

Using regional bird density distribution models to evaluate protected area networks and inform conservation planning

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Abstract. As data about populations of indicator species become available, proactive strategies that improve representation of biological diversity within protected area networks should consider finer-scaled evaluations, especially in regions identified as important through course-scale analyses. We use density distribution models derived from a robust regional bird abundance dataset, coupled with habitat conservation plans, to evaluate a network of protected areas and to inform conservation and biodiversity planning in the greater Klamath Siskiyou Bioregion, an area recognized globally as a region of outstanding biological diversity. Our novel modeling approach allowed for comparisons of abundance of conservation focal species on federal vs. non-federal lands, federal lands that are protected to maintain natural habitats vs. federal lands managed for multiple uses, and seven protected areas of interest. Our comparisons highlight conservation opportunities for suites of species associated with coniferous forests, oak woodlands, and grasslands. Specifically, we found that species associated with oak woodland and grassland habitats, both habitats of conservation concern, were not well represented in the Bioregion's existing protected areas. These species would benefit from expanding the regional protected area network to include their associated at-risk habitats. In contrast, our results suggest that coniferous forests birds are well represented in the Bioregion's protected areas. We identify management opportunities specifically associated with the restoration of fire-adapted ecosystems that would benefit coniferous forest focal species on both federally protected areas and other multiple-use lands. Our analysis provides an example of how a finer-scaled evaluation of a regional protected area network adds value to course-scale evaluations of protected areas and biological diversity. Data and results from this research were used to inform science-based expansion of the Bioregion's network of protected areas.

Key words: Avian Knowledge Network; birds; density distribution models; fire-adapted ecosystems; focal species; gap analysis; indicators; Klamath Siskiyou Ecoregion/Bioregion; Partners in Flight; protected areas; Special Feature: Science for Our National Parks' Second Century.

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INTRODUCTION

Globally, protected area networks provide important reservoirs of biodiversity (Rodrigues et al. 2004). However, opportunistic approaches commonly used to establish protected areas do not adequately preserve a diversity of ecosystems and their associated resources (Sullivan and Shaffer 1975, Pressey 1994, Scott et al. 2001). A more proactive strategy that uses spatially explicit information about both vegetation types and animal species to evaluate gaps in protected areas can improve representation of biological diversity within protected area networks at a coarse scale (Scott et al. 1993). This systematic approach is limited by the availability of data to ensure protected area networks adequately represent biodiversity at multiple scales, across and within regions (Scott et al. 1993, Carroll et al. 2010). As new or improved data about populations of indicator species become available, finer-scaled evaluations of protected areas should be prioritized, especially in regions identified as important through coarse-scale analyses (Rodrigues et al. 2004).

Status and trend monitoring of biological indicators (Fancy et al. 2009) across land management boundaries provides information that is critical to regional conservation and biodiversity planning (Hansen et al. 2011), including the design and management of protected area networks (Caro and O'Doherty 1999, Mazaris et al. 2008, Tsianou et al. 2013). Regional monitoring approaches enable assessment of the vulnerability of indicator species and their habitats based on their distribution across land ownerships (e.g., public vs. private) and land-use types (e.g., protected vs. multiple use), and can be used to design and evaluate protected areas networks. Importantly, such data-rich conservation planning can account for organisms and ecological processes that occur at a scale that is larger than the collection of protected areas within a region and therefore incorporate surrounding multiple-use public and private lands (Hansen and DeFries 2007).

Birds are widely recognized as useful indicators of ecosystem biodiversity and health (e.g., Gregory et al. 2003, Alexander 2011, NABCI 2014). While protected areas are important for maintaining bird species of conservation concern (Virkkala and Rajasärkkä 2007), birds have also been used

to identify priority habitats in protected areas including national parks (Debinski and Brussard 1994) and on other public and private lands (Vora 1997, NABCI 2011, 2013). Plus, regularly updated bird monitoring data are widely available for use in conservation planning (Gregory et al. 2003, Iliff et al. 2009). Such bird abundance data have been used to evaluate the representativeness of regional protected areas (Virkkala and Rajasärkkä 2007). Such data can also be used to identify gaps in representation of protected area networks as well as habitat management needs within existing networks of protected areas (Mazaris et al. 2013). Evaluating the distribution and abundance of birds across land management units, including protected area networks, can help to determine which units are best suited to maintain or improve bird populations and habitats while ensuring priority conservation objectives are being met across agency boundaries at larger landscape scales (NABCI 2011).

Because birds serve as effective indicators, bird conservation plans can serve as a catalyst for realizing broader ecosystem conservation objectives (Berlanga et al. 2010, Alexander 2011, NABCI 2014, Rosenberg et al. 2016). Such plans are produced by Partner in Flight, a network of more than 150 partner organizations throughout the Western Hemisphere who work to keep common birds common and to help species at risk by engaging in all aspects of landbird conservation, including science, research, planning, policy development, land management, and monitoring (Rosenberg et al. 2016). Regional Partners in Flight landbird conservation plans (Altman 2000*a, b*, CalPIF 2000*a, b*, 2002*a, b*, Altman and Alexander 2012) focus on both high-priority and more common species that are representative of unique habitat niches (Chase and Geupel 2005), building on the use of focal species as a multi-species umbrella for nature conservation (Lambeck 1997). The plans outline conservation objectives for these focal species; in turn, the habitat-based objectives inform conservation planning by integrating a diversity of ecological conditions across regional scales. Therefore, ecosystem management and strategic habitat conservation efforts can be informed and improved by integrating bird conservation objectives across protected areas and adjacent lands where focal species occur (Alexander 2011, Stephens et al. 2011).

Veloz et al. (2015) used bird count data from regional monitoring networks (including a National Park Service Inventory and Monitoring Program) and other monitoring efforts, aggregated and made available through Avian Knowledge Network (Ilf et al. 2009), to develop a novel density distribution modeling approach. The approach allows abundance models to be fitted to data from sites predicted to be occupied, resulting in models of bird density. The models can be used to optimize networks of protected areas to conserve populations of all species considered by providing refined and more precise estimates of areas of importance in relation to the regional population. Veloz et al. (2015) used the approach to prioritize areas in the U.S. Pacific Northwest for protecting birds, with results showing a concentration of high-ranking conservation areas in the Klamath Siskiyou Bioregion. Coupled with regional bird conservation plans, the modeling approach can also be used to further quantify the existing contribution of protected area networks to conservation within such priority regions and to better understand management needs and conservation opportunities within and outside of the region's protected areas.

In this study, using birds as indicators of priority habitats and habitat conditions, we further demonstrate how results from a density distribution modeling approach that uses robust bird abundance datasets can be applied to regional conservation planning and ecosystem management. We use data from an extensive region-wide bird monitoring network in the Klamath Siskiyou Bioregion (Alexander et al. 2004, Alexander 2011) to develop density distribution models for 16 conservation focal bird species. We hypothesize that current protected area allocations do not encompass adequate abundance of some conservation focal species and their habitats. To test this hypothesis, we use the models to evaluate the region's network of federally managed lands, and protected areas specifically, with respect to the distribution of conservation focal species. We then apply our results, within the context of continental, national, and regional bird conservation plans, to inform ecosystem management of protected and multiple-use lands based on related habitat-based bird conservation objectives.

METHODS

Study area

Our northern California and southwestern Oregon study area (Fig. 1) includes the Klamath Siskiyou Ecoregion as described by DellaSala et al. (1999) and the Upper Klamath Basin. Our study area is recognized globally as a region of great biological diversity and endemism, an area of conservation concern (Coleman and Kruckeberg 1999, DellaSala et al. 1999, Ricketts 1999, Dunk et al. 2006), and an area that is important for bird diversity (FWS and CWS 1986, Trail et al. 1997, Doremus and Tarlock 2003). We henceforth refer to this study area as the greater Klamath Siskiyou Bioregion (Bioregion; Fig. 1).

This Bioregion has three primary watersheds defined by the Klamath, Rogue, and Umpqua rivers, and encompasses the convergence of the

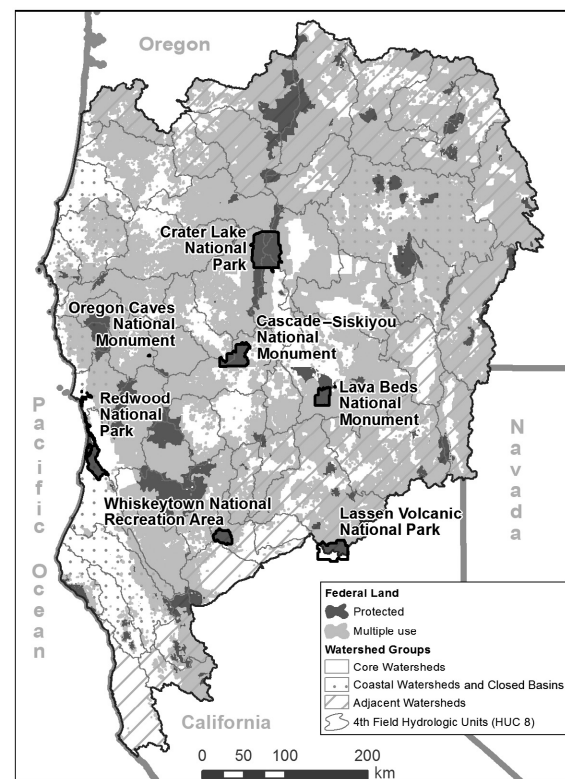


Fig. 1. Fourth field watersheds used to delineate the greater Klamath Siskiyou Bioregion study area, distribution of federal lands that are protected or that are managed for multiple use, and seven protected areas considered in analysis of bird distribution.

Cascade, Siskiyou, and Klamath mountains. The region's climate is an inland expression of a maritime climatic regime, with an average annual rainfall of 75–100 cm (Jimerson et al. 1996). Vegetation is diverse, consisting of a mix of habitats, ranging from redwood forests to the west and shrub-steppe to the east, with a mix of conifer and hardwood forests, and to a lesser extent riverine, meadow, and wetland habitats, distributed throughout.

To establish the greater Klamath Siskiyou Bioregion study area boundary (Fig. 1), we first mapped the fourth-order (i.e., fourth field) watersheds that make up the area's three primary rivers. We then added coastal watersheds within the southernmost and northernmost extents of Klamath and Umpqua watersheds. Next, we mapped the closed basins adjacent to the Upper Klamath River Basin. Lastly, we mapped all fourth field watersheds adjacent to the watersheds described above, adding five additional fourth field watersheds that extend into the range of these adjacent watersheds.

As in many regions of the western United States (NABCI 2011), several federal land management agencies (e.g., Bureau of Land Management, U.S. Forest Service, National Park Service, and U.S. Fish and Wildlife Service) manage large tracts of the landscape within our Bioregion study area, including protected areas, where conservation actions can be broadly implemented. The Bioregion includes seven protected areas of interest including the Bureau of Land Management Cascade–Siskiyou National Monument and six National Park Service units (Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National Park, and Whiskeytown National Recreation Area; Fig. 1). Because our process for outlining the study area was based on watersheds and was independent of land holdings, only a portion of the Lassen Volcanic National Park is included within the boundary.

Bird survey data

We used extensive georeferenced bird survey data that were collected throughout northwestern California and western Oregon and Washington (Veloz et al. 2015). A subset of the data were collected as part of a broad regional monitoring

network in the greater Klamath Siskiyou Bioregion (Alexander et al. 2004, Alexander 2011), including a concentration of surveys from the Cascade–Siskiyou National Monument and the six protected areas of the National Park Service Klamath Network Inventory and Monitoring Program (Alexander et al. 2008, Stephens et al. 2010).

Data were collected using a common “point count” breeding bird monitoring protocol (e.g., Ralph et al. 1993, Stephens et al. 2010) and submitted to the Avian Knowledge Network (Iliff et al. 2009, Veloz et al. 2015). During the breeding season (April to mid-August), five- or ten-minute count surveys were conducted, generally between sunrise and 10:00 hours. All individuals detected by sight or sound were recorded, and distance to each bird was estimated. Two datasets that included single-year surveys and repeat-year surveys at transects made up of five or more point count stations were queried. A larger dataset including 68,631 points along 2990 transects covering much of California, Oregon, and Washington was the same as used by Veloz et al. (2015). A second subset of the larger dataset included 31,697 points along 1508 routes from within the Bioregion. The analyses were limited to birds detected within 50 or 100 m depending on the original data source.

Spatial covariate data

Hybrid vegetation maps.—We created a hybrid vegetation classification scheme derived from the Gap Analysis Program (GAP) vegetation classification system (GAP 2011a). We initially considered all of the finest-resolution vegetation classes which occur in Washington, Oregon, and California, and then aggregated classes within higher classes where needed, to ensure we had a sufficient number of bird survey records for the resulting classes (see Appendix S1).

Climate variables.—High-resolution spatially interpolated PRISM (PRISM Climate Group 2015)-gridded (800 × 800 m) climate data were used to produce monthly climate summaries (Veloz et al. 2015). Using these data and an understanding of the physiological tolerances of focal species, we chose eight climate variables (total precipitation, standard deviation of precipitation, maximum and minimum breeding season temperatures, mean maximum and minimum temperature, mean monthly temperature range, and

temperature range across the breeding season) most likely to constrain occurrence during the breeding season (April–July). Collinearity was screened using correlation analysis using the pairs function from the raster library (Hijmans 2015) within R 3.1.1 (R Core Team 2014); pairs with $r \geq 0.80$ were not included in the same models. After screening, we retained mean breeding season temperature, temperature range across the breeding season, and total precipitation to use in the bird distribution models.

Density distribution modeling

Density distribution models were developed for the Bioregion. We followed the methodology used by Veloz et al. (2015). The approach uses abundance data, with climate and modeled vegetation, to predict probability of occurrence and abundance across a landscape (Fig. 2).

Breeding range and date filters.—We compiled data from all available sources in the Avian Knowledge Network for 16 focal species that were well represented in the data. For each

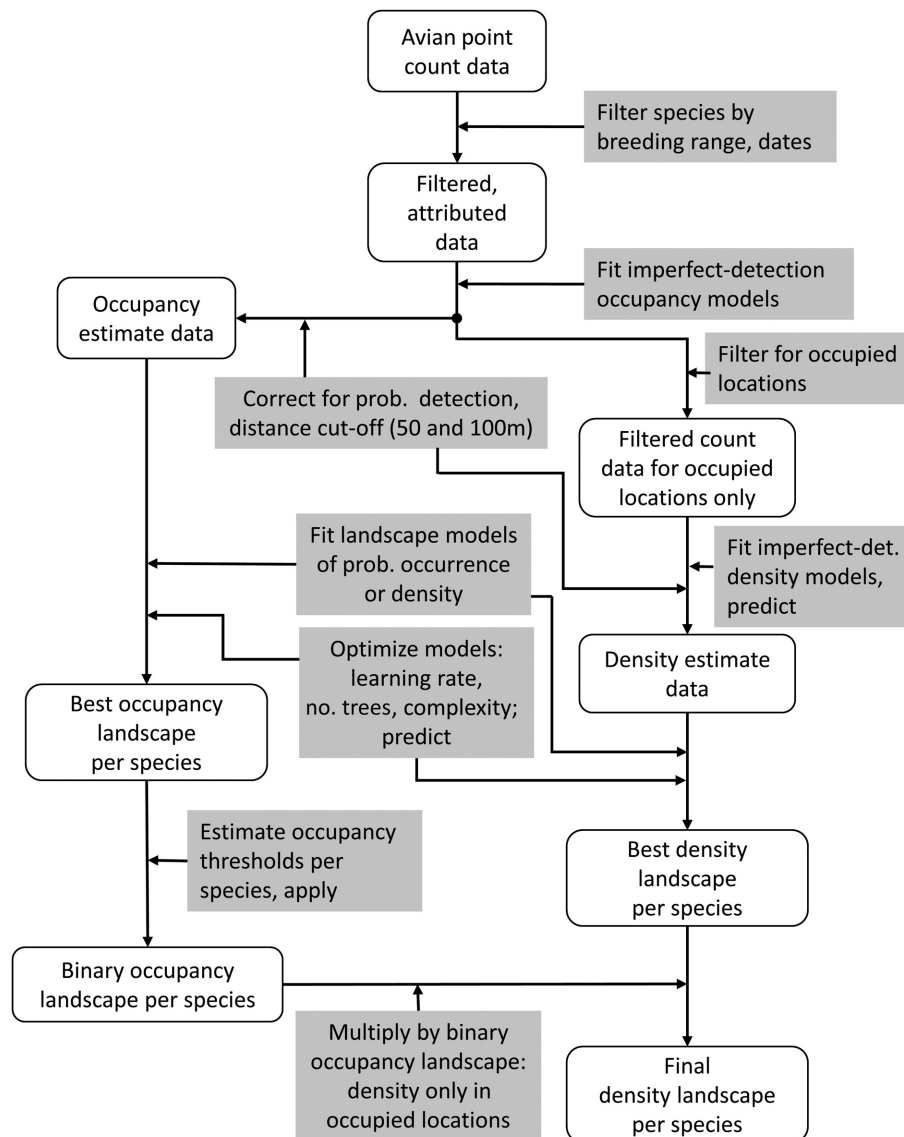


Fig. 2. Methodology flow chart outlining analysis steps taken to derive density distribution models for 16 bird species in the greater Klamath Siskiyou Bioregion.

species, counts that fell outside of species-specific breeding ranges and breeding season windows were not considered in the model. Breeding ranges were derived using Digital Distribution Maps of the Birds of the Western Hemisphere version 3.0 (Ridgely et al. 2007) provided by NatureServe (<http://www.natureserve.org/conservation-tools/digital-distribution-maps-birds-western-hemisphere>). Species-specific breeding season windows for filtering the bird data were based on information in the Birds of North America series (Poole 2005) and expert opinion. They ranged from an earliest start date of 1 April and latest end date of 15 August.

We produced individual estimates of density for two distance bins, within 50 m and within 100 m, and simply multiplied the former by four to combine results with those of the latter. We used the transects with repeated visits to estimate the probability of detection and then used these detection probabilities to correct counts from single-visit surveys, so as to use all of the bird evidence possible to train our landscape models.

Correcting for imperfect detection: point-level abundance/occupancy models.—We considered data for all locations from the larger dataset used by Veloz et al. (2015), and followed similar analytical methods except on one regard. As described in Veloz et al. (2015), in order to properly train the abundance model, we first split the dataset for each species into locations where the species was predicted to occur from locations where they did not occur. This split was done using an imperfect-detection occupancy model (simply “occupancy model”; MacKenzie 2006) to identify those locations where the species was predicted to be present. The occupancy model produces probabilities of occurrence which we converted to presence/absence by setting a threshold probability of occurrence above which the species was determined to occur. Unlike Veloz et al. (2015), we used the prevalence of each species in the study area, derived using the smaller sub-dataset, as its threshold, instead of the prevalence estimated from the larger (California–Oregon–Washington) dataset.

This difference in approach was to ensure that habitat heterogeneity, climate gradients, and habitat relationships accounted for in our model outputs were more study area specific. In Oregon, the response of species to vegetation cover can vary

(Betts et al. 2010). Additionally, the relative influence of the climate variables in the study area-specific models (see Appendix S2) differs from the Veloz et al.'s (2015) models that represent a broader climatic gradient. Therefore, this spatially refined approach was chosen to better account for region-specific influences of climate and vegetation class variables that are both meaningful in determining bird community distribution across regional, vegetation formation, and management unit scales within the Bioregion (Stephens et al. 2016).

We used the vegetation covariate data to attribute the point count locations and fit the imperfect-detection models. Using 78 different potential vegetation class covariates, we fit boosted regression tree models using the `gbm.step` function from the `dismo` package (Hijmans et al. 2015) in R (BRTs; Elith et al. 2008) for presence (i.e., binomial link) and abundance (i.e., Poisson link) to explore variable importance as a means to identify the relevant predictor variables in the data for each model, for each species (see Appendix S2). The important covariates were those that had an importance index >2% in the BRTs (i.e., present in regression models of at least 2% of all trees and branches). These BRTs had 1000 and 5000 trees (for occurrence and abundance models, respectively), interaction depth of three splits per tree, and learning rate (LR) of 0.001.

We fit these hierarchical imperfect-detection models of occupancy and density to the site-level data, using for each species the appropriate abundance or occupancy predictor variable, as identified with the BRT models and intercept-only detection models. This resulted in the model estimating a different abundance value for each year a point was surveyed. These estimates were then averaged across all years. As explained above, the density models were fitted solely to data from the sites determined to be occupied. Once the density models were fitted and evaluated for goodness of fit, we used them to predict the density (i.e., obtain estimates already corrected for probability of detection) and appended all sites predicted as unoccupied with abundance = 0. These predicted values are specific to each point, since each point was attributed with its own values of covariates. We then inflated the abundance values of points with distance cut-off of 50 m to four times the estimated abundance, to match the estimates from the 100-m cut-off sites.

Probability of occurrence landscape models.—Calibration of landscape probability of occurrence models was done using the corrected point-level presence/absence data from above. We removed records located outside of the study area and then fit an initial BRT model (5000 trees, tree complexity [TC] = 3, LR = 0.01) with a binomial link using all climate and vegetation variables. For each species, any variable with a relative influence less than 2% was removed as a possible predictor variable (see Appendix S2). We then subsampled the full dataset to 5000 records, matching the prevalence found in the Bioregion (per species), and ran exploratory models using the reduced set of variables and a range of LRs (0.01, 0.005, 0.001) and TCs (1–5) with a maximum of 10,000 trees. Results were reviewed and optimal TC and LR were chosen for each species. Using all records, final binomial models were run with optimized settings and then projected across the Bioregion. We created probability of occurrence surfaces and presence/absence surfaces using the binomial models and prevalence estimates, as previously described.

Using the point-level density estimates from above, landscape density models were run using the reduced set of vegetation variables derived from the landscape occurrence models and all climate variables. We ran exploratory models as done for the occurrence models, but using log-transformed density estimates and a Gaussian link. Similarly, results were reviewed and optimal TC and LR were chosen for each species. Using all records, final density models were run. Subsequently, we projected the density models across the Bioregion and multiplied them with the presence/absence projections, thereby converting those pixels where the species was not predicted to occur to 0 density.

Bird abundance across land ownership comparisons

We used the Protected Area Database for the United States (GAP 2011b) to query modeled bird density information to present the number of birds predicted to occur (i.e., abundance) within landowner types and specific management units. We used models that were derived for 16 focal species (Table 1, Fig. 3) from seven

Table 1. Partners in Flight regional conservation focal species representative of three habitat types (Altman 2000a, b, CalPIF 2000a, b, 2002a, b, Altman and Alexander 2012) and considered in analysis of bird distribution across federally managed and protected lands in the greater Klamath Siskiyou Bioregion.

Common name	Scientific name	Four-letter code
Grassland		
Horned Lark	<i>Eremophila alpestris</i>	HOLA
Vesper Sparrow	<i>Poocetes gramineus</i>	VESP
Oak Woodland		
Chipping Sparrow	<i>Spizella passerine</i>	CHSP
Downy Woodpecker†	<i>Picoides pubescens</i>	DOWO
House Wren	<i>Troglodytes aedon</i>	HOWR
White-breasted Nuthatch‡	<i>Sitta carolinensis</i>	WBNU
Coniferous Forest		
Brown Creeper	<i>Certhia americana</i>	BRCR
Hermit Warbler	<i>Setophaga occidentalis</i>	HEWA
Olive-sided Flycatcher	<i>Contopus cooperi</i>	OSFL
Orange-crowned Warbler	<i>Vermivora celata</i>	OCWA
Pacific Wren	<i>Troglodytes pacificus</i>	PAWR
Pacific-slope Flycatcher	<i>Empidonax difficilis</i>	PSFL
Purple Finch	<i>Haemorhous purpureus</i>	PUFI
Rufous Hummingbird	<i>Selasphorus rufus</i>	RUHU
Varied Thrush	<i>S. carolinensis</i>	VATH
Wilson's Warbler	<i>Cardellina pusilla</i>	WIWA

† Deciduous woodland.

‡ Eastside ponderosa pine woodland.

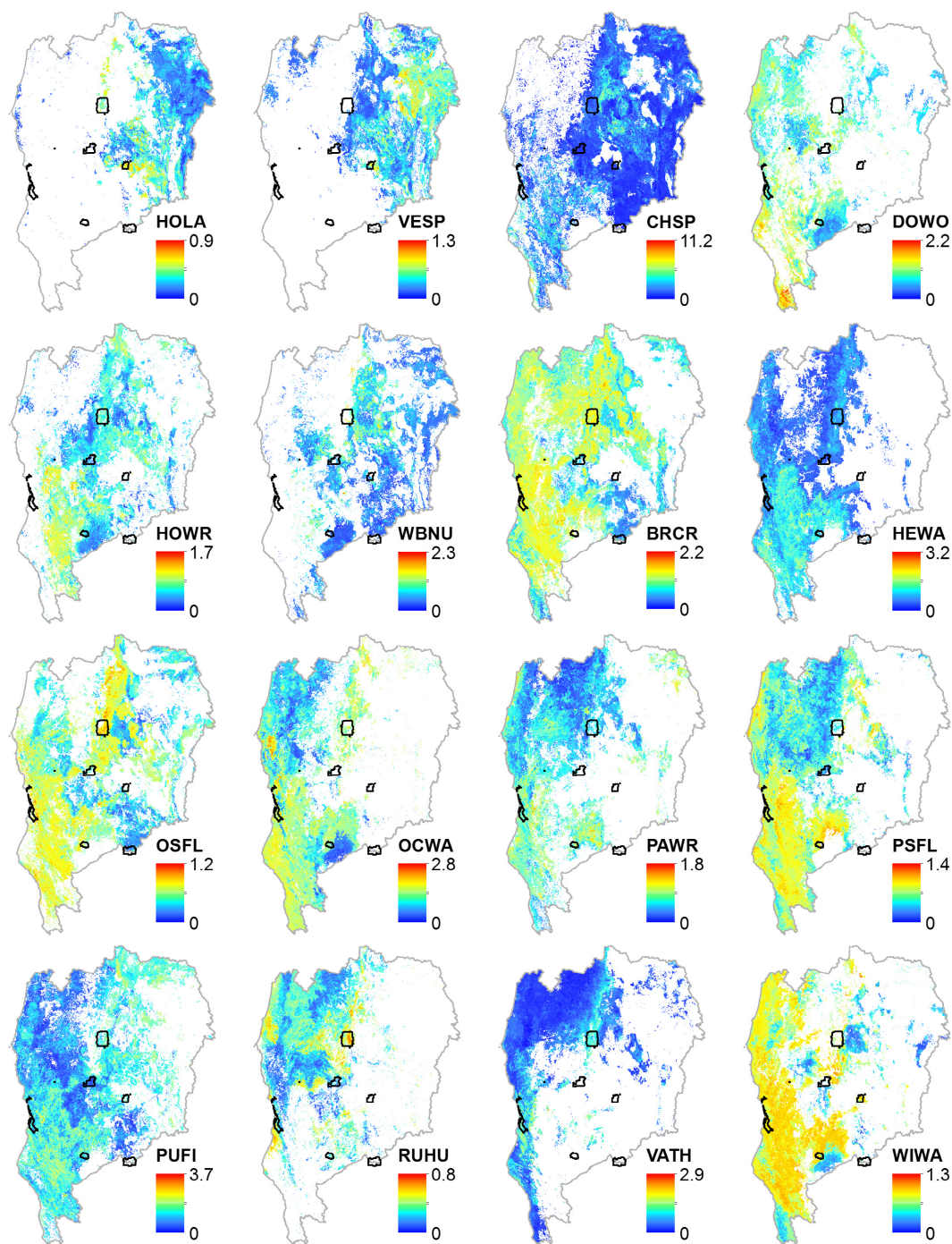


Fig. 3. Projected abundance maps of 16 Partners in Flight focal bird species (see Table 1 for common and scientific names) within the greater Klamath Siskiyou Bioregion and seven protected areas of interest (Cascade–Siskiyou National Monument, Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National Park, and Whiskeytown National Recreation Area; see Fig. 1 for map details).

Partner in Flight bird conservation plans; 10 species are associated with coniferous forest, four with oak woodland, and two with grassland habitat conservation objectives in Oregon, Washington, and California (Altman 2000a, b, CalPIF 2000a, b, 2002a, b, Altman and Alexander 2012). We calculated densities (the number of birds per square kilometer) for management units by dividing the total number of birds predicted to occur in the unit by the unit size.

First, we compared bird abundance based on predicted densities on federal vs. non-federal lands (see Appendix S3). We then compared bird abundance on federal lands based on protected status using State of the Birds (SOTBs) status categories (NABCI 2011). These categories include lands protected to maintain natural habitats (SOTBs Category 1, corresponding to GAP Status Codes 1 and 2), lands managed for multiple uses including conservation (SOTBs Category 2, corresponding to GAP Status Code 3), and lands with no permanent protection from development or conversion but that may be managed for conservation (SOTBs Category 3, corresponding to GAP Status Code 4). This third SOTBs Category made up <1% of the Bioregion. We compared predicted abundance on federal lands classified as SOTBs Category 1 (hereafter referred to as protected lands) vs. federal lands classified as SOTBs Categories 2 and 3 (hereafter referred to as multiple-use lands). We further considered federally protected lands comparing predicted bird abundance and density within the seven protected areas of interest along with other federally protected lands (Table 2; see Appendix S3). This analysis was run using a python script within ArcGIS 10.0 (ESRI 2011).

RESULTS

Federal lands make up 57% of the nearly 17.5 million-ha study area (Table 3, Fig. 1). The U.S. Forest Service and Bureau of Land Management manages the majority of these federal lands—66% (6,536,247 ha) and 32% (3,116,964 ha) of the land base, respectively. Protected lands make up nearly 10% of the Bioregion. Federal agencies manage nearly 93% (1,562,701 ha; Fig. 1) of these protected lands; nearly 16% of the federal land base in the Bioregion is protected (Table 3). The U.S. Forest Service manages more than 60% of

Table 2. Amount of federally protected lands within the Cascade–Siskiyou National Monument (CSNM), six National Park Service units (Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National Park, and Whiskeytown National Recreation Area), National Forests (USFS), U.S. Fish and Wildlife Service (USFWS) refuges, and other federally managed lands; number of study area point count locations by management unit or ownership.

Protected area	Area (ha)	Percentage	Points
CSNM	34,570	2	528
Crater Lake	73,566	5	230
Lassen	23,179	1	259
Lava Beds	19,079	1	372
Oregon Caves	189	0	15
Redwood	35,008	2	263
Whiskeytown	17,084	1	314
USFS	1,032,531	66	263
USFWS	72,469	5	223
Others	255,026	16	413
Total	1,562,701		2880

the federally protected lands, Bureau of Land Management 18%, National Park Service 10%, and U.S. Fish and Wildlife Service 4%.

Both grassland focal bird species were concentrated on federal lands where 67% or more of their abundance were predicted to occur (Fig. 3). The abundance on federal lands of one of these species, the Vesper Sparrow (*Poocetes gramineus*), included only 6% on protected lands (Fig. 4), with small numbers on one of the protected areas of interest near the center of the Bioregion at the western limit of the sparrow's core predicted distribution (Fig. 3).

Table 3. Amount of the greater Klamath Siskiyou Bioregion that is non-federally owned and amount of federally lands that are protected or that are managed for multiple use.

Ownership/protection status	Area (ha)	Percentage	Points
Non-federal	7,482,722	43	2812
Federal: protected	1,562,701	9	2880
Federal: multiple use	8,367,153	48	8005
Total	17,412,577		1,3697

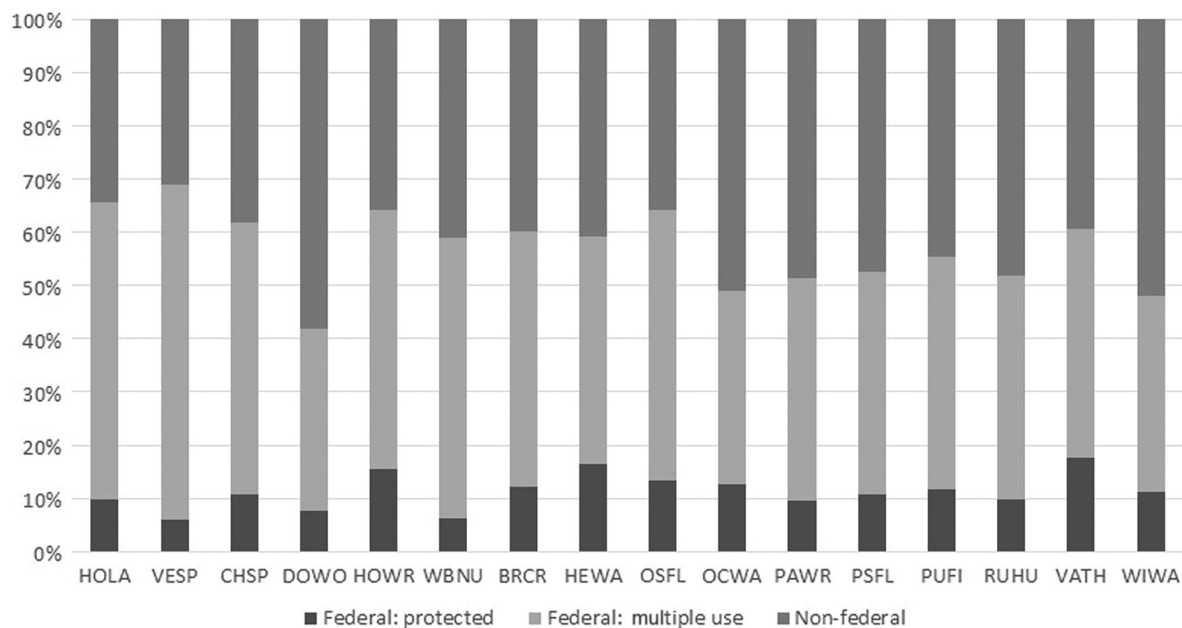


Fig. 4. Percentage of 16 Partners in Flight focal bird species (see Table 1 for common and scientific names) predicted abundance in the greater Klamath Siskiyou Bioregion within federal protected and multiple-use lands and non-federal lands.

Two of the oak woodland focal species, Chipping Sparrow (*Spizella passerine*) and House Wren (*Troglodytes aedon*), had greater than 60% of their abundance on federal lands (Fig. 3). Among the oak woodland birds, White-breasted Nuthatch (*Sitta carolinensis*) had the least amount of its predicted abundance on protected areas; only 6% of its total predicted abundance was on protected areas with <11% of its abundance on federal lands in protected areas (Fig. 4). However, its relative abundance on protected areas was the highest among oak birds on three of the units of interest (Table 4).

Four of the coniferous forest birds, Brown Creeper (*Certhia americana*), Hermit Warbler (*Setophaga occidentalis*), Olive-sided Flycatcher (*Contopus cooperi*), and Varied Thrush (*Ixoreus naevius*), had nearly 60% or more of their abundance on federal lands (Fig. 4). Protected areas encompassed >10% of their total abundance and >20% of their abundance on federal lands (Fig. 5). Two of these species, Brown Creeper and Varied Thrush, had relatively high abundance (7% or more of their abundance on federal lands) on one and two of the protected areas of interest, respectively (Fig. 6).

DISCUSSION

Our analysis of predicted bird abundance across federal and non-federal ownership, across federal lands designations (i.e., multiple use and protected), and on protected areas of interest demonstrates how birds as indicators (Chase and Geupel 2005), robust regional abundance datasets (Alexander et al. 2004, Alexander 2011), and a novel density distribution modeling approach (Veloz et al. 2015) can be used to (1) evaluate regional protected area networks at regional and management unit scales and (2) inform inter-agency and cross-ownership land management planning. The focal species that are central to the analysis have been identified as indicative of diverse ecological conditions with high conservation interest (Altman 2000a, b, CalPIF 2000a, 2002b, Altman and Alexander 2012). Thus, models that predict the distribution and abundance of these species allow for an analysis of gaps in habitat representation within the greater Klamath Siskiyou Bioregion's network of protected areas. Furthermore, the analysis also highlights conservation opportunities within the Bioregion.

Table 4. Density (number of birds per square kilometer) of 16 Partners in Flight focal species (see Table 1 for common and scientific names) on federally protected lands within the Cascade–Siskiyou National Monument (CSNM), six National Park Service units (Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National Park, and Whiskeytown National Recreation Area), National Forests (USFS), U.S. Fish and Wildlife Service (USFWS) Refuges, and other federally lands.

Species (four-letter code)	CSNM	Crater Lake	Lassen	Lava Beds	Oregon Caves	Redwood	Whiskeytown	USFS	USFWS refuges	Other federal
BRCR	0.7	2.1	0.7	0.1	1.5	2.1	0.8	1.7	0.1	0.5
CHSP	0.8	2.0	0.5	1.1	0.0	0.9	2.1	2.0	0.7	1.3
DOWO	0.1	0.1	0.0	0.0	1.3	1.5	1.2	0.4	0.0	0.3
HEWA	0.5	1.0	0.2	0.0	0.5	1.1	1.3	1.3	0.0	0.3
HOLA	0.0	0.2	0.0	0.8	0.0	0.0	0.0	0.1	0.2	0.2
HOWR	0.4	0.8	0.0	0.1	0.5	0.0	0.8	0.8	0.0	0.2
OCWA	0.0	0.9	0.0	0.0	0.6	2.3	1.8	1.3	0.0	0.5
OSFL	0.3	0.9	0.4	0.2	0.7	0.5	0.7	0.8	0.0	0.3
PAWR	0.1	0.4	0.0	0.0	0.6	1.2	1.0	0.5	0.0	0.2
PSFL	0.3	0.3	0.0	0.0	0.7	1.3	1.1	0.8	0.0	0.3
PUFI	0.7	1.3	0.1	0.7	1.7	1.8	2.0	1.6	0.2	0.6
RUHU	0.2	0.6	0.0	0.0	0.5	0.5	0.2	0.2	0.0	0.0
VATH	0.0	1.4	0.0	0.0	0.9	1.7	0.0	0.6	0.0	0.2
VESP	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.2	0.4
WBNU	0.4	0.4	0.1	0.3	0.6	0.0	0.3	0.2	0.1	0.3
WIWA	0.1	0.2	0.1	1.0	1.0	1.4	1.3	0.7	0.0	0.4

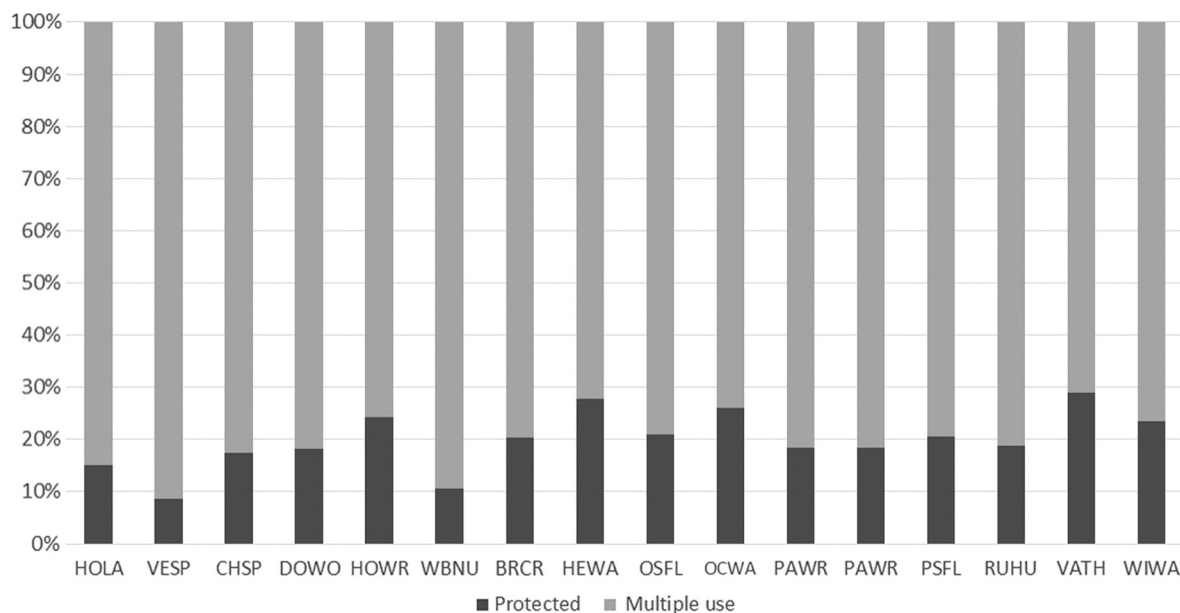


Fig. 5. Percentage of 16 Partners in Flight focal bird species (see Table 1 for common and scientific names) predicted abundance on greater Klamath Siskiyou Bioregion federal lands that are protected or that are managed for multiple use.

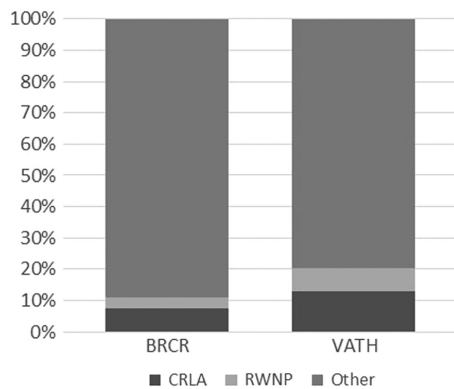


Fig. 6. Percentage of Brown Creeper (*Certhia americana*, BRCR) and Varied Thrush (*Sitta carolinensis*, VATH) predicted abundance on greater Klamath Siskiyou Bioregion federally protected lands within Crater Lake National Park (CRLA) and Redwood National Park (RWNP).

Protected areas evaluation

We hypothesized that the current protected area network in the Bioregion does not encompass adequate abundance of certain species and thus their habitats. Large-scale policy-based recommendations suggest that 10–12% of a nation's area be targeted for protection; more evidence-based approaches call for even higher amounts of protection (Tear et al. 2005). The area of the greater Klamath Siskiyou Bioregion currently protected is at the low end of suggested thresholds and the protected areas are not adequately protecting specific bird species and habitats of conservation concern.

Two conservation focal species, the oak woodland-associated White-breasted Nuthatch and the grassland-associated Vespers Sparrow, are underrepresented on protected lands. Within the Bioregion, they are representative of habitats identified among the United States', as well as North America's, most at-risk bird habitats (NABCI 2014, 2016). The nuthatch is a species of conservation interest because it is an indicator of mature oak habitats, a high-priority habitat in the western part of the Bioregion (Altman and Stephens 2012). There is increasing concern about the conservation status of the Oregon Vesper Sparrow (*Poocetes gramineus affinis*; Altman 2000a), a subspecies of this grassland bird that occurs within the western portions of its predicted distribution in the Bioregion (Fig. 3).

These results highlight gaps in the Bioregion's network of protected areas at fine spatial scales. Given these gaps, the models can be used to identify protected areas that encompass underrepresented priority species and habitats, as well as areas for future protection. In this case, our models show that oak woodland and grassland birds and their habitats occur within the Cascade-Siskiyou National Monument and on adjacent multiple-use lands. The data and results from this research were used to inform the January 2017 18,425-ha science-based expansion of the Monument (Obama 2017; E. J. Frost et al., *unpublished manuscript*) that increased the amount of these at-risk birds and habitats occurring within the Bioregion's network of protected areas.

In contrast to oak woodlands and grasslands, our results suggest that the Bioregion's protected areas better encompass mature coniferous forest focal species (Altman and Alexander 2012), including Brown Creeper, Hermit Warbler, and Varied Thrush. In the Pacific Northwest, public land management agencies prioritize the restoration and protection of old-growth forest conditions (FWS 2011). Our results, and specific measures of abundance within the units of interest, highlight the importance of protected areas, and two parks (Crater Lake and Redwoods National Parks), for protecting old-growth forests. The abundance of these species on federal lands in general also highlights the U.S. Forest Service and Bureau of Land Management among the Bioregion's important stewards of old-growth forests, given the amount of federal lands these agencies manage.

Land management planning

Here, we show how models of bird distribution and abundance, along with habitat-based conservation objectives, can be used to address priority management challenges and identify conservation opportunities on protected areas, other federal lands, and non-federal lands. We use our results to address a regional conservation priority that is also a management challenge in many regions of the world—the restoration of fire-adapted ecosystems (DellaSala and Hanson 2015). This further demonstrates how the focal species approach prescribed by Partners in Flight offers solutions to ecosystem conservation challenges and serves as a catalyst for better

ecosystem management (Alexander 2011, Rosenberg et al. 2014).

A century of fire suppression, coupled with intensive forest management, has become a management and bird conservation challenge in western coniferous forests (Huff et al. 2005, NABCI 2016). Altman and Alexander (2012) offer habitat-based conservation objectives designed to overcome the challenge of restoring and managing fire-adapted ecosystems that characterize western forests. Coupled with our density distribution modeling, these objectives can inform conservation design in the greater Klamath Siskiyou Bioregion.

Our results show that Olive-sided Flycatcher (a coniferous forest focal species) abundance is concentrated on federal lands in the Bioregion. This species is a Watch List Species undergoing significant declines in western forests (NABCI 2014); it is associated with structurally complex post-burn habitats (Altman and Alexander 2012, Stephens et al. 2015). The abundance of two additional coniferous forest species in decline (Wilson's Warbler and Orange-crowned Warbler) was concentrated on non-federal lands (Altman and Alexander 2012). These species are associated with deciduous understories, a habitat condition that is believed to have decreased on the landscape as a result of intensive forest management and post-fire restoration that emphasizes conifer-dominated habitats (Altman and Hagar 2007).

Conservation objectives for these three species call for landscape-scale management that includes ecological processes, such as wildfire, and post-disturbance restoration that results in habitat heterogeneity across landscapes (Altman and Alexander 2012). Such conservation objectives coupled with our distribution models can guide large-scale spatially explicit landscape conservation planning (Will et al. 2005) across public and private multiple-use and protected lands to better restore the fire-adapted ecosystem conditions that historically characterized the greater Klamath Siskiyou Bioregion.

CONCLUSION

Distribution and abundance models for landbird species serve as a tool for evaluating conservation opportunities. We demonstrated this using a group of western birds for which federal

agencies have high stewardship responsibility (NABCI 2011) and bird distribution models that were novel in that they both (1) incorporated abundance (Veloz et al. 2015) and (2) were derived at a regional scale using a robust regional dataset. In combination, these modeling advancements provided a regionally relevant level of detail that had not previously been available for evaluating the protected area network of the greater Klamath Siskiyou Bioregion.

Our use of Partners in Flight focal species that represent a variety of ecological conditions needed to recover and sustain diverse landbird populations (Chase and Geupel 2005, Rosenberg et al. 2016) further illustrates how birds can serve as indicators to inform the setting of broad ecosystem management objectives, as others have shown (e.g., Alexander et al. 2007, Alexander 2011, Stephens et al. 2011). Additionally, this approach provides monitoring metrics that when applied will quantify the effectiveness of achieving such objectives. This analysis also demonstrated the value of integrating monitoring programs in protected areas, such as those implemented by the National Park Service (Fancy et al. 2009, Stephens et al. 2010), with broader regional monitoring networks (Alexander et al. 2004, Alexander 2011) and using ecoinformatics systems like Avian Knowledge Network to support regional data syntheses.

Our analysis, while informative for three important suites of species—coniferous forest, oak woodlands, and grasslands—is not comprehensive in covering all suites of species and associated habitats in the greater Klamath Siskiyou Bioregion. Further work would benefit from including additional species representative of riparian, shrub-steppe, high-elevation forests, and high-elevation meadows, all of which would likely require additional data collection.

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