Forecasting the Impact of Climate Change on Terrestrial Biodiversity and Protected Areas in the Pacific Northwest

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Chapter 1: Incorporating vegetation change projections into bioclimatic models for vertebrate species in western North America

Abstract

Due to changing climatic conditions, species ranges are expected to shift throughout the course of this century. Modeling subsequent shifts in suitable habitat for animal species, and the resulting changes in species assemblages, represent critical information for resource planners and managers. Developing robust suitability models for large geographic areas can be challenging, in part due to insufficient sampling data and to computational limits associated with modeling large geographies at a fine-grained spatial resolution. To overcome these challenges, I developed a method to model habitat suitability in which I built correlative climate suitability models for 366 terrestrial animal species at a relatively coarse spatial resolution for the entire North American continent using species range maps and 23 bioclimatic variables. I then applied the models to both current and projected future climate data downscaled to a moderately fine resolution for western North America. I refined the resulting climate suitability projections by applying a filter that limited suitability to areas in which suitable biomes were projected to be present. I verified my modeling results using an independent species occurrence data set, finding a median accuracy rate of 70%. I found that incorporating information about biomes into the models resulted in projections of larger climate-driven changes in suitability—on average a difference of about 10%. My results also indicate that study species are more likely to see climate-driven losses than gains in habitat suitability. The percentage of study species projected to undergo a significant net decrease in habitat suitability was double the percentage projected to experience a net increase. These results highlight the shortcomings of many broad-scale models and highlight the need to take finer scale vegetation patterns into account. They also indicate that while many animal species could potentially benefit from climate-change induced increases in habitat suitability, the majority of species may suffer from substantial decreases, complicating future conservation efforts.

Introduction

Animal species will face a host of challenges in the coming century due to human-induced changes in biological and physical systems. Of the many drivers of change affecting global biodiversity, anthropogenic climate change is commonly highlighted as one of the leading threats (Sala et al. 2000; Chapin et al. 2000). Species turnover rates associated with climate change are projected to range, on average, from 25% to 38% for vertebrates in the western hemisphere (Lawler et al. 2009) and from 45% to 63% for plants across Europe (Thuiller et al. 2004). At a global scale, projections of climate-induced species extinction rates over the course of this century range from 18% to 35% by 2050 (Thomas et al. 2004). Mounting empirical evidence indicates that human-induced climate change is already influencing many plant and animal species. Important changes in phenology have been observed, including earlier arrivals of migratory birds (Sparks 1999; Cotton 2003), changes in plant and animal populations and reproduction (Post and Stenseth 1999), and shifts in the timing of seasonal flowering events (McCarty 2001). In addition, latitudinal and elevational shifts in species ranges have been recorded for mammals, birds, and invertebrates (Hickling et al. 2006).

The factors that determine the distribution patterns of animal species are numerous, and the relationships between these factors and a species distribution can be complex. Factors such as climate, vegetation, land use, and biotic interactions can all limit a species distribution, however, these factors affect individual species at different spatial and temporal scales. Several hierarchical frameworks have been proposed for understanding the effects of limiting factors on species distribution, with some focused on animal resource selection (MacKey and Lindenmayer 2001; Morrison et al. 2006), and others focused on the concept of scale domains, in which abiotic limiting factors such as climate and land cover limit distributions at a coarse scale, whereas biotic factors affect distributions at a finer scale (Pearson and Dawson 2003).

The role of climate in determining species distributions has been well established for mammals (Humphries et al. 2002; Moritz et al. 2008), birds (Wasser 1986; Root 1988), and amphibians (Blaustein et al. 2001; Adams and Bury 2002). Because the effect of various physical and biotic factors on every species is unique, species can exhibit highly divergent responses to environmental changes, including shifting, contraction, and expansion of distributions. Many obligate species that occupy restricted environmental niches are expected to experience contractions in distribution as a result of increasing surface temperatures, such as the American Pika (*Ochotona princeps*), a high-elevation montane obligate species occurring throughout western North America. Pikas are predicted to experience, on average, a 73% decrease in suitable habitat, based on a 4°C increase in surface temperature by 2080 (Calkins et al. 2012). Conversely, the Mountain pine beetle (*Dendroctonus ponderosae*) has benefited from rising temperatures by increasing in abundance in habitats with historically less suitable climate conditions (Cudmore et al. 2010). Given that trends in distributions vary by species, resource managers should, at the very least, expect to encounter more novel species assemblages this century (Williams et al. 2007).

Species distribution modeling

Species distribution modeling (SDM) - also commonly referred to as "habitat suitability modeling" and "niche modeling" - originated in studies from the late 1960s and 70s as ecological gradient modeling (Whittaker 1967; Peet and Loucks 1977). Later advances in geographic information systems (GIS) and remote sensing technology facilitated an expansion and maturation of SDM approaches, giving rise to the wide array of SDM methods and algorithms available to researchers today (Franklin 2009 for review). Common early algorithmic approaches to distribution modeling included generalized additive models (Yee and Mitchell 1991), generalized linear models (Venables and Ripley 1999), and classification and regression trees (Breiman 1984). Newer methods based on machine-learning techniques like artificial neural networks (Lek and Guégan 1999), Maxent (Phillips et al. 2004), and Random Forests (Breiman 2001) perform well with non-parametric data, provide greater model flexibility, and can generally better handle data sets with a high level of dimensionality (Olden et al. 2008). The SDM approach is currently used in a variety of research disciplines, including biogeography, invasive species, conservation planning, and paleoecology.

Species distribution modeling can be an effective way to predict how species ranges may be affected by projected changes in climate (Thomas et al. 2004; L. Beaumont et al. 2005; Lawler et al. 2009), but this type of modeling relies on some key assumptions. First, one must assume that a species has reached a state of equilibrium with its environment (e.g., the species' range has finished expanding since the last major climate shift). Second, climate must be assumed to be the primary factor driving species range patterns at the scale of analysis, although this is relatively well-established (McCarty 2001). Because most empirically-based SDMs are not dynamic in nature, any distribution model should only be considered a "snapshot" in time.

Although significant advances have been made in the efficacy of species distribution modeling, important uncertainties remain (Araujo and Guisan 2006). A common criticism of SDMs that are based primarily on climate-related environmental factors (sometimes referred to as "climate envelope" models) centers on the fact that they often overlook the influence of biotic interactions on species distributions. Biotic interactions such as predation, competition, and parasitism can substantially limit distributions (MacArthur 1984), and so the projected output of a climate-based SDM could potentially provide an overly simplified or erroneous depiction of a species distribution (Davis et al. 1998). Dispersal ability can also determine how well individuals of a species can track environmental change (Malcolm et al. 2002). Another source of uncertainty stems from alternate modeling methods, each with the potential to produce valid simulations, that can yield significantly disparate results based purely on differing mathematical techniques employed by each model (Lawler et al. 2006, Elith and Leathwick 2009).

When developing climate-based distribution models, it is important to keep in mind the scales at which physical and biotic factors most impact a species. At a continental scale, abiotic factors such as regional or continental climate regimes are often the dominant limiting factor, whereas at finer resolutions, topography and land-cover become the primary limitations. At an even finer scale, biotic interactions prove to be the most important limiting factors (Pearson and Dawson 2003). To improve the accuracy of a distribution model at finer scales, factors other than climate (i.e. land cover and vegetation) can be included as environmental variables in the modeling process (Pearson et al. 2004).

Here, I combine SDMs based on climate variables with simple biome-level habitat associations to produce models that can project future impacts on species distributions based on projected changes in climate and vegetation, with a reasonable level of accuracy. I then examine how refining the climate suitability models with these biomes associations affects the current suitability for each study species, and also compare differences in mean expansion and contraction of future species habitat suitability as simulated by two global circulation model projections and one emission scenario.

Methods

Study Area and Species

The study area encompasses twelve ecoregions that represent the diversity of ecological realms found in the Northwestern United States and Southwestern Canada region of North America (hereafter referred to as the Pacific Northwest). Specifically, this area extends from 38° to 58° North latitude and 103° to 137° West longitude (Figure 1), which fully encloses the boundaries of the twelve ecoregions, covering an area of 6,895,788 square kilometers. The study area incorporates an array of climates, topography, and vegetation, ranging from the arid shrub-steppe of the Columbia Plateau in the south to the perennially moist coastal forests of British Columbia in the northwest, and east to the Rocky Mountains and Great Plains.

I built models for 237 bird, 117 mammal, and 12 amphibian species (Table 1). Species were chosen for inclusion in the study based on a simple set of criteria, largely driven by data availability. For an animal species to be included in the study, the species had to be primarily associated with terrestrial habitats, have a digitally map of its current range, have some portion of its current distribution intersect with the study area extent, and have climate suitability models with a specified minimum amount of predictive accuracy.

Data

To develop credible projections of shifts in a species distribution, the entire range of climatic conditions that comprise a species fundamental niche should be included (Thuiller et al. 2004). Because so many species in North America are wide-ranging, building distribution models based on future climatic conditions requires the development of models at a continental scale. Building models for such a vast area (24,710,000 km^2) introduces some fundamental logistical challenges to the modeling process. First, building an empirical correlative model using fine-scale climate data (for instance, comprised of 1-km^2 resolution grid cells) for an area the size of North America leads to severe computational limits for many modeling algorithms and computer resources, due to the sheer volume of data that must be processed. Second, obtaining a sufficient number of species presence data samples that adequately represents the full range of environments that can be occupied by the species is challenging, particularly in North America, where population centers are predominantly found south of 50° latitude. The majority of publicly-available species occurrence data for North America is found in the contiguous United States, yet many species have breeding ranges in northern Canada, where occurrence data is difficult to obtain, scarce, or non-existent.

For this study, digital species range maps were converted from polygons into 50-km^2 resolution grid cells representing species presences using the methodology described in Lawler et al. (2009). Although using point-based occurrence data to represent species presences is preferred when building correlative niche models, comprehensive occurrence data sets that adequately represent entire species ranges are generally unavailable, particularly for wide-ranging species with distributions extending into the subarctic and artic regions of North America. I used maps representing species ranges (Ridgley et al. 2003, Patterson et al. 2003), that at a coarse, continental scale were deemed to be adequate for representing species' climatic niches.

Recent historical climate variables were derived from the CRU CL 2.0 (New et al. 2002) and CRU TS 2.1 (Mitchell and Jones 2005) climatology data sets. Both the CRU CL 2.0 and CRU TS 2.1 data sets were constructed from climate station records spanning the years 1961 to 1990, which was then downscaled to a 10‘ latitude by 10‘ longitude global grid. The CRU CL

2.0 and CRU TS 2.1 data sets were then clipped to an envelope encompassing the study area, and downscaled further to a 30 arc-second resolution grid using a geographic distance-weighted bilinear interpolation method (Shafer and Bartlein, 2011). The downscaled 1961-1990 climate data set is comprised of 23 bioclimatic variables (Table 2), and covers an area of approximately 397 million ha (Figure 1). These bioclimatic variables represent environmental drivers that play an important role in limiting the distribution of vertebrate species.

Future climate conditions were simulated using two coupled atmospheric-oceanic general circulation models (AOGCMs), the Hadley CM3 model (Gordon et al. 2000), and the Canadian Centre for Climate Modeling and Analysis CGCM3.1 model (Flato et al. 2000). The Hadley CM3 model simulates future climate conditions that are warmer and drier relative to CGCM 3.1 model projections. I used one greenhouse-gas emissions scenario—the A2 scenario, as described by the IPCC Special Report on Emissions Scenarios (Nakicenovic et al. 2000). The A2 scenario represents a mid-high emission scenario, although actual observed emission rates from 2001-2007 exceeded rates predicted by this scenario (McMullen and Jabbour 2009). Projected future values for the 23 bioclimatic variables were applied to the same 30 arc-second latitude/longitude grid that was used to digitize the baseline climate data set. Future monthly bioclimatic variables were averaged to a 30-year mean, spanning the years 2070 to 2099.

Suitability models based solely on coarse-scale climatic variables will not reproduce the effects of wildlife-habitat associations and anthropogenic land use on species distribution patterns. Moreover, many fine-scale climate variations will most likely be omitted. To account for these issues, a map of wildlife-habitat associations was created for each study species, in order to both refine the climate suitability models and introduce vegetation patterns into the final habitat suitability models. The terrestrial habitat map for each species was built using modeled biome distributions developed by Rehfeldt et al. (2012), who used mapped biome classifications originally outlined by Brown et al. (1998). Rehfeldt et al. mapped current biome distributions for all of North America using the Random Forest algorithm, and then projected changes in future biome distributions associated with projected changes in climate based on three AOGCMs, two of which matched the two GCMs used to develop the climate suitability models for this study. Rehfeldt et al. used the t63 resolution of the CGCM 3.1 model, whereas I used the t47 resolution, however, I determined the differences to be minimal, being chiefly a difference in spatial resolution between the two variations of the CGCM 3.1 model. Anthropogenic land uses such as urban, residential and agriculture development have been shown to be associated with decreases in available habitat, habitat fragmentation, reduced permeability, and amplified edge effects (Wilcove et al. 1986). In the latter part of the 20th century, the Pacific Northwest experienced a major increase in urban and residential development, with a large percentage of low-density exurban development occurring on agricultural land, and along the wildland-urban interface (Theobald 2001). I incorporated land uses associated with urban, residential, and agricultural development by integrating maps of developed and agricultural lands derived from the USGS Gap National Land Cover database (2011) and British Columbia Broad Ecosystem Inventory (B.C. Ministry of Environment, 1997) into the modeling process. Although land-use will change over the course of this century (Alig et al., 2004; Bierwagen et al., 2010), robust land-use projections (Bierwagen et al., 2009) are only available for the U.S. portion of the study area. Consequently, I used data representing current land-use to refine both baseline and future habitat suitability models.

Climate Suitability Modeling

I developed predictive climate suitability maps for each of the 366 focal species based on bioclimatic data averaged over a 30-year span from 1961-1990, representing a baseline of recent historical climate conditions. To represent the full range of possible climatic conditions that can be found in each species range (Fig. 2), and due to the geographic restriction of downscaled 1-km^2 spatial resolution bioclimatic data to the study area extent, climate suitability models were developed first at a coarser resolution of 50-km^2 for the entire Western Hemisphere, using the modeling process as described in Lawler et al. (2009). I built the historical baseline climate suitability models for each species using the random forests algorithm (Breiman 2001) to correlate species presences with bioclimatic variables. Random forest is an ensemble-based machine-learning algorithm used for both classification and regression analysis producing relatively accurate predictions based on the combined results of multiple classification trees. Random forests has only been used recently in ecological studies (Cutler et al. 2007), but the approach has been shown to produce accurate results for species distribution models (Hernandez et al. 2008; Magness et al. 2008; Thomaes et al. 2008). The random forest algorithm generates multiple classification trees based on a large number of bootstrap samples from a study data set, and then combines the predictions from those classification trees. Strengths of the random forests algorithm include a novel method for estimating variable importance in the classification, high levels of predictive accuracy, and the ability to interpolate missing values (Cutler et al. 2007). The random forest models produce estimates of likelihood of correlation ranging from 0–1. To convert this range of values to a binary format representing “suitable” or “not suitable” habitat predictions, I determined a threshold value for each species model. The threshold value for each model was found by calculating the receiver operator characteristic (ROC) curve, and an equal weighting of the importance of false positives and false negatives, a technique summarized by Fielding and Bell (1997).

The accuracy of the 50-km^2 climate suitability models was ascertained by building a set of test models using a subset of 25% of the original presence and absence records. The proportion of correctly predicted presences (specificity) and absences (sensitivity) was calculated for each species test model, and those species models with a specificity score of .80 or greater were selected for inclusion in the fine-scale modeling process (these models had a minimum sensitivity of 0.95). For the climate suitability models, I then applied the 50-km^2 resolution climate suitability models to the downscaled 1-km^2 resolution climatic data to produce fine-scaled versions of the baseline and future projected climate suitability maps for each species (Fig. 3).

Species-Biome Relationships and Anthropogenic Land Use

To compensate for the inherent errors associated with applying a correlative suitability model built at a coarse 50-km^2 spatial resolution to a finer-scaled 1-km^2 resolution, I defined relationships between study species and biome types, and then refined the climate suitability models based on current and projected future biome distributions. To develop the species-biome relationships, NatureServe Explorer online database records were reviewed for each species to determine terrestrial habitat associations (NatureServe 2013). These habitat associations where then crosswalked to the mapped biome classifications developed by Rehfeldt et al. (2012) and recorded in a species-biome matrix (Table 3**)** as either suitable or unsuitable for each species record. A raster dataset was then built for each species based on the recorded species-biome attributes. For each of the climate suitability models, the species-biome relationship map was applied to the Random Forest predictive surface to refine the prediction of suitability. Those grid cells that were coded as having potential climate suitability (according to the Random Forests model) and suitable habitat (according to the species-biome association matrix) were considered part of the final habitat suitability map for each of the study species. Based on the assumption that urban, suburban, exurban and agricultural land-uses provide poor habitat quality for some animal species (Germaine and Wakeling, 2001; Hansen et al., 2005; McLaughlin and Mineau, 1995), grid cells attributed as such were specified as unsuitable in the climate suitability and species-biome association maps for all non-synanthropic species to produce a final habitat suitability map that more closely approaches that species' realized niche (Hutchinson 1957). The process to remove areas dominated by the urban gradient or agricultural lands was performed on both the baseline and future suitability models.

Habitat Suitability Model Accuracy Assessment

The fine-scale baseline habitat suitability models were tested for accuracy using an independent dataset of observation and collection records. These records, representing recorded species presences, were compiled in a database of georeferenced species occurrences. The data were obtained from eight state Natural Heritage Programs and two provincial Conservation Data Centres, and from a variety of natural history museum collection databases compiled by the Global Biodiversity Information Facility (Table 4). These data sources include records that were collected through designed surveys, as well as records collected opportunistically in areas that are easily accessible (i.e. near roads), or in close proximity to populated areas. In some areas, the density of occurrence records may be higher on public lands than on privately-owned lands due to greater access by government researchers and land managers. Occurrence records were included in the test dataset if the observation or collection date occurred during the baseline time period of 1961-1990, and if the records had a minimum spatial accuracy in decimal degrees of 111 meters at the equator (i.e. three significant figures).

To assess model accuracy, I determined the sensitivity of the current habitat suitability model for each study species. The accuracy assessment was conducted by analyzing geographically referenced occurrence records of known species locations in relation to the final synthesized current species habitat suitability maps. These occurrence records only represent presences, not absences. Consequently, only the sensitivity value of the models was calculated. Occurrence records were converted to 1-km^2 grid cells and overlaid with the predicted suitability maps, and those occurrence records that corresponded with suitable habitat grid cells were considered correct predictions. I determined that a minimum of 50 occurrence records per species was required to perform an adequate accuracy assessment, based on the minimum number of presence records that have been shown to be necessary for developing reasonably accurate species distribution models (Stockwell et al. 2002). Additionally, those species found to have only the breeding and year-round residency portions of their range intersecting the study area were included. Out of 366 study species, 86 species met these criteria (Table 5).

Results

Change in Habitat Suitability

As expected, the downscaled climate envelope models generally capture the broad limits of suitable climate for each species, but miss much of the fine-scale patterns associated with local variations in topography, elevation, and vegetation. Alpine, sub-alpine, ecological system embedded in more widespread matrix systems, and distinct biome boundaries were not captured at this scale. As an example, the downscaled climate map for the Northern Goshawk (*Accipiter gentilis*) includes montane and high-latitude boreal forests as suitable climate, but also includes many non-forested shrubland and grassland biomes, and agricultural areas (Fig. 3b). Because forest systems are critical for *Accipiter gentilis* (Squires and Reynolds, 1997), non-forested biomes such as shrublands, grasslands, alpine biomes, and agriculture-dominated lands were attributed as unsuitable and removed from the climate suitability map to produce the final habitat suitability map (Fig. 3c).

Incorporating habitat relationships based on biomes also had a major effect on the projected climate-driven changes in distributions (Fig. 4). The models generally predicted larger changes in suitability when habitat relationships were incorporated. The mean percent contraction and expansion in suitable climate, based on the climate suitability models, was (respectively) 27.2% and 26.03, compared to 37.03% and 32.35% for the biome-refined models. The effect, however, varied by species (Fig. 5). As an example, the Greater Sage Grouse (*Centrocercus urophasianus)* ranges throughout the western United States and southern regions of the Canadian provinces of Alberta and Saskatchewan, and is primarily associated with sagebrush habitat (Sveum et al. 1998). The climate suitability model included several areas not associated with sagebrush vegetation, as well as lands that are now devoted to agricultural purposes (Fig. 5a). Refining the Sage grouse climate suitability map by removing grid cells classified as an unsuitable biome or land-use type (including forest and woodlands, agricultural, and urban lands) resulted in 39% less suitable area in the final habitat suitability map (Fig. 5b). By comparison, the climate suitability model differs minimally from the final habitat suitability model for Merriam's Groundsquirrel (*Urocitellus canus*), another species reliant on arid shrubland habitats found throughout the Great Basin and the Columbia Plateau. Only 4% of the groundsquirrel's climate suitability footprint overlaps with Cascade-Sierran Montane and Rocky Mountain Conifer forest biomes, both deemed unsuitable for the ground squirrel (Fig. 5c and 5d).

More species were projected to experience losses in habitat suitability than were projected to experience gains (Fig. 6). Based on averaging both GCM projections, the percentage of species predicted to undergo at least a 5% net decrease (< -5%) in suitable habitat is nearly double (56.74%) the percentage of species predicted to have at least a 5% net increase (> 5%) in suitable habitat (28.28%). The percent of expansion and contraction of suitable habitat was also averaged by taxonomic group (Fig. 7). Considerable variation was found across taxonomic groups with respect to both contractions and expansions. Raptors, bats, and carnivores are projected to have the lowest average contraction in suitability (30-31%). Carnivores are projected to experience an average expansion of only 14%, whereas salamander and bat species are projected to undergo average expansions of 81% and 84%, respectively.

Significant differences in predicted changes in habitat suitability are apparent when comparing results based on the CGCM 3.1 and Hadley CM3 climate projections for many species, as exemplified by two study species, the Northern Goshawk (*Accipiter gentilis*) and the Greater Sage Grouse (*Centrocercus urophasianus*) (e.g., Fig. 8). In the case of the Northern Goshawk, habitat suitability is projected to contract by 15.29% according to the CGCM 3.1 projection (Fig. 8a), compared to 23.76% based on the Hadley CM3 projection (Fig. 8b), with the most notable contractions occurring in the Rocky and Blue Mountains, the southern portion of the Cascade Range, and the Fraser Plateau in south central British Columbia. In comparison, the Greater Sage grouse may undergo a substantial expansion in habitat suitability along the northern edge of its suitable range, with 1.92% expansion based on the CGCM3.1 projection (Fig. 8c), compared to 6.13% based on the Hadley CM3 projection (Fig. 8d), a difference of 76.15%.

The habitat suitability models based on each GCM tend to project similar trends in expansion and contraction for each species, however there are a cases when projections were markedly different, with one GCM predicting an overall increase while the other predicts the opposite (Figure 9). Although both GCMs project approximately the same average amount of contraction in suitability at 37%, the Hadley CM3 projects a greater average expansion in suitability at 39%, compared to 25.36% for the CGCM 3.1 model. Furthermore, a greater percentage of study species are projected to undergo an overall decrease (60.11%) versus an overall increase (39.62%) in suitable habitat according to the CGCM 3.1 model, compared to the Hadley CM3 model, which predicts an even split between the percentage of species that may undergo a net expansion versus contraction in suitable habitat.

Accuracy Assessment

Using the independent species occurrence and collection data, the percent of presences correctly predicted was calculated for each species in the subset of 86 species, resulting in a median of 69.92%, and mean of 67.22% (S.D. 24.02) correctly predicted. As expected, the models that performed the poorest were predominantly characterized by errors in the original species' range boundaries that were used to represent presences when building the coarse-scale climate suitability models, or by the inherent spatial bias found in many of the observational records. In contrast, the models with the best accuracy were wide-ranging species with extensive ranges.

Discussion

Although some recent studies projecting climate impacts on animal species distributions have taken vegetation systems and human land use into account (Hughes et al., 2012; Jongsomjit et al., 2013), most have not. My results indicate that the refinement process used to add associations with suitable biomes was successful in correcting errors of commission inherent in the downscaled climate suitability models. The observed result of incorporating habitat associations into the modeling process was to produce models that indicate more severe impacts on suitability, compared to the models based solely on climate variables, suggesting that models that ignore these associations may potentially underestimate climate impacts. How this refinement with biomes affected each habitat suitability map varied substantially between species.

There is also substantial variation in how the models project future changes in habitat suitability, however, the majority of animal species in the study will face contractions in the total amount of suitable habitat by the end of this century. These findings confirm the results of other research focused on the future impacts of climate change on species ranges and distributions. Large African mammals were found to have a median and mean contraction in range of 49% and 18%, respectively, based on the Hadley CM3 projection and A2 emission scenario by 2080 (Thuiller et al. 2006), whereas a study focused on 27 boreal and arctic land birds, also using the A2 Hadley CM3 model, projected an average reduction in range of 83.6% (Virkkala et al. 2008). Similarly, an analysis of 179 animal species encompassing a wide-range of taxa in South Africa, found that the majority of species (78%) examined were projected to undergo a contraction in range (Erasmus et al. 2002). One notable anomaly I discovered pertains to the twelve amphibian species included in the present study. A greater mean expansion in suitable habitat for amphibians (primarily driven by salamander species) was projected by both GCMs, with an average expansion of 63%, greater than both birds and mammals. This finding was also confirmed by an exploration of future shifts in the distribution of European amphibians performed by Araújo et al. (2006). The overall expansion of amphibians may be in part be due to warming trends affecting the northern region of the study area, potentially providing greater habitat suitability at the northern edge of many amphibian ranges that are currently restricted by cold annual temperatures. However, amphibians generally have restricted dispersal abilities, and so may be unable to take full advantage of this expanded suitability.

There are of course, limitations to the modeling approach demonstrated here. Although correlative distribution models can produce accurate results, they are typically only a static snapshot of a species distribution, representing environmental conditions over a limited time period, whereas ranges and population are dynamic over time (Sorte et al. 2007, Tingley et al. 2009), and high-impact stochastic events can have a substantial effect on species (Frederiksen et al., 2008). I used 30-year means of bioclimatic data to represent climatic conditions for the baseline correlative models. Thus I was unable to incorporate short-term extreme weather events, although it is possible to incorporate these types of stochastic events into distribution models (Bateman et al. 2011).

The global climate models used to project future climate changes have intrinsic limitations, based on differences in AOGCM algorithms and parameters (Lawler et al., 2006). There are also inherent assumptions associated with individual SRES emission scenarios regarding future economic and technological development (Nakicenovic et al. 2000). This study only included future climate projections from two GCMs and one emission scenario, primarily due to constraints on data availability. This may have limited the scope of my projections of future changes, with actual future climate conditions falling outside the range predicted by the CGCM 3.1 and Hadley CM3 model projections. Nevertheless, the profound differences in future suitability for many species that were simulated by these models underscore the importance of examining multiple projections when attempting to forecast future conditions. Despite the use of the highest emission scenario in the modeling process, these projections may still be considered conservative in light of recently observed trends in emissions (Le Quere et al., 2009; Raupach et al., 2007).

As described earlier, this modeling process included the post-hoc application of downscaled bioclimatic data to models built with coarse-scale bioclimatic inputs. Because the models were built with data representing coarse-grained environmental variables and species presences, fine-scale environmental gradients were not delineated by the Random Forest classification process. I assume that these errors in prediction were then carried over to the downscaled models. Refining the climate suitability outputs by removing areas that are classified as unsuitable biomes was intended to correct these types of error, however, although this process can rectify errors of commission, it cannot remedy errors of omission. Species-biome associations were determined by cross-walking NatureServe terrestrial habitats to the biome classifications developed by Rehfeldt et al. (2012), and then classifying each biome per species as suitable or unsuitable, a process which may have introduced errors in the species-biome association matrix. Because of the relatively coarse nature of the biome classification, many important fine-scale habitats were not incorporated into the habitat suitability maps. This is likely a less important issue for wide-ranging species than it is for habitat specialists. In addition, there are uncertainties associated with the biome mapping process as described by Rehfeldt et al. (2009), in particular regarding how biome boundaries were delineated, which likely affected the final species habitat suitability maps.

Despite these limitations, my investigation found significant future changes in suitable habitat for a wide variety of species, and the potential for altered species assemblages throughout western North America. Through the course of this research, I developed a novel method for building habitat suitability models using an approach that refines models built at a coarse scale to a spatial resolution that is more pragmatic for researchers and resource managers. Previous research has explored the construction of high-resolution distribution predictions by downscaling coarse-grain occurrence data (Bombi et al. 2011), however, this modeling was performed only for a small number of virtual species. My methodology presents several advantages over many common species distribution modeling techniques. First, this method takes advantage of IUCN and NatureServe species range data, which are currently available for a global array of 40,000 species (IUCN 2012). Second, the use of species range maps to train correlative distribution models, while potentially introducing significant errors of commission, may be considered as a potential alternative method for ameliorating the common problem of poor model performance due to spatially-biased training data (Phillips et al. 2009). In addition to other approaches to modeling with limited data resources (Hernandez et al. 2008), this method may prove particularly useful to those conducting similar analyses in regions with a paucity of observational species data.

Future studies could explore the incorporation of projected changes in human-dominated land uses into this modeling process, including urban and suburban expansion, to more accurately reflect future environmental conditions. This would also allow for the examination of the impacts of future habitat conversion and local climate change on, for instance, habitat specialists with limited dispersal ranges. Alternatively, a comparison of these models to suitability models built using fine-scaled bioclimatic variable and species presences, or to models using newer methods that incorporate biotic factors, could further illuminate the efficacy and accuracy of this method. Finally, the robustness of these projections of future climate change scenarios could be improved by using a higher number of SRES emission scenarios and CGM projections to predict current and future distributional changes, which would provide a more comprehensive portrayal of possible future outcomes.

I conclude that many animal species in western North America are likely to experience substantial changes in habitat suitability over the course of this century. I also found that using coarse species range data in combination with downscaled climate variables and vegetation data can produce reasonably accurate results for species inhabiting an expansive geographic area. The inclusion of data describing species-biome relationships, even if those relationships reflect relatively simple ecological associations, proved to have a profound impact on the amount of change projected by the suitability modeling process. Ideally, the methodology and results outlined here will prove valuable to researchers and practitioners who face the challenge of conserving faunal biodiversity in a rapidly changing world.

Figures

Figure 1: The study area

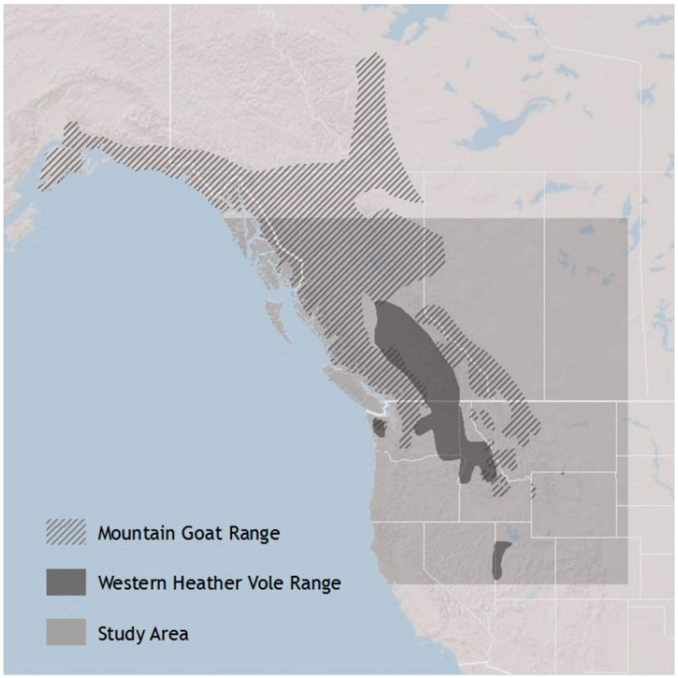

Figure 2: This map depicts the ranges of two focal species, the Mountain Goat *(Oreamnos americanus)* and Western Heather Vole *(Phenacomys intermedius)*. The Western Heather Vole's rage is encompassed within the study area, and the Mountain Goat's range falls partly outside.

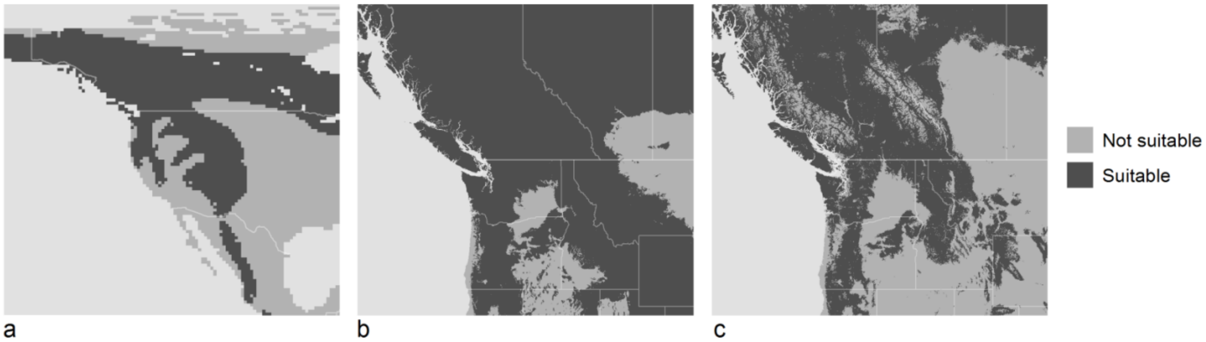

Figure 3: Suitability models representing baseline conditions for the Northern Goshawk (*Accipiter gentilis*), including (a) the 50-km^2 coarse-grained climate suitability model (b), the 1-km^2 climate suitability model, and (c) the final habitat suitability model after refinement with biomes.

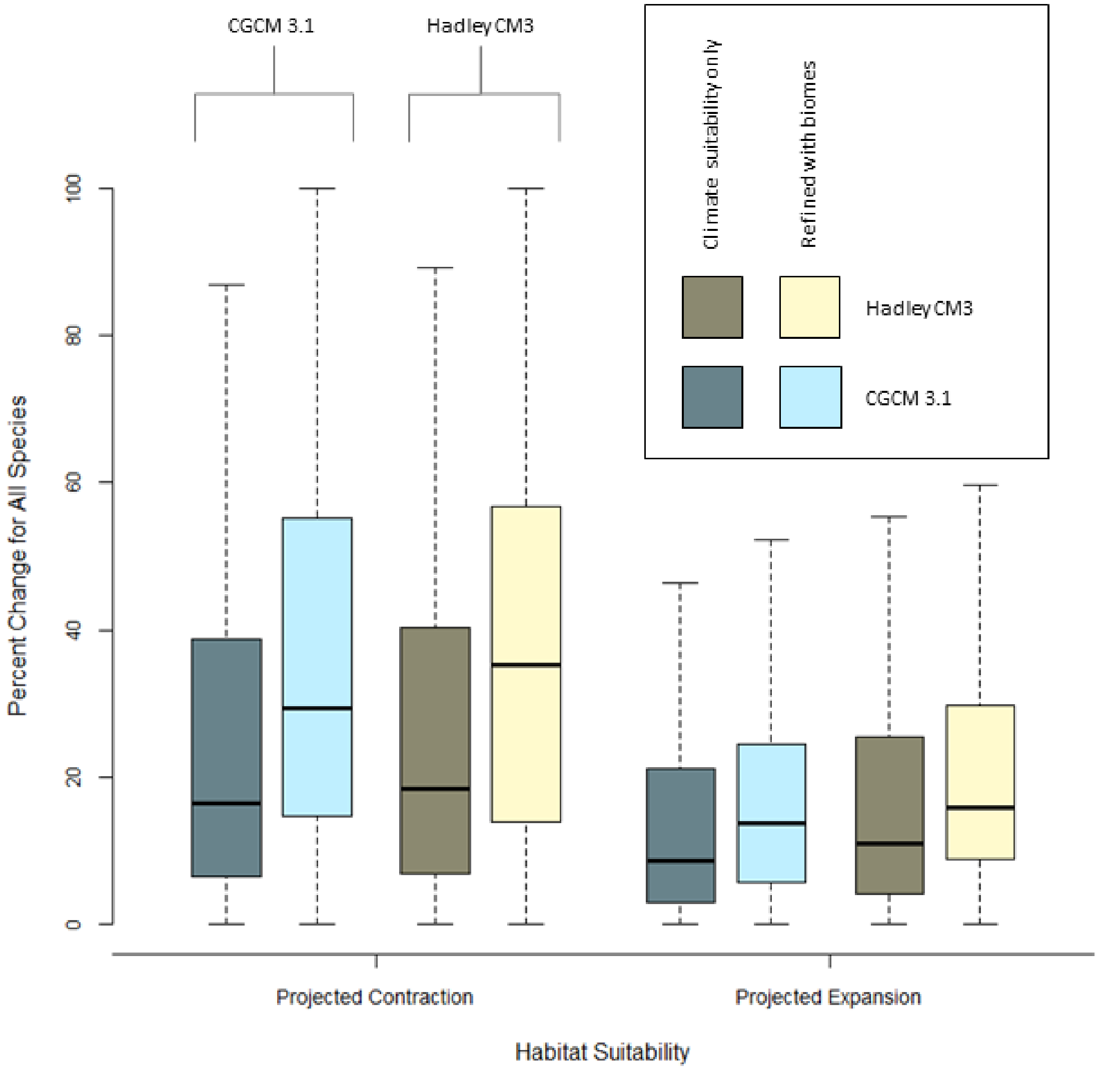

Figure 4: Projected changes in habitat suitability for all study species, grouped by mean expansion and contraction. Darker colors represent percent change in projected suitability for the climate suitability models, and lighter colors represent percent changes after refinement of the suitability maps with biome data.

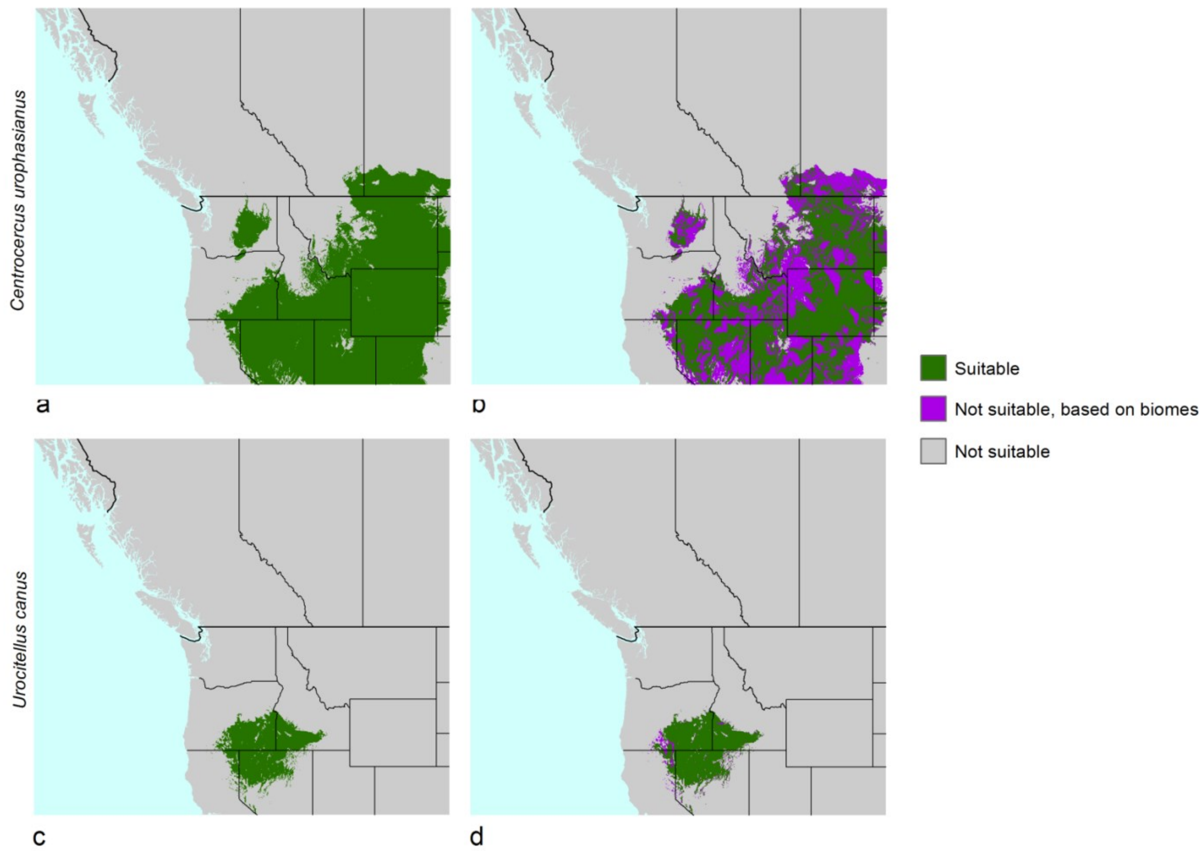

Figure 5: Differences in the effect of refining the climate suitability models by including biomes associated with each species. In the case of Greater Sage Grouse (*Centrocercus urophasianus*), suitable habitat as projected by the climate suitability model (a) is reduced by 39% after refine with associated biomes (b), compared to Merriam's Groundsquirrel (*Urocitellus canus*), which only loses 4% of suitable habitat after biome refinement (c and d).

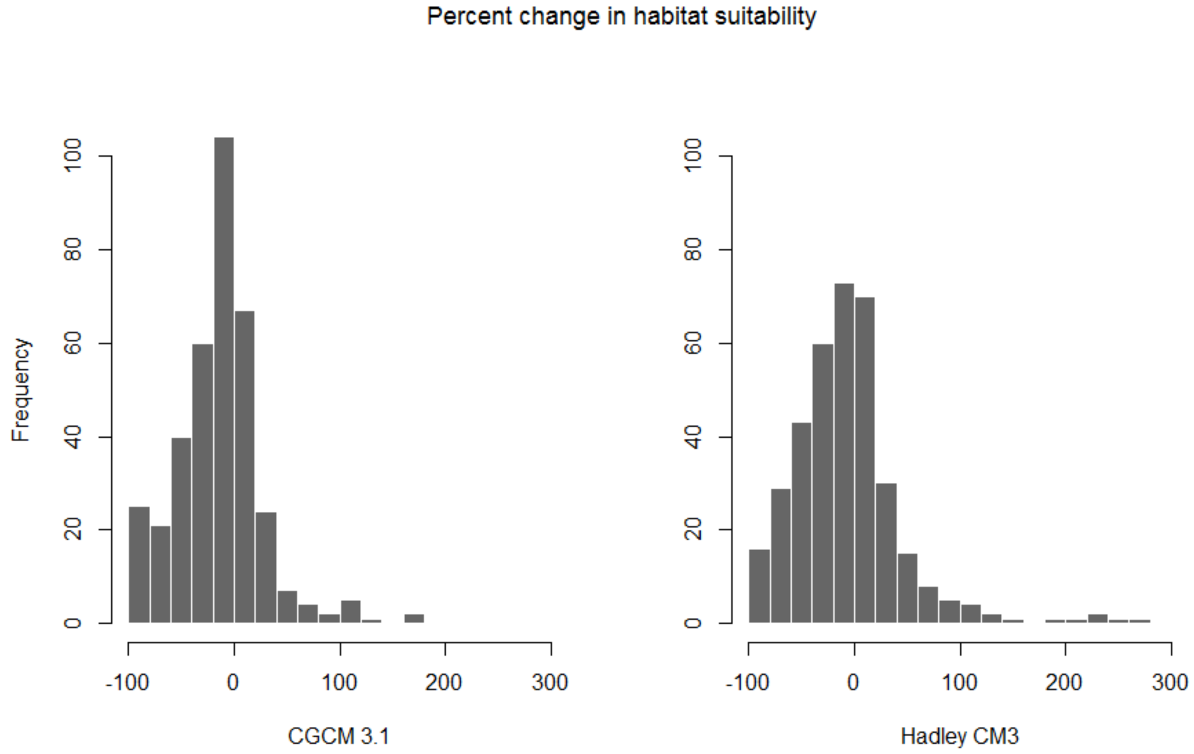

Figure 6: Distribution of values for percent change in suitable habitat of all study species, based on the biome-refined habitat suitability models. Outliers with expansion values >400% were not included in these graphs.

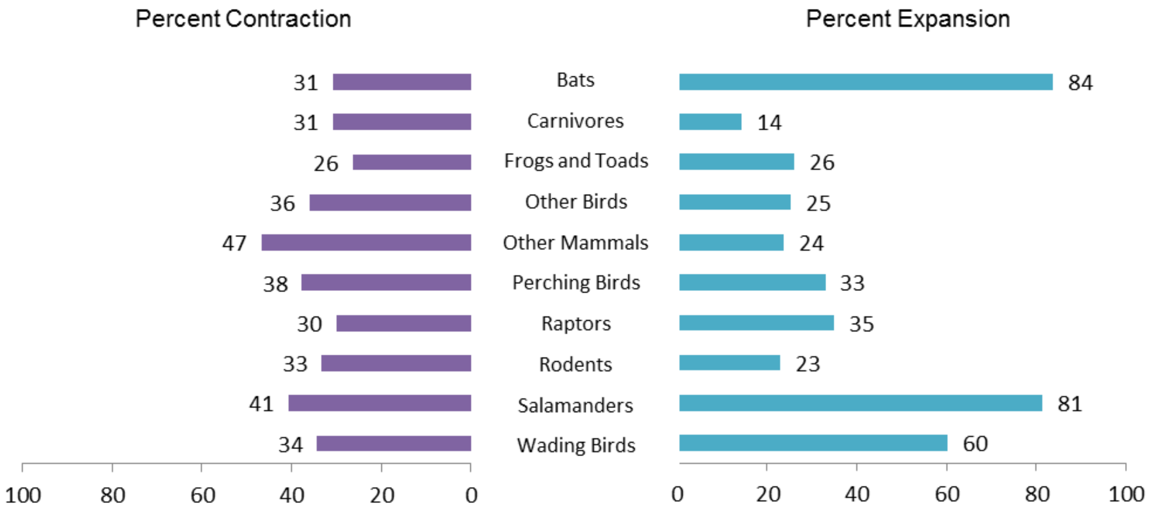

Figure 7: Projected contraction and expansion of suitable habitat, summarized by informal taxonomic groups. In general, there is more variation in projected expansion between taxonomic groups, compared to relatively consistent amounts of contraction.

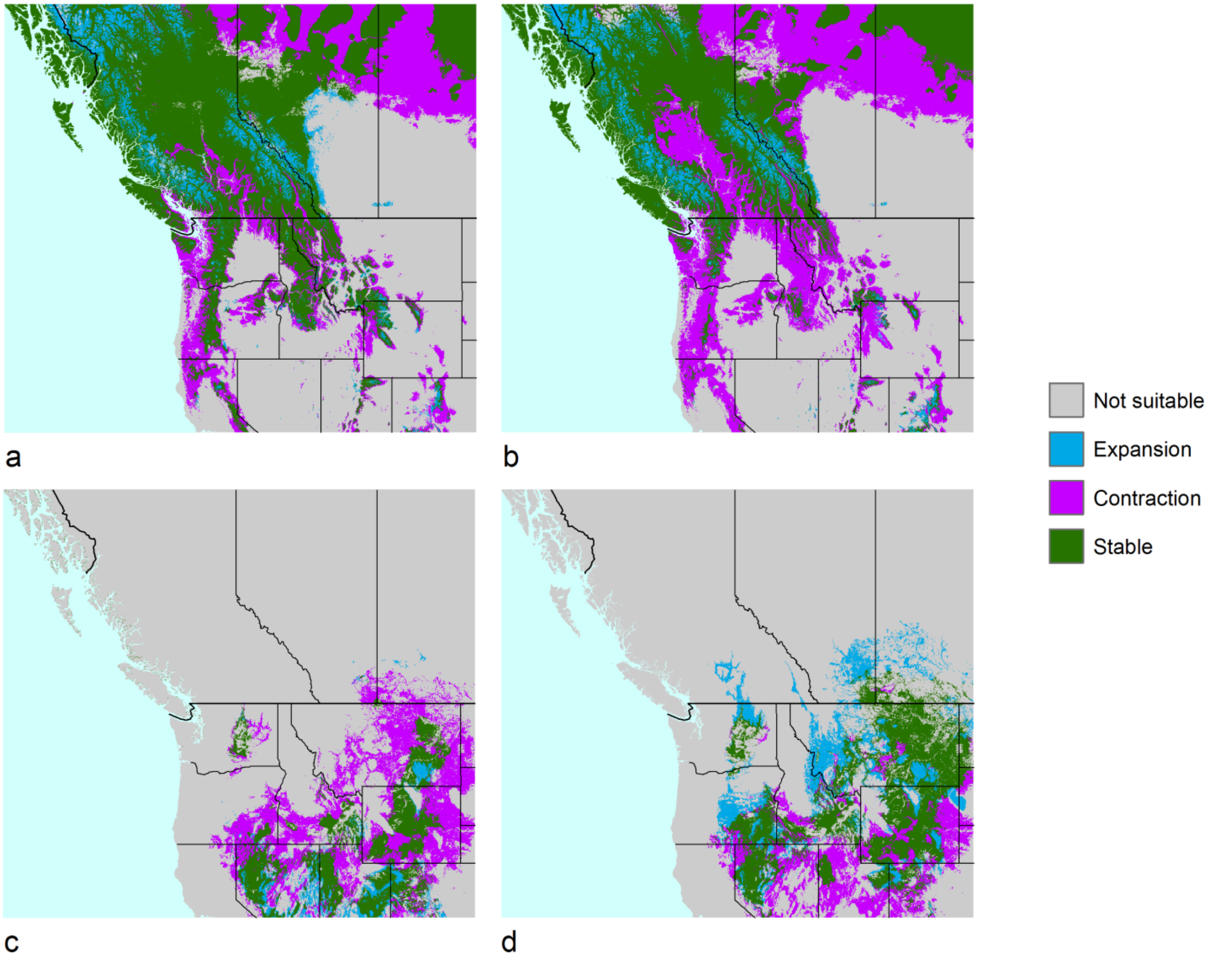

Figure 8: Predicted future change in habitat suitability based on the CGCM3.1 and Hadley CM3 projections for the Northern Goshawk (*Accipiter gentilis*), (a and b respectively), and the Greater Sage Grouse (*Centrocercus urophasianus*), (c and d, respectively).

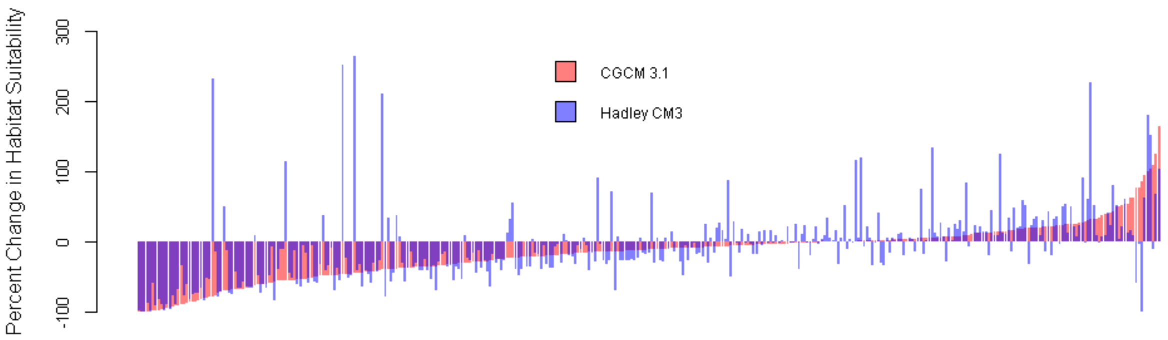

Figure 9: Total change in habitat suitability, sorted from the left by greatest amount of contraction (bars pointing down) to greatest amount of expansion (bars pointing up) for each of the CGCM 3.1 species suitability models (red), overlaid with the total change in habitat suitability for that same species based on Hadley CM3 projections (blue). Each bar represents one species. Purple represents agreement between both GCM projections.

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Appendix

Supplementary Tables

Table S1: Study Species
Scientific names, common names, and taxonomic categories, derived from NatureServe Explorer online database records.

Scientific Name	Common Name	Broad Taxonomic Group	Detailed Taxonomic Group	Range encompassed within study area
Accipiter cooperii	Cooper's Hawk	Birds	Raptors	No
Accipiter gentilis	Northern Goshawk	Birds	Raptors	No
Accipiter striatus	Sharp-shinned Hawk	Birds	Raptors	No
Aechmophorus clarkii	Clark's Grebe	Birds	Other Birds	No
Aechmophorus occidentalis	Western Grebe	Birds	Other Birds	No
Aegolius acadicus	Northern Saw-whet Owl	Birds	Other Birds	No
Aegolius funereus	Boreal Owl	Birds	Other Birds	No
Aeronautes saxatalis	White-throated Swift	Birds	Other Birds	No
Agelaius phoeniceus	Red-winged Blackbird	Birds	Perching Birds	No
Alces americanus	Moose	Mammals	Other Mammals	No
Ambystoma gracile	Northwestern Salamander	Amphibians	Salamanders	No
Ambystoma tigrinum	Tiger Salamander	Amphibians	Salamanders	No
Ammodramus bairdii	Baird's Sparrow	Birds	Perching Birds	No
Ammodramus leconteii	Le Conte's Sparrow	Birds	Perching Birds	No
Ammodramus savannarum	Grasshopper Sparrow	Birds	Perching Birds	No
Ammospermophilus leucurus	White-tailed Antelope Squirrel	Mammals	Rodents	No
Amphispiza belli	Sage Sparrow	Birds	Perching Birds	No
Amphispiza bilineata	Black-throated Sparrow	Birds	Perching Birds	No
Aneides ferreus	Clouded Salamander	Amphibians	Salamanders	No
Anthus rubescens	American Pipit	Birds	Perching Birds	No
Anthus spragueii	Sprague's Pipit	Birds	Perching Birds	No
Antrozous pallidus	Pallid Bat	Mammals	Bats	No
Aphelocoma californica	Western Scrub-Jay	Birds	Perching Birds	No
Aquila chrysaetos	Golden Eagle	Birds	Raptors	No
Arborimus albipes	White-footed Vole	Mammals	Rodents	No
Arborimus longicaudus	Red Tree Vole	Mammals	Rodents	Yes
Archilochus alexandri	Black-chinned Hummingbird	Birds	Other Birds	No
Archilochus colubris	Ruby-throated Hummingbird	Birds	Other Birds	No
Ardea alba	Great Egret	Birds	Wading Birds	No
Ardea herodias	Great Blue Heron	Birds	Wading Birds	No
Asio flammeus	Short-eared Owl	Birds	Other Birds	No
Asio otus	Long-eared Owl	Birds	Other Birds	No

Scientific Name	Common Name	Broad Taxonomic Group	Detailed Taxonomic Group	Range encompassed within study area
Athene cunicularia	Burrowing Owl	Birds	Other Birds	No
Bassariscus astutus	Ringtail	Mammals	Carnivores	No
Batrachoseps wrightorum	Oregon Slender Salamander	Amphibians	Salamanders	Yes
Blarina brevicauda	Northern Short-tailed Shrew	Mammals	Other Mammals	No
Bombycilla cedrorum	Cedar Waxwing	Birds	Perching Birds	No
Bombycilla garrulus	Bohemian Waxwing	Birds	Perching Birds	No
Bonasa umbellus	Ruffed Grouse	Birds	Other Birds	No
Botaurus lentiginosus	American Bittern	Birds	Wading Birds	No
Brachylagus idahoensis	Pygmy Rabbit	Mammals	Other Mammals	Yes
Bubo virginianus	Great Horned Owl	Birds	Other Birds	No
Buteo jamaicensis	Red-tailed Hawk	Birds	Raptors	No
Buteo lineatus	Red-shouldered Hawk	Birds	Raptors	No
Buteo platypterus	Broad-winged Hawk	Birds	Raptors	No
Buteo regalis	Ferruginous Hawk	Birds	Raptors	No
Buteo swainsoni	Swainson's Hawk	Birds	Raptors	No
Butorides virescens	Green Heron	Birds	Wading Birds	No
Calamospiza melanocorys	Lark Bunting	Birds	Perching Birds	No
Calcarius lapponicus	Lapland Longspur	Birds	Perching Birds	No
Calcarius ornatus	Chestnut-collared Longspur	Birds	Perching Birds	No
Calcarius pictus	Smith's Longspur	Birds	Perching Birds	No
Canis latrans	Coyote	Mammals	Carnivores	No
Carpodacus cassinii	Cassin's Finch	Birds	Perching Birds	No
Carpodacus mexicanus	House Finch	Birds	Perching Birds	No
Carpodacus purpureus	Purple Finch	Birds	Perching Birds	No
Castor canadensis	American Beaver	Mammals	Rodents	No
Catharus fuscescens	Veery	Birds	Perching Birds	No
Catharus guttatus	Hermit Thrush	Birds	Perching Birds	No
Catharus minimus	Gray-cheeked Thrush	Birds	Perching Birds	No
Catharus ustulatus	Swainson's Thrush	Birds	Perching Birds	No
Catherpes mexicanus	Canyon Wren	Birds	Perching Birds	No
Centrocercus urophasianus	Greater Sage Grouse	Birds	Other Birds	Yes
Cepphus columba	Pigeon Guillemot	Birds	Other Birds	No
Certhia americana	Brown Creeper	Birds	Perching Birds	No
Chaetodipus hispidus	Hispid Pocket Mouse	Mammals	Rodents	No
Chaetura pelagica	Chimney Swift	Birds	Other Birds	No
Chaetura vauxi	Vaux's Swift	Birds	Other Birds	No
Chlidonias niger	Black Tern	Birds	Other Birds	No
Chondestes grammacus	Lark Sparrow	Birds	Perching Birds	No
Chordeiles minor	Common Nighthawk	Birds	Other Birds	No
Cinclus mexicanus	American Dipper	Birds	Perching Birds	No

Scientific Name	Common Name	Broad Taxonomic Group	Detailed Taxonomic Group	Range encompassed within study area
Circus cyaneus	Northern Harrier	Birds	Raptors	No
Cistothorus palustris	Marsh Wren	Birds	Perching Birds	No
Cistothorus platensis	Sedge Wren	Birds	Perching Birds	No
Coccothraustes vespertinus	Evening Grosbeak	Birds	Perching Birds	No
Coccyzus erythropthalmus	Black-billed Cuckoo	Birds	Other Birds	No
Colaptes auratus	Northern Flicker	Birds	Other Birds	No
Colinus virginianus	Northern Bobwhite	Birds	Other Birds	No
Contopus cooperi	Olive-sided Flycatcher	Birds	Perching Birds	No
Contopus sordidulus	Western Wood-Pewee	Birds	Perching Birds	No
Corvus brachyrhynchos	American Crow	Birds	Perching Birds	No
Corvus corax	Common Raven	Birds	Perching Birds	No
Corynorhinus townsendii	Townsend's Western Big-eared Bat	Mammals	Bats	No
Coturnicops noveboracensis	Yellow Rail	Birds	Other Birds	No
Cyanocitta cristata	Blue Jay	Birds	Perching Birds	No
Cyanocitta stelleri	Steller's Jay	Birds	Perching Birds	No
Cynomys ludovicianus	Black-tailed Prairie Dog	Mammals	Rodents	No
Cypseloides niger	Black Swift	Birds	Other Birds	No
Dendragapus obscurus	Dusky Grouse	Birds	Other Birds	No
Dipodomys ordii	Ord's Kangaroo Rat	Mammals	Rodents	No
Dolichonyx oryzivorus	Bobolink	Birds	Perching Birds	No
Dryocopus pileatus	Pileated Woodpecker	Birds	Other Birds	No
Dumetella carolinensis	Gray Catbird	Birds	Perching Birds	No
Egretta thula	Snowy Egret	Birds	Wading Birds	No
Elanus leucurus	White-tailed Kite	Birds	Raptors	No
Empidonax alnorum	Alder Flycatcher	Birds	Perching Birds	No
Empidonax difficilis	Pacific-slope Flycatcher	Birds	Perching Birds	No
Empidonax flaviventris	Yellow-bellied Flycatcher	Birds	Perching Birds	No
Empidonax minimus	Least Flycatcher	Birds	Perching Birds	No
Empidonax oberholseri	Dusky Flycatcher	Birds	Perching Birds	No
Empidonax occidentalis	Cordilleran Flycatcher	Birds	Perching Birds	No
Empidonax traillii	Willow Flycatcher	Birds	Perching Birds	No
Empidonax wrightii	Gray Flycatcher	Birds	Perching Birds	No
Eptesicus fuscus	Big Brown Bat	Mammals	Bats	No
Eremophila alpestris	Horned Lark	Birds	Perching Birds	No
Erethizon dorsatum	North American Porcupine	Mammals	Rodents	No
Euderma maculatum	Spotted Bat	Mammals	Bats	No
Euphagus carolinus	Rusty Blackbird	Birds	Perching Birds	No
Euphagus cyanocephalus	Brewer's Blackbird	Birds	Perching Birds	No
Falcipennis canadensis	Spruce Grouse	Birds	Other Birds	No
Falco columbarius	Merlin	Birds	Raptors	No

Scientific Name	Common Name	Broad Taxonomic Group	Detailed Taxonomic Group	Range encompassed within study area
Falco mexicanus	Prairie Falcon	Birds	Raptors	No
Falco rusticolus	Gyrfalcon	Birds	Raptors	No
Falco sparverius	American Kestrel	Birds	Raptors	No
Fulica americana	American Coot	Birds	Other Birds	No
Gavia immer	Common Loon	Birds	Other Birds	No
Gavia pacifica	Pacific Loon	Birds	Other Birds	No
Gavia stellata	Red-throated Loon	Birds	Other Birds	No
Geomys bursarius	Plains Pocket Gopher	Mammals	Rodents	No
Geothlypis trichas	Common Yellowthroat	Birds	Perching Birds	No
Glaucidium gnoma	Northern Pygmy-Owl	Birds	Other Birds	No
Glaucomys sabrinus	Northern Flying Squirrel	Mammals	Rodents	No
Grus canadensis	Sandhill Crane	Birds	Wading Birds	No
Gulo gulo	Wolverine	Mammals	Carnivores	No
Gymnorhinus cyanocephalus	Pinyon Jay	Birds	Perching Birds	No
Haliaeetus leucocephalus	Bald Eagle	Birds	Raptors	No
Hirundo rustica	Barn Swallow	Birds	Perching Birds	No
Icteria virens	Yellow-breasted Chat	Birds	Perching Birds	No
Icterus bullockii	Bullock's Oriole	Birds	Perching Birds	No
Icterus galbula	Baltimore Oriole	Birds	Perching Birds	No
Icterus parisorum	Scott's Oriole	Birds	Perching Birds	No
Icterus spurius	Orchard Oriole	Birds	Perching Birds	No
Ixobrychus exilis	Least Bittern	Birds	Wading Birds	No
Ixoreus naevius	Varied Thrush	Birds	Perching Birds	No
Junco hyemalis	Dark-eyed Junco	Birds	Perching Birds	No
Lagopus lagopus	Willow Ptarmigan	Birds	Other Birds	No
Lanius excubitor	Northern Shrike	Birds	Perching Birds	No
Lanius ludovicianus	Loggerhead Shrike	Birds	Perching Birds	No
Larus argentatus	Herring Gull	Birds	Other Birds	No
Larus californicus	California Gull	Birds	Other Birds	No
Larus canus	Mew Gull	Birds	Other Birds	No
Larus delawarensis	Ring-billed Gull	Birds	Other Birds	No
Lasionycteris noctivagans	Silver-haired Bat	Mammals	Bats	No
Lasiurus borealis	Eastern Red Bat	Mammals	Bats	No
Lasiurus cinereus	Hoary Bat	Mammals	Bats	No
Lemmiscus curtatus	Sagebrush Vole	Mammals	Rodents	No
Lemmus trimucronatus	Nearctic Brown Lemming	Mammals	Rodents	No
Lepus americanus	Snowshoe Hare	Mammals	Other Mammals	No
Lepus californicus	Black-tailed Jackrabbit	Mammals	Other Mammals	No
Lepus townsendii	White-tailed Jackrabbit	Mammals	Other Mammals	No
Leucosticte tephrocotis	Gray-crowned Rosy-Finch	Birds	Perching Birds	No

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Lontra canadensis	North American River Otter	Mammals	Carnivores	No
Loxia curvirostra	Red Crossbill	Birds	Perching Birds	No
Loxia leucoptera	White-winged Crossbill	Birds	Perching Birds	No
Lynx canadensis	Canadian Lynx	Mammals	Carnivores	No
Lynx rufus	Bobcat	Mammals	Carnivores	No
Marmota caligata	Hoary Marmot	Mammals	Rodents	No
Marmota flaviventris	Yellow-bellied Marmot	Mammals	Rodents	No
Marmota monax	Woodchuck	Mammals	Rodents	No
Martes americana	American Marten	Mammals	Carnivores	No
Martes pennanti	Fisher	Mammals	Carnivores	No
Megaceryle alcyon	Belted Kingfisher	Birds	Other Birds	No
Melanerpes erythrocephalus	Red-headed Woodpecker	Birds	Other Birds	No
Melanerpes lewis	Lewis's Woodpecker	Birds	Other Birds	No
Melospiza georgiana	Swamp Sparrow	Birds	Perching Birds	No
Melospiza lincolnii	Lincoln's Sparrow	Birds	Perching Birds	No
Melospiza melodia	Song Sparrow	Birds	Perching Birds	No
Mephitis mephitis	Striped Skunk	Mammals	Carnivores	No
Microtus californicus	California Vole	Mammals	Rodents	No
Microtus longicaudus	Long-tailed Vole	Mammals	Rodents	No
Microtus montanus	Montane Vole	Mammals	Rodents	No
Microtus ochrogaster	Prairie Vole	Mammals	Rodents	No
Microtus oeconomus	Root Vole	Mammals	Rodents	No
Microtus pennsylvanicus	Meadow Vole	Mammals	Rodents	No
Microtus townsendii	Townsend's Vole	Mammals	Rodents	No
Microtus xanthognathus	Taiga Vole	Mammals	Rodents	No
Mimus polyglottos	Northern Mockingbird	Birds	Perching Birds	No
Mniotilta varia	Black-and-white Warbler	Birds	Perching Birds	No
Molothrus ater	Brown-headed Cowbird	Birds	Perching Birds	No
Mustela erminea	Ermine	Mammals	Carnivores	No
Mustela frenata	Long-tailed Weasel	Mammals	Carnivores	No
Mustela nivalis	Least Weasel	Mammals	Carnivores	No
Myadestes townsendi	Townsend's Solitaire	Birds	Perching Birds	No
Myiarchus cinerascens	Ash-throated Flycatcher	Birds	Perching Birds	No
Myiarchus crinitus	Great Crested Flycatcher	Birds	Perching Birds	No
Myotis californicus	Californian Myotis	Mammals	Bats	No
Myotis ciliolabrum	Western Small-footed Myotis	Mammals	Bats	No
Myotis evotis	Long-eared Myotis	Mammals	Bats	No
Myotis lucifugus	Little Brown Myotis	Mammals	Bats	No
Myotis septentrionalis	Northern Myotis	Mammals	Bats	No
Myotis thysanodes	Fringed Myotis	Mammals	Bats	No

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Myotis volans	Long-legged Myotis	Mammals	Bats	No
Myotis yumanensis	Yuma Myotis	Mammals	Bats	No
Neotoma cinerea	Bushy-tailed Woodrat	Mammals	Rodents	No
Neotoma fuscipes	Dusky-footed Woodrat	Mammals	Rodents	No
Neotoma lepida	Desert Woodrat	Mammals	Rodents	No
Nucifraga columbiana	Clark's Nutcracker	Birds	Perching Birds	Yes
Nycticorax nycticorax	Black-crowned Night-Heron	Birds	Wading Birds	No
Ochotona collaris	Collared Pika	Mammals	Other Mammals	No
Odocoileus hemionus	Mule Deer	Mammals	Other Mammals	No
Odocoileus virginianus	White-tailed Deer	Mammals	Other Mammals	No
Ondatra zibethicus	Common Muskrat	Mammals	Rodents	No
Onychomys leucogaster	Northern Grasshopper Mouse	Mammals	Rodents	No
Oporornis agilis	Connecticut Warbler	Birds	Perching Birds	No
Oporornis philadelphia	Mourning Warbler	Birds	Perching Birds	No
Oporornis tolmiei	MacGillivray's Warbler	Birds	Perching Birds	No
Oreoscoptes montanus	Sage Thrasher	Birds	Perching Birds	No
Pandion haliaetus	Osprey	Birds	Raptors	No
Passerculus sandwichensis	Savannah Sparrow	Birds	Perching Birds	No
Passerella iliaca	Fox Sparrow	Birds	Perching Birds	No
Passerina amoena	Lazuli Bunting	Birds	Perching Birds	No
Passerina caerulea	Blue Grosbeak	Birds	Perching Birds	No
Perisoreus canadensis	Gray Jay	Birds	Perching Birds	No
Perognathus fasciatus	Olive-backed Pocket Mouse	Mammals	Rodents	No
Perognathus flavescens	Plains Pocket Mouse	Mammals	Rodents	No
Perognathus flavus	Silky Pocket Mouse	Mammals	Rodents	No
Peromyscus keeni	Northwestern Deermouse	Mammals	Rodents	Yes
Peromyscus leucopus	White-footed Deermouse	Mammals	Rodents	No
Peromyscus maniculatus	North American Deermouse	Mammals	Rodents	No
Peromyscus truei	Pinon Deermouse	Mammals	Rodents	No
Phalacrocorax auritus	Double-crested Cormorant	Birds	Other Birds	No
Phalaenoptilus nuttallii	Common Poorwill	Birds	Other Birds	No
Pheucticus ludovicianus	Rose-breasted Grosbeak	Birds	Perching Birds	No
Pheucticus melanocephalus	Black-headed Grosbeak	Birds	Perching Birds	No
Pica hudsonia	Black-billed Magpie	Birds	Perching Birds	No
Picoides arcticus	Black-backed Woodpecker	Birds	Other Birds	No
Picoides pubescens	Downy Woodpecker	Birds	Other Birds	No
Picoides villosus	Hairy Woodpecker	Birds	Other Birds	No
Pinicola enucleator	Pine Grosbeak	Birds	Perching Birds	No
Pipilo chlorurus	Green-tailed Towhee	Birds	Perching Birds	No
Pipilo maculatus	Spotted Towhee	Birds	Perching Birds	No

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Piranga ludoviciana	Western Tanager	Birds	Perching Birds	No
Plectrophenax nivalis	Snow Bunting	Birds	Perching Birds	No
Plegadis chihi	White-faced Ibis	Birds	Wading Birds	No
Plethodon dunni	Dunn's Salamander	Amphibians	Salamanders	Yes
Plethodon elongatus	Del Norte Salamander	Amphibians	Salamanders	Yes
Plethodon vehiculum	Western Redback Salamander	Amphibians	Salamanders	Yes
Podiceps auritus	Horned Grebe	Birds	Other Birds	No
Podiceps grisegena	Red-necked Grebe	Birds	Other Birds	No
Podiceps nigricollis	Eared Grebe	Birds	Other Birds	No
Poecile gambeli	Mountain Chickadee	Birds	Perching Birds	No
Poliocitellus franklinii	Franklin's Ground Squirrel	Mammals	Rodents	No
Polioptila caerulea	Blue-gray Gnatcatcher	Birds	Perching Birds	No
Pooecetes gramineus	Vesper Sparrow	Birds	Perching Birds	No
Porzana carolina	Sora	Birds	Other Birds	No
Procyon lotor	Raccoon	Mammals	Carnivores	No
Progne subis	Purple Martin	Birds	Perching Birds	No
Psaltriparus minimus	Bushtit	Birds	Perching Birds	No
Pseudacris regilla	Northern Pacific Chorus Frog	Amphibians	Frogs and Toads	No
Ptychoramphus aleuticus	Cassin's Auklet	Birds	Other birds	No
Puma concolor	Cougar	Mammals	Carnivores	No
Quiscalus quiscula	Common Grackle	Birds	Perching Birds	No
Rallus limicola	Virginia Rail	Birds	Other Birds	No
Rana aurora	Northern Red-legged Frog	Amphibians	Frogs and Toads	Yes
Rangifer tarandus	Caribou	Mammals	Other Mammals	No
Regulus calendula	Ruby-crowned Kinglet	Birds	Perching Birds	No
Regulus satrapa	Golden-crowned Kinglet	Birds	Perching Birds	No
Reithrodontomys megalotis	Western Harvest Mouse	Mammals	Rodents	No
Reithrodontomys montanus	Plains Harvest Mouse	Mammals	Rodents	No
Rhyacotriton olympicus	Olympic Torrent Salamander	Amphibians	Salamanders	Yes
Riparia riparia	Bank Swallow	Birds	Perching Birds	No
Salpinctes obsoletus	Rock Wren	Birds	Perching Birds	No
Sayornis nigricans	Black Phoebe	Birds	Perching Birds	No
Sayornis phoebe	Eastern Phoebe	Birds	Perching Birds	No
Sayornis saya	Say's Phoebe	Birds	Perching Birds	No
Scalopus aquaticus	Eastern Mole	Mammals	Other Mammals	No
Scapanus orarius	Coast Mole	Mammals	Other Mammals	Yes
Scapanus townsendii	Townsend's Mole	Mammals	Other Mammals	No
Sciurus niger	Eastern Fox Squirrel	Mammals	Rodents	No
Selasphorus rufus	Rufous Hummingbird	Birds	Other birds	No
Setophaga castanea	Bay-breasted Warbler	Birds	Perching Birds	No

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Setophaga coronata	Yellow-rumped Warbler	Birds	Perching Birds	No
Setophaga magnolia	Magnolia Warbler	Birds	Perching Birds	No
Setophaga nigrescens	Black-throated Gray Warbler	Birds	Perching Birds	No
Setophaga palmarum	Palm Warbler	Birds	Perching Birds	No
Setophaga pensylvanica	Chestnut-sided Warbler	Birds	Perching Birds	No
Setophaga ruticilla	American Redstart	Birds	Perching Birds	No
Setophaga striata	Blackpoll Warbler	Birds	Perching Birds	No
Setophaga tigrina	Cape May Warbler	Birds	Perching Birds	No
Setophaga townsendi	Townsend's Warbler	Birds	Perching Birds	No
Setophaga virens	Black-throated Green Warbler	Birds	Perching Birds	No
Sialia currucoides	Mountain Bluebird	Birds	Perching Birds	No
Sialia mexicana	Western Bluebird	Birds	Perching Birds	No
Sialia sialis	Eastern Bluebird	Birds	Perching Birds	No
Sitta canadensis	Red-breasted Nuthatch	Birds	Perching Birds	No
Sitta carolinensis	White-breasted Nuthatch	Birds	Perching Birds	No
Sorex arcticus	Arctic Shrew	Mammals	Other Mammals	No
Sorex cinereus	Cinereus Shrew	Mammals	Other Mammals	No
Sorex haydeni	Prairie Shrew	Mammals	Other Mammals	No
Sorex hoyi	American Pygmy Shrew	Mammals	Other Mammals	No
Sorex merriami	Merriam's Shrew	Mammals	Other Mammals	No
Sorex monticolus	Dusky Shrew	Mammals	Other Mammals	No
Sorex nanus	Dwarf Shrew	Mammals	Other Mammals	No
Sorex palustris	American Water Shrew	Mammals	Other Mammals	No
Sorex preblei	Preble's Shrew	Mammals	Other Mammals	No
Sorex trowbridgii	Trowbridge's Shrew	Mammals	Other Mammals	No
Sorex tundrensis	Tundra Shrew	Mammals	Other Mammals	No
Sorex vagrans	Vagrant Shrew	Mammals	Other Mammals	No
Spea bombifrons	Plains Spadefoot	Amphibians	Frogs and Toads	No
Spea intermontana	Great Basin Spadefoot	Amphibians	Frogs and Toads	No
Sphyrapicus nuchalis	Red-naped Sapsucker	Birds	Other Birds	No
Sphyrapicus ruber	Red-breasted Sapsucker	Birds	Other birds	No
Sphyrapicus varius	Yellow-bellied Sapsucker	Birds	Other Birds	No
Spilogale gracilis	Western Spotted Skunk	Mammals	Carnivores	No
Spilogale putorius	Eastern Spotted Skunk	Mammals	Carnivores	No
Spiza americana	Dickcissel	Birds	Perching Birds	No
Spizella arborea	American Tree Sparrow	Birds	Perching Birds	No
Spizella breweri	Brewer's Sparrow	Birds	Perching Birds	No
Spizella pallida	Clay-colored Sparrow	Birds	Perching Birds	No
Spizella passerina	Chipping Sparrow	Birds	Perching Birds	No
Spizella pusilla	Field Sparrow	Birds	Perching Birds	No

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Stelgidopteryx serripennis	Northern Rough-winged Swallow	Birds	Perching Birds	No
Stercorarius longicaudus	Long-tailed Jaeger	Birds	Other Birds	No
Stercorarius parasiticus	Parasitic Jaeger	Birds	Other Birds	No
Sterna hirundo	Common Tern	Birds	Other Birds	No
Sterna paradisaea	Arctic Tern	Birds	Other Birds	No
Strix nebulosa	Great Gray Owl	Birds	Other Birds	No
Strix varia	Barred Owl	Birds	Other Birds	No
Sturnella neglecta	Western Meadowlark	Birds	Perching Birds	No
Surnia ulula	Northern Hawk Owl	Birds	Other Birds	No
Sylvilagus audubonii	Desert Cottontail	Mammals	Other Mammals	No
Sylvilagus nuttallii	Mountain Cottontail	Mammals	Other Mammals	No
Synaptomys borealis	Northern Bog Lemming	Mammals	Rodents	No
Tachycineta bicolor	Tree Swallow	Birds	Perching Birds	No
Tachycineta thalassina	Violet-green Swallow	Birds	Perching Birds	No
Tadarida brasiliensis	Brazilian Free-tailed Bat	Mammals	Bats	No
Tamiasciurus hudsonicus	Red Squirrel	Mammals	Rodents	No
Taxidea taxus	American Badger	Mammals	Carnivores	No
Thomomys bottae	Botta's Pocket Gopher	Mammals	Rodents	No
Thomomys talpoides	Northern Pocket Gopher	Mammals	Rodents	No
Thryomanes bewickii	Bewick's Wren	Birds	Perching Birds	No
Toxostoma rufum	Brown Thrasher	Birds	Perching Birds	No
Troglodytes aedon	House Wren	Birds	Perching Birds	No
Turdus migratorius	American Robin	Birds	Perching Birds	No
Tympanuchus phasianellus	Sharp-tailed Grouse	Birds	Other Birds	No
Tyrannus tyrannus	Eastern Kingbird	Birds	Perching Birds	No
Tyrannus verticalis	Western Kingbird	Birds	Perching Birds	No
Tyrannus vociferans	Cassin's Kingbird	Birds	Perching Birds	No
Tyto alba	Barn Owl	Birds	Other Birds	No
Urocitellus canus	Merriam's Ground Squirrel	Mammals	Rodents	No
Urocitellus parryii	Arctic Ground Squirrel	Mammals	Rodents	No
Urocitellus richardsonii	Richardson's Ground Squirrel	Mammals	Rodents	No
Urocitellus spilosoma	Spotted Ground Squirrel	Mammals	Rodents	No
Urocitellus tridecemlineatus	Thirteen-lined Ground Squirrel	Mammals	Rodents	No
Urocitellus variegatus	Rock Squirrel	Mammals	Rodents	No
Urocyon cinereoargenteus	Gray Fox	Mammals	Carnivores	No
Ursus americanus	American Black Bear	Mammals	Carnivores	No
Vireo cassinii	Cassin's Vireo	Birds	Perching Birds	No
Vireo gilvus	Warbling Vireo	Birds	Perching Birds	No
Vireo olivaceus	Red-eyed Vireo	Birds	Perching Birds	No
Vireo philadelphicus	Philadelphia Vireo	Birds	Perching Birds	No

Scientific Name	Common Name	Broad Taxonomic Group	Detailed Taxonomic Group	Range encompassed within study area
Vireo solitarius	Blue-headed Vireo	Birds	Perching Birds	No
Vulpes macrotis	Kit Fox	Mammals	Carnivores	No
Vulpes velox	Swift Fox	Mammals	Carnivores	No
Vulpes vulpes	Red Fox	Mammals	Carnivores	No
Wilsonia canadensis	Canada Warbler	Birds	Perching Birds	No
Wilsonia pusilla	Wilson's Warbler	Birds	Perching Birds	No
Xanthocephalus xanthocephalus	Yellow-headed Blackbird	Birds	Perching Birds	No
Zapus hudsonius	Meadow Jumping Mouse	Mammals	Rodents	No
Zapus princeps	Western Jumping Mouse	Mammals	Rodents	No
Zapus trinotatus	Pacific Jumping Mouse	Mammals	Rodents	No
Zenaida macroura	Mourning Dove	Birds	Other Birds	No
Zonotrichia albicollis	White-throated Sparrow	Birds	Perching Birds	No
Zonotrichia atricapilla	Golden-crowned Sparrow	Birds	Perching Birds	No
Zonotrichia leucophrys	White-crowned Sparrow	Birds	Perching Birds	No

Table 2: Bioclimatic Variables

These 23 bioclimatic variables were used to develop current climate suitability models for each of the study species.

Bioclimatic Variable Name
annual potential evapotranspiration
chilling period of days with a mean temperature less than or equal to 5 degrees Celsius
December-February potential evapotranspiration
December-February total precipitation
growing degree days on a 0 degrees Celsius base
growing degree days on a 5 degrees Celsius base
June-August potential evapotranspiration
June-August total precipitation
March-May potential evapotranspiration
March-May total precipitation
mean annual temperature
mean temperature of the coldest month
mean temperature of the warmest month
mean temperature of the warmest month minus mean temperature of the coldest month
potential evapotranspiration for days with mean temperatures greater than -4 degrees Celsius
potential evapotranspiration for days with mean temperatures greater than 5 degrees Celsius
September-November potential evapotranpiration
September-October total precipitation
total annual precipitation
total annual snow water equivalent
total precipitation of the driest month
total precipitation of the wettest month
total precipitation of the wettest month minus total precipitation of the driest month

Table 3: Species-Biome Associations

Associations between study species and biomes. 1 = association, 0 = no association.

Scientific Name	Tamaulipan Thornscrub	Interior Chaparral	Great Basin Montane Scrub	Great Basin Conifer Woodland	California Chaparral	Madrean Montane Conifer Forest	Oregonian Deciduous and Evergreen Forests	Semi-evergreen Forest	California Evergreen Forest and Woodland	Cascade-Sierran Subalpine Conifer Forest	Western Alpine Tundra	California Valley Grassland	California Coastalscrub	Interior Cedar-Hemlock Conifer Forest	Cloud Forest	Southeastern Deciduous and Evergreen Forests	Mohave Desertscrub	Oregonian Coastal Conifer Forest	Cascade-Sierran Montane Conifer Forest	Sonoran Desertscrub	Sitka Coastal Conifer Forest	Adirondack-Appalachian Subalpine and Tundra	Great Basin Desertscrub	Chihuahuan Desertscrub	Semidesert Grassland	Rocky Mountain Subalpine Conifer Forest	Great Basin Shrub-Grassland	Rocky Mountain Montane Conifer Forest	Alaskan-Alpine Tundra	Northern Tundra	Alaska-Yukon Subarctic Conifer Forest	Plains Grassland	Northeastern Deciduous Forest	Canadian Taiga	Urban	Agriculture
Accipiter cooperii	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Accipiter gentilis	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Accipiter striatus	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Aechmophorus clarkii	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	0	1	0	0
Aechmophorus occidentalis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	0	0	0	0	1	1	1	0	1	1	1	0	1	0	0
Aegolius acadicus	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	0	0
Aegolius funereus	0	0	1	1	0	1	0	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	1	0	1	1	0	0
Aeronautes saxatalis	1	1	1	1	1	0	1	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	1
Agelaius phoeniceus	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	1	0	1	1	0	0	1	1	1	1	1	1
Alces americanus	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	1	1	0	0	0	1	1	1	1	1	1	0	1	1	0	0
Ambystoma gracile	0	0	0	0	0	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ambystoma tigrinum	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	0
Ammodramus bairdii	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
Ammodramus leconteii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
Ammodramus savannarum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
Ammospermophilus leucurus	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0
Amphispiza belli	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Amphispiza bilineata	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Aneides ferreus	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthus rubescens	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	1	0	0	1	0	1
Anthus spragueii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
Antrozous pallidus	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	1	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Aphelocoma californica	1	1	1	1	1	0	1	0	1	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0
Aquila chrysaetos	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	0	0
Arborimus albipes	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arborimus longicaudus	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Archilochus alexandri	1	1	1	1	1	0	1	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Archilochus colubris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Ardea alba	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	1	0	1	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	1
Ardea herodias	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	0	1	1	1	1	0
Asio flammeus	1	1	1	1	0	1	1	1	0	1	1	0	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1
Asio otus	1	1	1	1	1	0	1	0	1	1	0	0	0	0	0	1	0	1	1	1	0	0	1	1	0	1	1	1	0	0	0	1	1	1	1	1
Athene cunicularia	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	1	1
Bassariscus astutus	1	1	1	1	1	0	1	0	1	0	0	0	1	0	0	0	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0
Batrachoseps wrightorum	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blarina brevicauda	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Bombycilla cedrorum	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	1	0	0	1	1	1	0	0	1	1	1	1	1	1
Bombycilla garrulus	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0

Scientific Name	Tamaulipan Thornscrub	Interior Chaparral	Great Basin Montane Scrub	Great Basin Conifer Woodland	California Chaparral	Madrean Montane Conifer Forest	Oregonian Deciduous and Evergreen Forests	Semi-evergreen Forest	California Evergreen Forest and Woodland	Cascade-Sierran Subalpine Conifer Forest	Western Alpine Tundra	California Valley Grassland	California Coastalscrub	Interior Cedar-Hemlock Conifer Forest	Cloud Forest	Southeastern Deciduous and Evergreen Forests	Mohave Desertscrub	Oregonian Coastal Conifer Forest	Cascade-Sierran Montane Conifer Forest	Sonoran Desertscrub	Sitka Coastal Conifer Forest	Adirondack-Appalachian Subalpine and Tundra	Great Basin Desertscrub	Chihuahuan Desertscrub	Semidesert Grassland	Rocky Mountain Subalpine Conifer Forest	Great Basin Shrub-Grassland	Rocky Mountain Montane Conifer Forest	Alaskan-Alpine Tundra	Northern Tundra	Alaska-Yukon Subarctic Conifer Forest	Plains Grassland	Northeastern Deciduous Forest	Canadian Taiga	Urban	Agriculture
Bonasa umbellus	1	1	1	1	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Botaurus lentiginosus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0
Brachylagus idahoensis	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Bubo virginianus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Buteo jamaicensis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Buteo lineatus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0
Buteo platypterus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Buteo regalis	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Buteo swainsoni	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1
Butorides virescens	0	0	0	0	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calamospiza melanocorys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Calcarius lapponicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	0
Calcarius ornatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
Calcarius pictus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0
Canis latrans	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Carpodacus cassinii	1	1	1	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
Carpodacus mexicanus	1	1	1	1	1	0	1	0	1	1	0	0	1	0	0	0	1	0	1	1	0	0	1	1	1	0	1	1	0	0	0	1	1	0	1	1
Carpodacus purpureus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	0
Castor canadensis	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Castor canadensis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1	0	1	1	1	1	1	0	0
Catharus fuscescens	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Catharus guttatus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	0	1	0	1	1	0	0
Catharus minimus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Catharus ustulatus	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Catherpes mexicanus	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0
Centrocercus urophasianus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Cepphus columba	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Certhia americana	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	1	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Chaetodipus hispidus	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Chaetura pelagica	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	1	1
Chaetura vauxi	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Chlidonias niger	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1	1
Chondestes grammacus	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	1	0	1	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Chordeiles minor	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	0	1
Cinclus mexicanus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Circus cyaneus	1	1	1	0	1	0	0	0	0	0	1	1	1	0	0	0	1	0	0	1	0	1	1	1	1	0	1	0	1	1	0	1	0	0	0	1
Cistothorus palustris	1	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	1	1	0	1
Cistothorus platensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1
Coccothraustes vespertinus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Coccyzus erythropthalmus	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	0	1
Colaptes auratus	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0
Colinus virginianus	0	0	1	1	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	1	1	0	0	1
Contopus cooperi	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Contopus sordidulus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0

Scientific Name	Tamaulipan Thornscrub	Interior Chaparral	Great Basin Montane Scrub	Great Basin Conifer Woodland	California Chaparral	Madrean Montane Conifer Forest	Oregonian Deciduous and Evergreen Forests	Semi-evergreen Forest	California Evergreen Forest and Woodland	Cascade-Sierran Subalpine Conifer Forest	Western Alpine Tundra	California Valley Grassland	California Coastalscrub	Interior Cedar-Hemlock Conifer Forest	Cloud Forest	Southeastern Deciduous and Evergreen Forests	Mohave Desertscrub	Oregonian Coastal Conifer Forest	Cascade-Sierran Montane Conifer Forest	Sonoran Desertscrub	Sitka Coastal Conifer Forest	Adirondack-Appalachian Subalpine and Tundra	Great Basin Desertscrub	Chihuahuan Desertscrub	Semidesert Grassland	Rocky Mountain Subalpine Conifer Forest	Great Basin Shrub-Grassland	Rocky Mountain Montane Conifer Forest	Alaskan-Alpine Tundra	Northern Tundra	Alaska-Yukon Subarctic Conifer Forest	Plains Grassland	Northeastern Deciduous Forest	Canadian Taiga	Urban	Agriculture
Corvus brachyrhynchos	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	0	1	1	0	0	1	1	1	1	1	1
Corvus corax	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1
Corynorhinus townsendii	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0	0	0	1	1	0	1
Coturnicops noveboracensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Cyanocitta cristata	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Cyanocitta stelleri	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Cynomys ludovicianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
Cypseloides niger	0	0	0	0	0	1	0	1	0	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Dendragapus obscurus	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	1	0	0	0	0	0
Dipodomys ordii	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Dolichonyx oryzivorus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
Dryocopus pileatus	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Dumetella carolinensis	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	0	1
Egretta thula	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	0
Elanus leucurus	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Empidonax alnorum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0	1
Empidonax difficilis	0	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Empidonax flaviventris	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Empidonax minimus	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Empidonax oberholseri	1	1	1	1	1	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0
Empidonax occidentalis	0	0	0	1	0	1	0	1	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Empidonax traillii	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	1	0	1	0	0	1	1	1	0	0	0	1	0	0	0	0
Empidonax wrightii	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Eptesicus fuscus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	1	1	1
Eremophila alpestris	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1	1	1	1	0	1	0	1	1	0	1	0	0	0	1
Erethizon dorsatum	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Euderma maculatum	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Euphagus carolinus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	0	0
Euphagus cyanocephalus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	0	0	1	1	1	0	1
Falcipennis canadensis	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Falco columbarius	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	1	0	1	1	1	1	0	0	0	1	1	1	0	1
Falco mexicanus	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	1	1	0	1	0	0	0	1
Falco rusticolus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	1	1	0	0
Falco sparverius	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	1	1	1	1	0	1
Fulica americana	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1
Gavia immer	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	1	1	0	1	1	0	0
Gavia pacifica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0
Gavia stellata	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0
Geomys bursarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1
Geothlypis trichas	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	1	1	0	1	1	1	1	1	0	0
Glaucidium gnoma	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Glaucomys sabrinus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Grus canadensis	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1	1	1	1	0	0
Gulo gulo	0	0	0	1	0	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0

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Gymnorhinus cyanocephalus	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	0	0
Haliaeetus leucocephalus	0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Hirundo rustica	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	0	1	1	1	1	0	1
Icteria virens	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	1	1
Icterus bullockii	0	0	1	1	1	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
Icterus galbula	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	1	0	1	0	1	1	1	1	0	0	0	1	1	1	0	0
Icterus parisorum	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0
Icterus spurius	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	0
Ixobrychus exilis	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0	0	1	1	0	0	0
Ixoreus naevius	0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Junco hyemalis	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Lagopus lagopus	0	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Lanius excubitor	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Lanius ludovicianus	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	1	1	0	0	1
Larus argentatus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	0
Larus californicus	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	1	1	1
Larus canus	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	1	1	0	1	0	1
Larus delawarensis	0	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	1
Lasionycteris noctivagans	0	0	0	1	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	1	1	1	0	0
Lasiurus borealis	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Lasiurus cinereus	0	0	0	1	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	1	1	1	0	0
Lemmiscus curtatus	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Lemmus trimucronatus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0
Lepus americanus	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Lepus californicus	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Lepus townsendii	1	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	1	1	1	1	0	1	0	1	0	0	1	0	0	0	1
Leucosticte tephrocotis	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Lontra canadensis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	1	1	1	1	1	0	0
Loxia curvirostra	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Loxia leucoptera	0	0	0	1	0	1	1	1	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Lynx canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0
Lynx canadensis	0	0	1	1	0	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1	1	1	0	1	1	0	0
Lynx rufus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	0	1	1	1	1	0	0
Marmota caligata	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0
Marmota flaviventris	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	1	0	0	0	0	0
Marmota monax	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	0	1
Martes americana	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Martes pennanti	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Megaceryle alcyon	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Melanerpes erythrocephalus	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Melanerpes lewis	0	0	1	1	0	0	0	0	1	1	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Melospiza georgiana	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	1	1	1	0	0
Melospiza lincolnii	0	0	1	1	0	1	0	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	1	1	0	1	1	0	0
Melospiza melodia	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	1

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Mephitis mephitis	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	1	1	1	1	0	0	0	1	1	1	0	0	1	0	0	1	1	1	1	1	1
Microtus californicus	0	0	0	0	1	0	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Microtus longicaudus	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Microtus montanus	0	0	1	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	0	1	0	0	0	0	1
Microtus ochrogaster	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1
Microtus oeconomus	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0
Microtus pennsylvanicus	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	1
Microtus townsendii	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
Microtus xanthognathus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Mimus polyglottos	1	1	1	0	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Mniotilta varia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Molothrus ater	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	1	1	0	0	0	1	0	1	1	1
Mustela erminea	0	0	0	1	0	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1	1	1	0	1	1	0	0
Mustela frenata	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1
Mustela nivalis	1	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Myadestes townsendi	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Myiarchus cinerascens	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	1	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Myiarchus crinitus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Myotis californicus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0
Myotis ciliolabrum	1	1	1	1	0	0	1	0	1	1	0	1	0	0	0	0	1	0	1	1	0	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1
Myotis evotis	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0
Myotis lucifugus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1
Myotis septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Myotis thysanodes	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	1	0	1	1	0	0	1	0	1	1	1	1	0	0	0	1	0	0	1	1
Myotis volans	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0
Myotis yumanensis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0
Neotoma cinerea	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0
Neotoma fuscipes	0	0	0	1	1	0	1	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neotoma lepida	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0
Nucifraga columbiana	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
Nycticorax nycticorax	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0	0
Ochotona collaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0
Odocoileus hemionus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	1	0	1	1	1	1	0	0	1	1	0	1	0	1
Odocoileus virginianus	1	1	1	1	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	1
Ondatra zibethicus	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	0	0	1	1	1	1	0	1
Onychomys leucogaster	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	0
Oporornis agilis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Oporornis philadelphia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
Oporornis tolmiei	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	0	1	1	0	0	0	0	0	1	0	0
Oreoscoptes montanus	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Pandion haliaetus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	1	0	0	0	1	1	1	0	0	1	0	1	1	1	1
Passerculus sandwichensis	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	1
Passerella iliaca	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0
Passerina amoena	1	1	1	1	1	0	1	0	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

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Passerina caerulea	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	1	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	0
Perisoreus canadensis	0	0	1	1	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Perognathus fasciatus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1
Perognathus flavescens	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Perognathus flavus	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Peromyscus keeni	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Peromyscus leucopus	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	0	0	1
Peromyscus maniculatus	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Peromyscus truei	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Phalacrocorax auritus	0	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0	1	1	0	1	0	1	1	0	1	1	1	0	0	0	1	0	1	0	0
Phalaenoptilus nuttallii	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Pheucticus ludovicianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0
Pheucticus melanocephalus	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0
Pica hudsonia	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Picoides arcticus	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Picoides pubescens	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0
Picoides villosus	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	1	1	1	1	0
Pinicola enucleator	1	1	1	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	1	1	0	0
Pipilo chlorurus	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Pipilo maculatus	1	1	1	1	1	0	1	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	0	1	1	0	0	0	1	1	0	1	0
Piranga ludoviciana	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	0
Plectrophenax nivalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	1	0	0	0	0
Plegadis chihi	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Plethodon dunni	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plethodon elongatus	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plethodon vehiculum	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Podiceps auritus	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	1	1	1	1	1	1	0	1	0	1
Podiceps grisegena	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	1	1	1	1	0	1	0	0
Podiceps nigricollis	1	1	1	1	1	0	1	0	0	1	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1	0	0
Poecile gambeli	1	1	1	1	1	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	1	1	1	0
Poliocitellus franklinii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Polioptila caerulea	1	1	1	1	1	0	1	0	1	0	0	0	1	1	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	0	0
Pooecetes gramineus	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1	0	1
Porzana carolina	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0	1
Procyon lotor	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	0	0	1	1	1	1	1
Progne subis	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1
Psaltriparus minimus	1	1	1	1	1	0	1	0	1	0	0	0	1	0	0	1	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0
Pseudacris regilla	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1
Ptychoramphus aleuticus	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	1	0	1	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Puma concolor	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	0	0	0	1	1	0	0
Quiscalus quiscula	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1	1	1
Rallus limicola	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	0	0
Rana aurora	0	0	0	0	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rangifer tarandus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0

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Regulus calendula	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1
Regulus satrapa	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Reithrodontomys megalotis	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Reithrodontomys montanus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
Rhyacotriton olympicus	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Riparia riparia	1	1	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	0	1
Salpinctes obsoletus	1	1	1	1	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	1	0
Sayornis nigricans	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Sayornis phoebe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Sayornis saya	1	1	1	1	1	0	1	0	1	0	1	0	0	0	0	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1
Scalopus aquaticus	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1
Scapanus orarius	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	0	1	1	1	1
Scapanus townsendii	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Sciurus niger	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Selasphorus rufus	0	0	0	1	0	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	1	0	0	0	1	0	1	1	1	1	0	0	1	1	0
Setophaga castanea	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Setophaga coronata	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0
Setophaga magnolia	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1
Setophaga nigrescens	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Setophaga palmarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Setophaga pensylvanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Setophaga ruticilla	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Setophaga striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Setophaga tigrina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Setophaga townsendi	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Setophaga virens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Sialia currucoides	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0	0	1	0	1	1	0	1
Sialia mexicana	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0	0	0	0	0	0	1
Sialia sialis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
Sitta canadensis	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Sitta carolinensis	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	0	1	1	1	0	0
Sorex arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	1	0	1	0	0
Sorex cinereus	1	1	1	0	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0
Sorex haydeni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Sorex hoyi	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	0	0
Sorex merriami	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	0	0
Sorex monticolus	0	0	0	0	0	1	1	1	0	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Sorex nanus	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
Sorex palustris	1	1	1	1	1	0	1	0	1	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	1	1	0	0
Sorex preblei	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Sorex trowbridgii	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sorex tundrensis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0
Sorex vagrans	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
Spea bombifrons	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1

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Spea intermontana	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Sphyrapicus nuchalis	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Sphyrapicus ruber	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0
Sphyrapicus varius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Spilogale gracilis	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	1	0	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Spilogale putorius	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1
Spiza americana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Spizella arborea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	1
Spizella breweri	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0	0
Spizella pallida	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	1	0	1	0	0
Spizella passerina	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	0	0
Spizella pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
Stelgidopteryx serripennis	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1	0	0	0	1	0	0	0	0
Stercorarius longicaudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Stercorarius parasiticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0
Sterna hirundo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0
Sterna paradisaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	0
Strix nebulosa	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Strix varia	0	0	0	0	0	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0
Sturnella neglecta	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Surnia ulula	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Sylvilagus audubonii	1	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1
Sylvilagus nuttallii	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0
Synaptomys borealis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1	0	0
Tachycineta bicolor	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Tachycineta thalassina	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Tadarida brasiliensis	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	1	0	0	1	0
Tamiasciurus hudsonicus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Taxidea taxus	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1
Thomomys bottae	1	1	1	0	1	0	0	0	1	1	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Thomomys talpoides	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1
Thryomanes bewickii	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	1	1
Toxostoma rufum	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0
Troglodytes aedon	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1
Turdus migratorius	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1
Tympanuchus phasianellus	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	1	0	1
Tyrannus tyrannus	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1
Tyrannus verticalis	1	1	1	1	1	0	1	0	1	1	0	0	0	1	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Tyrannus vociferans	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Tyto alba	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	1	1
Urocitellus canus	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1
Urocitellus parryii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0
Urocitellus richardsonii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Urocitellus spilosoma	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1

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Urocitellus tridecemlineatus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	1
Urocitellus variegatus	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	0
Urocyon cinereoargenteus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	0	1	0	0	1	1
Ursus americanus	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Vireo cassinii	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	0	1	1	0	0
Vireo gilvus	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Vireo olivaceus	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0
Vireo philadelphicus	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	1	1	0	1
Vireo solitarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1	0	0
Vulpes macrotis	1	1	1	1	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0
Vulpes velox	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1
Vulpes vulpes	1	1	1	1	1	0	1	0	1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	0	1
Wilsonia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Wilsonia pusilla	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0
Xanthocephalus xanthocephalus	1	1	1	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	1
Zapus hudsonius	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	0	0
Zapus princeps	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0
Zapus trinotatus	0	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0
Zenaida macroura	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1
Zonotrichia albicollis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	1	0
Zonotrichia atricapilla	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	1	0	0	1	0	0
Zonotrichia leucophrys	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0	1	1	0	0

Table 4: Species Occurrence Data Sources

Sources for species occurrence data used to assess the predictive accuracy of the habitat suitability models representing baseline conditions.

Data Publisher	Dataset Name
Arctos	Division of Mammals, Museum of Southwestern Biology, Albuquerque, NM.
Arctos	DMNS Bird Collection
Arctos	Museum of Southwestern Biology, Albuquerque, NM.
Arctos	MVZ Bird Catalog
Arctos	MVZ Herp Catalog
Arctos	MVZ Mammal Catalog
Avian Knowledge Network	eBird Bird Observation Checklist Database
Avian Knowledge Network	Hawk Migration Association of North America - HawkCount
Avian Knowledge Network	Project FeederWatch
Borror Laboratory of Bioacoustics	Borror Laboratory of Bioacoustics
British Columbia Conservation Data Centre	BCCDC Occurrences
California Academy of Sciences	CAS Bird Collection Catalog
California Academy of Sciences	CAS Herpetology Collection Catalog
California Department of Fish and Game	California Natural Diversity Database
Canadian Biodiversity Information Facility	Crispin S. Guppy Collection
Canadian Biodiversity Information Facility	North West Territories and Nunavut Bird Checklist, Canada
Canadian Biodiversity Information Facility	Ontario Nest Records
Canadian Biodiversity Information Facility	Provincial Museum of Alberta, Edmonton, AB, Canada. Birds (Aves)
Canadian Biodiversity Information Facility	Royal British Columbia Museum
Canadian Museum of Nature	Canadian Museum of Nature Bird Collection
Cornell University Museum of Vertebrates	Bird Collection
Cornell University Museum of Vertebrates	Mammal Collection
Delaware Museum of Natural History	Delaware Museum of Natural History Bird Collection
Field Museum	FMNH Mammals Collections
Field Museum	FMNH Ornithology Collections
Idaho Fish and Game	Idaho Conservation Data Center Database
James R. Slater Museum of Natural History	Terrestrial vertebrates
Los Angeles County Museum of Natural History	Vertebrate specimens
Louisiana State University Museum of Natural Science	Mammal specimens
Michigan State University Museum	Vertebrate specimens
Montana Natural Heritage Program	Point Observation Databases for Animals in Montana
Museum of Comparative Zoology, Harvard University	MCZ Ornithology Collection
National Museum of Natural History	NMNH Vertebrate Zoology Birds Collections
National Museum of Natural History	NMNH Vertebrate Zoology Herpetology Collections

Data Publisher	Dataset Name
New Brunswick Museum	NBM birds
New Mexico Biodiversity Collections Consortium	New Mexico Biodiversity Collections Consortium database
Oregon Biodiversity Information Center	ORBIC Occurrences
Royal Ontario Museum	Bird specimens
Royal Ontario Museum	Herp specimens
Sam Noble Oklahoma Museum of Natural History	Mammals Specimens
San Diego Natural History Museum	Bird specimens
San Diego Natural History Museum	Herp specimens
Santa Barbara Museum of Natural History	Santa Barbara Musem of Natural History
Texas Cooperative Wildlife Collection	TCWC Vertebrate Collections
University of Alberta	University of Alberta Museums Mammalogy Collection
University of Alberta	University of Alberta Museums, Ornithology Collection
University of Colorado Museum of Natural History	CUMNH Bird Collection
University of Colorado Museum of Natural History	CUMNH Mammal Collection
University of Kansas Biodiversity Research Center	Bird Collection
University of Kansas Biodiversity Research Center	Mammal Collection
University of Michigan Museum of Zoology	Bird specimens
University of Nebraska State Museum	UNSM Vertebrate Specimens
University of Washington Burke Museum	Bird Specimens
University of Washington Burke Museum	Mammal Specimens
University of Wyoming	Wyoming Natural Diversity Database
Washington Department of Fish and Wildlife	Priority Habitat and Species
Washington Department of Fish and Wildlife	WDFW Owl Site Centers
Yale University Peabody Museum	Peabody Ornithology DiGIR Service

Table 5: Species Included in Accuracy Assessment

Study species for which accuracy of the predictive models was assessed. The sample size values are the number of occurrence records used in the accuracy assessment per species. The sensitivity values are the percent of correctly predicted presences.

Scientific Name	Common Name	Sample Size	Sensitivity
Accipiter cooperii	Cooper's Hawk	65	34.55
Aechmophorus clarkii	Clark's Grebe	96	57.89
Aegolius funereus	Boreal Owl	101	95.00
Agelaius phoeniceus	Red-winged Blackbird	171	97.98
Ambystoma tigrinum	Tiger Salamander	112	36.00
Amphispiza belli	Sage Sparrow	517	93.76

Scientific Name	Common Name	Sample Size	Sensitivity
Aneides ferreus	Clouded Salamander	981	92.66
Aquila chrysaetos	Golden Eagle	10522	82.74
Bassariscus astutus	Ringtail	61	24.59
Brachylagus idahoensis	Pygmy Rabbit	205	12.50
Bubo virginianus	Great Horned Owl	129	91.73
Buteo jamaicensis	Red-tailed Hawk	61	95.08
Canis latrans	Coyote	215	89.27
Carpodacus mexicanus	House Finch	114	71.01
Centrocercus urophasianus	Greater Sage Grouse	14437	90.40
Cinclus mexicanus	American Dipper	116	39.29
Colaptes auratus	Northern Flicker	152	88.37
Cyanocitta stelleri	Steller's Jay	83	54.55
Dipodomys ordii	Ord's Kangaroo Rat	137	66.13
Dryocopus pileatus	Pileated Woodpecker	82	46.25
Glaucomys sabrinus	Northern Flying Squirrel	117	84.71
Gulo gulo	Wolverine	161	9.55
Hirundo rustica	Barn Swallow	50	63.16
Icterus bullockii	Bullock's Oriole	71	53.70
Lasionycteris noctivagans	Silver-haired Bat	120	57.75
Lepus americanus	Snowshoe Hare	74	84.00
Lynx canadensis	Canadian Lynx	940	33.69
Lynx rufus	Bobcat	51	91.67
Martes americana	American Marten	179	87.86
Megaceryle alcyon	Belted Kingfisher	54	38.46
Melospiza melodia	Song Sparrow	183	82.58
Microtus longicaudus	Long-tailed Vole	175	83.17
Microtus montanus	Montane Vole	124	78.57
Microtus ochrogaster	Prairie Vole	52	82.14
Microtus pennsylvanicus	Meadow Vole	93	36.84
Microtus townsendii	Townsend's Vole	104	48.89
Molothrus ater	Brown-headed Cowbird	98	91.30
Mustela erminea	Ermine	59	89.13
Mustela frenata	Long-tailed Weasel	55	63.04
Myotis yumanensis	Yuma Myotis	60	73.08
Nucifraga columbiana	Clark's Nutcracker	83	67.95
Nycticorax nycticorax	Black-crowned Night-Heron	138	48.06
Ondatra zibethicus	Common Muskrat	137	69.51
Onychomys leucogaster	Northern Grasshopper Mouse	86	70.21
Oporornis tolmiei	MacGillivray's Warbler	85	53.52
Oreoscoptes montanus	Sage Thrasher	596	93.54
Passerculus sandwichensis	Savannah Sparrow	82	68.66

Scientific Name	Common Name	Sample Size	Sensitivity
Passerina amoena	Lazuli Bunting	72	52.83
Peromyscus keeni	Northwestern Deermouse	617	35.36
Peromyscus maniculatus	North American Deermouse	1345	98.57
Phalaenoptilus nuttallii	Common Poorwill	54	54.55
Pheucticus melanocephalus	Black-headed Grosbeak	54	57.14
Picoides villosus	Hairy Woodpecker	74	87.30
Pipilo chlorurus	Green-tailed Towhee	55	36.73
Pipilo maculatus	Spotted Towhee	126	60.95
Plethodon dunni	Dunn's Salamander	82	77.22
Plethodon elongatus	Del Norte Salamander	737	32.43
Plethodon vehiculum	Western Redback Salamander	609	87.39
Poecile gambeli	Mountain Chickadee	206	83.66
Pooecetes gramineus	Vesper Sparrow	62	90.38
Pseudacris regilla	Northern Pacific Chorus Frog	269	88.18
Rana aurora	Northern Red-legged Frog	61	84.48
Rhyacotriton olympicus	Olympic Torrent Salamander	135	20.00
Scapanus orarius	Coast Mole	90	90.63
Scapanus townsendii	Townsend's Mole	127	91.67
Sialia currucoides	Mountain Bluebird	75	53.33
Sialia mexicana	Western Bluebird	111	8.11
Sorex monticolus	Dusky Shrew	338	93.20
Sorex trowbridgii	Trowbridge's Shrew	416	84.93
Sorex vagrans	Vagrant Shrew	358	66.32
Spea bombifrons	Plains Spadefoot	58	66.67
Spea intermontana	Great Basin Spadefoot	93	40.00
Sphyrapicus nuchalis	Red-naped Sapsucker	112	45.19
Sphyrapicus ruber	Red-breasted Sapsucker	74	53.45
Spizella breweri	Brewer's Sparrow	656	97.34
Strix nebulosa	Great Gray Owl	324	31.58
Strix varia	Barred Owl	53	30.77
Sturnella neglecta	Western Meadowlark	114	59.14
Tamiasciurus hudsonicus	Red Squirrel	327	69.63
Thomomys talpoides	Northern Pocket Gopher	330	84.13
Turdus migratorius	American Robin	202	99.22
Tyto alba	Barn Owl	92	98.73
Ursus americanus	American Black Bear	114	67.89
Vireo gilvus	Warbling Vireo	60	81.25
Zapus princeps	Western Jumping Mouse	104	81.82
Zapus trinotatus	Pacific Jumping Mouse	186	74.49

Chapter 2: Forecasting the impacts of climate change on protected areas in western North America

Abstract

Protected areas are a fundamental component of many conservation strategies. They safeguard some of the best examples of unfragmented natural lansdcapes in many regions, provide important habitat for many rare and threatened species and communities, and serve as a refuge from a human-dominated world. As temperatures continue to rise and precipitation patterns shift due to anthropogenic climate change, vegetation systems and species communities are expected to undergo substantial changes. Protected area managers, confronted with a host of rapidly changing ecological conditions, can develop more effective climate adaptation strategies with an improved understanding of trends in these changes. In this study, I attempt to assess future ecological change by analyzing three impact measures. I model future projected changes in temperature and precipitation, shifts in major vegetation systems, and species turnover for the Pacific Northwest region of North America. These measures were calculated for the entire study area, then summarized by protected areas. Similar geographic variations were found for all three measures, with areas in close proximity to the Pacific Coast exhibiting the most moderate changes, compared to increasingly greater changes projected along a longitudinal gradient toward the continental interior. Moderately strong correlations were found between vegetation change and species turnover, species turnover and longitude, and climate change and longitude, and climate change and elevation. The resulting spatial variations in these measures underscores the importance of developing appropriate climate adaptation strategies in response to disparate trends in future environmental change.

Introduction

Current and future changes in climatic conditions represent a major challenge for natural resource managers. Shifts in species ranges toward the poles and higher elevations have already been observed (Parmesan and Yohe 2003), and continued shifts in species distribution have been consistently projected in response to predicted future changes in climate suitability (Araujo et al. 2005; Thuiller et al. 2005) and shifts in human land-use patterns (Pekin and Pijanowski 2012). The formation of novel climates and no-analog biological communities is expected to occur (Williams and Jackson, 2007a), and by the end of this century, between 12% and 39% of the terrestrial surface of the Earth may be associated with novel climates (Williams et al. 2007b).

Protected areas can play a critical role in protecting biodiversity in a changing climate (Hannah et al. 2007). In addition to providing direct economic returns associated with ecosystem services and tourism (Knowler et al., 2003; Nyaupane and Poudel, 2011), the benefits of protected areas are numerous. These areas often contain the only remaining large contiguous patches of natural land cover in a region, thereby safeguarding critical habitat for sensitive species, providing protection for watersheds, and helping to maintain functioning ecological processes. Forested protected areas can store significant amounts of carbon, and can potentially capture future carbon (Lopez-Toledo et al. 2012). Protected area networks can serve as buffers to reduce the impact of extreme weather events and other natural disasters (MacKinnon et al., 2011). These areas are also important for species resilience in the face of climate change, as they are more likely to preserve favorable climate conditions than areas with insufficient protection (Araujo et al., 2011) and have been shown to be disproportionately important for species expanding their ranges and colonizing newly suitable areas in response to climate change (Thomas et al. 2012).

Many species, however, are at risk of losing significant portions of their representation within existing protected areas due to future climate change (Araújo et al. 2004; Hannah et al. 2005). In particular, protected areas characterized by high-elevations, mountainous topography, wetlands, abrupt land-use transitions, or by a high number of species at the southernmost limits of their geographic ranges are particularly vulnerable to the loss of the species and ecological systems that managing agencies have been mandated to protect (Shafer 1999). Therefore, protected area managers are faced with the daunting task of managing a shifting tide of species and ecosystems within finite, immovable boundaries. Protected areas vary widely in their vulnerability to future environmental changes, based on dissimilarities in biomes, available critical habitat, elevation range, latitude, and landscape condition (Magness et al. 2011).

Here, I explore the relative projected impact of climate change on the sites within a protected area network in western North America. Specifically, I used three measures of projected change: change in climate, shifts in vegetation, and species turnover to assess potential impacts. I first calculated these measures separately across the entire study area. I then summarized these measures by protected area unit, and using a combination of the three measures I ranked all protected areas within the network by potential future climate impacts. This examination of potential climate-change impacts complements a growing effort to develop systematic climate-change impact assessments of species and ecosystems (Williams et al., 2008). Although conducting a full vulnerability assessment of the protected area network that includes measures of sensitivity and adaptive capacity is beyond the scope of this research, these results provide important information for protected area managers to consider when developing and implementing climate-change adaptation strategies.

Methods

Study Area

The study area represents a major portion of the western North American continent, in total comprising 6,895,788 km^2 (Chapter 1). This area includes a broad range of climates, biomes, and topography, extending from its northeast corner at approximately -136° W., 58° N. latitude, on Yakobi Island in Southeastern Alaska, south to 38° N. in the Point Reyes area of northern California, and east to -102° W. longitude in the Great Plains. Elevations range from sea level to the summit of Mount Rainier at 4394 m. A diversity of biomes are found in the study area, including alpine, subalpine grasslands and forests, wet and dry montane and low-elevation forests, temperate grasslands, and arid shrublands and desert. All were mapped to a grid comprised of 30-second × 30-second (approximately 1 km^2) cells, for a total of 6,874,095 cells. I determined that this grid-cell resolution would effectively capture variations in these ecological measures, yet maintain relatively accurate area values for the protected area network.

Data Sources

I used protected area boundaries from the World Database of Protected Areas (WDPA), a comprehensive global data set of terrestrial and marine protected areas developed and maintained by UNEP and IUCN (2010). WDPA protected areas are organized by IUCN Protected Area Management Categories, a system that classifies protected areas according to consistencies in management approach and intent (Dudley 2008). Protected area polygon records that intersected the study area boundary were extracted from the WDPA database, including 29 WDPA records with only partial coverage (Table 1), however, these records only comprise 2% of the total number of WDPA records used in the study. This record set was then filtered to include only those records with an IUCN category of Ia, Ib, II, III, or IV. These categories represent protected areas for which a primary management objective is protection of species or ecosystems (Table 2). Additionally, all protected areas with a primary focus on marine or aquatic resources were removed. Many of the remaining protected areas were comprised of disconnected parcels of land, some of which span relatively large geographic areas. For these particular protected areas, each polygon was considered and analyzed as a separate record if it was spatially disconnected from other polygons representing the same management unit. This subset of records was then further refined by selecting only those records with a total area greater than or equal to 10 km^2, to minimize the potential for a mismatch between the study area's 1-km^2 grid cells and the protected area boundaries, and to more closely match the resolution of the original climate data, which served as input for the species habitat suitability models. WDPA polygon records were converted to a raster data format and mapped to the 1-km^2 resolution grid. The final protected area data set included 1252 records, and covered 8.2% percent of the total study area, with protected area sizes ranging from 10.05 km^2 to 11,223.19 km^2.

Recent historical annual climatic values (Chapter 1), averaged over a 30-year time period from 1961 to 1990, were developed by first downscaling CRU CL 2.0 (New et al., 2002) and CRU TS 2.1 (Mitchell and Jones 2005) climate data sets to a 10' × 10' global grid, which were then further downscaled and clipped to the study's 1-km^2 analysis grid (Shafer and Bartlein, 2011). Projected future values for these climatic variables, averaged over a 30-year time period spanning the years 2070 to 2099, were derived from two coupled atmospheric-oceanic general circulation models (AOGCMs), the Canadian Centre for Climate Modeling and Analysis CGCM 3.1 model (Flato et al. 2000), and the UK Meteorology Office's Hadley CM3 model (Gordon et al. 2000) run for the A2 SRES emissions scenario. These models forecast two different potential climate regimes, one with high levels of precipitation year round and warmer winters, and another which is overall slightly drier, but with intense, warm summers, respectively. The A2 emission scenario projects a mid-high level of future greenhouse-gas emissions, however, recorded emission rates are higher than the majority of even the most severe emission projections (McMullen and Jabbour, 2009).

Baseline and future vegetation was represented by biomes mapped to a 30-second × 30-second grid (Rehfeldt et al., 2012). Rehfeldt et al. mapped biomes according to a hierarchal classification system first outlined by Brown et al. (1998) which delineates vegetation systems into three levels of organization: major formations, third-order formations, and biomes. I also used future projections of biome distributions developed by Rehfeldt et al. (2012) that corresponded with the two AOGCMs and A2 emission scenario used in my study. Biomes were originally mapped by Rehfeldt et al. (2012) for the entire North American continent. I clipped and aligned biome datasets to my study analysis grid for recent historical climate conditions, resulting in 22 biomes, and future climate conditions, resulting in 33 biomes as projected by the CGCM 3.1 model, and 28 biomes for the Hadley CM3 projection (Table 3).

Changes in habitat suitability were modeled for 366 terrestrial animal species, including 12 amphibians, 237 birds, and 117 mammals. Current climate suitability was modeled using the Random Forests algorithm (Breiman 2001), correlating known species range locations with a suite of 23 bioclimatic variables to predict climate suitability at a coarse resolution of 50 km^2 grid cells, spanning the entire Western hemisphere. These coarse-resolution climate suitability models were then applied to two versions of the same set of bioclimatic variables, previously downscaled to a 1-km^2 grid cell resolution, to develop current and future fine-scale climate suitability maps. Species-biome relationship maps reflecting current and future climate conditions were then built based on the mapped biomes. Species-biome relationships were derived from terrestrial habitat associations summarized per species by NatureServe (2013). The relationships were then used to map current and future biome suitability for each of the study species. These methods are described in greater detail in Chapter 1.

Climate change

Changes in future climate conditions were determined using a variation of the standard Euclidean distance (SED) equation described by Williams et al. (2007) to calculate projected changes in eight climatic variables. Based on previous studies examining climate change hot spots (Diffenbaugh et al., 2008), I used mean annual temperature and mean annual precipitation for the winter, spring, summer, and autumn quarters, averaged over the baseline (1961-1990) and future (2070-2099) 30-year time periods. Each of these climatic variable data sets were normalized then input into the following equation to calculate the SED values per grid cell:

$$SED = \sqrt{\sum_{i}^{8}(x_i - y_i)^2}$$

where *SED* represents the summarized standard Euclidean distance, x_i equals the baseline climate variable, and y_i equals the projected future climate variable. The calculation was performed using climate variables derived from both of the GCMs used in this study, resulting in two standard Euclidean distance data sets. Finally, the mean SED values were calculated per protected area, for each GCM projection.

Vegetation change

Vegetation change was examined by mapping changes in major vegetation types on a cell-by-cell basis, and by calculating a biome turnover rate for each protected area. To illustrate broad spatial patterns of vegetation change occurring in the study area, I reclassified biomes mapped by Rehfeldt el al. (2012) to a higher-order classification within the Brown et al. (1998) vegetation classification system, called third-order formations. The difference in current and future formation map datasets was then calculated, resulting in a map representing areas of major vegetation change. In addition, I calculated the biome turnover rate per protected area, representing changes in major vegetation type that are projected to occur by the end of the century. To summarize these changes by protected area, I first counted the number of biomes per protected area for which all grid cells representing that biome disappear in the future time period (contraction), the total number of biomes that had no representative grid cells in the baseline time period, but have a least one or more grid cells shifting to within the boundary of the protected area in the future time period (expansion), and the total number of biomes that maintain at least one representative grid cell in both current and future time periods (stable). I included these three metrics in a measure of turnover using the following equation:

$$BTRPA = \frac{(e + c)}{(e + c + s)}$$

where *BTRPA* represents the biome turnover rate per protected area, *e* is the total number of biome expansions within each area, *c* is the total number of biome contractions, and *s* is the total number of biomes that are present in each protected area in both baseline and future time periods.

Species turnover

The animal species suitability turnover rate is a measure of changes in suitable habitat within a specified area, which can potentially lead to community destabilization when associated with warming temperatures (Hillebrand et al., 2010). For each species, the raster dataset representing future habitat suitability was intersected with the current habitat suitability dataset. Grid cells where then determined to be either unsuitable habitat, future suitable habitat that is currently unsuitable (expansion), future unsuitable habitat that is currently suitable (contraction), or currently suitable and projected to be suitable in the future (stable). I calculated species turnover on a cell-by-cell basis using the following equation:

$$STR = \sum_{i=1}^{n} \frac{(e + c)}{(e + c + s)}$$

where *STR* represents the species suitability turnover rate, *e* is the total number of cells of predicted habitat suitability expansion, *c* is the total number of cells of predicted suitability contraction, and *s* is the total number of cells that were suitable for both baseline and future time periods. This calculation produced an animal species suitability turnover value for each grid cell for the entire study area (Figure 2c). Although individual species dispersal rates will ultimately determine how effectively species can emigrate from unsuitable climates to colonize new suitable climate spaces, I did not include dispersal as a factor in the species turnover rate—my calculations assume complete dispersal into newly-suitable habitats. To further delineate and examine areas of unusually high or low concentrations of animal species turnover, I performed a geographic hot-spot analysis using the Getis-Ord Gi* statistic (Getis and Ord 1992). The Getis-Ord Gi* equation calculates a z-score per grid cell, defining spatial clusters of z-values that are significantly higher or lower than the average, thus delineating "hot" and "cold" spots (Figure 3).

To calculate species turnover per protected area, I used a slight variation of the aforementioned equation, however, I used a different set of values to calculate the species turnover rate:

$$STRPA = \frac{(e + c)}{(e + c + s)}$$

In this case, *STRPA* is the species turnover rate per protected area, *e* represents the total number of species for which there is no suitability within the protected area for the current time period, but at least one grid cell is projected to be suitable in the future time period (expansion), *c* represents the number of species that lose all grid cells with suitable habitat within the protected area by the end of the century (contraction), and s is the number of species that have at least one grid cell of suitable habitat in both the current and future time periods (stable).

I also briefly examined correlations between climate change, vegetation shifts, and animal species turnover rates (summarized by protected area), and a small number of additional summarized variables including mean and maximum elevation, latitude, longitude, and protected area size. My intention was to discover any potentially significant relationships between these variables, with the idea that variations in one or more of the impact measures could be linked to other measures, or to the inherent characteristics of protected areas found within the study region. The species turnover rate exhibited a moderate positively skewed distribution, and was transformed to a normal distribution with a square-root transformation, whereas protected area size exhibited a severe positive skew and was transformed to a normal distribution by taking the inverse log.

Finally, I simultaneously mapped all three impact measures to highlight those reserves that will potentially experience both the least and greatest amount of change. Protected areas were categorized as having a high likelihood of being impacted if at least two of the three measures fell within the highest (fourth) quartile of values for that measure. Protected areas categorized as being the least likely to be impacted had at least two measures within the lowest (first) quartile of each value. I did not attempt to further classify the remaining areas that did not fall into either of these categories.

Results

Both climate projections resulted in significant changes for much of the region. Nonetheless, as noted above, these changes differed between the two GCM projections. The CGCM 3.1 model projects that the greatest change in temperature will occur during the winter quarter, warming by 4.83 °C by the end of the century, with mean winter precipitation increasing by 45.72 cm, whereas the Hadley CM3 model projects a future increase in mean temperature of 3.08 °C for the winter quarter, and an increase of 30.55 cm for mean precipitation in the same quarter. Overall, the magnitude of climate change (as measured by SED) gradually increases in a longitudinal gradient from west to east, with the lowest values concentrated along the Pacific coast, and the highest values in the northeastern quadrant of the study area, and along the Rocky and Coastal Mountain ranges, with some increase in climate change values also associated with northern latitudes for the CGCM 3.1 projection (Figure 1a). Additionally, projected changes tend to be larger at higher elevations than at lower elevations. Changes in the magnitude of SED values, averaged by each protected area, exhibit the most distinctive spatial patterns of the three summarized measures, with below-average SED values transitioning to above average values as the distance from the Pacific Ocean increases (Figure 3a).

Fifty one percent and 48% of the study region is projected to experience a major change in biome by the end of the century based on the outputs of the CGCM 3.1 and Hadley CM3 GCMs, respectively. Both projections predict little to no change along the coastal lowlands and mountains, the Great Plains, and throughout the arid shrub-steppe of the Columbia Plateau, whereas both predict vegetation shifts at high elevations, throughout the mountains in the continental interior, and along the southernmost edge of the taiga forests (Figure 1b). With regard to the summarized protected area biome turnover rates, high BTR values are prominent along the entire Rocky Mountain range, with low BTR values also limited to northwestern region of the study area, along the B.C. coast and Coastal Mountains (Figure 3b).

The average species turnover rate for the study area was 35% (Figure 1c). Areas associated with significantly higher than average STR values appear to be clustered along the Northern and Southern regions of the Rocky Mountains and throughout the higher elevations of the Great Basin, whereas areas with lower than average STR values are found along the West Coast, the Cascade and Coastal Mountains, lower elevations in the Great Basin, and large contiguous areas of the Great Plains region (Figure 2). Protected areas were found to have species turnover rates of 22% and 24% on average, for the CGCM 3.1 and Hadley CM3 projections, respectively. The distribution of STR values summarized by protected area exhibits a strong positive skew, with two protected areas – the Quandry Peak / Special Interest Botanical Reserve in Colorado, and the Mount Terry Fox Provincial Park in British Columbia – being considered outliers, having STR values greater than 0.90. The smallest turnover rate (0.02) was associated with the Rock Creek Wilderness Area in western Oregon, and the largest (0.92) with the Mount Terry Fox Provincial Park.

There are interesting differences between the impact measures projected to occur within the study's protected area network versus the entire study region. The average climate change projected to occur within the study's protected area network is 0.42 SED, slightly less than an average climate change value of 0.51 SED for the entire study area. In contrast, my results indicate that protected areas will experience greater shifts in vegetation (on average 60% percent of area within the network will undergo significant changes in biomes) compared to only 42% vegetation change averaged for the whole study region. Species turnover rates are essentially the same within protected areas and for the study area as a whole, at 0.35 and 0.32 respectively.

Many of the spatial patterns of climate change, vegetation shift, and species turnover, when summarized by protected areas, are similar across the three impact measures (Figure 3). Protected areas in the lowest quartile of projected climate change and turnover rates are generally found along the Pacific coast, the majority being associated with wet, maritime coniferous forests, with the exception of a couple of protected areas found east of the Cascade Range, specifically the Saddle Mountain National Wildlife Refuge and East Fork High Rock Canyon Wilderness Area, both of which are predominantly characterized by arid shrubland biomes. The projected biome turnover rates, when summarized by protected area, differ slightly from this broad pattern, primarily for protected areas found along the Cascade Range, most likely due to severe contractions projected for alpine biomes. Protected areas associated with the highest quartile of projected climate change and turnover rates are currently characterized by Rocky Mountain subalpine conifer forest, Great Basin conifer woodland, and Taiga biomes

Moderate correlations were found between the transformed STR and BTR (r = 0.614, Figure 4a), transformed STR and latitude (r = -0.415, Figure 4d), and BTR and mean elevation (r = 0.458, Figure 4b). I found stronger correlations between transformed STR and longitude (r =

0.66, Figure 4e), and SED and longitude (r = 0.64, Figure 4c). The BTR values, when plotted against other variables, exhibit a clustering of values at 0 (no biome turnover), the median, and 1.0 (total biome turnover). I found no correlation between the species turnover rate and protected area size, nor between size and the other two impact measures (Figure S1).

Mapping the highest and lowest combined quartiles of STR, BTR and SED values summarized by protected area resulted in 24% of protected areas determined as being the most potentially impacted, and 24% as least impacted, based on agreement between both GCM projections. Spatial clustering of protected areas based on the these combined measures is readily apparent (Figure 5). A significant disparity is evident between the mean elevation of protected areas in the highest impact category at 1830.89 meters and the lowest-risk category at 228.83 meters ($p < 0.0001$). Geographically, low-risk protected areas appear to be clustered along coastal regions of the study area, generally in close proximity to the Pacific Ocean. In contrast, protected areas associated with the highest level of potential impacts are generally found within the continental interior, with the majority straddling higher elevations along the continental divide.

Discussion

Climate change will not affect all areas equally. Even within specific geographic regions, there are significant differences in expected temporal and spatial patterns of climate change. For example, temperature is projected to increase by 2°C to 3°C throughout North America, compared to 5°C in the northern extent of the continent. Precipitation is projected to increase by 15% in the northern regions of North America during the winter quarter, and decrease by 20% in the southern regions (Solomon et al. 2007). As temperature and precipitation patterns change and biomes shift in response to anthropogenic warming, species ranges are expected to change as well. The animal species suitability and biome turnover rate measures used in this study are cumulative values representing the projected changes in habitat suitability and vegetation for a large number of species, and are considered a proxy for ecological disturbance. The results of my research suggest that species associated with high-altitude alpine, sub-arctic boreal forests, and arid biomes, and species with some portion of their habitat intersecting these biomes, could be subject to some of the greatest changes in the study area by the end of this century. These results confirm previous studies on the impact of climate change on alpine biomes, taiga forests, and arid lands (Gonzalez et al., 2010), and species associated with these systems.

The species turnover rate calculated in this study is generally lower than turnover rates found in related studies. For the mid-high A2 emission scenario, Lawler et al. (2009) estimated average turnover rates of 38% for 2954 amphibians, birds, and mammals in North and South America. Peterson et al. (2002) modeled changes in distribution for 1870 species in Mexico, and found maximum species turnover rates of 45%. In Europe, Thuiller et al. (2005) projected future distribution shifts for 1350 plant species, using the A2 emission scenario with the CGCM2 and Hadley CM3 models, and estimated average species turnover rates between 45% and 55%. I found a minimal difference in the rate of turnover projected to occur within protected areas (0.35) versus the turnover rate averaged over the total area of the study (0.33). This suggests that, on average, the size of protected areas within the study area may be too small to encompass the majority of shifts in suitable habitat projected to occur (over half of the protected areas within the study region are less than 50 km^2 in size), or that the current configuration of the protected area network is less than optimal for species forced to relocate based on altered biome distributions. Although the largest protected area within the study area is Jasper National Park at 11,220 km^2, there are much larger protected areas globally (IUCN and UNEP 2010), and so perhaps a relationship does exist between the largest protected areas and lower turnover rates. Additionally, regarding the lack of disparity between turnover rates within protected areas compared to the entire study area, my results contradict the findings of a recent study which found that designated protected areas within Europe are projected to protect species from the impacts of climate change better than unprotected areas (Araujo et al., 2011).

High turnover rates associated with the alpine and subalpine ecological systems are likely driven by the simultaneous contraction of alpine tundra and expansion of montane forest biomes. Both the Western Alpine Tundra and Rocky Mountain Subalpine Conifer forest biomes in the Northern Rockies are projected to almost disappear by the end of the century, with Western Alpine Tundra shrinking in area by an average of 99.6%, and the Alaska-Alpine Tundra biome contracting in area by 91.4%. Species associated with these biomes, such as the Gyrfalcon (*Falco rusticolus*), Dwarf Shrew (*Sorex nanus*), Tundra Shrew (*Sorex tundrensis*), Neartic Brown Lemming (*Lemmus trimucronatus*), Snow Bunting (*Plectrophenax nivalis*), and the Long-tailed Jaeger (*Sterocorarius longicaudus*) could subsequently lose significant portions of potentially suitable habitat throughout the study area. Within the study area, species associated with the alpine biomes are projected to lose an average of 32% of their suitable habitat. This contraction of the alpine and tundra biomes coincides with a major expansion of adjacent montane forest biomes, forcing the transitional boundary between these two vegetation systems higher in elevation.

By contrast, areas bordering the Pacific Ocean, from Vancouver Island to northern California, are projected to experience significantly lower than average climate change and turnover rates, and thus comparatively less ecological disturbance. Wet coniferous forests currently dominate from low elevations along the Pacific Coast, the Olympic Peninsula, Vancouver Island, and the lower elevations of the Coastal Mountains in western British Columbia, east to the upper west slopes of the Cascade Range, and then transition to drier coniferous forests in the continental interior. The Sitka Coastal Conifer Forest biome—characterized by maritime climate conditions—is projected to undergo an expansion in area of 60%, potentially colonizing new areas along the western front of the Northern Rockies. Interior-Cedar Hemlock Conifer forests are also projected to expand in area by an average of 68%. For the 125 study species associated with these two forest biomes, this increase represents a possible expansion of suitable habitat into formerly inhospitable alpine regions. Overall, species associated with coniferous forests are projected to expand by 12%. This relative stability found in the biomes and regions adjacent to the Pacific Ocean is supported by studies on the effects of large water bodies on temperature and precipitation (Schneider and Mastrandrea, 2011).

Projected outcomes vary for other notable biomes within the study area. The Taiga biome spans the globe at high northern latitudes, and is expected to shift north as temperatures increase throughout this century (Gonzalez et al. 2010). Within the study area, the southern edge of the Canadian Taiga biome shifts northward, replaced by an expanding Plains Grassland biome. Arid and semi-arid biomes found across the topologically diverse southern region of the study are characterized by more complex changes. Based on the CGCM 3.1 projection, the Mojave Desertscrub biome expands by 99.9%, at the expense of a shrinking Great Basin Conifer Woodland biome. Thus 22 species associated with the Mojave Desertscrub biome could inhabit areas formerly occupied by 110 species associated with the conifer woodland biome.

Protected Areas Impacts

Projected changes in climate, vegetation, and animal species turnover, when summarized by protected area, appear to conform to the previously-described spatial patterns. In general, the Pacific Ocean has a moderating influence on climate conditions and vegetation shifts. Protected areas found within this zone of moderation may experience only minor alterations in species assemblages and vegetation patterns, whereas managers of protected areas in the interior can expect higher than average changes in temperature and precipitation, substantial shifting of vegetation system distributions, and higher-than-average animal species turnover. In particular, managers of protected areas in the Taiga and boreal forests of northern British Columbia and Alberta could witness a fundamental shift in the dominant biomes, from forests to grasslands.

Correlations

The lack of correlation between climate change, biome and species turnover, and the size of protected area was unexpected, and contradicts my initial assumption. I logically assumed that smaller protected areas would be more impacted than larger protected areas, with more area to allow shifting biomes and species ranges to remain within the protected area boundaries. These findings, however, appear to confirm the results of other studies which have found no relationship between extinction rates and reserve size (Parks and Harcourt 2002), nor between turnover rates and habitat area (Hinsley et al., 1995). This lack of correlation between the species turnover rate and size of protected area is most likely due to the extremely skewed size values of the protected areas examined in this study. The majority (79%) of the protected areas within the study region are less than 200 km^2 and less than 1% are greater than 4000 km^2 (Figure 6). Accordingly, this lack of relationship between protected area size and turnover rate may be due to the relatively low upper limit in sizes (11,221 km^2) of the protected areas within the study area, restricting my ability to find any reduction in turnover rate in large reserves. This finding might also suggest that protected areas will need to be considerably greater in size than they are currently, to be resilient to the effects of climate change. Future studies that incorporate protected area networks with considerably larger protected areas may find a clearer relationship between reserve size and turnover.

Uncertainties

The species suitability turnover rate is a summation of changes to habitat suitability for a relatively large number of species. By necessity the species habitat suitability models are a simplification of how a species inhabits a landscape. These models are correlative, and do not take into account important limiting factors such a species-specific dispersal rates, biotic interactions, and major stochastic events, nor do they consider evolutionary mechanisms for short-term adaptations. Thus the habitat suitability models contain inherent errors and uncertainties, which will carry over to the cumulative species suitability turnover surface. Similarly, boundaries between biomes as depicted by Rehfeldt et al. (2012) are also a necessary simplification of what in fact may be gradual transitions between vegetation communities. Just as I did not expect abrupt geographic edges between biomes, I did not expect shifts in species ranges to be smooth transitions of species assemblages in which a community of species associated with one biome disappears en masse to be replaced at once by a new community. This shifting of habitats and species ranges may instead result in the gradual development of novel species assemblages. In addition to these uncertainties, there is the issue of inherent variations in climate model projections. Although I only use two GCM models for my projections, there are many others that can be examined. Considering more than one set of potential future outcomes can provide planners and managers with more comprehensive information when planning for a range of plausible future scenarios.

It should also be mentioned that although both climatic factors and species-biome associations were used to develop and refine the final habitat suitability maps for each study species, shifts in the distribution of biomes appear to be more closely associated with variations in the STR. It is important to note that these two measures are not independent. The current and future biome distributions were used to refine suitability for each species, and had a measurable impact on the amount of projected expansion and contraction in ranges (Chapter 1).

When reviewing the species turnover rates presented here, there is a fundamental assumption that should be considered. The species turnover rate represents the cumulative result of mapping the projected shifts in suitable habit for a relatively large number of species. However, the innate dispersal ability of each species was not incorporated into these projections. Thus, a species that has a considerable increase in suitable habitat projected to occur by the end of the century may not actually be able to reach the newly suitable areas within that time period, which is particularly true for species with limited dispersal abilities, such as many amphibians and small mammals. Consequently, areas that are projected to experience high rates of species turnover may be overestimating the number of species that can successfully colonize and occupy newly suitable habitat. Therefore, the species turnover rate should only be viewed as biological proxy for climate-induced ecological change, and not as a precise prediction of future species assemblages in any given geographic area.

Management Implications

As the effects of climate change continue to manifest in new and profound ways, efforts to minimize the deleterious effects of human-induced climate change through the development of adaptation strategies have been taken up with mounting urgency (Mawdsley et al., 2009). Information provided by this research may prove applicable when used to inform the development of many of these strategies. As an example, hot spots of ecological change can be characterized as areas that may undergo major shifts in vegetation, climate, or animal species assemblages. Managers and planners may want to focus on strategies involving the management and restoration of ecosystem function in these areas, instead of focusing on maintaining or recreating a historical ecological condition or species assemblage. Because STR hot spots represent areas of increased rates of species range shifts, efforts to improve landscape permeability may increase the likelihood of successful species colonization and emigration (Mawdsley et al. 2009). By contrast, one might consider cold spots of species turnover and vegetation change to represent potential climate refugia in which appropriate strategies may include expanding the current extent of existing protected areas, designation of new protected areas (Hannah et al., 2002), and the restoration of existing natural areas (Harris et al., 2006). It is also important to keep in mind that although high-elevation montane environments are projected to experience higher-than-average levels of ecological change associated with climate change, these areas may also serve as important refugia, as they could represent some of the coldest environments remaining within an accessible distance to many species as temperatures rise across the landscape.

Resource managers of protected areas within the high-impact category can expect significant changes in temperature and precipitation, major shifts in vegetation systems, and alterations in species composition. Managers and planners must engage in conservation triage, deciding on the best option from an array of difficult management alternatives, including whether to abandon or intensify management efforts in areas that may suffer the worst impacts, while closely monitoring other areas based on the level of change they are projected to undergo. Although this study does not offer specific solutions to this dilemma, it does highlight areas of the Pacific Northwest region that deserve more in depth attention and research on how to adapt to a changing climate.

Figures

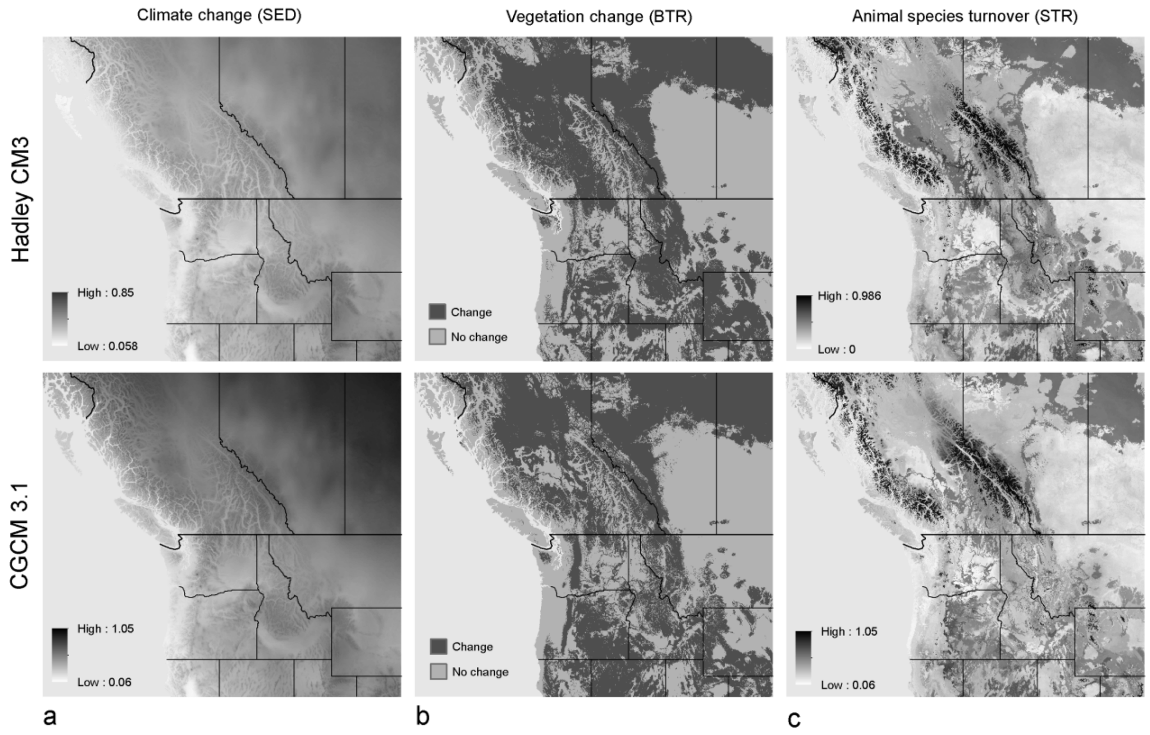

Figure 1: Climate change represented by the standard Euclidean distance (SED) for 8 temperature and precipitation variables (a), change in vegetation calculated represented as biome turnover rate (BTR) (b), and animal species suitability turnover rate (STR) (c) for the study area.

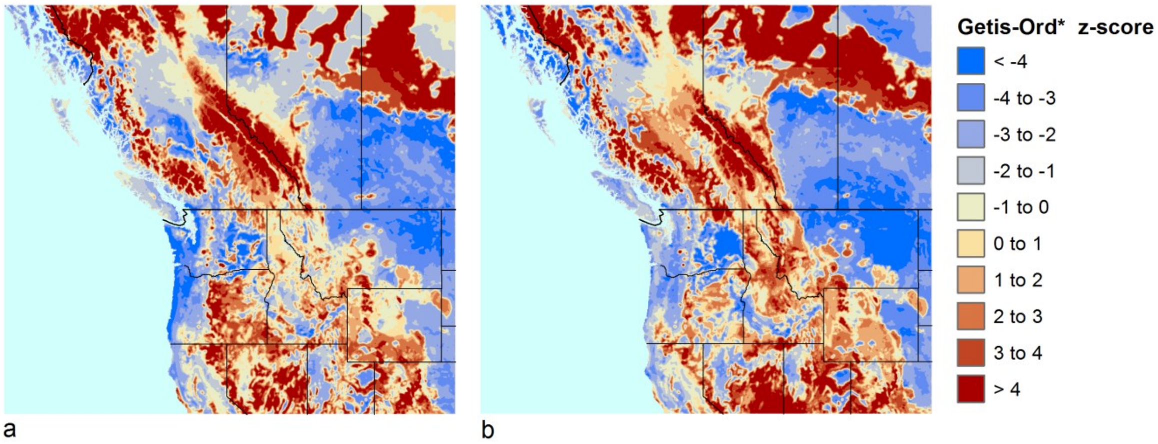

Figure 2: Hot and cold spots of animal species turnover rates (STR) based on the CGCM 3.1 (a) and Hadley CM3 (b) projections. Red areas represent STR values higher than 1 standard deviation from the mean, and blue represent areas less than 1 standard deviation.

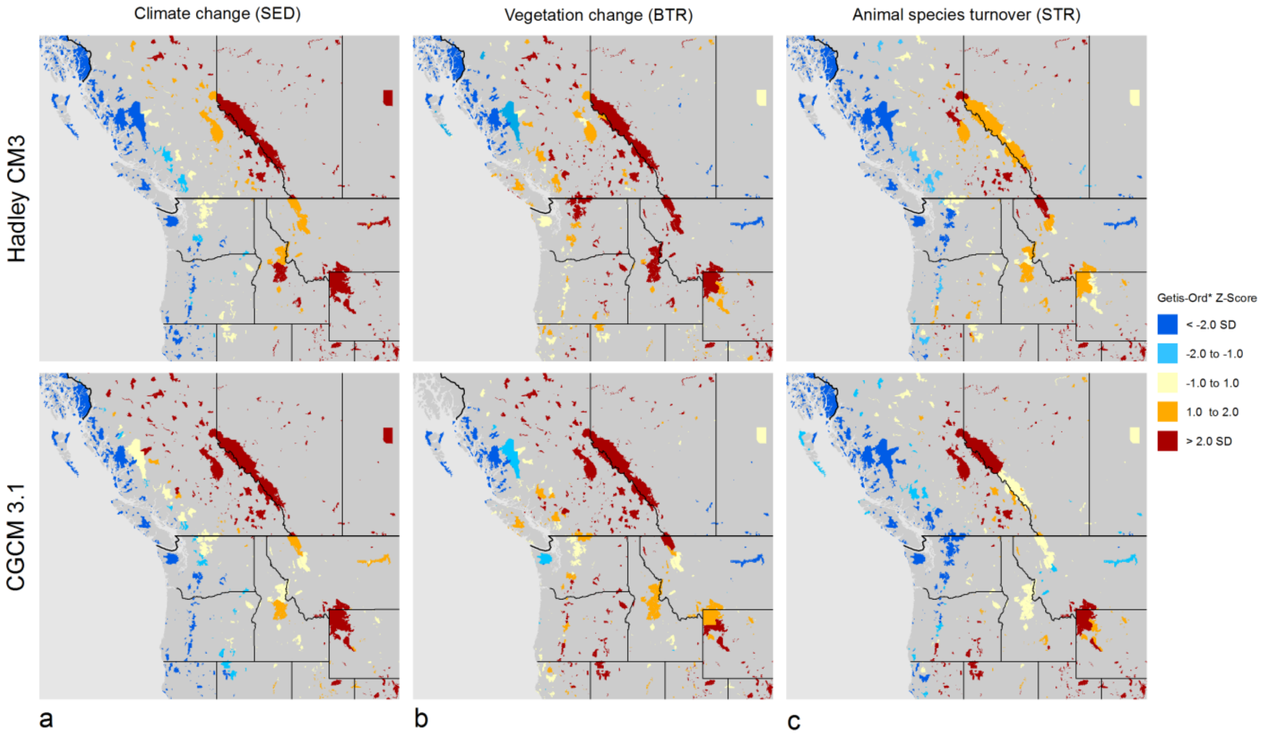

Figure 3: Hot and cold spots of climate change as standard Euclidean distance for 8 temperature and precipitation variables (a), vegetation change as biome turnover rate (b), animal species suitability turnover rate (c), and summarized by protected areas.

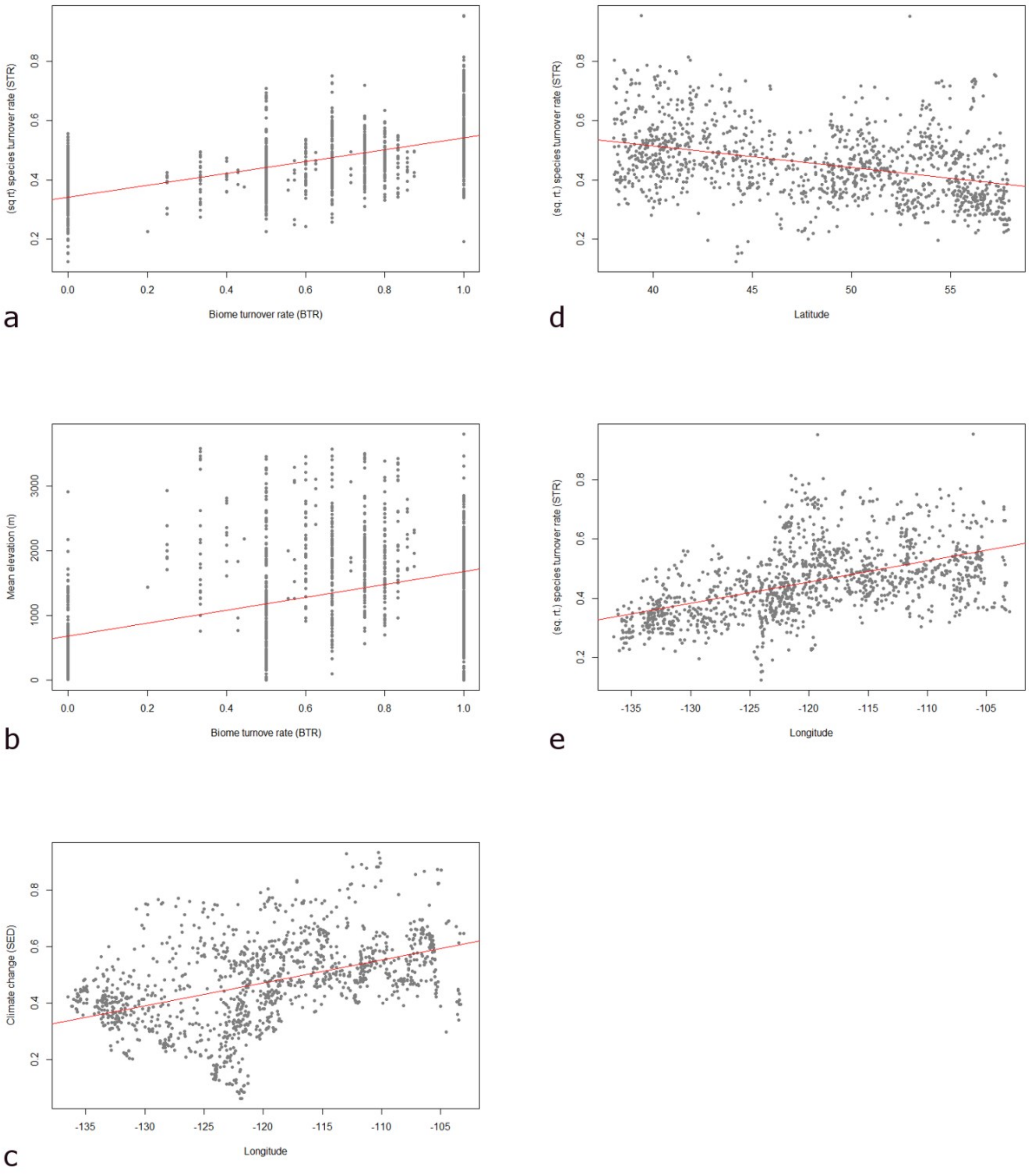

Figure 4: Relationships between species turnover rate (STR) and biome turnover rate (BTR) (a), BTR and mean elevation (b), climate change represented by standard Euclidean distance (SED) and longitude (c), STR and latitude (d), and STR and longitude (e). Each dot in the scatterplot represents one protected area record. Plots are from the CGCM 3.1 model projections.

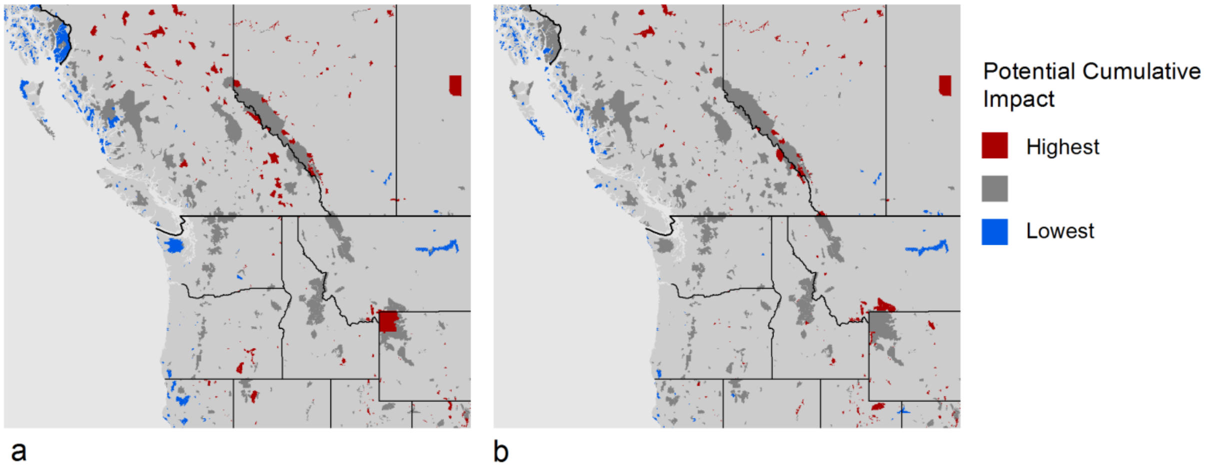

Figure 5: Map illustrating protected areas with lowest (blue) and highest (red) potential climate change impacts, based on the CGCM 3.1 (a) and Hadley CM3 (b) projections. The protected areas were categorized by quartile for each of the three summarized metrics: species suitability turnover rate (STR), biome turnover rate (BTR), and Euclidean distance for the climate change variables (SED). Protected areas associated with 4th quartiles for at least two metrics were included in the highest impact category, and areas with values in the 1st quartile for at least two metrics were classified as lowest impact.

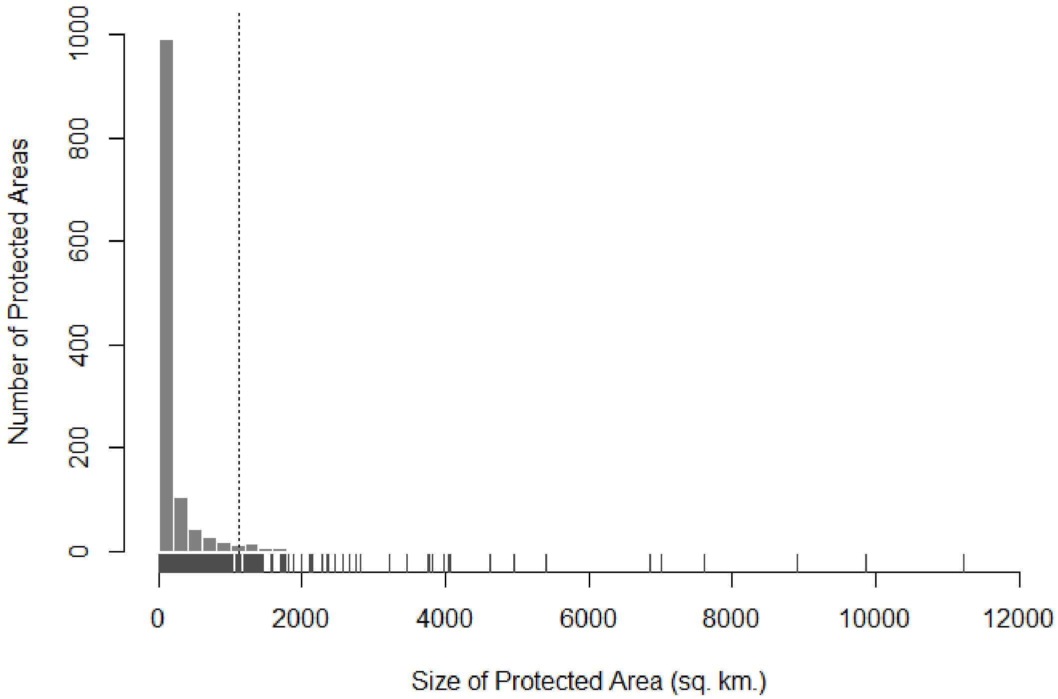

Figure 6: The distribution of protected areas sizes in sq. km. (n = 1252). The dark grey tick marks underneath the histogram represent individual protected area records. The dashed line represents the 95th percentile of size values. The vast majority (79%) of protected areas within the study region are less than 200 km^2.

Tables

Table 1: Protected Areas that Partially Overlap with the Study Area Boundary.

Protected Area Name	Designation	Management Authority	IUCN Category	County	Area Sq. Km.
Canyonlands	National Park	National Park Service (NPS)	II	USA	1,198.63
Capitol Reef	National Park	National Park Service (NPS)	II	USA	871.02
Admiralty Island	National Monument	US Forest Service (USFS)	III	USA	23.06
Misty Fjords	National Monument	US Forest Service (USFS)	III	USA	4.66
Dry Creek Basin	State Wildlife Management Area	State Fish and Wildlife	IV	USA	38.16
Mount Sneffels	Wilderness Area	US Forest Service (USFS)	Ib	USA	58.93
Purgatoire River	State Wildlife Management Area	State Fish and Wildlife	IV	USA	3.27
Sangre De Cristo	Wilderness Area	US Forest Service (USFS)	Ib	USA	487.34
Slumgullion Earthflow National Natural Landmark	National Natural or Historic Landmark	US Forest Service (USFS)	III	USA	2.55
Tongass National Forest Non- Monument	Non-Wilderness Monument	US Forest Service (USFS)	III	USA	588.32
Tongass National Forest Old Growth Habitat	Old Growth Habitat	US Forest Service (USFS)	IV	USA	4,521.23
Tongass National Forest Special Interest Area	Special Interest Area	US Forest Service (USFS)	III	USA	681.84
Tongass National Forest	Wilderness Area	US Forest Service (USFS)	Ib	USA	10,045.96
Tongass National Forest Monument	National Monument	US Forest Service (USFS)	III	USA	11,171.00
Tongass National Forest Monument Research Natural Area	National Monument	US Forest Service (USFS)	III	USA	88.26
Tongass National Forest Land Use Designation	LUD: Land Use Designation II	US Forest Service (USFS)	III	USA	2,669.66
Uncompahgre	Wilderness Area	Bureau of Land Management (BLM)	Ib	USA	365.33
Chadron Creek Ranch	State Wildlife Management Area	State Fish and Wildlife	IV	USA	8.27
Hoover	Wilderness Area	US Forest Service (USFS)	Ib	USA	443.83
Killdeer Mountains	State Wildlife Management Area	State Fish and Wildlife	IV	USA	25.28
Kwadacha Wilderness	Class A Park	Government of British Columbia	Ib	CAN	1,265.67
Mount Edziza	Class A Park	Government of British Columbia	Ib	CAN	2,577.33
Stikine River	Class A Park	Government of British Columbia	Ib	CAN	2,508.78
Khutzeymateen Inlet West	Conservancy	Government of British Columbia	II	CAN	3.40
Lax Kwaxl / Dundas-Melville Islands	Conservancy	Government of British Columbia	II	CAN	310.03
Khutzeymateen Inlet	Conservancy	Government of British Columbia	II	CAN	121.54
Ksi X'anmas	Conservancy	Government of British Columbia	II	CAN	315.56
Wales Harbour	Conservancy	Government of British Columbia	II	CAN	6.26
Stan Price	State Game or Wildlife Sanctuary	State Department of Natural Resources	IV	USA	2.37

Table 2: IUCN Protected Area Categories

Only those protected area records designated with these categories were included in the study.

Ia - Strict Nature Reserve

- Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphical features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.

Ib - Wilderness Area

- Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.

II - National Park

- Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.

III - Natural Monument or Feature

- Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.

IV - Habitat/Species Management Area

- Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.

Table 3: Biomes Types

Biomes mapped by Rehfeldt et al. 2012, and originally developed by Brown et al. 1998, which intersect the study area in either baseline or future climate scenarios.

Adirondack-Appalachian Subalpine and Tundra
Alaskan-Alpine Tundra
Alaska-Yukon Subarctic Conifer Forest
California Chaparral
California Coastalscrub
California Evergreen Forest and Woodland
California Valley Grassland
Canadian Taiga
Cascade-Sierran Montane Conifer Forest
Cascade-Sierran Subalpine Conifer Forest
Chihuahuan Desertscrub
Cloud Forest
Great Basin Conifer Woodland
Great Basin Desertscrub
Great Basin Montane Scrub
Great Basin Shrub-Grassland
Guerrero-Guatemala Dry Deciduous Forest
Guerrero-Guatemala Evergreen (Oak) Woodland
Gulf Coastal Grassland
Interior Cedar-Hemlock Conifer Forest
Interior Chaparral
Madrean Montane Conifer Forest
Madrean-Transvolcanic Woodland
Mohave Desertscrub
Northeastern Deciduous Forest
Northern Tundra
Oregonian Coastal Conifer Forest
Oregonian Deciduous and Evergreen Forests
Pacific Coast Thornscrub
Plains Grassland
Rocky Mountain Montane Conifer Forest
Rocky Mountain Subalpine Conifer Forest
San Lucas Pine-Oak Woodland
Savanna Grasslands
Semidesert Grassland
Semi-evergreen Forest
Sinaloa Dry Deciduous Forest
Sitka Coastal Conifer Forest
Sonoran Desertscrub
Southeastern Deciduous and Evergreen Forests

Tamaulipan Thornscrub
Transvolcanic-Guatemalan Conifer Forest
Tropical Rain Forest
Western Alpine Tundra
Yucatan Dry Deciduous Forests
Yucatan-Tamaulipas Semi-Deciduous Forest

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Appendix

Figure S1: Correlations between variables summarized by protected areas examined for the study. Each point represents one protected area record.