating scheme. Under this rating scheme habitats are ranked as: 1) High; 2) Medium; 3) Low; and 4) unsuitable (Nil). Ratings assumptions are as follows:

- The shorelines and shallows of primary streams, lakes, and wetlands represent optimal (high suitability) living, foraging, and reproductive habitat for spotted sandpiper throughout the breeding season, especially where these areas intersect stony terrain and bare substrates valuable for feeding, which are also characterized by low herbaceous and woody cover valuable for nesting / predator avoidance.

- Secondary and tertiary streams have limited value as living, foraging, and reproductive habitat, in decreasing order of importance (medium, low suitability).

- Contamination due to mining has a detrimental impact on water quality and riparian invertebrate communities, with higher level trophic consequences for bird reproduction, thus negatively affecting spotted sandpiper breeding habitat.

Model Description

Spotted sandpiper models were constructed to represent the spring / summer season. The HSI model implemented for spotted sandpiper incorporated baseline habitat suitability rankings based on stream order classifications, and wetlands and lacustrine features, which were buffered and ranked as outlined in the Ratings Assumptions and in **Table 1.2-206**. To account for the value of bare ground, stony shores, and open herbaceous areas favoured by spotted sandpiper, vectors representing stony fluvial substrates were integrated with areas lacking young, mature, and old growth forest cover to create an index highlighting this ideal habitat type. In this index, open, stony shorelines and unforested river margins were multiplied by the congruent scale factor of 1, and all areas outside penalized (multiplied) by the reduction scale factor of 0.5. The HSI model for spotted sandpiper can be generalized as follows, where: RWF = ranked water features; (SS + ESV) = stony shores + early seral vegetation index; and MC = potential mine contamination.

RWF x (SS + ESV) x MC

Table 1.2-206 Habitat Attributes Modelled for Spotted Sandpiper

Variable	Source	Description
Rivers	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygons reduced to line work; outlines buffered 25 m to represent shorelines and shallows; rasterized and ranked as high suitability habitat; raster integrated with other water features based on 4-class rating scheme; river features adopted instead of Strahler stream orders because of the more accurate contours
Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Line work buffered by 20 m for fourth and fifth order streams and 15 m for first, second, and third order streams; resulting polygons reduced to line work; outlines buffered by 25 m to represent shorelines and shallows. Fourth and fifth order streams ranked as medium suitability and first, second, and third order streams ranked low; raster integrated with other water features based on 4-class rating scheme
Wetlands and lacustrine features	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygons reduced to line work; outlines buffered 25 m to represent shorelines and shallows; rasterized and ranked as high suitability habitat; raster integrated with other water features based on 4-class rating scheme
Stony shores	BC Soil Survey Soil Landscapes of Canada (Alberta)	Areas mapped as 'Stony' OR 'Very stony' AND 'Fluvial' extracted and intersected with water feature margins; rasterized with a burn value of 1; reduction scale factor of 0.5 applied to the inverse area (this index was integrated with the unforested shoreline index to accentuate ideal habitat and penalize unsuitable habitat)
Unforested (open) shoreline habitat	Digital Elevation Model for British Columbia – CDED – 1:250,000: https://catalogue.data.gov.bc.ca/dataset/7 b4fef7e-7cae-4379-97b8-62b03e9ac83d KBRCE (2019) disturbance dataset Human Footprint Inventory (2019)	Forested areas mapped as 'old', 'mature', or 'young' extracted and intersected with water feature margins; rasterized with a reduction scale factor of 0.5; congruent scale factor applied to inverse area (this index was integrated with the stony shores index to accentuate ideal habitat and penalize unsuitable habitat)

Variable	Source	Description
Potential mine contamination	Digital Elevation Model for British Columbia – CDED – 1:250,000: https://catalogue.data.gov.bc.ca/dataset/7 b4fef7e-7cae-4379-97b8-62b03e9ac83d Human Footprint Inventory (2019) KBRCE (2019) disturbance dataset	Downstream stream segments, wetlands, and lacustrine features intersected with mine footprints; 2km mine proximity raster calculated and integrated with DEM; results normalized on decimal scale (0 to 1); model raster multiplied by resulting index to apply a penalty to downstream water features in proportion to mine proximity and water flow

1.2.5.25 Harlequin Duck HSI Model

Habitat Requirements

Harlequin ducks (*Histrionicus histrionicus*) overwinter in coastal marine waters and migrate inland to breed along fast-moving rivers and mountain streams on rocky islands or banks during the spring snow and ice melt (Cassirer et al., 1993; Smith et al., 2000). Breeding harlequins are generally found in undisturbed, low-gradient, meandering mountain streams flowing through dense riparian areas, among woody debris and mid-stream features such as boulders (BC CDC, 1995; Smith, 1998, 1999; Spahr et al., 1991; Wiggins, 2005). Islands in braided, multichannel streams represent ideal nesting sites, providing protection from predators (Machmer, 2001; Robertson et al., 1999; Smith 1998, 1999; Wiggins, 2005). Nesting occurs in hollows under the cover of bushes, crevices among boulders, cavities in cliff faces and trees, in puffin burrows, or other small hidden sites (BC CDC, 1995; Cassirer et al., 1993; Ehrlich et al., 1992), typically within 5–10 m proximity to water (Robertson et al., 1999; Wiggins, 2005). When overwintering, the harlequin's diet includes crustaceans, mollusks, insects, echinoderms, and fish (Cottam, 1939); when breeding, their diet consists mostly of insects and fish roe (Dzinbal & Jarvis, 1984).

Numerous scale-dependent factors influence harlequin duck habitat selection (Heath et al., 2008). Certain habitat characteristics appear to be widely favoured by Harlequin ducks, including: wide riparian vegetative zones; braided, multi-channel streams with eddies and islands for nesting and roosting; moderate stream channel gradients (1–7%); and clean water of low acidity, clear enough to support foraging for benthic macro-invertebrates (Machmer, 2001; Wiggins, 2005; Wright, 1998). A GAP analysis of breeding habitat for dippers in Wyoming, which provides an excellent representation of their occurrence in this region, emphasized clear, fast-flowing streams (where harlequins are found in association with American dipper), mountain rivers and lakes, streams ≥10m wide, low-gradient streams with braided channels, and good water quality (Oakleaf et al., 2003).

Harlequin ducks can occur in association with streams with a mature to old growth overstory, occurring less frequently in association with herbaceous banks (Oakleaf et al., 2003). Streamside vegetation, such as shrubs, can also be important habitat for harlequin ducks (e.g., nesting sites characterized by >50% streamside shrub cover; Spahr et al. 1991). Although vegetation cover is thought to be helpful as a means of predator avoidance (Machmer, 2001; Spahr et al., 1991), vegetation cover may also potentially hinder a hen's ability to detect predators (MacCallum et al., 2016). Harlequin ducks can prefer rocky substrates (e.g., cobble and boulder, Machmer, 2001; Vermeer, 1983; Wiggins, 2005), which are known to host higher abundances of aquatic invertebrates (Willson et al., 2008). However, harlequin ducks may also avoid areas with a high proportion of gravel substrate (e.g., Machmer, 2001).

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of harlequin ducks, justifying a 4-class HSI rating scheme. Under this rating scheme habitats are ranked as: 1) High; 2) Medium; 3) Low; and 4) unsuitable (Nil). Ratings assumptions are as follows:

- Braided streams, with nearby vegetation cover, represent optimal (high suitability) breeding and foraging habitat for harlequin ducks.
- Lake and wetland margins, where they lie in proximity to riverine water features, also provide potential breeding and foraging habitat (medium suitability where there is surrounding vegetation cover, low suitability where there is no surrounding vegetation cover)
- Streams flowing over fine sediments support lower abundances of aquatic invertebrates and are therefore less valuable (= low suitability) as breeding and foraging habitat
- Contamination due to mining has a detrimental impact on water quality and riparian invertebrate communities, with higher level trophic consequences for bird reproduction, thus negatively affecting harlequin breeding habitat

Model Description

Harlequin duck models were constructed to represent the spring / summer season. The northern goshawk The HSI model implemented for harlequin ducks incorporated water features which were buffered and ranked according to the parameters set out in **Table 1.2-217**. The interstices of major riverine channels were buffered and rasterized, with braided channels retaining a congruent scale factor (1) and areas outside braided channels penalized with a reduction scale factor (0.5). A similar index was generated where buffered water features intersecting vegetation cover was rasterized with a congruent scale factor and the inverse area penalized with a reduction scale factor of 0.5. A soil coarseness index was also applied to penalize reaches flowing over fine sediments. Finally, the potential mine contamination index was applied to penalize water features downstream from mine footprints. A generalized formula for the harlequin duck HSI is as follows, where WF = buffered and ranked water features; BC = braided channel index; VC = vegetation cover index; SC = soil coarseness index; and MC = the potential mine contamination index.

RWF x BC x MC x VC x SC x MC

Table 1.2-217 Habitat Attributes Modelled for Harlequin Duck

Variable	Source	Description
Rivers	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygon rasterized and ranked as high suitability habitat (=3); integrated with other water features; rivers adopted instead of stream orders because of their more accurate contours and features such as mid-stream islets
Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Line work buffered by 20 m for fourth and fifth order streams and 15 m for first, second, and third order streams; rasters ranked as high suitability (=3) integrated with other water features
Wetlands and lacustrine features	BC Freshwater Atlas Wetlands	Polygons clipped by buffered (100 m) riverine features; rasterized and ranked as high suitability habitat; raster integrated with other water features
Braided channels	BC Freshwater Atlas BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Interstices of streams selected and buffered 300 m; resulting vector manually edited to remove interstices of lesser streams, retaining only the interstices of major channels; rasterized with congruent scale factor of 1; inverse area rasterized with reduction scale factor of 0.5
Potential mine contamination	Digital Elevation Model for British Columbia – CDED – 1:250,000: https://catalogue.data.gov.bc.ca/dataset/7 b4fef7e-7cae-4379-97b8-62b03e9ac83d Human Footprint Inventory (2019) KBRCE (2019) disturbance dataset	Downstream stream segments, wetlands, and lacustrine features intersected with mine footprints; 2km mine proximity raster calculated and integrated with DEM; results normalized on decimal scale (0 to 1); model raster multiplied by resulting index to apply a penalty to downstream water features in proportion to mine proximity and water flow
Vegetation cover	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI)	All vegetation cover classes (structural stages 1-7) extracted and intersected with water features; rasterized with a congruent scale factor of 1; reduction scale factor of 0.5 applied to inverse area

1.2.5.26 Mallard Duck HSI Model

Habitat Requirements

Among the habitat types analyzed in studies of mallard (*Anas platyrhynchos*) habitat selection, four are recognized as being particularly important: agricultural crops, emergent herbaceous wetlands, open water, and woody wetlands (Drilling et al., 2002; Wickham et al., 2013). Nesting usually occurs on the ground in concealing vegetation within 0.8 km of water (Palmer, 1976), though mallards may occasionally nest in trees or other atypical areas (BC CDC, 1994). A combination of food availability and habitat structure are key predictors of mallard habitat use. Invertebrate abundances are a major factor determining duck pair use, with emergent vegetation becoming increasingly important during the brood phase (Nummi & Pöysä, 1993; Pöysa, 2001). Mallards are known to eat aquatic plants, seeds, acorns, cultivated grains, insects, molluscs, invertebrates, amphibians, fish eggs, and small fish—a diverse diet that varies according to the stage of the breeding cycle, food availability, and interspecific and intraspecific competition (BC CDC, 1994; Krapu et al., 1997).

There is significant spatial and temporal variability in mallard habitat use (Beatty et al., 2014; LaGrange & Dinsmore, 1989). At the local scale, non-breeding mallards have been found to select for habitat based on proximity to cropland, emergent wetland, open water, and woody wetland, whereas, at a broader spatial scale, variables such as proximity to wetlands and total wetland area became more important (Beatty et al., 2014). Seasonal patterns also emerged, highlighting the importance of different habitats at different times of year (e.g., woody wetlands during winter and spring migration, and cultivated crops after foraging flights at the local scale in winter). These seasonal patterns correspond with changes in food availability and foraging habits exhibited among many waterbird species, including mallards, as they shift from a seed-based diet in autumn and early winter to natural wetland food resources in late winter and spring (Frederickson & Heitmeyer, 1988; Arzel et al., 2006; Tidwell et al., 2013). Seasonal differences in habitat selection also relate to breeding behaviours. For example, woody wetlands provide suitable cover for pairing activities in late winter and spring migration (LaGrange & Dinsmore, 1989; Reid et al., 1989; Arzel et al., 2006). While some habitats were found to be particularly important at different times of year, two factors emerged as important throughout all seasons: proximity to open water and emergent wetlands (Beatty et al., 2014).

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of mallard ducks, justifying a 4-class rating scheme. Under this rating scheme habitats are ranked as: 1) high; 2) medium; 3) low; and 4) unsuitable (nil). Ratings assumptions are as follows:

- Areas within 200 m of wetlands and lakes represent optimal living, foraging, and reproductive habitat (high suitability) for mallards year round
- Areas within 100 m of primary and secondary streams are of secondary importance (medium suitability) as habitat, primarily for living, and foraging, but also for reproduction
- Croplands represent important (medium suitability) wintering habitat for foraging
- Tertiary streams represent potential habitat (low suitability) for living and foraging

- Mallards are dabbling ducks and so primarily use shallow waters, mostly limited to within 50m of the margins of water bodies

- Contamination due to mining has a detrimental impact on water quality and riparian invertebrate communities, with higher trophic level consequences for bird reproduction, thus negatively affecting mallard breeding habitat

Model Description

Mallard duck models were constructed to represent the spring / summer season. The HSI model developed for MD incorporated water features buffered and ranked according to the habitat requirements detailed in the Ratings Assumptions and in **Table 1.2-228**. The line work of water features was buffered to represent shoreline nesting habitat and dabbling foraging habitat. Crops were ranked for their importance as winter foraging habitat, but were not buffered as they are not recognized as important breeding habitat. Finally, a potential mine contamination index was applied following the same approach taken to HSI models developed for other aquatic birds. A general formula for the HSI developed for mallard duck is as follows, where: RWF = ranked water features; RC = ranked croplands; SC = soil coarseness index; and MC = potential mine contamination index.

(RWF + RC) x SC x MC

Table 1.2-228 Habitat attributes modelled for mallard duck

Variable	Source	Description
Streams	BC Freshwater Atlas Stream Network AltaLIS Hydrography - Alberta	Line work for first, second and third order streams buffered by 25 m; that of fourth and fifth order streams buffered 50 m; and that of sixth, seventh, and eighth order streams buffered 75 m; polygons representing stream orders 4-8 reduced to line work; outlines buffered 50 m; the output clipped by the original polygons to derive shapes representing the inner margins of streams; the original polygons representing these same stream orders buffered 200 m and the shape of the streams removed to represent 200 m buffer zones of potential nesting habitat around streams; layers representing inner and outer buffers merged and polygon rasterized with values for medium (2) suitability habitat; a similar process was repeated for streams of other orders, based on parameters defined in ratings assumptions.

Variable	Source	Description
Wetlands and lacustrine features	BC Freshwater Atlas AltaLIS Hydrography - Alberta	Polygons buffered 200 m; rasterized and ranked as high suitability (3) nesting habitat; polygons also reduced to line work and buffered inward by 50 m to represent dabbling / foraging habitat; raster integrated with other water features based on 4-class rating scheme
Crops	Earth Observation for Sustainable Development of Forests Land Cover	Shapes of annual and perennial crops rasterized and ranked as medium suitability (2) habitat
Potential mine contamination	Digital Elevation Model for British Columbia – CDED – 1:250,000: https://catalogue.data.gov.bc.ca/dataset/7b4fef7e-7cae-4379-97b8-62b03e9ac83d KBRCE (2019) disturbance dataset Human Footprint Inventory (2019)	Downstream stream segments intersected with mine footprints; 2 km mine proximity raster calculated and integrated with DEM; results normalized on decimal scale (0 to 1); model raster multiplied by resulting index to apply a penalty to downstream water features in proportion to mine proximity and water flow

1.2.5.27 Amphibian Models

1.2.5.28 Amphibian Candidate Variables

A selection of variables expected to influence VC amphibian species were derived from various digitized GIS resources (Table 1.2-39).

Table 1.2-239 Habitat variables expected to influence VC amphibians

Habitat Variable	Derived From	Details
Solar Radiation	Calculated from Elevation covariate using ArcGis 10.7, Spatial Analyst toolbox; Area Solar Radiation	Average value per grid cell (kWh/m^2). Raster calculated at $200m^2$ cell size, resampled to $25m^2$ for analysis.
Slope	Calculated from Elevation	Average value per grid cell (%)

Habitat Variable	Derived From	Details
	covariate using ArcGIS 10.7; Slope tool	
Stony shores	BC Soil Survey Soil Landscapes of Canada (Alberta)	Areas mapped as 'Stony' OR 'Very stony' AND 'Fluvial' extracted and intersected with water feature margins; rasterized with a burn value of 1; reduction scale factor of 0.5 applied to the inverse area (this index was integrated with the unforested shoreline index to accentuate ideal habitat and penalize unsuitable habitat)
Shrubs	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Shrub containing habitat derived from TEM. Area coverage per grid cell (%)
Snow cover	NASA Terra/MODIS Snow Cover (10 year average)	Averaged snow cover index value per grid cell
Forest Edge	Vegetation Resource Inventory (VRI) Alberta Vegetation Inventory (AVI)	Average distance to edge of forested areas per grid cell
Terrain Ruggedness	Calculated using vector ruggedness measure (VRM) of terrain in ArcGis 10.7 script; available from Environmental Systems Research Institute ArcScripts website	Average VRM index value per grid cell
Curvature	Calculated using a curvature ArcGis 10.7 script: available from Environmental Systems Research Institute ArcScripts website	Area curvature per grid cell
Grasslands, Crops, Pasture and Open Canopy Forest	Terrestrial Ecosystem Mapping (TEM) site series: GA03, Gb, Gb04, Gb20, Gg, Gg12, Xv BC & AB: Government of Canada, Agriculture & Agri-Food Canada, Annual Crop Inventory 2018	Area coverage per grid cell (%)
Canopy Cover	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Agriculture	Agriculture & Agri-Food Canada,	Area coverage per grid cell (%)

Habitat Variable	Derived From	Details
	Annual Crop Inventory 2018	
Avalanche Chutes and Alpine Areas	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM) Predictive Ecosystem Mapping (PEM)	Area coverage per grid cell (%)
Riparian Areas	BC Freshwater Atlas (Wetlands) AltaLIS Hydrography - Alberta	Average distance to riparian areas per grid cell (m)
Deciduous Forest	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Coniferous Forest	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) EOSD Land Cover Classification	Area coverage per grid cell (%)
Early Seral Forest	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Mid Seral Forest	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Old and Mature Forests	Alberta Vegetation Inventory (AVI) BC Vegetation Resource Inventory (VRI) Terrestrial Ecosystem Mapping (TEM)	Area coverage per grid cell (%)
Wetlands	BC Freshwater Atlas (Wetlands) AltaLIS Hydrography - Alberta	Average distance to rivers per grid cell (m)
Rivers	BC Freshwater Atlas (Wetlands) AltaLIS Hydrography - Alberta	Average distance to rivers per grid cell (m)
Streams	BC Freshwater Atlas (Wetlands) AltaLIS Hydrography - Alberta	Average distance to streams per grid cell (m).
Roads	GeoBC Atlas, Integrated	Average area of buffered roads per grid

Habitat Variable	Derived From	Details
	Transportation Network Ministry of FLNRORD, EV CEMF AltaLIS Access - Alberta	cell. Buffer size scaled proportionally to road class.
Burns	BC Fire Perimeters – Historical AB Historic Wildfire Perimeters	Merged fire perimeters, all fires between 10-25 years. Area per grid cell
Cutblocks/ Logging	Harvested Areas of BC (Consolidated Cutblocks) Alberta AVI post inventory cutblocks	Area coverage per grid cell (%)
Mining Areas	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC BC: Ministry of FLNRORD, EV CEMF BC: VRI - Forest Vegetation Composite Polygons and Rank 1 Layer. AB: Alberta Biodiversity Monitoring Institute, Human Footprint Inventory 2016	Area coverage per grid cell (%)
Built-up Areas	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC (last modified 2019-09-05) AB: Residential areas from Alberta Biodiversity Monitoring Institute, Human Footprint Inventory 2016 AB: Waste disposal areas, residential areas, leisure areas, liquid storage areas, buildings, ritual cultural areas from Topographic Data of Canada - CanVec Series	Area coverage per grid cell (%)
Farmed Areas	BC: Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer, Ministry of FLNRORD – GeoBC BC: Ministry of FLNRORD, EV CEMF BC: VRI - Forest Vegetation Composite Polygons and Rank 1 Layer. AB: Alberta Biodiversity Monitoring Institute, Human	Area coverage per grid cell (%)

Habitat Variable	Derived From	Details
	Footprint Inventory 2016	
Human Influence	Global Human Influence Index (1995-2004)	Average global human influence index value per grid cell

1.2.5.29 Western Toad Occupancy Model

Occupancy models for western toad were based upon data collected via a combination of MFLNROD surveys, tech amphibian surveys, and wetland surveys. A total of 182 sites were used in the model with a maximum of 30 observations (occasions) per site, models were constructed to represent the spring / summer season. Models were run using a single season occupancy model fit with RPresence and Presence software. As there were very few toad detections and models ran poorly, the best model was used that defined known western toad habitats. Model averaging was not conducted. The model beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using a chi squared goodness of fit test with 10,000 bootstraps on the top model for summer, χ^2= 72147007.77, P value=0.02, ĉ=0.24. Models and beta values of variables correspond to those presented in the amphibian existing conditions report and are shown in **Table 1.2-** and **Table 1.2-41**.

Table 1.2-40 Showing the Top Models Describing Western Toad Occupancy in the LSA, and a Null Model for Comparison

Model	AICc	DeltaAICc	AIC weights	Parameters	Loglikelihood
psi(BU + CCC + PSR + FRM + SLP + PRA + LWA + SHR)p()	306.19	0	0.76	11	297.97
psi(PSR + LWA)p()	309.11	2.92	0.18	4	290.06
psi(BU + FRM + SLP + EL + SHR + PSR + LWA)p()	312.21	6.02	0.03	9	308.14
psi(.)p(.)	312.64	6.45	0.03	2	304.41
psi(SLP + EL)p()	313.47	7.27	0.02	4	307.33
psi()p()	314.51	8.32	0.00	2	306.29

Table 1.2-41 Showing Beta Values and Standard Errors of Variables Describing Western Toad occupancy in the LSA

Variable	Beta	SE
Built Up (BU)	-0.10	0.16
Percentage farmland (FRM)	0.02	0.10
Slope (SLP)	-0.21	0.19
Percent Canopy Closure C (CCC)	-1.04	0.37
Open Canopy AB (CAB)	-0.68	0.36
Shrub cover (SHR)	0.27	0.41
Minimum Distance to Primary or Secondary Rivers (PSR)	-5.67	0.97
Percent Area Lake and Wetland (LWA)	-0.09	0.44
Percent Area Riparian (PRA)	-0.09	0.44

1.2.5.30 Columbia Spotted Frog Resource Selection Function

The Columbia spotted frog resource selection function was based on upon data collected via a combination of MFLNROD surveys, tech amphibian surveys, and wetland surveys. A total of 142 sightings of Columbia spotted frog and frog spawn were used in the model. Models were constructed to represent the spring / summer season only. Models were run using a used / available study design resource selection function in MLwin software. Each used location was paired to 20 random locations within a 1 km radius, simulating actual availability for each sampled frog. Models were run using Markov Chain Monte Carlo, and Deviance Information Criteria (DIC) was used to rank models. The derived beta values were used in ArcGIS Raster Calculator to project the final GIS based distribution model. Model fit was tested using receiver operating characteristics (ROC) where the area under the curve AUC = 0.862, indicated a very good model fit. Models and beta values of variables correspond to those presented in the Columbia spotted frog existing conditions report and are shown in **Table 1.2-442** and **Table 1.2-443**.

Table 1.2-42 Showing the Top Models Describing Columbia Spotted Frog Habitat Selection in the LSA.

Model	DIC	DeltaDIC	Parameters
D_STR, SLP, ESS	877.1	0	4
D_STR, SLP, ESS, D_RIP	903.9	26.8	5
D_STR, SLP, ESS, D_RIP, ELE	905.3	28.2	6

D_STR, ESS, D_RIP, RUG	912.2	35.1	5
D_STR, ESS, D_RIP, ELE	971.6	94.5	5
D_STR, ESS, D_RIP, ELE, CUR, D_MN	972.8	95.7	7
D_STR, ESS, D_RIP, ELE, CUR	973.2	96.1	5

Table 1.2-43 Showing Beta Values and Standard Errors of Variables Describing Columbia Spotted Frog Habitat Selection in the LSA

Variable	Beta	SE
Early Seral Stage Forest (ESS)	1.9	0.27
Dist. To Streams (STR)	-0.54	0.31
Slope (SLP)	-0.22	0.03
Elevation (ELE)	0.35	0.50
Dist. to Mines (D_MN)	-0.0001	0.000
Dist. to Riparian (D_RIP)	-0.005	0.002
Dist. to Built up Areas (D_BU)	0.26	0.28
Curvature (CURV)	-0.21	0.40
Ruggedness (RUG)	-5.1	0.41

1.2.5.31 Insect Modelling

1.2.5.32 Insect Candidate Variables

A selection of variables expected to influence VC insects were derived from various digitized GIS resources (Table 1.2-44).

Table 1.2-44 Habitat attributes modelled for Gillette's checkerspot

Variable	Source	Model Description
Forest cover / structural stages	EOSD Land Cover; Vegetation Resource Inventory (VRI)	Herbaceous, shrub, mature forests, and old growth forests combined with wetlands; these potential habitats uniformly ranked as optimal (high suitability) before modifying the value of habitat in areas lying outside of the ideal conditions

Variable	Source	Model Description
Wetlands	BC Freshwater Atlas Wetlands Alberta Merged Wetland Inventory	All wetland features merged with raster representing the extent of suitable herbaceous and forested habitat for Gillette's checkerspot
Crown closure	Vegetation Resource Inventory (VRI) Alberta Vegetation Inventory (AVI)	Open areas with low crown closure (<50%) selected; output raster multiplied with raster representing forested communities to select areas of open stand structure suitable for Gillette's checkerspot
BEC Zones	BC Biogeoclimatic Zones Crown TEM	Raster created with BEC Zones = 'ESSF' AND 'MS' selected for the RSA For the LSA, BEC units selected included: ESSFdk1/110,111 AND MSdw/101,110,111; raster multiplied with foregoing rasters to limit Gillette's checkerspot habitat to BEC units known to support *Lonicera involucrata*
Elevation	DEM	Raster representing elevations >=1,200 m AND <= 1,800 m multiplied with foregoing inputs to limit habitat to Gillette's checkerspot's known elevational niche
Aspect	DEM	Aspects with azimuth >= 180° AND <= 270° derived from DEM; values representing optimal aspects merged as congruent scale factor (1) with inverse area (reduction scale factor, 0.5) to produce an index penalizing areas outside of optimal aspects for Gillette's checkerspot
Riparian areas	DEM / Terrain curvature	Terrain with low curvature (<0.45) derived from DEM to represent riparian areas; an index constructed with congruent scale factor (1) representing riparian areas with low curvature and reduction scale factor (0.5) representing areas with high terrain curvature

1.2.5.33 Gillette's Checkerspot HSI Model

Habitat Requirements

Gillette's checkerspots (*Euphydryas gillettii*) occur in small, discrete colonies amidst natural openings in moist, mountainous, forested ecosystems characterized by Engelmann spruce (*Picea engellmannii*) and sub-alpine fir (*Abies lasiocarpa*), in both montane and subalpine zones (Cannings, 2004; Dulc, 2016; Dulc & Hobbs 2013; Kondla, 2005). Gillette's checkerspot is primarily limited by the occurrence of black twinberry (*Lonicera involucrata*), the butterfly's larval foodplant. Ideal habitat for the Gillette's checkerspot includes areas exhibiting an abundant cover of black twinberry, and abundant nectar sources among composite flowers in the Asteraceae family (Williams, 1988). Suitable habitat includes open riparian areas with small streams flowing through, though drier (mesic) marsh habitats without obvious flowing water are also known to support the butterfly (Williams, 1988).

Disturbances caused by forest harvest, road and power-line construction, or fire, create ephemeral openings suitable for Gillette's checkerspots (Canning, 2004; Dulc, 2016; Dulc & Hobbs, 2013; Guppy & Shepard, 2001; Williams, 1988; Williams, 1995). Colonies are understood to be relatively stable, persisting for multiple generations in undisturbed non-ephemeral sites; in ephemeral sites caused by disturbances, however, forest succession may lead to localized extirpations (Dulc, 2016).

Gillette's checkerspot typically occur at elevations up to 2,100 m within BC (Cannings, 2004), however, a recent review of 2,374 Gillette's checkerspot from 2008–2015 suggests that this species is limited to elevations between 1,253–1,779 m in the province (J. Hobbs pers. com., 2020).

Ratings Assumptions

There is a moderate level of knowledge of the habitat requirements of Gillette's checkerspot, justifying a 4-class rating scheme. Under this rating scheme habitats are ranked as: 1) high; 2) medium; 3) low; and 4) unsuitable (nil). Ratings assumptions are as follows:

- Open herbaceous and shrub communities (structural stages 1–3), and mature and old growth forests (structural stages 6-7) with low canopy closure (<50%), represent optimal living, foraging, and reproductive habitat (high suitability) for Gillette's checkerspot, especially where these environments intersect with riparian areas and southern exposures.
- The elevational niche for Gillette's checkerspot ranges from approximately 1,200–1,800 m.
- Reproductive habitat for Gillette's checkerspot is limited to BEC units supporting black twinberry (*Lonicera involucrata*), the butterfly's larval food plant.
- High elevation wetlands, meadows, and riparian communities represent important reproductive and foraging habitat for Gillette's checkerspot, hosting important nectaring plants such as *Senecio, Aster, Agroseris, Geranium, Erigeron*, and fragrant white rein orchid (*Platanthera dilatata*), as well as the Gillett checkerspot's larval foodplant, *Lonicera involucrata*.

Model Description

Gillette's checkerspot models were constructed to represent the spring / summer season. The HSI model for Gillette's checkerspot was constructed with all potential habitat types (open mature and old growth forests, herbaceous, shrub, and wetlands) integrated and uniformly ranked as high suitability habitat. The resulting raster was modified by limiting the extent of potential habitat to the known elevational niche for Gillette's checkerspot, and to biogeoclimatic units known to support *Lonicera involucrata*, the Gillette's checkerspot's larval foodplant. The model was further modified by indices representing optimal aspects and riparian areas known to support Gillette's checkerspot at northerly latitudes of its range. The formula representing the HSI model for Gillette's checkerspot can be generalized as follows, where: RF = ranked mature and old growth forests; CC = low crown closure (<50%); RESV = ranked early seral vegetation cover; RW = ranked wetlands; E = elevational niche; BEC = BEC units supporting

Gillette's checkerspot's larval food plant; A = an index penalizing areas outside of optimal aspects; and R = an index penalizing areas outside of areas of low terrain curvature, incorporated as a proxy for riparian areas:

(RF(CC) + RES + RW) x E x BEC x A x R

Clear cuts were also selected as potential habitat for the Gillette's checkerspot. Although the literature discriminates between the relative importance of ephemeral habitats such as clear cuts and undisturbed, non-ephemeral habitats, it was not possible to consistently parse these areas using available spatial data. Thus, clear cuts were uniformly ranked alongside all other suitable habitats. Areas where crown closure data were unavailable were masked when implementing the model. Including the mask of areas where crown closure data is unavailable may result in the overestimation of suitable habitat but ensures that the extent of suitable habitat is not underestimated. Habitat attributes incorporated into the HSI model for Gillette's checkerspot are summarized in **Table 1.2-43**.

1.3 References

Allan, D., Erickson, D., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater biology*, *37*(1), 149-161.

Anderson, T. (2002). *Conservation assessment for the American dipper in the Black Hills National Forest, South Dakota and Wyoming*. US. Forest Service, Rocky Mountain Region, Black Hills National Forest. Custer, South Dakota. 35pp.

Apps, C. & C. Lamb (2019). Scale-integrated grizzly bear habitat modeling to inform environmental assessment for NWP coal's Crowne Mountain Project. Prepared for NWP Coal Canada Ltd. and Keefer Ecological Services.

Arzel, C., Elmberg, J., & Guillemain, M. (2006). Ecology of spring-migrating Anatidae: a review. *Journal of Ornithology*, *147*(2), 167-184.

Barber R. E. (1996). Joy-Bird. *American Forests 102*, 34-35.

BC Conservation Data Centre. (1994). Species Summary: *Anas platyrhynchos*. B.C. Ministry of Environment.

BC Conservation Data Centre. (1995). Species Summary: *Histrionicus histrionicus*. B.C. Ministry of Environment.

BC Conservation Data Centre. (2015). *Species Summary: Myotis lucifugus*. BC Ministry of Environment.

BC Ministry of Environment. (2016). Best Management Practices for Bats in British Columbia, Chapter 1: Introduction to the Bats of British Columbia. B.C. Ministry of Environment, Victoria, BC. 108 pp.

Beatty, W. S., Webb, E. B., Kesler, D. C., Raedeke, A. H., Naylor, L. W., & Humburg, D. D. (2014). Landscape effects on mallard habitat selection at multiple spatial scales during the non-breeding period. *Landscape ecology*, *29*(6), 989-1000.

Boyce, M. S., Vernier, P. R., Nielsen, S. E., & Schmiegelow, F. K. (2002). Evaluating resource selection functions. *Ecological modelling*, *157*(2-3), 281-300.

Boyles, J. G., & Willis, C. K. (2010). Could localized warm areas inside cold caves reduce mortality of hibernating bats affected by white-nose syndrome? *Frontiers in Ecology and the Environment*, *8*(2), 92-98.

Burger, A. E. (2015). Spotted Sandpiper. In P. J. A. Davidson, R. J. Cannings, A. R. Couturier, D. Lepage, and C. M. Di Corrado (Eds.). *The atlas of the breeding birds of British Columbia, 2008-2012*. Bird Studies Canada, Delta, B.C.

Burnham, K.P. & Anderson, D.R. (2002) Model Selection and Multimodel Inference: A Practical Information-theoretic Approach. Springer-Verlag, New York, USA.

Burns, L. E., Frasier, T. R., & Broders, H. G. (2014). Genetic connectivity among swarming sites in the wide ranging and recently declining little brown bat (M yotis lucifugus). *Ecology and evolution*, *4*(21), 4130-4149.

Campbell, R. W., Dawe, N. K., McTaggart-Cowan, I., Cooper, J. M., Kaiser, G. W., & McNall, M. C. E. (1990). *Birds of British Columbia, Vol. 2. Nonpasserines: Diurnal Birds of Prey through Woodpeckers* (New edition edition, Vol. 2). UBC Press.

Campbell, R. W., Dawe, N. K., McTaggart-Cowan, I., Cooper, J. M., Kaiser, G. W., McNall, M. C. E., & Smith, G. E. J. (1997). American Dipper (Cinclus mexicanus swainson). *The birds of British Columbia*, *3*, 336-343.

Campbell, R. W., & Ryder, G. R. (2013). American Dipper Nesting in an Abandoned Pileated Woodpecker Nest-Cavity in British Columbia. *Wildlife Afield, 10*(1)*,* 44-46.

Cannings, R. J. (2004). *Appendix 5 of Accounts and Measures for Managing Identified Wildlife*. Victoria, B.C.: BC Ministry of Water, Land and Air Protection. Retrieved from http://a100.gov.bc.ca/pub/eswp/reports.do?elcode=IILEPK4010.

Cassirer, E. F., Schirato, G., Sharpe, F., Groves, C. R., & Anderson, R. N. (1993). Cavity nesting by harlequin ducks in the Pacific Northwest. *The Wilson Bulletin*, 691-694.

COSEWIC. (2013). Assessment and status report on the Little Brown Myotis, Myotis lucifugus, Northern Myotis, Myotis septentrionalis, and the Tri-colored Bat, Perimyotis subflavus in Canada.

Cotter, P. (2018). *American dipper* (Cinclus mexicanus). Southeast Alaska Conservation Assessment. Retrieved from https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/alaska/seak/era/cfm/Documents/7.7_AmericanDipper.pdf

Craig, J., & Holroyd, S. (2013). *Kootenay Community Bat Project*. Community Bat Programs of BC. http://www.bcbats.ca/attachments/KCBP_FAQ_WEB_Dec2013.pdf

Doyle, F. I., & Smith, J. N. M. (1994). Population response of northern goshawks to the 10-year cycle in numbers of snowshoe hares. *The Northern Goshawk: ecology and management*, *122.*

Drilling N., Titman R., & McKinney F. (2002). Mallard (Anas platyrhychos). In: Pool A, Gill F (eds) Birds North America. Academy of Natural Sciences, American Ornithologists' Union, Philadelphia, PA.

Dulc, S. (2016). *Gillett's Checkerspot inventory in southeastern BC.* Ministry of Forests, Lands, and Natural Resource Operations.

Dulc, S., & Hobbs, J. (2013). Gillett's Checkerspot Inventory and Monitoring in the Flathead River Basin: 2013 Surveys – Final Report*.* Great Northern Landscapes: Conservation Cooperative. Retrieved from www.auroraecological.com/assets/aurora-gillettes.pdf

Dzinbal, K.A., & Jarvis, R.L. (1984). Coastal feeding ecology of Harlequin Ducks in Prince William Sound, Alaska, during summer. *In* Marine birds: their feeding ecology and commercial fisheries relationships. *Edited by* D.N. Nettleship, G.A. Sanger, and P.F. Springer. Canadian Wildlife Service, Ottawa, ON. 610 pp.

Ehrlich, P. R., Dobkin D. S., & Wheye D. (1992). *Birds in Jeopardy: the imperiled and extinct birds of the United States and Canada, Including Hawaii and Puerto Rico.* Stanford University Press, Stanford, California. 259 pp.

Environment Canada. (2015). Recovery Strategy for Little Brown Myotis (*Myotis lucifugus*), Northern Myotis (*Myotis septentrionalis*), and Tri-colored Bat (*Perimyotis subflavus*) in Canada [Proposed]. *Species at Risk Act* Recovery Strategy Series. Environment Canada, Ottawa. ix + 110 pp.

Feck, J., & Hall Jr, R. O. (2004). Response of American dippers (*Cinclus mexicanus*) to variation in stream water quality. *Freshwater Biology*, *49*(9), 1123-1137.

Finn, S. P. (2000). Multi-scale habitat influences on northern goshawk occupancy and reproduction on Washington's Olympic Peninsula. (MS thesis, Boise State University).

Finn, S. P., Marzluff, J. M., & Varland, D. E. (2002). Effects of landscape and local habitat attributes on northern goshawk site occupancy in western Washington. *Forest Science*, *48*(2), 427-436.

Fredrickson, L. H., & Heitmeyer, M. E. (1988). Waterfowl use of forested wetlands of the southern United States: an overview. *Waterfowl in winter. University of Minnesota Press, Minneapolis, Minnesota, USA*, 307-323.

Gillies, C.S., Hebblewhite, M., Nielsen, S.E., Krawchuk, M.A., Aldridge, C.L., Frair, J.L., Saher, D.J., Stevens, C.E. and Jerde, C.L., (2006) Application of random effects to the study of resource selection by animals. *Journal of Animal Ecology*, *75*(4), pp.887-898.

Grindal, S. D., Morissette, J. L., & Brigham, R. M. (1999). Concentration of bat activity in riparian habitats over an elevational gradient. *Canadian Journal of Zoology*, *77*(6), 972-977.

Guppy, C. S., & Shepard, J. H. (2001). *Butterflies of British Columbia: Including Western Alberta, Southern Yukon, the Alaska Panhandle, Washington, Northern Oregon, Northern Idaho, Northwestern Montana*. Royal British Columba Museum, UBC Press.

Harrower, W. L. (2007). *Nesting requirements of the northern goshawk (*Accipiter gentilis atricapillus*) in southeastern British Columbia* (MS thesis, University of Victoria).

Hawkins, C. P., Murphy, M. L., & Anderson, N. H. (1982). Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology*, *63*(6), 1840-1856.

Hawthorne, V. M. (1979). Use of nest boxes by dippers on Sagehen Creek, California. Western Birds, 10, 215-216.

Heath, J. P., Montevecchi, W. A., & Robertson, G. J. (2008). Allocating foraging effort across multiple time scales: behavioral responses to environmental conditions by Harlequin Ducks wintering at Cape St. Mary's, Newfoundland. *Waterbirds*, *31*(sp2), 71-80.

Hilty, S. L. (2020). Characterizing summer roosts of male little brown bats (*Myotis* Lucifugus) in lodgepole pine-dominated forests. Doctorial dissertation, Montanta State University, Bozeman.

Hines, J.E. (2006) PRESENCE – Software to estimate patch occupancy and related parameters. Version 12.37. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, USA.

Holdren, C. E., & Ehrlich, P. R. (1981). Long range dispersal in checkerspot butterflies: Transplant experiments with Euphydryas gillettii*. Oecologia*, *50*, 125–129.

Holloway, G. L., & Barclay, R. M. (2001). Myotis ciliolabrum. *Mammalian species*, *2001*(670), 1-5.

Iverson, G. C. (1996). *Conservation assessment for the northern goshawk in southeast Alaska* (Vol. 387). US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Jung, K., Kaiser, S., Böhm, S., Nieschulze, J., & Kalko, E. K. (2012). Moving in three dimensions: effects of structural complexity on occurrence and activity of insectivorous bats in managed forest stands. *Journal of Applied Ecology*, *49*(2), 523-531.

Kenward, R. (2006). *The goshawk.* Bloomsbury Publishing PLC.

Kingery, H. E. (1996). *American dipper: Cinclus mexicanus*. *The birds of North America 229,*1-28.

Klinkenberg, Brian. (Editor) (2019). E-Fauna BC: Electronic Atlas of the Fauna of British Columbia. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver.

Kondla, N. G. (2005). Gillett's Checkerspot in the southern headwaters at risk (SHARP) project area. Alberta, Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 96, Edmonton, AB. 39 pp. Retrieved from http://aep.alberta.ca/fish-wildlife/species-at-risk/species-at-risk-publications-web-resources/species-at-risk-general/documents/SAR096-SHARP-GillettsCheckerspotInSHARParea-Feb2005.pdf

Krapu, G. L., Greenwood, R. J., Dwyer C. P., Kraft K. M., & Cowardin L. M. (1997). Wetland use, settling patterns, and recruitment in mallards. *Journal of Wildlife Management 61*, 736-746.

LaGrange, T. G., & Dinsmore, J. J. (1989). Habitat use by mallards during spring migration through central Iowa. *The Journal of wildlife management*, 1076-1081.

Loegering, J. P., & Anthony, R. G. (2006). Nest-site selection and productivity of American Dippers in the Oregon Coast Range. *The Wilson Journal of Ornithology*, *118*(3), 281-294.

Luszcz, T. M., & Barclay, R. M. (2016). Influence of forest composition and age on habitat use by bats in southwestern British Columbia. *Canadian Journal of Zoology*, *94*(2), 145-153.

MacCallum, B., Feder, C., Godsalve, B., Paibomesai, M. I., & Patterson A. (2016). Habitat use by harlequin ducks (Histrionicus histrionicus) during brood-rearing in the Rocky Mountains of Alberta. *Canadian Wildlife Biology and Management, 5(2)*, 32-45.

Machmer, M. M. (2001). Salmo River harlequin duck inventory, monitoring and brood habitat Assessment. *Report prepared for the Columbia Basin Fish and Wildlife Compensation Program. By Pandion Ecological Research Ltd. and the Salmo Watershed Streamkeepers Society. 54pp*.

MacKenzie, D. I., & Bailey, L. L. (2004). Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics*, *9*(3), 300-318.

MacKenzie, D. I., & Hines, J. (2018). RPresence: R interface for program PRESENCE. *R package version*, *2*(9).

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Andrew Royle, J., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*(8), 2248-2255.

Mahon, T. (2008). Foraging habitat selection and home range size of Northern Goshawks in northwest British Columbia. Morice and Lakes Innovative Forest Practices Agreement, Houston, B.C. Unpublished report.

Mahon, T. (2009). Northern Goshawks in west-central British Columbia: 10-year project summary. Bulkley Valley Centre for Natural Resources Research and Management, Smithers, British Columbia. Unpublished report.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. & Erickson, W.P. (2002) *Resource selection by animals*, 2nd edn. Kluwer Academic Publishers, Dordrecht, the Netherlands.

McClaren, E. L., & Pendergast, C. L. (2003). Relationship between forest age class distribution around Northern Goshawk nests and occupancy and nest productivity patterns at three spatial scales. BC Min. Water, Land and Air Protection, Nanaimo, BC. *Unpublished report*.

Ministry of Environment, Lands and Parks Resource Inventory Branch (MoELP), (1999). British Columbia Wildlife Habitat Rating Standards. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/whrs.pdf

Nummi, P., & Pòysá, H. (1993). Habitat associations of ducks during different phases of the breeding season. *Ecography*, *16*(4), 319-328.

Nagorsen, D. W., & Brigham, R. M. (1993). *Bats of British Columbia* (Vol. 1). UBC press.

Norberg, U. M., & Rayner, J. M. (1987). Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *316*(1179), 335-427.

Norquay, K. J., Martinez-Nuñez, F., Dubois, J. E., Monson, K. M., & Willis, C. K. (2013). Long-distance movements of little brown bats (Myotis lucifugus). *Journal of Mammalogy*, *94*(2), 506-515.

Oakleaf, B., Patla S., and Taylor K. (2003). Harlequin duck inventories and technique development. *Wyoming Game and Fish Department, Lander, WY*. Unpublished report.

Osborn, S. A. (1999). *Factors affecting the distribution and productivity of the American Dipper (*Cinclus mexicanus*) in western Montana: does streamside development play a role?* (MS thesis). University of Montana, Missoula, MT.

Pacifici, K., Reich, B. J., Dorazio, R. M., & Conroy, M. J. (2016). Occupancy estimation for rare species using a spatially-adaptive sampling design. *Methods in Ecology and Evolution*, *7*(3), 285-293.

Parks Canada. (2020). Banff National Park – Bird Watching. Government of Canada. https://www.pc.gc.ca/en/pn-np/ab/banff/activ/oiseaux-birds

Penteriani, V. (2002). Goshawk nesting habitat in Europe and North America. *Ornis Fennica*, *79*, 149-163.

Pöysä, H. (2001). Dynamics of habitat distribution in breeding mallards: assessing the applicability of current habitat selection models. *Oikos*, *94*(2), 365-373.

Price, F. E., & Bock, C. E. (1983). *Population Ecology of the Dipper (*Cinclus mexicanus*) in the Front Range of Colorado.* Allen Press, Inc.

Reed, J. M., Oring, L. W., & Gray, E. M. (2013). Spotted Sandpiper (Actitis macularius). *The Birds of North America Online*. https://doi.org/10.2173/bna.289

Reid F. A., Kelley J. R. Jr., T. S. Taylor, & L. H. Fredrickson (1989). Upper Mississippi Valley wetlands—refuges and moist-soil impoundments. In: Smith L. M., Pederson R. L., Kaminski R. M. (eds). Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, TX.

Robertson, G. J., Cooke F., Goudie, I. R., & Boyd. S. W. (1999). Within-year fidelity of harlequin ducks to a moulting and wintering area. *Occasional Papers-Canadian Wildlife Service*, 44-50.

Royle, J. A., & Dorazio, R. M. (2008). *Hierarchical modeling and inference in ecology: the analysis of data from populations, metapopulations and communities*. Elsevier.

Segers, J. L., & Broders, H. G. (2014). Interspecific effects of forest fragmentation on bats. *Canadian Journal of zoology*, *92*(8), 665-673.

Soberon, J. and Peterson, A.T. (2005) Interpretation of models of fundamental ecological niches and species' distributional areas. Biodiversity Informatics 2, 1–10.

Smith, C. (I998). Harlequin Ducks Histrionicus histrionicus in Kananaskis Country, Alberta. Unpublished technical report, Alberta Environmental Protection, Canmore, AB.

Smith, C. (I999). Harlequin Duck research in Kananaskis Country, Alberta in 1998: Kananaskis River and Elbow River. Unpublished technical report, Alberta Natural Resources Service, Canmore, AB.

Spahr, R. (1991). *Threatened, endangered, and sensitive species of the Intermountain Region*. US Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT. 520 pp.

Squires, J. R., & Kennedy, P. L. (2006). Northern goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology, 31*, 8–62.

Squires, J. R., & Reynolds, R. T. (1997). Northern Goshawk (*Accipiter gentilis*). *The Birds of North America, 298*, 32.

Stephens, R. M. (2001). *Migration, habitat use, and diet of northern goshawks (Accipiter gentilis) that winter in the Uinta Mountains, Utah* (Doctoral dissertation). University of Wyoming, Laramie, WY.

Stephens, V., & Lofts, S. (1988). Species Notes for Mammals. Volume 1 in A. P. Harcombe (tech. ed.). Wildlife Habitat Handbooks for the Southern Interior Ecoprovince. Ministry of Environment and Ministry of Forests.

Stuart-Smith, A. K., Harrower, W. L., Mahon, T., McClaren, E. L., & Doyle, F. I. (2012). A scientific basis for managing northern goshawk breeding areas in the interior of British Columbia: best management practices. *FORREX Series* (29).

Swystun, M. B., Lane, E. E., & Brigham, R. M. (2007). Cavity roost site availability and habitat use by bats in different aged riparian cottonwood stands. *Acta Chiropterologica*, *9*(1), 183-191.

Tidwell, P. R., Webb, E. B., Vrtiska, M. P., & Bishop, A. A. (2013). Diets and food selection of female mallards and blue-winged teal during spring migration. *Journal of Fish and Wildlife Management*, *4*(1), 63-74.

Tornberg, R., & Colpaert, A. (2001). Survival, ranging, habitat choice and diet of the Northern Goshawk Accipiter gentilis during winter in Northern Finland. *Ibis*, *143*(1), 41-50.

Vermeer, K. (1983). Diet of the harlequin duck in the Strait of Georgia, British Columbia. *The Murrelet*, *64*(2), 54-57.

Vonhof, M. J., & Barclay, R. M. (1996). Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. *Canadian Journal of Zoology*, *74*(10), 1797-1805.

Wayland, M., Casey, R., & Woodsworth, E. (2007). A dietary assessment of selenium risk to aquatic birds on a coal mine affected stream in Alberta, Canada. *Human and Ecological Risk Assessment*, *13*(4), 823-842.

White, C. M., Lloyd, G. D., & Richards, G. L. (1965). Goshawk Netting in the Upper Sonoran in Colorado and Utah. *The Condor*, *67*(3), 269-269.

Wickham, J. D., Stehman, S. V., Gass, L., Dewitz, J., Fry, J. A., & Wade, T. G. (2013). Accuracy assessment of NLCD 2006 land cover and impervious surface. *Remote Sensing of Environment*, *130*, 294-304.

Wiggins, D. (2005). Harlequin Duck (Histrionicus histrionicus): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Accessed on January 7, 2021 from: http://www.fs.fed.us/r2/projects/scp/ assessments/harlequinduck.pdf.

Williams, E. H. (1988). Habitat and range of Euphydryas gillettii (Nymphalidae). *Journal of the Lepidopterists' Society. 42*(1), 37–45.

Williams, E. H. (1995). *Fire-burned habitat and reintroductions of the butterfly Euphydryas gillettii (Nymphalidae*). Journal of the Lepidopterists' Society *49*(3), 183–191.

Williams, E. H., Holdren C. E., & Erlich, P. R. (1984). The life history and ecology of Euphydryas gillettii Barnes (Nymphalidae). *Journal of the Lepidopterists' Society. 38*(1), 1–12.

Willson, M. F., & Kingery, H. E. (2011). American Dipper (*Cinclus mexicanus*), version 1.0. *In Birds of the World (P. G. Rodewald, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA.*

Willson, M. F., Pendleton, G. W., & Hocker, K. M. (2009). Distribution and abundance of nesting American Dippers near Juneau, Alaska. W. *Birds 40*, 191-209.

Wright, K. G. & Clarkson, P.V. (1998). Harlequin Duck moulting ecology and banding synopsis in the Straight of Georgia, British Columbia: 1997 progress report. Unpublished report. Harlequin Conservation Society, West Vancouver, British Columbia, Canada.

Younk, J. V., & Bechard, M. J. (1994). Breeding ecology of the Northern Goshawk in high-elevation aspen forests of northern Nevada.