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Projected effects of climate change on the distribution and abundance of North Pacific birds and their habitats

Final report to the North Pacific Landscape Conservation Cooperative

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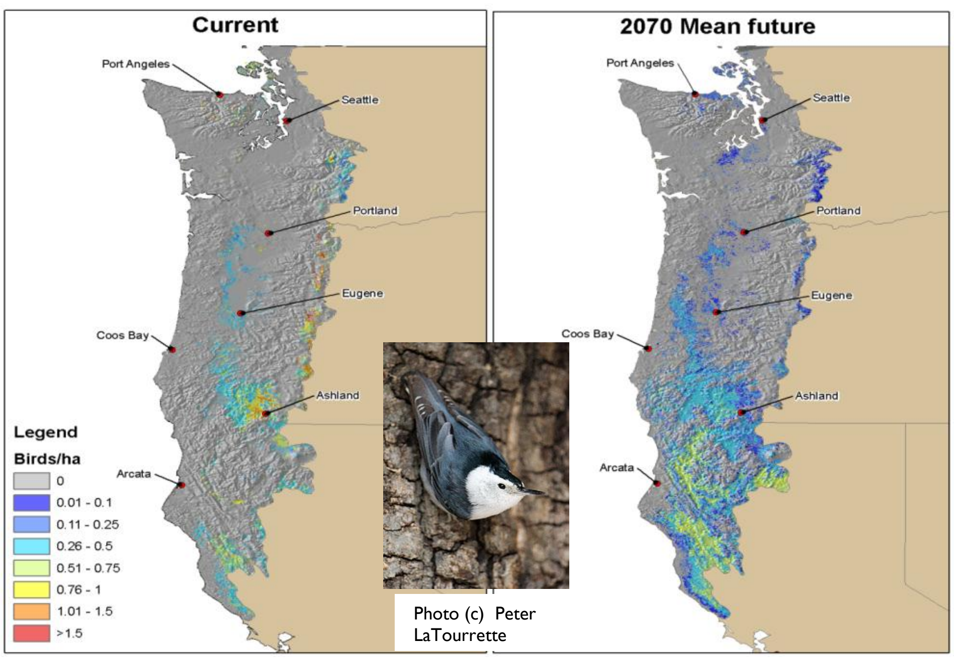

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Executive summary

We acquired, federated and curated approximately one million new observations to the Avian Knowledge Network. We used these new observations, in addition to millions of existing records, to model the distribution and abundance of 26 species of land birds in the southern portion of the North Pacific Landscape Conservation Cooperative (NPLCC) region including CA, OR and WA. The models were based on climate and modeled vegetation. Using the models we created maps of the distribution and abundance of each species for current (late 20th century) conditions and projected the models to future conditions (2070) based on five regional climate models. The bird models were also used to create maps of conservation priorities for all species and for species indicative of four different habitat types: conifer forest, oak woodlands, grasslands and riparian forest. We created a web based decision support tool (http://www.avianknowledgenorthwest.net/distributionmodels) and at (http://data.prbo.org/apps/nplcc/) where the results from the project can be viewed, queried and downloaded, including reports of model results for user defined regions.

The tool we developed can be used to support climate change adaptation planning in several ways. The models can be used to assess whether planned projects are likely to meet objectives given projected future changes. Additionally, the models can be used to identify areas of conservation priorities or restoration opportunities which account for a range in plausible future climate conditions. Coupled with regional conservation plans, such as *Habitat Conservation for Landbirds in Coniferous Forests of Western Oregon and Washington* (http://www.orwapif.org/conservation-plans), models can be used to identify quantifiable habitat objectives for focal bird species. The models can also be used to develop quantitative scenarios to be used for scenario planning exercises.

We anticipate that there may be many further applications of our tool and we plan to continue to work with NPLCC stakeholders to ensure that the tool is used to support conservation planning. We have already presented the results from the project to the NPLCC steering committee and through a webinar sponsored by the NPLCC (http://bit.ly/YCYUfU). We plan to highlight the application of our results in real conservation planning efforts through the website to illustrate how the tool and products can be used and to encourage others to use the tool for their projects.

Aggregate existing bird distribution and abundance data

American Bird Conservancy and Klamath Bird Observatory led the effort to acquire new avian observation data which resulted in close to one million new bird records from approximately 25 studies or data sets being added to the Avian Knowledge Network (AKN) database (Figure 1). The data came from numerous sources including American Bird Conservancy, Klamath Bird Observatory, The Nature Conservancy, Portland Audubon, City of Portland, Institute for Bird Populations, National Park Service, U.S. Forest Service, U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Fort Lewis Military Installation, Washington Department of Fish and Wildlife, and Oregon Department of Fish and Wildlife. Data was solicited through a widely distributed announcement (appendix 1), and by personal requests through Partners in Flight and other professional networks and partnerships.

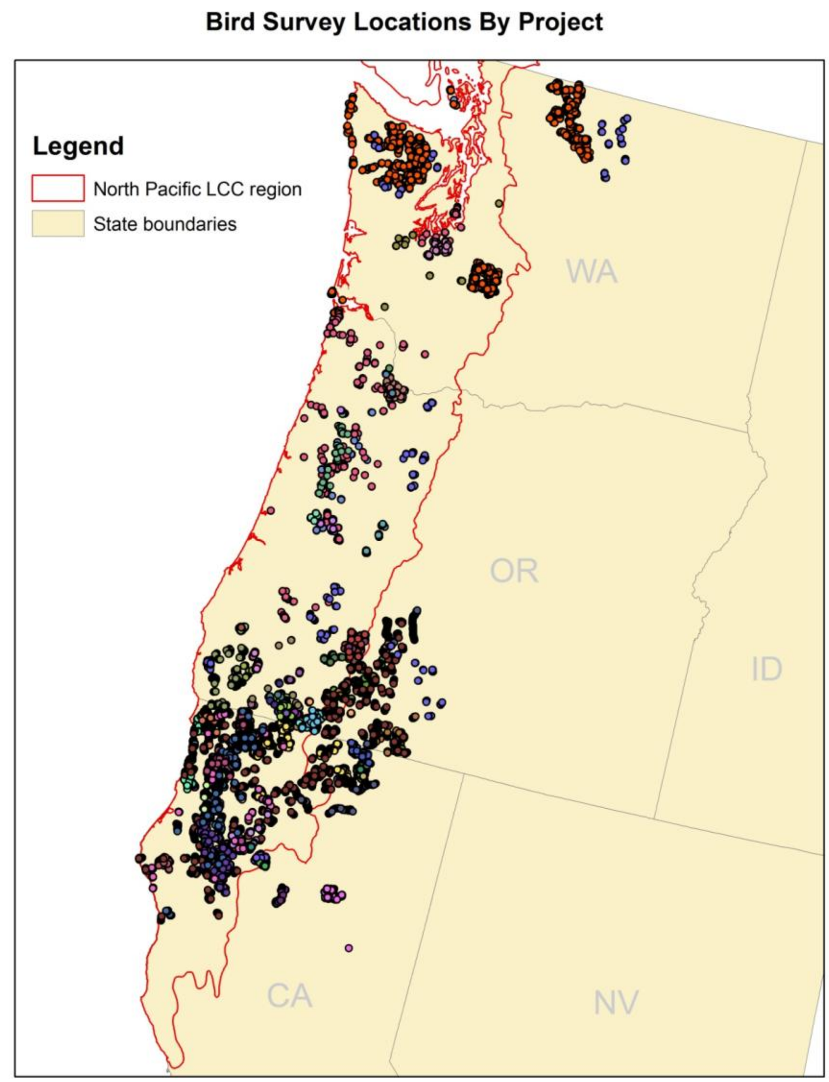

Figure 1. Avian observations acquired, federated and curated in the Avian Knowledge Network Different colors indicate different projects which provided the data (legend not shown).

As the data were collected using various protocols designed for specific project objectives, considerable effort was required to federate the newly acquired data into the AKN. Data were federated using metadata and data mapping tools previously developed by PRBO Conservation Science and the Klamath Bird Observatory through a process that included consulting with the project leaders that originally collected the data. As a side benefit, Klamath Bird Observatory was able to leverage funds from this project to develop the Avian Knowledge Northwest (http://www.avianknowledgenorthwest.net/). The site is a new regional node of the Avian Knowledge Network and can be used to view the data collected from this project as well as the mapping interface which displays the products from the NPLCC funded project. Owners of the data now have online access to the data and can utilize available data query/visualization resources. This aspect of the project significantly increased the amount and spatial extent of data available for our distribution modeling efforts, which had included millions of records collected by PRBO, Klammath Bird Observaotry, Redwood Sciences Laboratory but was restricted geographically to California and southern Oregon.

Spatial covariate data

We acquired contemporary climate data to calibrate our vegetation and bird distribution models from the PRISM Climate Group (http://www.prism.oregonstate.edu/). Data for future climate conditions were obtained from the North American Regional Climate Change Assessment Program (NARCCAP; http://www.narccap.ucar.edu/; (Mearns et al. 2009)). The future climate data come from a suite of high resolution regional climate models (RCM) forced with the Special Report on Emission Scenarios (SRES) A2 scenario, a high CO_2 emissions scenario. The projections from these future climate models comprise a range of plausible future conditions for the NPLCC region. The data were downloaded from the Earth System Grid (http://www.earthsystemgrid.org/project/narccap;(Mearns 2007)) and include the following five combinations of three regional climate models with boundary conditions driven by three different general circulation models (GCM):

1) CRCM CCSM = the Canadian Regional Climate Model (CRCM) with boundary conditions driven by the Community Climate System Model (CCSM)

2) RCM3 CGCM3 = the Regional Climate Model v3 (RCM3) with boundary conditions driven by the Third Generation Coupled Global Climate Model (CGCM3)

3) RCM3 GFDL = the Regional Climate Model v3 (RCM3) with boundary conditions driven by the Geophysical Fluid Dynamics Laboratory Global Climate Model (GFDL)

4) WRFG CGCM3 = the Weather Research Forecasting Grell Model (WRFG) with boundary conditions driven by the Third Generation Coupled Global Climate Model (CGCM3)

5) WRFG CCSM = the Weather Research Forecasting Grell Model (WRFG) with boundary conditions driven by the Community Climate System Model (CCSM)

Monthly total precipitation, max temperature, and minimum temperature grids were originally created at a ~50km resolution. We took several steps to downscale the grids to approximately match the resolution of the current PRISM data: To match the PRISM data units, precipitation was converted from kg per square meter to mm and temperature was converted from Kelvin to degrees Celsius. We then created monthly averages for each variable by year and averaged these monthly grids across 30-year windows. The modeled current period included the years 1969-1998 (2000). The modeled future period included the years 2040-2069

(2070). We calculated delta (Δ) values between these two time periods for each variable and then applied this delta to the PRISM data set as follows:

<u>Climate delta calculation</u>
ΔRCM min temp = RCM Future min temp - RCM Current min temp

ΔRCM max temp = RCM Future max temp - RCM Current max temp

ΔRCM precipitation = RCM Future precipitation/RCM Current precipitation

The delta rasters were then resampled to the finer scale resolution of the PRISM grids using bilinear interpolation. Once the delta rasters were resampled, they were integrated with the historic PRISM grids as follows:

<u>Apply delta calculation to current climate</u>
Downscaled future min temp = PRISM min temp + resampled ΔRCM min temp

Downscaled future max temp = PRISM max temp + resampled ΔRCM min temp

Downscaled future precipitation = PRISM precipitation * resampled ΔRCM precipitation

Vegetation model climate variables

To model the distribution of vegetation we chose to use bioclimatic variables which have been frequently used in modeling exercises. We used the downcaled future grids and the current PRISM grids to create 19 bioclimatic variables (http://www.worldclim.org/bioclim) using the package "dismo" in R (Hijmans et al. 2012). We created a correlation matrix to examine the relationships between the bioclimatic variables. When variables were highly correlated with one another ($r \geq 0.8$), we retained the one that was least correlated with the remaining layers. We cut a total of ten variables, leaving the following nine in our model: mean diurnal range (mean tmax - mean tmin), temperature seasonality (standard deviation of temp * 100), mean temperature of the wettest quarter, mean temperature of the driest quarter, mean temperature of the coldest quarter, precipitation seasonality (coefficient of variation), precipitation of wettest quarter, precipitation of driest quarter, and precipitation of coldest quarter.

Bird model climate variables

Based on possible physiological tolerances we hypothesized that 8 climate variables could constrain the distribution of birds during months when birds typically breed in the NPLCC region (April - July) for use in the bird models. Variables included total precipitation, standard deviation of precipitation, max and min temperatures across the breeding season, mean max and min temperature, mean monthly temperature range, and temperature range across the breeding season. After examining correlations between the predictor variables we retained mean temperature of the breeding season, temperature range across the breeding season and total precipitation to use in the bird models.

Geophysical variables

We included several different geophysical variables in our vegetation models. Soil data were based on the State Soil Geographic database (STATSGO) and downloaded from the Center for Environmental Informatics (http://apps.cei.psu.edu/cei_wp/; (Miller and White 1998)). Seven soil variables were included in the vegetation models including sand, silt, and clay fraction, soil porosity, soil pH, permeability, and available water content (AWC). All layers reflect characteristics measured at the topsoil level (5cm depth) except for AWC which reflects available water at 100 cm to better capture the root zone depth. We included stream distance as an index of riparian conditions. Stream distance was calculated as the distance to the closest year-round stream (i.e., not including intermittent streams or washes or springs). We calculated distance from the center of a raster pixel to the nearest stream using the ArcGIS Spatial Analyst tool 'Euclidean Distance'. Stream locations and types were obtained from the National Hydrological Dataset of 2010 for Washington and Oregon. Slope was calculated in degrees using the ArcGIS Spatial Analyst tool 'Slope'. For slope the input digital elevation model (DEM) was a clipped portion of USGS's Global Multi-resolution Terrain Elevation Data 2010 (Danielson and Gesch 2011) at a resolution of 7.5 arcseconds. We natural log transformed the slope before modeling. Solar radiation was calculated using the ArcGIS Spatial Analyst tool 'Area Solar Radiation'. We used the same DEM as above for the input. Following guidance provided by ESRI we cut up the study area into blocks of 1-degree latitude and calculated the solar radiation separately for each and mosaicked the resulting rasters together.

Climate Change Summary

Here we briefly review the projected changes in climate for the variables we used in our bird distribution and abundance models. All of the models project that breeding season (April – July) mean temperatures will increase between 2000 and 2070. The RCM3_GFDL model projects the least amount of warming while the other four models project mean breeding season temperatures within 0.2 °C of each other (Figure 2). The models using the RCM3 regional climate model showed a smaller change in the projected future temperature range from current, approximately ±0.5 °C, compared to the other models which showed decreases in temperature range between one and two °C (Figure 3). The decreases in temperature range are likely due to increases in minimum temperatures during the breeding season. Total breeding season projections for precipitation vary widely among the five future models (Figure 4). The models using the CCSM general circulation model to force the regional climate models show declines in precipitation from present with the CRCM_CCSM model projecting the driest conditions (Figure 4). On the other hand the models using the CGCM3 general circulation model project wetter conditions in the future (Figure 4). The RCM3_GFDL model projects little change in precipitation from present (Figure 4).

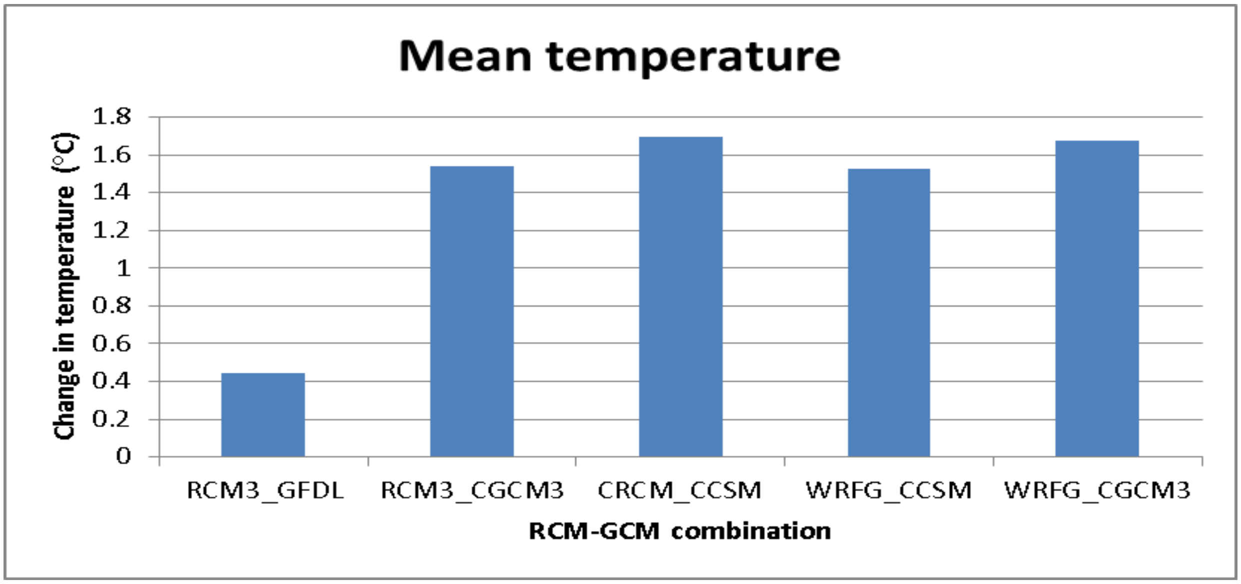

Figure 2. Change in mean breeding season temperature between observed climate from 1969-1998 and five future climate models for 2040-2069. The values represent the spatial mean for the CA, OR and WA portions of the NPLCC.

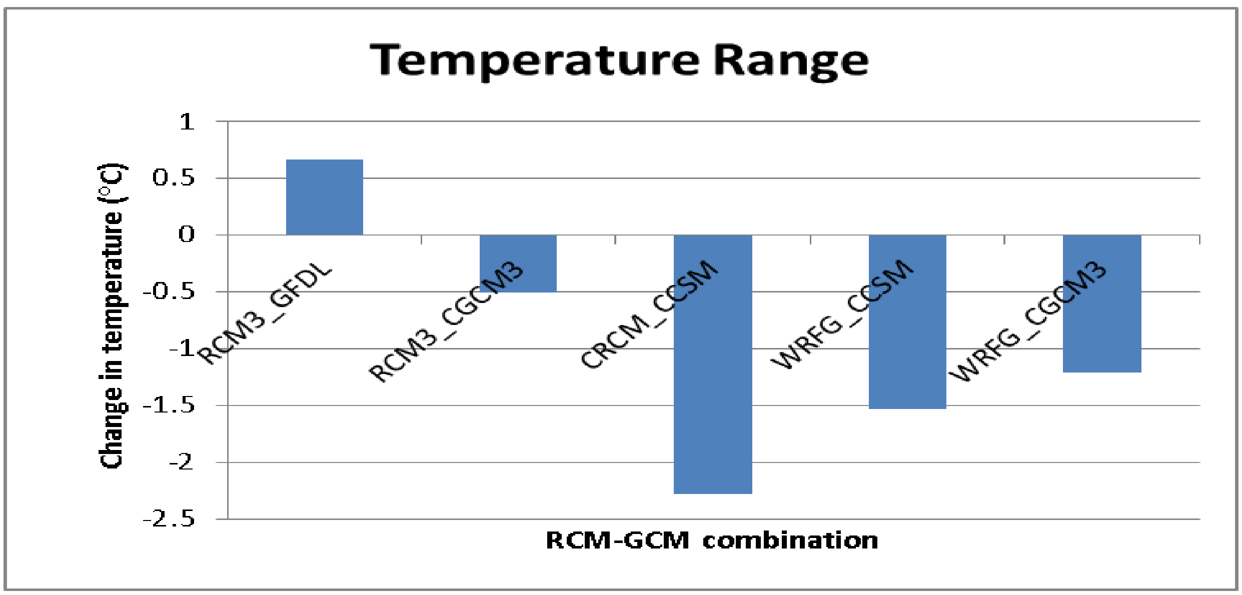

Figure 3. Change in the range of temperature during the breeding season (maximumn monthly temperature - minimum monthly temperature) from observed climate from 1969-1998 and five future climate models for 2040-2069. The values represent the spatial mean for the CA, OR and WA portions of the NPLCC.

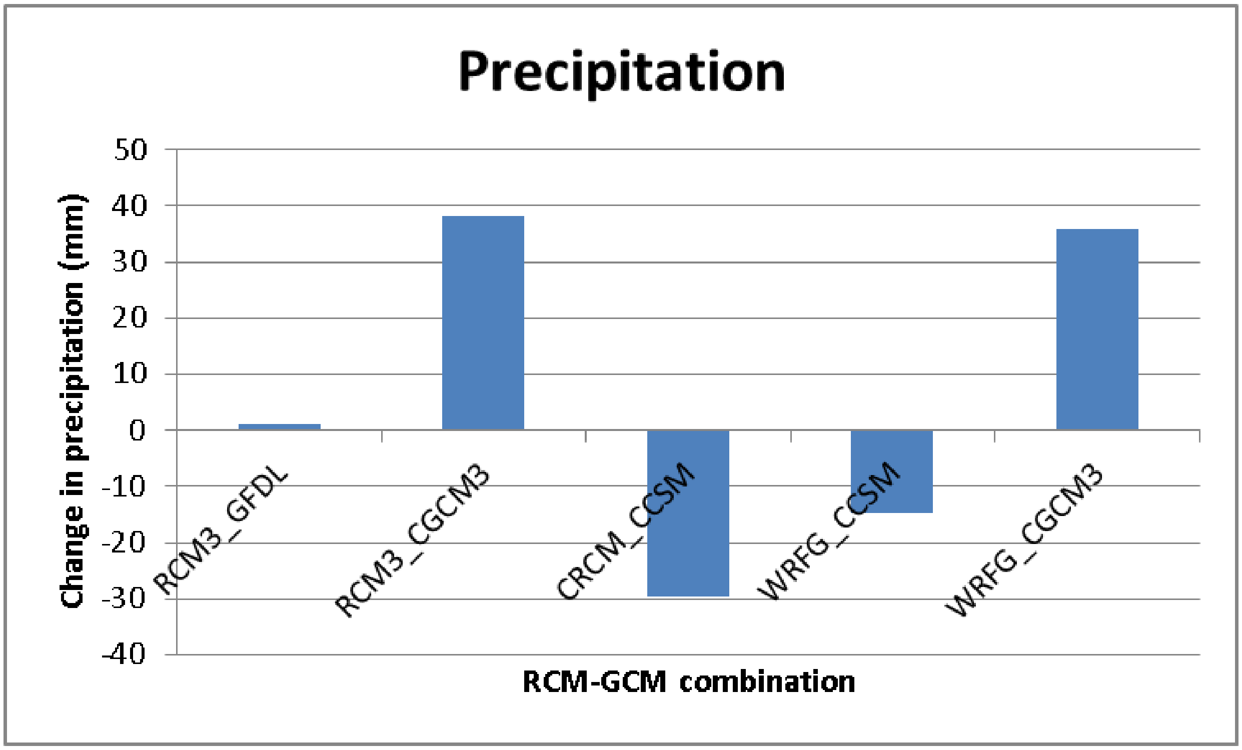

Figure 4. Change in total precipitation during the breeding season from observed climate for 1969-1998 and five future climate models for 2040-2069. The values represent the spatial mean for the CA, OR and WA portions of the NPLCC.

Vegetation modeling

The first step for modeling the distribution of the birds was to develop models of vegetation response to climate change so that models of bird distributions could be modeled as a response to both changes in climate and vegetation cover. We modeled the potential distribution of 78 different vegetation types based on hybrid vegetation maps we created and current climate, topographic variables and soil characteristics. Our hybrid vegetation classes including the original vegetation types are shown in appendix 2.

Hybrid vegetation maps

We created a hybrid vegetation classification scheme derived from the GAP vegetation classification system (http://gapanalysis.usgs.gov/gaplandcover/). We initially considered all of the vegetation classes which occur in Washington, Oregon and California. Whenever we had an adequate number of avian observation records within the finest GAP class (Ecological System), we modeled that class using current climate and geophysical variables. When there were insufficient avian observations available within a class we moved to a higher (lower resolution) class to model (lower classes are based on the NVCS standards http://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/NVCS_V2_FINAL_2008-02.pdf/download

We modeled the probability of occurrence of each vegetation class using boosted regression tree models (Elith et al. 2008), using the climate and soil covariates explained above as predictors. We selected the optimal number of trees, tree complexity and learning rate following an optimization routine described in Elith et al. (2008). We standardized the results of the vegetation models by dividing the probability of occurrence for each class by the sum of the probability of occurrence for all vegetation classes in each pixel. In this way the values for a given class at a pixel receive lower values if many classes have a high probability of occurrence. We do not attempt to determine which vegetation class will dominate a cell but rather retain the modeled probability of occurrence of all vegetation classes. The statistical models were projected to current and future climate conditions to make maps for all six sets of conditions (1 current, 5 future models).

There are a number of important assumptions our models make with regards to the spatial and temporal predictions we apply here. First, our models implicitly account for species interactions as they use current distributions of vegetation classes to calibrate the models. However, novel associations of species in the future could lead to unexpected species interactions which could limit the accuracy of our projections. Also, we assume that dispersal is not a barrier for the vegetation classes we consider here even though the dispersal abilities of species will likely play a major role in the composition of future vegetation communities. Similarly, we do not consider explicit mechanisms which will allow vegetation class transitions such as fire or other disturbances.

Vegetation model results

In general, our vegetation models had high predictive accuracy for current climate conditions. We compared the modeled probability of occurrence for each vegetation class to the observed vegetation classes derived from our hybrid GAP map using the area under the receiver operating characteristic curve (AUC). AUC is a metric of how well a model discriminates presences from absences where 1.0 equals perfect discrimination and 0.5 means occurrences are discriminated from absences no better than random. Values less than 0.5 indicate discrimination worse than random. Our models had an average AUC of 0.97 (± 0.04 standard deviation).

We also assessed vegetation community turnover by calculating the Bray-Curtis distance between each map pixel between current and future projections for each future climate model (Stralberg et al. 2009). Several distinct patterns emerge from this analysis. First the Northern Cascades are projected to have high vegetation community turnover in all five climate models (Figure 5). The second strongest pattern is that we project high vegetation turnover throughout the NPLCC region for the WRFG regional climate models (Figure 5). Finally, we project less vegetation turnover in the Willamette Valley for the RCM3_CGCM3 model than in any of the other future climate models.

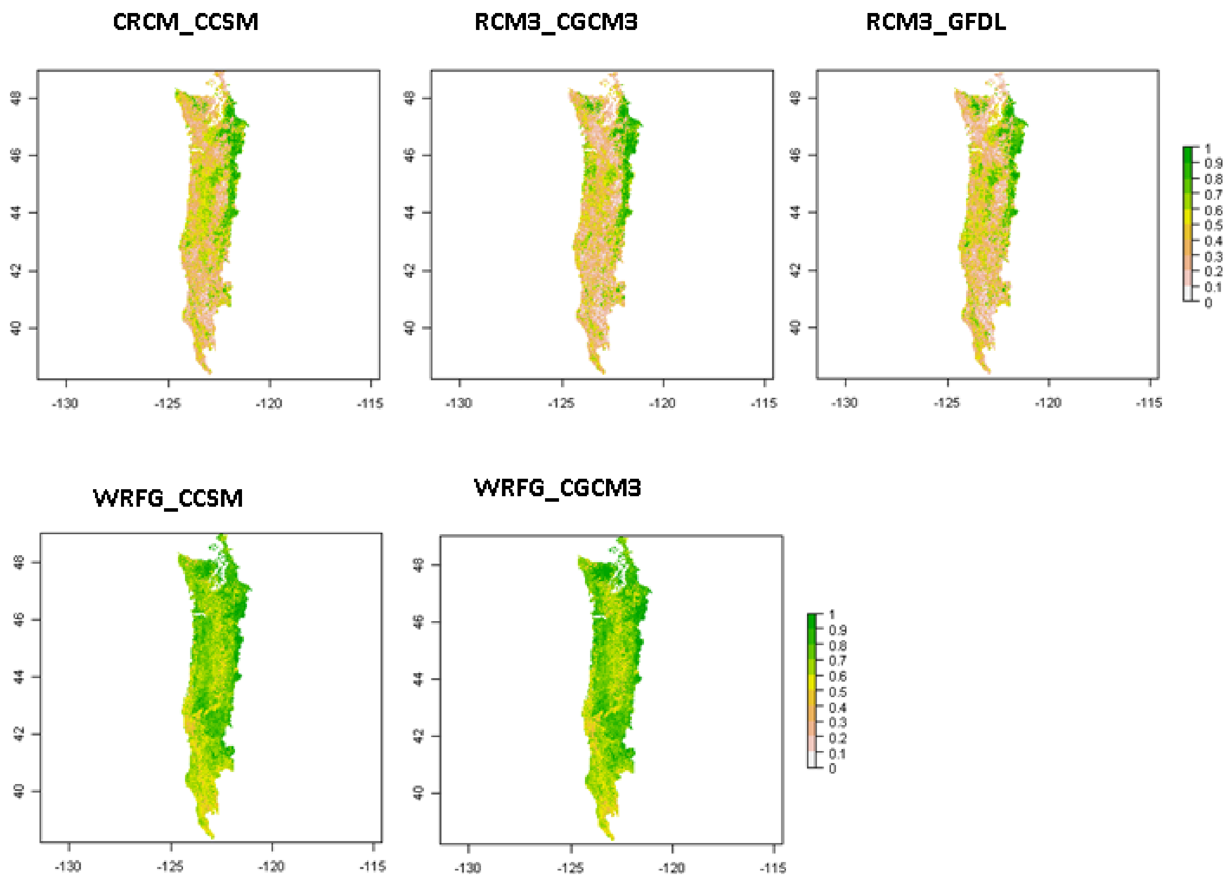

Figure 5. Vegetation community turnover between current and future climate for five different regional climate models. Projected values range from 0 (no turnover) to 1 (complete turnover).

Bird distribution and abundance models

Filtering the bird data

Bird data consisted of geo-referenced point count data from several sources available via the Avian Knowledge Network (http://www.avianknowledge.net/). Breeding range was based on the Digital Distribution Maps of the Birds of the Western Hemisphere Version 3.0 (Ridgley et al. 2007) provided by NatureServe via http://www.natureserve.org/getData/birdMaps.jsp. For each species, any point that fell outside of the breeding range was not considered in the model.

Breeding season window varied between species and ranged between a starting date of April 1st and an ending date of August 15th. Dates were based on information taken from the Birds of North America series (Poole 2005) and expert opinion. For each species, any record collected outside of its breeding season was not considered in the model.

After compiling data from all available sources in the Avian Knowledge Network for the 26 target species, we further filtered the data to include projects where repeated visits were used, that had at least 5 points surveyed, and where the cut-off detection radius was either 50 or 100m. (We produced individual estimates of abundance for both distance categories and simply multiplied the former by 4 to combine results with those of the latter.) This ensured that all data available was used, not just data conforming to either a 50m or a 100m cut-off distance.

Correcting for imperfect detection and site-level abundance models

We were interested in constructing an abundance model for all species at all locations in the dataset. Thus we considered data for all locations. However, this meant that, for any one species, a large percentage of the locations had no detections. This was problematic because some of these non-detections reflected true absence of the species, while others were simply the result of low detection probabilities; i.e., imperfect detection. In order to correct for this and properly train the abundance model, we first split the dataset for each species into locations where the species was predicted to occur and locations where it was not, and then used the first set to train the abundance model. This split was done using an imperfect-detection occupancy model (simply “occupancy model”) to identify those locations where the species was predicted to be present. Both the occupancy model and the abundance model for each species included vegetation classes as covariates of occupancy and abundance. The occupancy model also included the transect to which a point belonged as covariate. Because there are 78 different potential vegetation class covariates to use in each model, we fit boosted regression tree models (BRTs) for occurrence (i.e., binomial link) and abundance (poisson link) to explore variable importance as a means to identifying the relevant predictor vegetation classes in the data for each model, for each species. The important covariates were those that had an importance index > 2% in the BRTs. The BRTs had 1,000 and 5,000 trees (for occurrence and abundance models, respectively), interaction depth of 3 and learning rate of 0.001.

The BRT models cannot properly account for the hierarchical repeated sampling structure in the data. Rather than “collapse” the dataset with some summary metric for count or occurrence values across all visits to each point each year, we considered each visit to a point as an independent sample. In classical regression models this approach has the effect of underestimating the variance around covariate slopes. However, with the BRTs we were solely interested in identifying the potentially important covariates, not the magnitude or significance of their influence. The proper estimation of covariate effects was done with the hierarchical repeated-sampling imperfect detection models (the occupancy and abundance models.

We then fit hierarchical imperfect-detection models of occupancy and abundance to the site-level data, using for each species the appropriate abundance or occupancy predictor vegetation classes, as identified with the BRT models, and intercept-only detection models. We note that we were not interested in estimating a trend over time, so we did not include a numerical covariate for year. This resulted in the model estimating a different abundance value for each year a point was surveyed. These estimates were then averaged across all years. Once the occupancy models were fit, the predicted probability of occupancy was estimated for each site and hurdled with the average estimate of naive occupancy, so that probabilities of occurrence equal or higher than the naive occupancy were considered to be occupied sites and the rest as unoccupied. As explained above, the abundance models were then fitted solely to data from the sites predicted to be occupied. Once the abundance models were fitted and evaluated for goodness of fit, we used them to predict the abundance for the data (i.e., corrected for probability of detection) and appended all sites predicted as unoccupied with abundance = 0. At this point we also inflated the abundance values of sites with distance cut-off of 50m to four times the estimated abundance, to match the estimates from the 100-m cut-off sites.

In the interest of using as complete a dataset as possible for the landscape models, we used information from the imperfect detection models to correct estimates of abundance from data we had initially filtered out (i.e, those data sets with repeated visits to fewer than 5 points or those with only a single visit per year) thus ensuring to include data for these locations only if the species had been detected there. In these cases, we calculated the mean of all detections for each site within each year, and corrected this mean with the estimated mean probability of detection for the species. Despite all our cautions, estimates from these datasets sometimes still resulted in unrealistic abundance estimates. Any estimates exceeding the maximum obtained with the imperfect detection model for the species were re-calibrated to never exceed that maximum.

Because we wanted to use data from locations where the species was not present (abundance = 0), and because the data mining models used to construct the landscape models would require integer values in the response variable if we were to use a Poisson link, we opted to fit BRTs for abundance using the transformed estimates (i.e., the log of the abundance estimates) with a Gaussian (normal) link. This meant adding 1 to all estimates (so as to be able to estimate logarithms of abundance of sites with abundance = 0). Thus, the predicted values from these models were back-transformed by exponentiating results and subtracting 1.

Probability of occurrence and abundance across the landscape

Using the corrected presence/absence data from above, we fit an initial BRT model (5000 trees, tree complexity (TC) = 3, learning rate (LR) = 0.01) with a binomial (Bernoulli) link using all climate and vegetation variables. For each species, any variable with a relative influence less than 2% was removed as a possible predictor variable. We then subsampled the full data set to 5000 total records, matching the prevalence found in the total data set (per species).We ran exploratory models with this subsample and the reduced set of variables using a range of learning rates (.01, .005, .001) and a range of tree complexities (1 through 5) with a maximum of 10,000 trees. Results were reviewed and optimal TC and LR were chosen for each species. Using all records, final binomial models were run with optimized settings and then projected across the study area landscape.

We created both probability of occurrence surfaces and presence/absence surfaces using the binomial models. Presence/absence models were created by taking the probability models and thresholding them based on the species specific prevalence within the data set.

Abundance models

Abundance models were run using the vegetation variables filtered from step 2 above and all climate variables. We ran exploratory models with this subsample and the reduced set of variables in the same way as done for the occurrence models, but using a Gaussian link. Similarly, results were reviewed and optimal TC and LR were chosen for each species. Using all records, final abundance models were run. Subsequently, we projected the abundance models across the study area landscape and hurdled them with the occupancy model, thereby converting to 0 abundance those pixels where the species was not predicted to occur.

Bird model results

Consistent with observations of historic climate change events (Williams et al. 2004), the species in our models varied considerably in their response to climate change both within and among habitat types (Figure 6). By comparing the results across the five climate change models we implemented, we can assess the sensitivity of each species to projected climate change for the region. We are also able to examine how each species individually is projected to respond to climate change for each climate model.

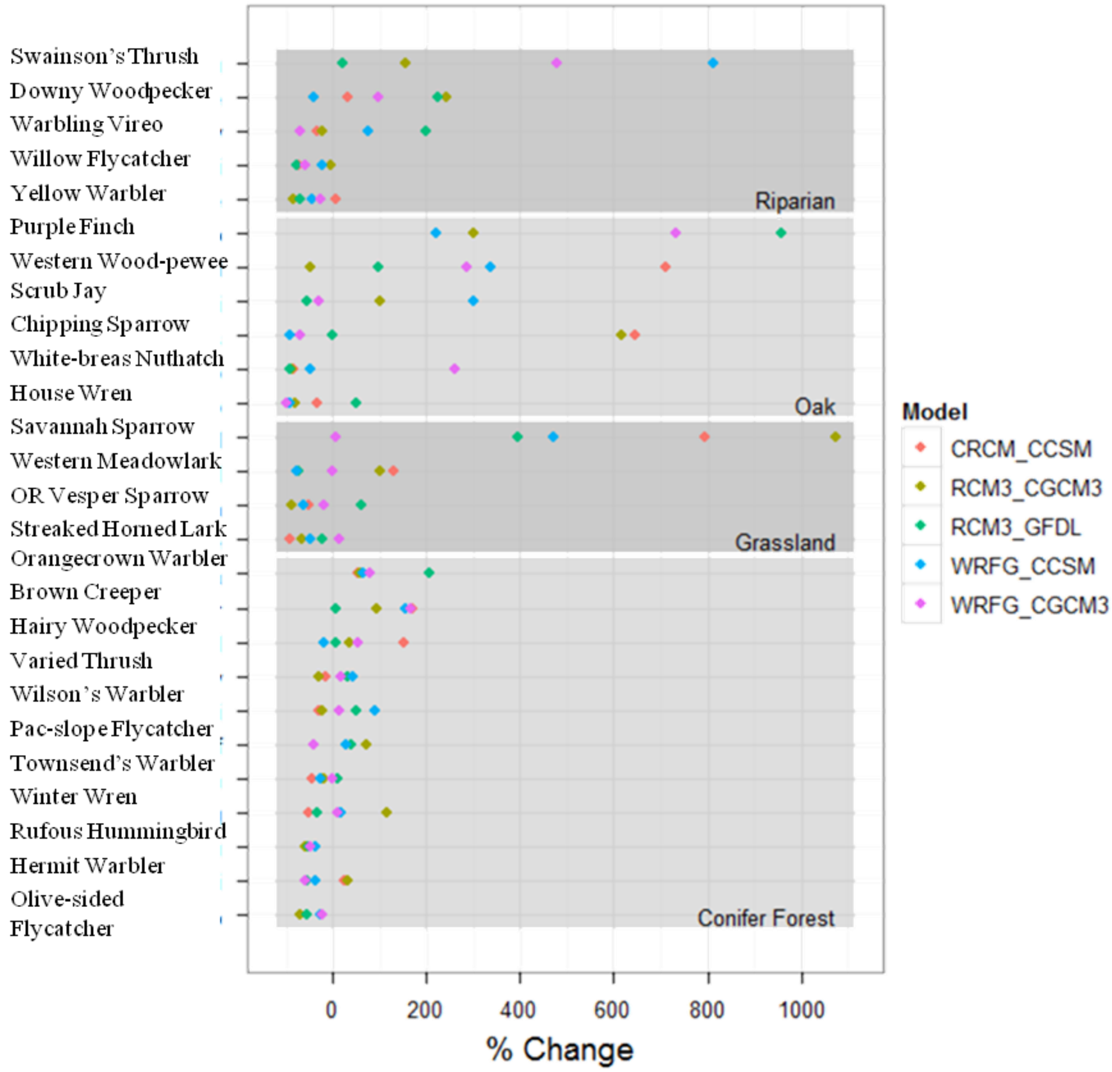

Figure 6. Projected percent change in abundance from current (late 20th century) to future (2070) climate for 26 land bird species within the North Pacific LCC region of CA, OR and WA. Each colored point represents the projection using a single regional climate model/general circulation model combination. Species are partitioned into habitat types which they are known to indicate.

Conifer forest birds

In terms of region wide abundance, our models indicate that conifer forest birds will be the least sensitive to projected climate change within the NPLCC region than the other three habitat types we examined (Figure 6). However, the spatial distributions and patterns of high and low density are projected to change.

Despite the relatively small changes in abundance of conifer forest associated species, there are some striking differences in the responses among this group of eleven species. For example we project that Orange-crowned Warbler (*Oreothlypis celata*) and Brown Creeper (*Certhia Americana*) will increase in abundance for all five future climate models (Figure 6). On the other hand, we project that Rufous Hummingbird (*Selasphorus rufus*) and Olive-sided Flycatcher (*Contopus cooperi*) will decline in abundance for every future climate model (Figure 6). For the rest of the conifer forest associated species the direction and magnitude of projected abundance change depends upon which climate model was used (Figure 6).

Grassland birds

For two of the grassland associated species we modeled, Oregon Vesper Sparrow (*Pooecetes gramineus*) and Streaked Horned Lark (*Eremophila alpestris*), we project a decline in abundance in the future for a majority of the future climate models (Figure 6). In contrast, we project an increase in abundance in the future for Savanna Sparrow (*Passerculus sandwichensis*) for all five climate models, with maximum percent increases of over 1000% for the WRFG_CGCM3 future model (Figure 6).

Oakland woodland birds

We project a wide range of responses for the six oak woodland species particularly among the five climate models we tested. For example, we project a decline in abundance of Western Wood-peewee (*Contopus sordidulus*) for the RCM3_CGCM3 climate model while we project an approximately 700% increase in abundance in the future for the CRCM_CCSM model (Figure 6). We project a similar range of responses between climate models for Chipping Sparrow (*Spizella passerine*) with some of the biggest differences in the spatial patterns of densities found in coastal regions of northern California and southern Oregon and in the Willamette Valley (Figure 7).

We also don't find any clear patterns related to the response of species to the five future climate models. For example, we project House Wren (*Troglodytes aedon*) to have their smallest NPLCC wide abundance for the WRFG_CGCM3 model and their largest abundance with the RCM3_GFDL model while we projected the exact opposite response for White-breasted Nuthatch (*Sitta carolinensis*) (Figure 6). For Western Wood-peewee, we project intermediate responses for the WRFG_CGCM3 and RCM3_GFDL models (Figure 6).

Riparian birds

The range of responses of riparian habitat associated bird species was similar to what we project for Conifer forest associated species. The exception to that pattern is Swaison's Thrush (*Catharus ustulatus*) for which we project increases in the future under all five future climate models (Figure 6). In contrast to the Swaison's Thrush, we project a decrease in abundance in the future for Willow Flycatcher (*Empidonax traillii*) and Yellow Warbler

(*Setophaga petechia*) (Figure 6). On the other hand we project a range in the direction of responses for Warbling Vireo (*Vireo gilvus*) (Figure 6.)

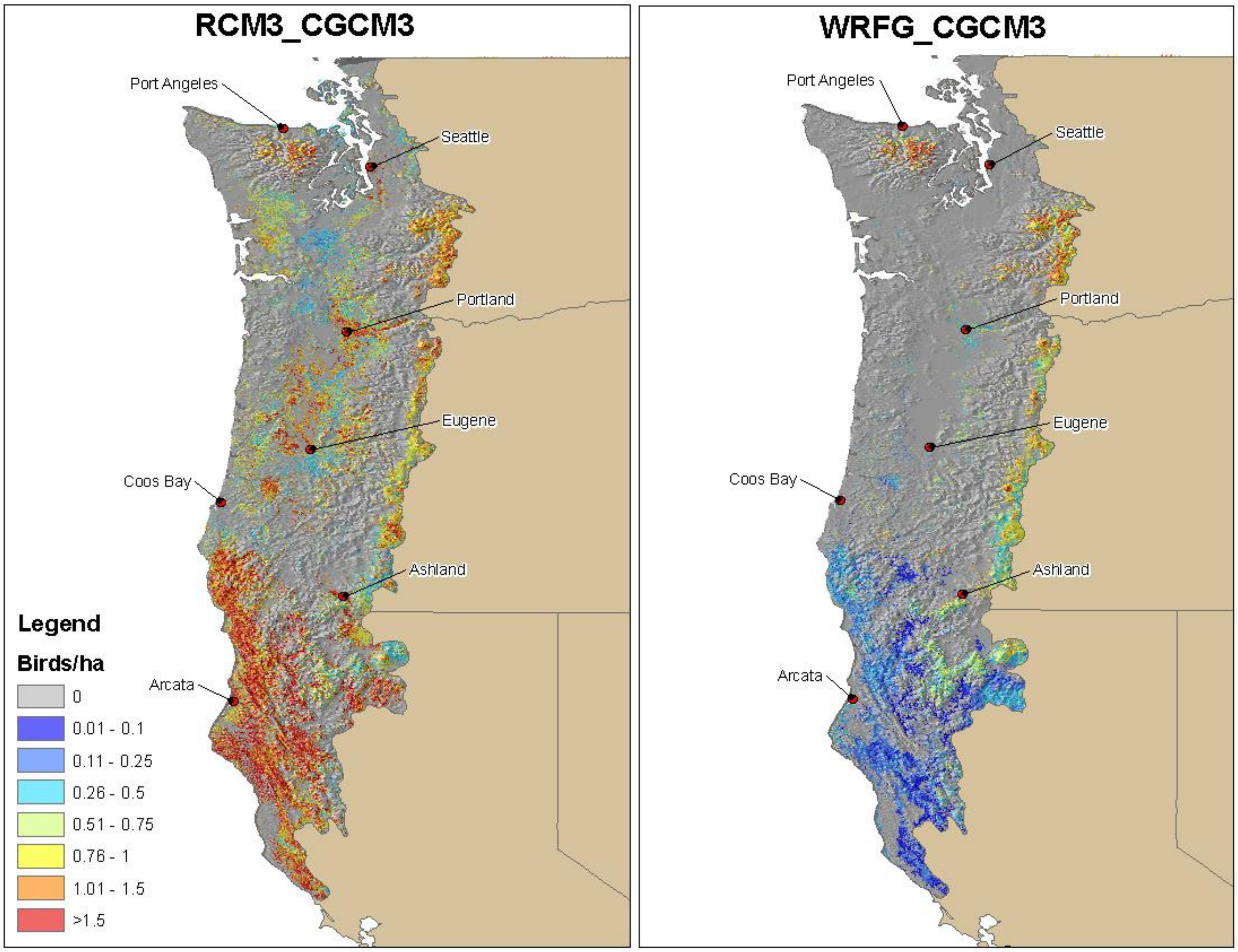

Figure 7. Projected densities for Chipping Sparrow at 2070 for the RCM3_CGCM3 and WRFG_CGCM3 climate models.

Avian Sampling Coverage

We compared the environmental conditions sampled from our avian observation surveys (which included locations outside of the NPLCC region) to the environmental conditions represented in every map pixel in the NPLCC region for current and future climate conditions. This analysis provides a graphic representation of the unsampled environmental space in the study area and it shows where our avian distribution and abundance models are extrapolating our bird projections beyond the range of the data used to calibrate the models. This information could be used to help inform where future monitoring efforts could be targeted to fill in potentially important information gaps.

Methods

We calculated the Euclidean distance from the standardized climate variables between the climate values represented in each map pixel and the climate values represented in all of the avian observation points. We then retain the minimum Euclidean distance as the best match between the climate conditions in the avian observation data and the climate conditions in each map pixel. High Euclidean distance values indicate where map pixels represent novel climate conditions with respect to the conditions found in the avian observation dataset. The climate variables were all scaled by subtracting the spatial mean (mean for all map pixels for the respective climate variable for current conditions) from each pixel and dividing by the spatial standard deviation (standard deviation for all map pixels for the respective climate variable for current conditions). The standardization allows the temperature and precipitation variables to be compared using the same units. Spatial means and spatial standard deviations were derived for current climate conditions and used to scale both the current and future climate datasets.

Results

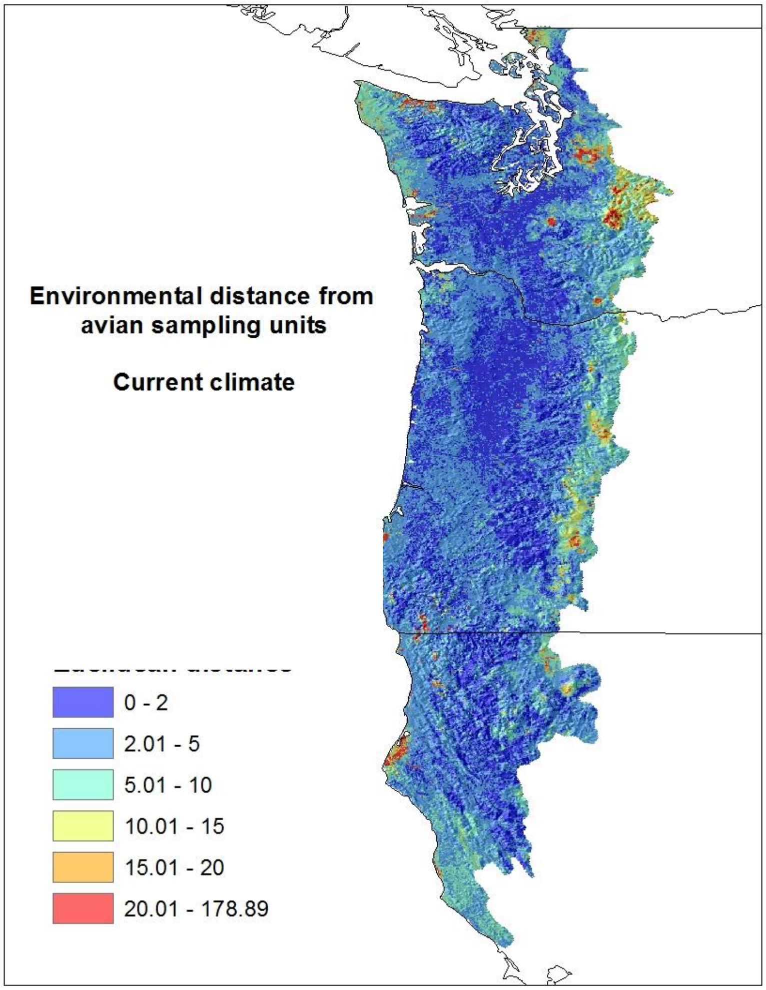

Figure 8. Representation of how well our avian observation sampling adequately samples the range of climate conditions present in the southern NPLCC region for current climate conditions. Warmer colors indicate climate conditions not sampled by our avia

In general we found that our avian observation data do a good job of sampling the total environmental space (Figure 8). However, climate conditions at high elevation, particularly in the northern Cascade mountains, were not sampled well by our avian observations (Figure 8). Additionally, we identified coastal regions near Eureka CA and near Langois OR which were also not sampled well.

Future conditions are not sampled as well as the current conditions. Our avian observations do the poorest job of sampling the climate conditions projected by the WRFG regional climate models. Future climate conditions in high elevation areas of Olympic National Park are not sampled well by our avian observation data across all climate models. There is considerable spatial variation in the location of pixels with high Euclidean distance values among the five climate models. Maps of the

Euclidean distance from the individual climate models can be paired with the respective bird models to determine where areas of high uncertainty exist.

Conservation Prioritization Maps

Climate change presents a challenge to traditional conservation approaches as species change their locations to track suitable environmental conditions. So it is possible that by only conserving areas which currently are important for sustaining biodiversity, we may be losing areas that will be important in the future. We developed maps of conservation prioritization that take into account current as well as potential future bird distributions. These maps provide a broad level ranking of the landscape indicating where conservation and restoration efforts should be directed to plan for both current and projected future conditions.

Methods

We used the conservation planning software Zonation 3.10 (Moilanen et al. 2005) to create our landscape rankings using the “core-area” Zonation algorithm. Zonation works by iteratively removing pixels from the landscape, at each iteration the lowest valued pixels are rmeoved. At each step the algorithm seeks to maintain core areas for all species thus, pixels are not necessarily ranked by species richness but by how important they are for all species.

The projections for each species/climate model combination are considered an individual “species” in the analysis. This assures that both current and future conditions are considered simultaneously in our analysis (Carroll et al. 2010, Veloz et al. 2013). To the extent possible, we also integrated the uncertainty inherent in the future projections for each species by down-weighting pixels using an uncertainty value. For each species, this uncertainty value is the standard deviation of the projected density at each pixel across the five future climate models. The uncertainty values are subtracted from the raw density value in each of the five future models for each species prior to running the Zonation algorithm. This procedure results in higher ranking pixels representing sites in the future where there is agreement among the five climate models.

We created five landscape prioritization maps with one using all 26 species and the other four using only species which are indicative of one of four habitat types: conifer forest, oak woodland, riparian and grasslands.

Results

The prioritization maps for each of the four different habitat associations show distinct spatial patterns (Figure 9). The conservation priority maps can be used to identify areas where management actions to promote specific habitat types would be most beneficial for populations of birds associated with those types both for current and future climate conditions.

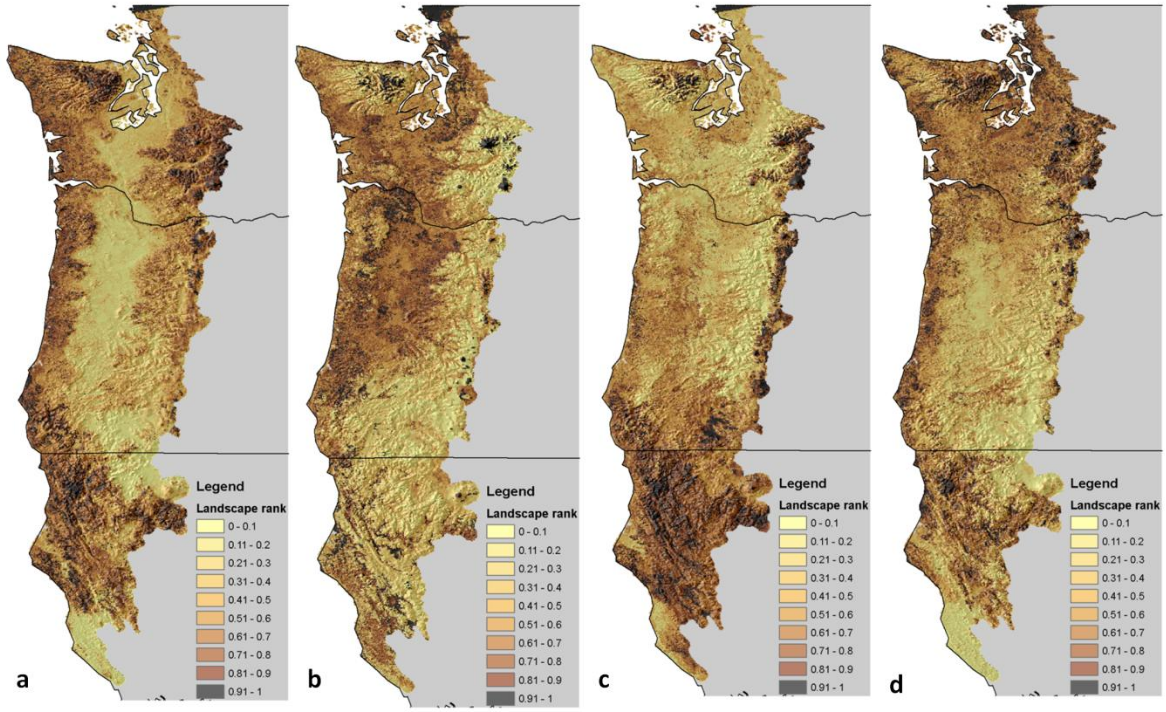

Figure 9. Landscape conservation ranking for conifer forest (a), grassland (b), oak woodland (c) and riparian (d) habitat associated species.

Online Decision Support Tool

We created an online interactive decision support tool to display the spatial products from our project, facilitate queries of the data and distribute the data to users (http://data.prbo.org/apps/nplcc/). The primary interface is an interactive map showing the results for the bird distribution and abundance models, avian sampling coverage and landscape prioritization analyses. For the bird models, users can choose to view maps of density (birds/ha), probability of occurrence, or presence absence. The user must select the habitat type of interest, the bird species and the climate model used in the projection. To the right of the map the predictor variables which were found to be most important in the bird model are listed in order from highest to lowest relative influence. Additionally, the user can click on the link of the species name to get more information about the species from the Cornel lab of Ornithology. Users can query the maps by mousing over pixels of interest; pixel values appear in the grey tool bar above the map. The user can also draw a polygon and a report is generated summarizing the input climate variables, changes in density across all of the species, and more detailed summaries of the individual species being displayed on the map. Users can also draw a box of a subset of the study region and download a clipped portion of the viewed map. By visiting the “download” section of the site, users can download any of the spatial layers we created along with associated metadata.

We will use the site to publicize any application or use of the tool for management, science or other purposes. In this way we hope to demonstrate to other users how the tool can help with their management needs.

Recommended Management Applications

Here we mention several uses of our tool and products to support management or decision making. We anticipate that there will be many uses of our data products and this is not mean to be an exhaustive list.

We emphasize that our projections are models of the system. Users should not treat the maps as predictions that precisely indicate conditions for the future. The climate models used in our analysis are calibrated with scenarios that are one plausible (not necessarily likely) realization of the future and each uses different physical representations of our global and regional climate system with strengths and weakness. Stated simply, each of the future models we use represents a plausible state of the future but reality could also fall somewhere in between these projections. Users should avoid attempting to select the most "accurate" of the five future models we provide but rather examine how species respond to each of the models and evaluate how their management actions would change for each situation. Management actions which are successful based on projections from each of the five future models are likely to be more robust to our uncertainty in future climate conditions (Veloz et al. 2013).

Our density maps are a spatially rich representation of the variation of habitat quality across the landscape. The models can be used to prioritize conservation or restoration actions at various scales. By examining results for each of the climate models, users can assess how sensitive their species of interest is to projected climate change or identify areas which show consistent responses across climate scenarios.

Both our bird model maps and our avian sampling coverage maps can be used to guide future modeling efforts. Our bird models can be considered a hypothesis of how species will respond to climate change. Long term monitoring studies seeking to detect and attribute the effects of climate change could use our maps to guide the design of future modeling efforts, possibly allowing more powerful observations to be made with less effort. The maps may also help identify areas with new or previously unknown populations or areas of high quality habitat. The avian sampling coverage maps can be used to focus future monitoring efforts to where climate conditions have not been sampled by previous monitoring efforts.

Presentations and Outreach – demonstrating model application

We have presented the results of our project to the NPLCC steering committee and through an NPLCC sponsored webinar. We have also presented results from the project, and their potential application, at the North American Ornithological Conference in August of 2012 and most recently at the Association of Fish and Wildlife Agencies Teaming with Wildlife and Natural Resource Management Conference in April 2013. In addition, the models were used in a traveling workshop that was attended by nearly 150 NGO and federal and state agency personnel at four locations in Oregon and Washington. At these workshops we demonstrated how the tools coupled with bird conservation plans, such as *Habitat Conservation for Landbirds in Coniferous Forests of Western Oregon and Washington* (Altman and Alexander 2012) (http://www.orwapif.org/conservation-plans), can be used to support natural resource planners to assess conservation needs, set quantifiable management objectives, evaluate management alternatives.

Our presentations have highlighted the value of broad-scaled data acquisition, the science behind the development of the distribution and abundance models, and the practical applications of the models for natural resource management decision making. The leading organizations are actively engaging with managers and stakeholders within the NPLCC to assure wide use of the models and associated decision support system. The Nature Conservancy in partnership with the Oregon Department of Fish and Wildlife are using these products as part of the Willamette Synthesis Update to help set conservation priorities and this has resulted in US Fish and Wildlife Service interest in using our tools to further inform conservation planning in the Willamette Valley. The Association of Fish and Wildlife Agencies have invited us to demonstrate how these, and other Avian Knowledge Network tools can be used to support the revision of state wildlife action plans. We are also helping our partners with applying our products for use in updating the conservation plan for the Columbia Land Trust. We are collaborating with the Klamath National Forest to use the models for assessing restoration needs and rank the Forest's watersheds based on conservation opportunities. The models are also being used to quantify the conservation values of protected lands managed in southern Oregon and northern California within the National Park Service Klamath Network and Bureau of Land Management National Landscape Conservation System. We will continue to engage stakeholders to promote the use of our tool and data products.

Acknowledgments

We would like to thank the North Pacific Landscape Conservation Cooperative for funding our work. In addition we would like to thank the National Park Service, the Oregon Department of Fish and Wildlife, the Redwood Sciences Lab, Portland Audobon, The Nature Conservancy, the US Army Corps of Engineers, the US Geological Survey, the US Forest Service, the Washington Department of Fish and Wildlife, the Department of Defense- Joint base Lewis-McChord, the City of Portland Environmental Services and Karen Viste-Sparkman and other contributors to the California Avian Data Center for providing the data used in our analyses. This is PRBO contribution number 1936.

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Appendix 1. Request letter sent to acquire avian observation data for the proposed project.

Request for Landbird Data to Support Climate Change and Conservation Modeling

PRBO Conservation Science, in cooperation with Klamath Bird Observatory and American Bird Conservancy, has received funding from the North Pacific Landscape Conservation Cooperative to analyze data and develop tools to assess the projected consequences of climate change on the distribution and abundance of 25-30 priority/focal landbird species in western Oregon and Washington and northwestern California. Models for each species will be presented under three future climate scenarios of low, medium and high projected temperature increases for the Pacific Northwest, similar to work previously conducted in California by PRBO (http://data.prbo.org/cadc2/index.php?page=climate-change-distribution). The results will be disseminated via online decision support tools, websites, direct outreach to stakeholders in the region (e.g., webinars), and the peer reviewed literature. The products will allow managers to identify the locations of highest current and future conservation priorities for landbirds and the ecosystems upon which they rely, assess the degree of uncertainty associated with these projections, explore the conservation possibilities under different future climate scenarios, and examine “what if” climate change scenarios between habitats and/or species.

In order to develop models that best represent landbird species and their habitats, we are requesting electronic contributions of datasets which will be archived in the Avian Knowledge Network (hosted at the California Avian Data Center: http://data.prbo.org/cadc). The format of contributed data sets can be variable, and generally all your data fields are acceptable, although for our modeling purposes it must contain at a minimum the following variables: date, XY coordinates (coordinate system, datum, and estimate of horizontal accuracy), species, and how many individuals of that species. Additionally, information on the protocol, study area, and study design is helpful to understand the scope and context of the data. Of course, information on the contact person also is necessary. We recognize that there are likely as many different formats as there are datasets, so based on past experiences we suggest you send a sample of what you have so that we can determine the most efficient method for data upload.

Our partnership is part of the Avian Knowledge Alliance promoting the use of avian monitoring data to advance bird conservation, while honoring the intellectual ownership rights of data contributors. As a contributor to this project, you may choose from seven sharing levels with regards to the availability of your data (http://data.prbo.org/apps/common/deju/fieldhelp/DataStatus.php), ranging from not used beyond this project to publicly available for download as well as via interactive maps and other visualization tools. Regardless of the level of availability chosen, your data can be made accessible to you and will be backed up and archived via the Avian Knowledge Network’s data management infrastructure.

Your contributions are important to developing the best models and tools to project future climate change and conservation scenarios, so we greatly appreciate any and all contributions. Please contact me about your potential contributions. In addition to this announcement, I will likely be contacting many of you that I know to personally request your help. Thanks in advance for your cooperation.

Bob Altman, American Bird Conservancy, baltman@abcbirds.org, 541-745-5339

Appendix 2.

Vegetation classes used for modeling. The final name is the final hybrid classification we used for our modeling. The other three columns represent the finest vegetation type classifications from the GAP landcover dataset (finer to coarser classes from left to right).

Final Name	GAP Ecolsys_lu Name	GAP Macro Name	GAP Form Name
California Coastal Scrub and Chaparral (macro hybrid)	Southern California Coastal Scrub	California Coastal Scrub	Mediterranean Scrub
California Coastal Scrub and Chaparral(macro hybrid)	Northern California Coastal Scrub	Cool Pacific Coastal Beach, Dune & Bluff Vegetation	Temperate & Boreal Scrub & Herb Coastal Vegetation
California Coastal Scrub and Chaparral (macro hybrid)	Northern and Central California Dry-Mesic Chaparral	California Chaparral	Mediterranean Scrub
California Coastal Scrub and Chaparral(macro hybrid)	California Mesic Chaparral	California Chaparral	Mediterranean Scrub
California Serpentine Woodland and Chaparral	Klamath-Siskiyou Xeromorphic Serpentine Savanna and Chaparral	California Chaparral	Mediterranean Scrub
California Serpentine Woodland and Chaparral	California Xeric Serpentine Chaparral	California Chaparral	Mediterranean Scrub
California Serpentine Woodland and Chaparral	Mediterranean California Mesic Serpentine Woodland and Chaparral	California Chaparral	Mediterranean Scrub
California Subalpine Woodland	Northern California Mesic Subalpine Woodland	Vancouverian Subalpine Forest	Cool Temperate Forest
California Subalpine Woodland	Mediterranean California Subalpine Woodland	Vancouverian Subalpine Forest	Cool Temperate Forest
Coastal California and Central Valley Grassland (macro hybrid)	California Northern Coastal Grassland	Southern Vancouverian Lowland Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Coastal California and Central Valley Grassland (macro hybrid)	Northern California Claypan Vernal Pool	Western North American Vernal Pool	Temperate & Boreal Freshwater Wet Meadow & Marsh
Coastal California and Central Valley Grassland (macro hybrid)	California Central Valley and Southern Coastal Grassland	California Annual & Perennial Grassland	Mediterranean Grassland & Forb Meadow
Coastal California and Central Valley Grassland (macro hybrid)	California Mesic Serpentine Grassland	California Annual & Perennial Grassland	Mediterranean Grassland & Forb Meadow
Columbia Plateau Low Sagebrush Steppe and Shrubland	Columbia Plateau Silver Sagebrush Seasonally Flooded Shrub-Steppe	Western North American Montane Wet Meadow & Low Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Columbia Plateau Low Sagebrush Steppe and Shrubland	Columbia Plateau Scabland Shrubland	Great Basin & Intermountain Dwarf Sage Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Columbia Plateau Low Sagebrush Steppe and Shrubland	Columbia Plateau Low Sagebrush Steppe	Great Basin & Intermountain Dwarf Sage Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Cultivated Cropland	Orchards Vineyards and Other High Structure Agriculture	Woody Agricultural Vegetation	Woody Agricultural Vegetation
Cultivated Cropland	Cultivated Cropland	Herbaceous Agricultural Vegetation	Herbaceous Agricultural Vegetation
Developed, Urban	Developed, Medium Intensity	Developed & Urban	Developed & Urban
Developed, Urban	Developed, High Intensity	Developed & Urban	Developed & Urban
Developed, Urban	Developed, Low Intensity	Developed & Urban	Developed & Urban
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Great Basin Xeric Mixed Sagebrush Shrubland	Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Inter-Mountain Basins Big Sagebrush Shrubland	Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Inter-Mountain Basins Montane Sagebrush Steppe	Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland

Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Inter-Mountain Basins Semi-Desert Grassland	Great Basin & Intermountain Dry Shrubland & Grassland	Cool Semi-Desert Scrub & Grassland
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Inter-Mountain Basins Semi-Desert Shrub Steppe	Great Basin & Intermountain Dry Shrubland & Grassland	Cool Semi-Desert Scrub & Grassland
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Columbia Plateau Steppe and Grassland	Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Great Basin & Intermountain (Sagebrush) Shrubland & Steppe (macro+2 in dry shrubland)	Inter-Mountain Basins Big Sagebrush Steppe	Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe	Cool Semi-Desert Scrub & Grassland
Inter-Mountain Basins Alkaline-Saline Wetland or Wash	Inter-Mountain Basins Alkaline Closed Depression	Cool Semi-Desert Alkali-Saline Wetland	Salt Marsh
Inter-Mountain Basins Alkaline-Saline Wetland or Wash	Inter-Mountain Basins Greasewood Flat	Cool Semi-Desert Alkali-Saline Wetland	Salt Marsh
Inter-Mountain Basins Alkaline-Saline Wetland or Wash	Inter-Mountain Basins Wash	Great Basin & Intermountain Xero-Riparian Scrub	Cool Semi-Desert Scrub & Grassland
Inter-Mountain Basins Alkaline-Saline Wetland or Wash	Inter-Mountain Basins Playa	Cool Semi-Desert Alkali-Saline Wetland	Salt Marsh
Inter-Mountain Mixed Desert Scrub (macro/div hybrid)	Mojave Mid-Elevation Mixed Desert Scrub	Mojave-Sonoran Semi-Desert Scrub	Warm Semi-Desert Scrub & Grassland
Inter-Mountain Mixed Desert Scrub (macro/div hybrid)	Inter-Mountain Basins Mixed Salt Desert Scrub	Great Basin Saltbrush Scrub	Cool Semi-Desert Scrub & Grassland
Inter-Mountain Mixed Desert Scrub (macro/div hybrid)	Inter-Mountain Basins Active and Stabilized Dune	Intermountain Basin Cliff, Scree & Rock Vegetation	Cool Semi-Desert Cliff, Scree & Rock Vegetation
Introduced Upland Vegetation - Grassland	Introduced Upland Vegetation - Annual Grassland	Introduced & Semi Natural Vegetation	Introduced & Semi Natural Vegetation
Introduced Upland Vegetation - Grassland	Introduced Upland Vegetation - Perennial Grassland and Forbland	Introduced & Semi Natural Vegetation	Introduced & Semi Natural Vegetation
Mediterranean California Foothill and Lower Montane Riparian Woodland	Mediterranean California Foothill and Lower Montane Riparian Woodland	Warm Mediterranean & Desert Riparian, Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Mediterranean California Foothill and Lower Montane Riparian Woodland	Mediterranean California Serpentine Foothill and Lower Montane Riparian Woodland and Seep	Warm Mediterranean & Desert Riparian, Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
merge to Recently Harvested Forest?	Harvested Forest - Grass/Forb Regeneration	Recently Disturbed or Modified	Recently Disturbed or Modified
merge to Recently Harvested Forest?	Harvested Forest-Shrub Regeneration	Recently Disturbed or Modified	Recently Disturbed or Modified
merge to Recently Harvested Forest?	Harvested Forest - Northwestern Conifer Regeneration	Recently Disturbed or Modified	Recently Disturbed or Modified
North Pacific Foothill and Lower Montane Riparian Woodland and Shrubland	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
North Pacific Foothill and Lower Montane Riparian Woodland and Shrubland	Columbia Basin Foothill Riparian Woodland and Shrubland	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Northern Rocky Mountain-Vancouverian Hardwood-Conifer Swamp	North Pacific Hardwood-Conifer Swamp	Vancouverian Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Northern Rocky Mountain-Vancouverian Hardwood-Conifer Swamp	Northern Rocky Mountain Conifer Swamp	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Temperate Pacific Maritime Coastal Sand Dune and Strand	North Pacific Maritime Coastal Sand Dune and Strand	Cool Pacific Coastal Beach, Dune & Bluff Vegetation	Temperate & Boreal Scrub & Herb Coastal Vegetation
Temperate Pacific Maritime Coastal Sand Dune and Strand	Mediterranean California Northern Coastal Dune	Warm Pacific Coastal Beach, Dune & Bluff Vegetation	Temperate & Boreal Scrub & Herb Coastal Vegetation
North Pacific Shrub and Herbaceous Bald, Bluff, or Headland (new)	North Pacific Herbaceous Bald and Bluff	Southern Vancouverian Lowland Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
North Pacific Shrub and Herbaceous Bald, Bluff, or Headland (new)	North Pacific Hypermaritime Shrub and Herbaceous Headland	Southern Vancouverian Lowland Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland

Northern Rocky Mountain Montane Mixed Conifer Forest (macro hybrid)	Northern Rocky Mountain Western Larch Savanna	Northern Rocky Mountain Lower Montane & Foothill Forest	Cool Temperate Forest
Northern Rocky Mountain Montane Mixed Conifer Forest (macro hybrid)	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	Northern Rocky Mountain Lower Montane & Foothill Forest	Cool Temperate Forest
Northern Rocky Mountain Montane Mixed Conifer Forest (macro hybrid)	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	Northern Rocky Mountain Lower Montane & Foothill Forest	Cool Temperate Forest
Northern Rocky Mountain Montane Mixed Conifer Forest (macro hybrid)	Sierran-Intermontane Desert Western White Pine-White Fir Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
Northern Rocky Mountain-Vancouverian Alpine-Montane Wet Meadow (macro-hybrid)	Temperate Pacific Montane Wet Meadow	Western North American Montane Wet Meadow & Low Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Northern Rocky Mountain-Vancouverian Alpine-Montane Wet Meadow (macro-hybrid)	Rocky Mountain Subalpine-Montane Mesic Meadow	Rocky Mountain-Vancouverian Subalpine & High Montane Mesic Grass & Forb Meadow	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Alpine-Montane Wet Meadow (macro-hybrid)	Rocky Mountain Alpine-Montane Wet Meadow	Western North American Montane Wet Meadow & Low Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Northern Rocky Mountain-Vancouverian Alpine-Upper Montane Dry Grassland	North Pacific Alpine and Subalpine Dry Grassland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Alpine-Upper Montane Dry Grassland	Northern Rocky Mountain Subalpine-Upper Montane Grassland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Juniper Woodland and Savanna (new cat)	Great Basin Pinyon-Juniper Woodland	Intermountain Singleleaf Pinyon - Western Juniper Woodland	Cool Temperate Forest
Northern Rocky Mountain-Vancouverian Juniper Woodland and Savanna (new cat)	Inter-Mountain Basins Juniper Savanna	Intermountain Singleleaf Pinyon - Western Juniper Woodland	Cool Temperate Forest
Northern Rocky Mountain-Vancouverian Juniper Woodland and Savanna (new cat)	Columbia Plateau Western Juniper Woodland and Savanna	Intermountain Singleleaf Pinyon - Western Juniper Woodland	Cool Temperate Forest
Northern Rocky Mountain-Vancouverian Montane Woodland and Shrubland (macro hybrid)	North Pacific Broadleaf Landslide Forest and Shrubland	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
Northern Rocky Mountain-Vancouverian Montane Woodland and Shrubland (macro hybrid)	Northern Rocky Mountain Subalpine Deciduous Shrubland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane Woodland and Shrubland (macro hybrid)	North Pacific Montane Shrubland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane Woodland and Shrubland (macro hybrid)	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane-Foothill Grassland (new)	Columbia Basin Foothill and Canyon Dry Grassland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane-Foothill Grassland (new)	Columbia Basin Palouse Prairie	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane-Foothill Grassland (new)	North Pacific Montane Grassland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Montane-Foothill Grassland (new)	Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	Northern Rocky Mountain-Vancouverian Montane & Foothill Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Northern Rocky Mountain-Vancouverian Volcanic Rock and Cinder Land	Columbia Plateau Ash and Tuff Badland	Intermountain Basin Cliff, Scree & Rock Vegetation	Cool Semi-Desert Cliff, Scree & Rock Vegetation
Northern Rocky Mountain-Vancouverian Volcanic Rock and Cinder Land	North Pacific Active Volcanic Rock and Cinder Land	Vancouverian Cliff, Scree & Rock Vegetation	Temperate & Boreal Cliff, Scree & Rock Vegetation
Northern Rocky Mountain-Vancouverian Volcanic Rock and Cinder Land	Inter-Mountain Basins Volcanic Rock and Cinder Land	Intermountain Basin Cliff, Scree & Rock Vegetation	Cool Semi-Desert Cliff, Scree & Rock Vegetation

Open Water (Fresh)	Temperate Pacific Freshwater Aquatic Bed	Open Water	
Open Water (Fresh; group w/freshwater aquatic veg)	Open Water (Fresh)	Open Water	Open Water
Pacific Marine and Estuarine Saltwater Aquatic Vegetation (form)	North Pacific Maritime Eelgrass Bed	Temperate Pacific Seagrass Vegetation	Marine & Estuarine Saltwater Aquatic Vegetation
Pacific Marine and Estuarine Saltwater Aquatic Vegetation (form)	Mediterranean California Eelgrass Bed	Temperate Pacific Seagrass Vegetation	Marine & Estuarine Saltwater Aquatic Vegetation
Pacific Marine and Estuarine Saltwater Aquatic Vegetation (form)	Temperate Pacific Intertidal Mudflat	Temperate Pacific Intertidal Shore	Marine & Estuarine Saltwater Aquatic Vegetation
Pasture/Hay	Pasture/Hay	Herbaceous Agricultural Vegetation	Herbaceous Agricultural Vegetation
Pasture/Hay	Disturbed, Non-specific	Recently Disturbed or Modified	Recently Disturbed or Modified
Recently Burned (general)	Recently burned grassland	Recently Disturbed or Modified	Recently Disturbed or Modified
Recently Burned (general)	Recently burned shrubland	Recently Disturbed or Modified	Recently Disturbed or Modified
Recently Burned (general)	Recently burned forest	Recently Disturbed or Modified	Recently Disturbed or Modified
Rocky Mountain Lodgepole Pine Forest	Rocky Mountain Poor-Site Lodgepole Pine Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
Rocky Mountain Lodgepole Pine Forest	Rocky Mountain Lodgepole Pine Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
Rocky Mountain Montane Riparian Woodland and Shrubland	Rocky Mountain Lower Montane Riparian Woodland and Shrubland	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Rocky Mountain Montane Riparian Woodland and Shrubland	Rocky Mountain Subalpine-Montane Riparian Woodland	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Rocky Mountain Montane Riparian Woodland and Shrubland	Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	Rocky Mountain and Great Basin Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Rocky Mountain Subalpine Spruce-Fir Forest and Woodland (drop moisture class)	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
Rocky Mountain Subalpine Spruce-Fir Forest and Woodland (drop moisture class)	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
Temperate Pacific Bog and Fen (new)	Mediterranean California Serpentine Fen	North Pacific Bog & Fen	Temperate & Boreal Bog & Fen
Temperate Pacific Bog and Fen (new)	Mediterranean California Subalpine-Montane Fen	North Pacific Bog & Fen	Temperate & Boreal Bog & Fen
Temperate Pacific Bog and Fen (new; for above)	North Pacific Bog and Fen	North Pacific Bog & Fen	Temperate & Boreal Bog & Fen
Western North American Alpine and Subalpine Bedrock, Scree, & Ice (hybrid form)	Rocky Mountain Alpine Bedrock and Scree	Rocky Mountain Alpine Cliff, Scree & Rock Vegetation	Polar & Alpine Cliff, Scree & Rock Vegetation
Western North American Alpine and Subalpine Bedrock, Scree, & Ice (hybrid form)	North American Alpine Ice Field	Barren	Barren
Western North American Alpine and Subalpine Bedrock, Scree, & Ice (hybrid form)	Mediterranean California Alpine Bedrock and Scree	Vancouverian Alpine Cliff, Scree & Rock Vegetation	Polar & Alpine Cliff, Scree & Rock Vegetation
Western North American Alpine and Subalpine Bedrock, Scree, & Ice (hybrid form)	North Pacific Alpine and Subalpine Bedrock and Scree	Vancouverian Alpine Cliff, Scree & Rock Vegetation	Polar & Alpine Cliff, Scree & Rock Vegetation
Western North American Alpine Dwarf-Shrubland, Tundra, & Fell-field (hyprid macro)	Mediterranean California Alpine Dry Tundra	Vancouverian Alpine Scrub, Forb Meadow & Grassland	Alpine Scrub, Forb Meadow & Grassland
Western North American Alpine Dwarf-Shrubland, Tundra, & Fell-field (hyprid macro)	Rocky Mountain Alpine Tundra/Fell-field/Dwarf-shrub Map Unit	Vancouverian Alpine Scrub, Forb Meadow & Grassland	Alpine Scrub, Forb Meadow & Grassland

Western North American Alpine Dwarf-Shrubland, Tundra, & Fell-field (hyprid macro)	Mediterranean California Alpine Fell-Field	Vancouverian Alpine Scrub, Forb Meadow & Grassland	Alpine Scrub, Forb Meadow & Grassland
Western North American Alpine Dwarf-Shrubland, Tundra, & Fell-field (hyprid macro)	Rocky Mountain Alpine Fell-Field	Rocky Mountain Alpine Scrub, Forb Meadow & Grassland	Alpine Scrub, Forb Meadow & Grassland
Western North American Alpine Dwarf-Shrubland, Tundra, & Fell-field (hyprid macro)	North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow	Vancouverian Alpine Scrub, Forb Meadow & Grassland	Alpine Scrub, Forb Meadow & Grassland
Western North American Cliff, Canyon, Bedrock, & Barrens	Klamath-Siskiyou Cliff and Outcrop	Vancouverian Cliff, Scree & Rock Vegetation	Temperate & Boreal Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	North Pacific Montane Massive Bedrock, Cliff and Talus	Vancouverian Cliff, Scree & Rock Vegetation	Temperate & Boreal Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	North Pacific Coastal Cliff and Bluff	Cool Pacific Coastal Beach, Dune & Bluff Vegetation	Temperate & Boreal Scrub & Herb Coastal Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Central California Coast Ranges Cliff and Canyon	California Cliff, Scree & Rock Vegetation	Mediterranean Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Mediterranean California Serpentine Barrens	California Cliff, Scree & Rock Vegetation	Mediterranean Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Quarries, Mines, Gravel Pits and Oil Wells	Quarries, Mines, Gravel Pits and Oil Wells	Current and Historic Mining Activity
Western North American Cliff, Canyon, Bedrock, & Barrens	Sierra Nevada Cliff and Canyon	Vancouverian Cliff, Scree & Rock Vegetation	Temperate & Boreal Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Inter-Mountain Basins Cliff and Canyon	Intermountain Basin Cliff, Scree & Rock Vegetation	Cool Semi-Desert Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Undifferentiated Barren Land	Barren	Barren
Western North American Cliff, Canyon, Bedrock, & Barrens	Rocky Mountain Cliff, Canyon and Massive Bedrock	Rocky Mountain Cliff, Scree & Rock Vegetation	Temperate & Boreal Cliff, Scree & Rock Vegetation
Western North American Cliff, Canyon, Bedrock, & Barrens	Unconsolidated Shore	Barren	Barren
Rocky Mountain Subalpine-Montane Riparian Shrubland	Rocky Mountain Subalpine-Montane Riparian Shrubland	Western North American Montane Wet Meadow & Low Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
California Coastal Closed-Cone Conifer Forest and Woodland	California Coastal Closed-Cone Conifer Forest and Woodland	California Forest & Woodland	Warm Temperate Forest
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	California Forest & Woodland	Warm Temperate Forest
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	California Forest & Woodland	Warm Temperate Forest
East Cascades Oak-Ponderosa Pine Forest and Woodland	East Cascades Oak-Ponderosa Pine Forest and Woodland	Californian-Vancouverian Foothill & Valley Forest & Woodland	Warm Temperate Forest
Mediterranean California Mixed Evergreen Forest	Mediterranean California Mixed Evergreen Forest	Californian-Vancouverian Foothill & Valley Forest & Woodland	Warm Temperate Forest
North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland	North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland	Californian-Vancouverian Foothill & Valley Forest & Woodland	Warm Temperate Forest
North Pacific Oak Woodland	North Pacific Oak Woodland	Californian-Vancouverian Foothill & Valley Forest & Woodland	Warm Temperate Forest
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	Northern Rocky Mountain Lower Montane & Foothill Forest	Cool Temperate Forest
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest

Northern Rocky Mountain Subalpine Woodland and Parkland	Northern Rocky Mountain Subalpine Woodland and Parkland	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland	California Montane Jeffrey Pine-(Ponderosa Pine) Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland	Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
Mediterranean California Mesic Mixed Conifer Forest and Woodland	Mediterranean California Mesic Mixed Conifer Forest and Woodland	Southern Vancouverian Montane & Foothill Forest	Cool Temperate Forest
California Coastal Redwood Forest	California Coastal Redwood Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Hypermaritime Sitka Spruce Forest	North Pacific Hypermaritime Sitka Spruce Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Mesic Western Hemlock-Silver Fir Forest	North Pacific Mesic Western Hemlock-Silver Fir Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Wooded Volcanic Flowage	North Pacific Wooded Volcanic Flowage	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
Mediterranean California Red Fir Forest	Mediterranean California Red Fir Forest	Vancouverian Subalpine Forest	Cool Temperate Forest
North Pacific Maritime Mesic Subalpine Parkland	North Pacific Maritime Mesic Subalpine Parkland	Vancouverian Subalpine Forest	Cool Temperate Forest
North Pacific Mountain Hemlock Forest	North Pacific Mountain Hemlock Forest	Vancouverian Subalpine Forest	Cool Temperate Forest
North Pacific Lowland Riparian Forest and Shrubland	North Pacific Lowland Riparian Forest and Shrubland	Vancouverian Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
North Pacific Montane Riparian Woodland and Shrubland	North Pacific Montane Riparian Woodland and Shrubland	Vancouverian Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
North Pacific Shrub Swamp	North Pacific Shrub Swamp	Vancouverian Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
California Central Valley Riparian Woodland and Shrubland	California Central Valley Riparian Woodland and Shrubland	Warm Mediterranean & Desert Riparian, Flooded & Swamp Forest	Temperate Flooded & Swamp Forest
Willamette Valley Upland Prairie and Savanna	Willamette Valley Upland Prairie and Savanna	Southern Vancouverian Lowland Grassland & Shrubland	Temperate Grassland, Meadow & Shrubland
Mediterranean California Subalpine Meadow	Mediterranean California Subalpine Meadow	Rocky Mountain-Vancouverian Subalpine & High Montane Mesic Grass & Forb Meadow	Temperate Grassland, Meadow & Shrubland
California Montane Woodland and Chaparral	California Montane Woodland and Chaparral	Cool Interior Chaparral	Temperate Grassland, Meadow & Shrubland
North Pacific Avalanche Chute Shrubland	North Pacific Avalanche Chute Shrubland	Western North American Lowland Freshwater Wet Meadow, Marsh & Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
North Pacific Intertidal Freshwater Wetland	North Pacific Intertidal Freshwater Wetland	Western North American Lowland Freshwater Wet Meadow, Marsh & Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Temperate Pacific Freshwater Emergent Marsh	Temperate Pacific Freshwater Emergent Marsh	Western North American Lowland Freshwater Wet Meadow, Marsh & Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Temperate Pacific Freshwater Mudflat	Temperate Pacific Freshwater Mudflat	Western North American Lowland Freshwater Wet Meadow, Marsh & Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
Willamette Valley Wet Prairie	Willamette Valley Wet Prairie	Western North American Montane Wet Meadow & Low Shrubland	Temperate & Boreal Freshwater Wet Meadow & Marsh
North American Arid West Emergent Marsh	North American Arid West Emergent Marsh	Warm Desert Freshwater Shrubland, Meadow & Marsh	Temperate & Boreal Freshwater Wet Meadow & Marsh
Temperate Pacific Tidal Salt and Brackish Marsh	Temperate Pacific Tidal Salt and Brackish Marsh	Open Water (Brackish/Salt)	

Introduced Upland Vegetation - Treed	Introduced Upland Vegetation - Treed	Introduced & Semi Natural Vegetation	Introduced & Semi Natural Vegetation
Open Water (Brackish/Salt)	Open Water (Brackish/Salt)	Open Water	Open Water
Developed, Open Space	Developed, Open Space	Developed & Urban	Developed & Urban
California Central Valley Mixed Oak Savanna	California Central Valley Mixed Oak Savanna	California Forest & Woodland	Warm Temperate Forest
California Coastal Live Oak Woodland and Savanna	California Coastal Live Oak Woodland and Savanna	California Forest & Woodland	Warm Temperate Forest
Mediterranean California Mixed Oak Woodland	Mediterranean California Mixed Oak Woodland	Californian-Vancouverian Foothill & Valley Forest & Woodland	Warm Temperate Forest
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	Northern Rocky Mountain Lower Montane & Foothill Forest	Cool Temperate Forest
Rocky Mountain Aspen Forest and Woodland	Rocky Mountain Aspen Forest and Woodland	Rocky Mountain Subalpine & High Montane Conifer Forest	Cool Temperate Forest
North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest	North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Lowland Mixed Hardwood-Conifer Forest and Woodland	North Pacific Lowland Mixed Hardwood-Conifer Forest and Woodland	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	Vancouverian Lowland & Montane Rainforest	Cool Temperate Forest
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	Vancouverian Subalpine Forest	Cool Temperate Forest
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	Intermountain Singleleaf Pinyon - Western Juniper Woodland	Cool Temperate Forest

Appendix 3. Species list for modeling

Habitat Type	Species	Scientific name
Oak	Scrub Jay	Aphelocoma californica
Oak	White-breasted Nuthatch	Sitta carolinensis
Conifer Forest	Rufous Hummingbird	Selasphorus rufus
Conifer Forest	Winter Wren	Troglodytes hiemalis
Grassland	Savannah Sparrow	Passerculus sandwichensis
Grassland	Oregon Vesper Sparrow	Pooecetes gramineus affinis
Conifer Forest	Orange-crowned Warbler	Oreothlypis celata
Riparian	Yellow Warbler	Setophaga petechia
Oak	House Wren	Troglodytes aedon
Riparian	Warbling Vireo	Vireo gilvus
Conifer Forest	Hermit Warbler	Setophaga occidentalis
Conifer Forest	Townsend's Warbler	Setophaga townsendi
Conifer Forest	Wilson's Warbler	Cardellina pusilla
Conifer Forest	Pacific-slope Flycatcher	Empidonax difficilis
Grassland	Streaked Horned Lark	Eremophila alpestris strigata
Conifer Forest	Brown Creeper	Certhia americana
Oak	Chipping Sparrow	Spizella passerina
Oak	Purple Finch	Carpodacus purpureus
Grassland	Western Meadowlark	Sturnella neglecta
Conifer Forest	Hairy Woodpecker	Picoides villosus
Riparian	Downy Woodpecker	Picoides pubescens
Conifer Forest	Varied Thrush	Ixoreus naevius
Riparian	Swainson's Thrush	Catharus ustulatus
Conifer Forest	Olive-sided Flycatcher	Contopus cooperi
Oak	Western Wood-pewee	Contopus sordidulus
Riparian	Willow Flycatcher	Empidonax traillii