Evaluation of avian focal species for KIPZ forest plan monitoring

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Vision: Native bird populations are sustained in healthy ecosystems

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Abstract

The planning rule directs individual National Forests and Grasslands to monitor focal species representing desired conditions that are identified in their forest plans but difficult to measure directly. The Kootenai and Idaho Panhandle (KIPZ) National Forests selected 5 avian focal species – Chipping Sparrow, Dusky Flycatcher, Hammond’s Flycatcher, Olive-sided Flycatcher, and Hairy Woodpecker – to represent conditions desired under planned changes in how they manage fuels and fire. The habitat relationships for which these species were selected, however, had not been empirically evaluated within these forests prior to this report. We developed predictions based on species’ habitat descriptions, and then tested our predictions using breeding landbird and vegetation data from the Integrated Monitoring in Bird Conservation Regions (IMBCR) program and vegetation data from the USFS Northern Region’s Existing Vegetation Mapping Program (VMAP). We analyzed population abundance or occupancy in relation to vegetation covariates, and then evaluated whether covariate relationships matched the expected direction (e.g., positive, negative) implied in species’ habitat descriptions. Most but not all estimated covariate relationships were consistent with our predictions. Additionally, we found statistically supported relationships described in the broader literature but not identified in KIPZ focal species’ habitat descriptions. After refining species’ habitat descriptions to include relationships reported here, KIPZ managers may see a need for additional focal species to represent other desired conditions. We suggest ways of formally integrating focal species monitoring into KIPZ forest management by incorporating empirically estimated habitat relationships into management evaluation.

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Introduction

The U.S. Forest Service (hereafter USFS) manages forest vegetation structure and composition to maintain ecological integrity, support a diversity of plants and animals, and provide ecosystem services. Wildlife populations are a key component of these 3 objectives, so forest plans include desired conditions for wildlife habitat. Monitoring is required to verify management effectiveness for wildlife and other resources. The 2012 Planning Rule requires monitoring focal species to address desired conditions (36 CFR § 219.19). Focal species are intended to inform ecological integrity and the presence or quality of ecological characteristics that are difficult to measure or monitor directly. As such, focal species should relate functionally with ecological characteristics of interest (e.g., vegetation attributes that provide important habitat features for a species). The current planning rule mandates monitoring of at least one focal species by each forest, with local resource specialists and forest planners being responsible for determining which species to monitor and which ecological characteristics they are supposed to represent.

Restoring wildfire and associated vegetation conditions represent central management goals for both the Kootenai and Idaho Panhandle National Forests (hereafter KIPZ forests). Acres burned by wildfire and prescribed fire therefore represent key metrics in monitoring plans for these forests (U.S. Forest Service 2016a, b). Wildfire is central to maintaining canopy openings and landscape heterogeneity, which provide critical habitat components for many species of wildlife (Fontaine and Kennedy 2012, Latif et al. 2016b). These conditions are difficult to define and quantify in a universally relevant manner, however. The KIPZ forests therefore identified an assemblage of 5 avian focal species to help monitor desired vegetation conditions promoted by fire: Chipping Sparrow (*Spizella passerina*), Dusky Flycatcher (*Empidonax oberholseri*), Hammond's Flycatcher (*Empidonax hammondii*), Olive-sided Flycatcher (*Contopus cooperi*), and Hairy Woodpecker (*Dryobates villosus*) (U.S. Forest Service 2016a, b). Forest monitoring plans identify these as focal species because of the habitat conditions with which they purportedly associate. KIPZ forests contracted the Ecosystem Research Group (hereafter ERG) to summarize focal species habitat associations and model potential population responses to management (ERG 2012). Based on habitat simulations under different management alternatives of the KIPZ forest plans, ERG projected that focal species populations would increase or be maintained within the historic range of variability under the selected KIPZ management plans. With this information, KIPZ forests moved to implement these plans, along with focal species monitoring to verify expected population trends across the KIPZ landscape.

Since 2010, the KIPZ forests, in conjunction with the USFS Northern Region (which contains the KIPZ forests), have monitored the 5 avian focal species and other landbirds using Integrated Monitoring in Bird Conservation Regions (IMBCR). IMBCR is a breeding landbird monitoring program carried out by numerous federal and state agency partners and not-for-profit organizations. By leveraging ongoing broad-scale monitoring, this approach is cost effective and places forest-level population trends in a regional context (Pavlacky et al. 2017). Thus, by comparing population trends regionally, forest biologists can assess whether trends likely reflect forest-level management practices versus broader environmental or climatic changes. To bolster this monitoring approach, KIPZ forests intensified IMBCR sampling within their boundaries in 2013–2017. Our ability to evaluate management actions with this approach, however, is limited by our understanding of focal species' ecology. KIPZ monitoring plans and ERG (2012) draw habitat relationships from available scientific literature without empirical verification within KIPZ forests. Furthermore, focal species relationships with wildfire and prescribed fire have not been quantified for KIPZ forests. Consequently, we have limited knowledge to distinguish forest management from other potential drivers of population trends.

We aimed to improve understanding of focal species' habitat relationships to inform interpretation of trends identified from IMBCR in KIPZ forests. We started with 3 questions:

1. Do focal species' populations associate with habitat conditions as described in KIPZ monitoring plans and ERG (2012)?
2. Do habitat descriptions in monitoring plans and ERG (2012) comprehensively describe habitat associations for focal species?
3. Do focal species populations favor areas burned by prescribed fire and wildfire?

We leveraged IMBCR and broad-scale environmental monitoring for KIPZ forests to help answer these questions. For questions 1 and 2, we tested predictions derived from focal species' habitat descriptions described in KIPZ forest monitoring plans and the supporting ERG report (hereafter *species habitat descriptions*), and published literature. For question 1, we focused on testing predictions from species' habitat descriptions, whereas for question 2, we focused on testing predictions derived from the literature but not from species' habitat descriptions. When reviewing available data (MTBS 2018 and the USFS FACTS database), we found IMBCR sampling units did not extensively intersect areas impacted by wildfire and prescribed fire, so we put question 3 aside during analysis but returned to it when discussing our findings.

Methods

Bird surveys

IMBCR is the largest breeding-bird monitoring program in North America that has a spatially balanced sampling design implemented with professional surveyors. The program is administered by Bird Conservancy of the Rockies and relies on multiple governmental and NGO partners, including USFS Regions 1, 2, 3, and 4, for funding, data acquisition, data management, and knowledge generation relevant to land management and biological conservation. Sampling covers much of the Great Plains, intermountain regions, and western U.S. Sampling design and data collection protocols are described in detail by Pavlacky et al. (2017) and Hanni et al. (2018). In short, primary survey units are 3281-ft^2 grids consisting of 4×4 arrays of evenly spaced (820 ft) survey points (secondary units). Survey grids are distributed in a spatially balanced manner across strata defined by geopolitical boundaries and funding partners' needs. Strata are nested within super-strata and Bird Conservation Regions, allowing estimation of abundance, occupancy, population trends, and other parameters at various spatial scales. Surveyors visit each point once for 6 min during the breeding season (dates vary by elevation and state; Hanni et al. 2018) between 0.5 hours before to 5 hours after sunrise. Surveyors record all individual birds detected by species, along with distances to detected individuals and the timing of detections within the 6-min survey period (Hanni et al. 2018).

We analyzed data from IMBCR surveys conducted from 2010–2017 across KIPZ (Table 1, Figure 1). During this 8-year period, surveys occurred at 1008 points nested in 74 grids (mean = 13.6 points per grid) within KIPZ forests. We surveyed these grids and points over 8 years but not every one in every year. Thus, over the 8-year sampling period, we completed 3530 surveys of points during 363 grid visits.

Table 1. Number of sampling units (top panel) and number of detections by species (bottom panel) represented in monitoring data used to evaluate focal species for the Kootenai and Idaho Panhandle National Forest monitoring plans. Survey points are nested within 3281-ft^2 grids in 4×4 arrays. Each unit (point / grid) was surveyed at most once per year. *n* units = the number of units (point / grid) surveyed. *n* detections = the sum of all detections of individuals recorded across all points for Hairy Woodpecker (HAWO), Olive-sided Flycatcher (OSFL), Hammond's Flycatcher (HAFL), Dusky Flycatcher (DUFL), and Chipping Sparrow (CHSP).

	2010	2011	2012	2013	2014	2015	2016	2017	All years
				n units					
points	242	153	394	520	407	554	651	609	1,008
grids	25	18	37	54	40	63	63	63	74
				n detections					
HAWO	26	6	18	22	17	13	25	22	149
OSFL	16	2	19	27	28	28	45	43	208
HAFL	28	62	38	108	72	60	69	69	506
DUFL	39	19	88	70	62	79	112	96	565
CHSP	76	52	178	304	330	345	403	270	1,958

[a] At some grids in some years, fewer than 16 points were surveyed due to access limitations, safety, or logistical constraints.

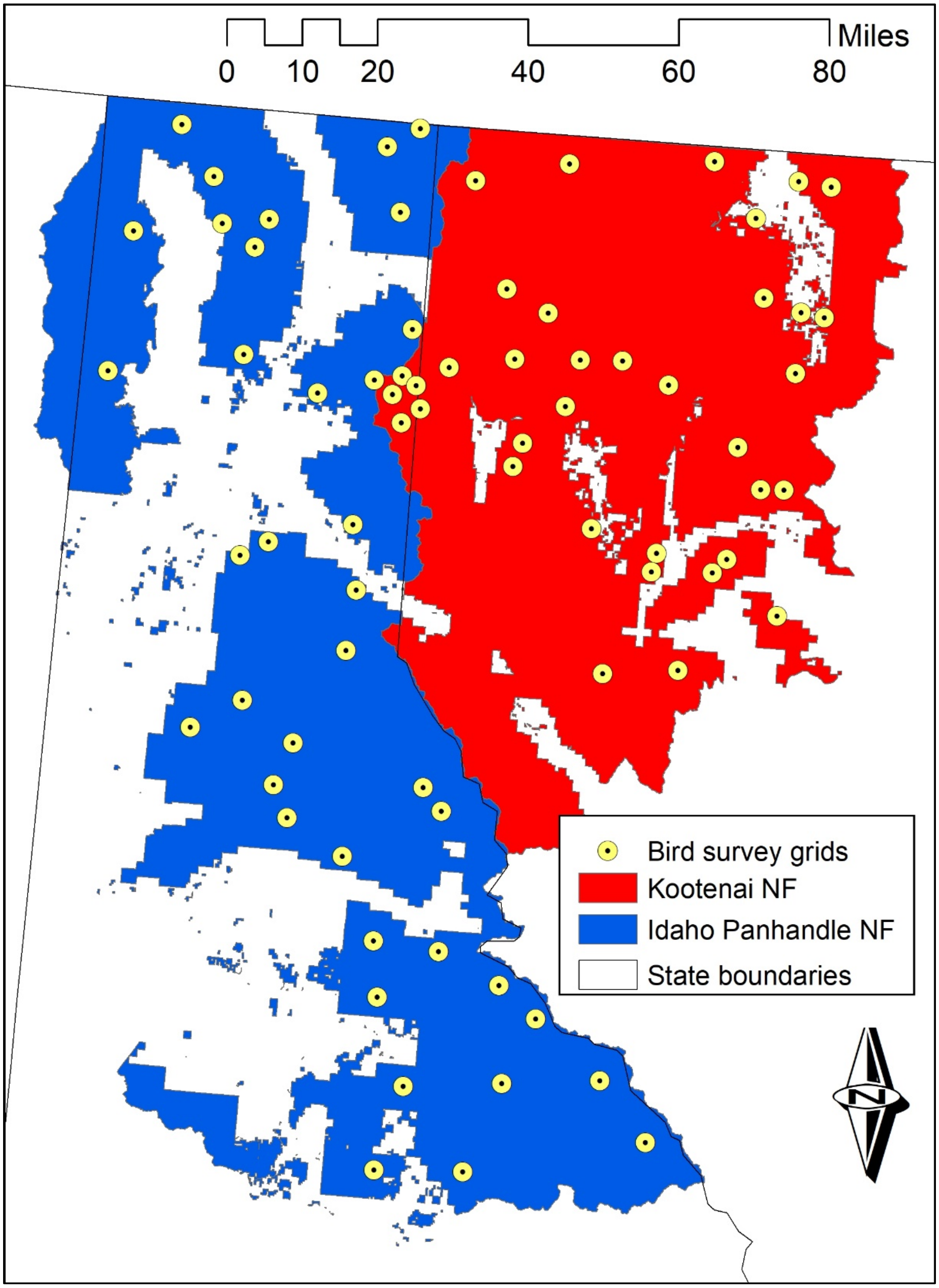

Figure 1. Survey grids for the Integrated Monitoring in Bird Conservation Regions program, 2010-2017.

Environmental data and predictions

We compiled 15 covariates quantifying 9 habitat features (Table 2) referenced in species habitat descriptions (Table 3, Appendix A) and literature (Sedgwick 1994, Hansen et al. 1995, Middleton 1998, Hutto and Young 1999, Covert-Bratland et al. 2006, Altman and Sallabanks 2012, Pereyra and Sedgwick 2015, Marks et al. 2016, Jackson et al. 2018). We derived 10 covariates from VMAP, a remotely sensed, field verified, spatial polygon data source, providing wall-to-wall coverage of the study area and designed to inform forest management (Berglund et al. 2009). Additionally, we supplemented VMAP with 5 field-measured covariates recorded alongside bird surveys at IMBCR sampling units (i.e., ocular estimates within a 164-ft radius of each secondary sampling unit; Hanni et al. 2018). Although referenced in focal species habitat descriptions, we were unable to compile covariates describing tree densities from VMAP or IMBCR data sources. We initially considered additional covariates quantifying the presence and size of canopy openings associated with sampling units, but these were no more useful than canopy cover for testing our predictions (described further below), so we excluded them from the final analysis. We only quantified riparian habitat at finer spatial scales because riparian vegetation never extended far enough to cover meaningful portions of landscapes (3280ft radius) associated with grids. Although aspen (*Populus tremuloides*) is mentioned in species habitat descriptions, our sampling units did not represent sites with aspen sufficiently to include it in our analysis. We included 4 covariates describing tree species composition to represent and control for variation in occupancy and abundance (described further below in *Data Analysis*) among forest types of management interest (Table 2).

We predicted covariate relationships based primarily on species' habitat descriptions (Table 3, Appendix A), but also relationships described in the literature (Sedgwick 1994, Hansen et al. 1995, Middleton 1998, Hutto and Young 1999, Covert-Bratland et al. 2006, Altman and Sallabanks 2012, Pereyra and Sedgwick 2015, Marks et al. 2016, Jackson et al. 2018). Habitat descriptions sometimes described a range of habitats where species could occur, which do not necessarily imply linear relationships with particular habitat features. Nevertheless, we did our best to develop predictions that represented major habitat components, while acknowledging areas of subjectivity in interpreting species habitat descriptions.

Chipping Sparrow. – We predicted Chipping Sparrow relationships with 6 covariates (Table 4). Predicted negative relationships with canopy cover and tree size reflected the habitat components of "openings and early successional forests" (monitoring plans). A predicted positive relationship with conifer dominance reflected "strong preference for conifers" (ERG). A predicted positive relationship with shrubs reflected the "low-growth woodlands with shrubby vegetation" component (ERG). A predicted positive relationship with ponderosa pine (*Pinus ponderosa*) dominance reflected the "ponderosa pine forests" component (ERG). Hutto and Young (1999) also described a positive relationship with snags for this species.

Dusky Flycatcher. – We predicted Dusky Flycatcher relationships with 7 covariates. We expected trees would be relatively small in "open areas with scattered trees" and "forest edges, agricultural borders, and shrub habitats" (ERG). We expected limited but still some canopy cover in "relatively open habitats, including mixed coniferous forests, willow riparian zones, and open ecotonal woodlands." We therefore predicted finding maximum abundance at relatively low but not zero canopy cover. Positive relationships with shrubs and riparian reflected components of "riparian zones" and "shrub habitats", respectively (ERG). The predicted positive relationship with conifer dominance reflected the "mixed conifer forest" (ERG) and "open coniferous forest" (monitoring plan) components. Finally, predicted positive relationships with Douglas fir [*Pseudotsuga menziesii*] and ponderosa pine dominance reflected the "woodlands of Douglas fir [and] ponderosa pine" (ERG).

Table 2. Habitat covariates compiled for modeling avian focal species abundance and occupancy.

Habitat feature	Covariate	Source	Description	Scales (ac)[a]
Tree size	TreeSiz10	VMAP	Percent area with mean tree diameter ≥ 10 in for associated stand (for CHSP, OSFL)	12, 776
	TreeSiz15	VMAP	Percent area with mean tree diameter ≥ 15 in for associated stand (for HAWO, HAFL)	12, 776
Canopy cover	CanCov_VMAP	VMAP	Percent canopy cover in associated stand	12, 776
	CanCov_IMBCR	IMBCR	Percent canopy cover within 164ft	2
Snags, standing dead	percDead[b]	VMAP	Percent of tree canopy dead	12, 776
	NumSnags[b]	IMBCR	Number of snags counted within 164 ft of survey point	2
Conifer dominance	Conifer_VMAP	VMAP	Percent area dominated by conifer tree species (DOM_GRP_40 = 8035, 8065, 8135, 8045, 8125, 8055, 8075, 8155, 8085, 8015, 8025, 8095, 8105, 8115)	12, 776
	Conifer_IMBCR	IMBCR	Percent of canopy (relative cover) composed of conifer	2
Ponderosa pine	PIPO	VMAP	Percent area dominated by ponderosa pine (DOM_GRP_40 = 8015 - MX-PIPO)	776
Spruce-fir	SpFir	VMAP	Percent area dominated by spruce and fir species (DOM_GRP_40 = 8035 - MX-ABGR, 8065 - MX-ABLA, 8075 - MX-PIEN)	776
Douglas fir	PSME	VMAP	Percent area dominated by Douglas fir (DOM_GRP_40 = 8025 - MX-PSME)	776
Lodgepole pine	PICO	VMAP	Percent area dominated by lodgepole pine (DOM_GRP_40 = 8055 - MX-PICO)	776
Riparian	Ripar_VMAP	VMAP	Percent area dominated by riparian species (DOM_GRP_60 = 3190 - GRASS-WET, 8140 - BEPA, 8190 - FRPE, 8160 - POPUL, 8170 - POTR5)	12
	Ripar_IMBCR	IMBCR	Percent of canopy (relative cover) composed of riparian species (alder, aspen, birch, balsam poplar, willow, cottonwood, wild rose)	2
Shrubs	ShrubLnd	VMAP	Percent area classified shrubland (DOM_GRP_60 = 3320 - SHRUB-XERIC, or 3330 - SHRUB-MESIC)	12, 776
	ShrubCov[b]	IMBCR	Percent shrub cover	2

[a] 2 ac corresponds with the 164-ft radius measurement plot for IMBCR vegetation data, 12 ac corresponds with the 410-ft radius survey point neighborhood, and 776 ac corresponds with a 3,280-ft radius neighborhood of the grid center. VMAP covariates were initially compiled at a 30-m pixel resolution, and then averaged across the 2 neighborhoods centered on survey points (12 ac) or grid center points (776 ac).

[b] Missing values for these covariates were imputed during model-fitting using vague priors.

Table 3. Focal species' habitat descriptions in KIPZ forest monitoring plans. These descriptions condense and highlight key components appearing in more extensive descriptions in the Ecosystem Research Group report (ERG 2012). Selection of these species to focus monitoring is based on these and ERG descriptions.

Species	Habitat description
Chipping Sparrow	"openings and early successional forests"
Hairy Woodpecker	"coniferous forests, including large-tree stands, which contain snags"
Olive-sided Flycatcher	"openings and early successional forests that contain residual conifers or snags, such as would be expected to occur after a fire"
Dusky Flycatcher	"open coniferous forests, open areas with scattered trees, brushy areas, and riparian habitats"
Hammond's Flycatcher	"mature coniferous forests that contain canopy openings"

Hammond's Flycatcher. – We predicted Hammond's Flycatcher relationships with 5 covariates (Table 4). A predicted positive relationship with tree size reflected habitat components "mature forest" and "mature and old-growth stands" (monitoring plan, ERG). Considering the component "dense forests (70–100% canopy cover)" (ERG), we predicted maximum abundance with canopy cover >70%, but assuming Hammond's Flycatcher "require openings and airspace in the canopy" (ERG), we modeled a quadratic relationship potentially allowing us to find maximum abundance below 100% canopy cover. The predicted positive relationships with conifer dominance and riparian reflected references to "coniferous … forests" and "riparian areas" (ERG). Predicted relationships with snags reflected relationships described by Hutto and Young (negative; 1999) and Hansen et al. (positive with large snags; 1995).

Olive-sided Flycatcher. – We predicted Olive-sided Flycatcher relationships with 5 covariates. A predicted negative relationship with tree size reflected "early successional forests" (monitoring plan). Based on the expected associations with various types of "openings," we predicted Olive-sided Flycatchers would associate with relatively low levels of canopy cover. Considering the described components "forest edges" and "semi-open forest stands" (ERG), however, we predicted we would see maximum abundance at >0% canopy cover. Predicted positive relationships with snags, conifer dominance, and riparian to reflect components "early post-fire communities," "coniferous forests," and "rivers" (ERG).

Hairy Woodpecker. – We specified predictions for Hairy Woodpecker relationships with 3 covariates (Table 4). We predicted a positive relationship with covariates quantifying snags (Table 4), definitively described as a key habitat component for Hairy Woodpeckers (monitoring plan, ERG). We also predicted a positive relationship with tree size to reflect habitat descriptions of "mid- and large-sized snags" (ERG) and "large-tree stands" (monitoring plan), recognizing that the importance of larger trees is not definitively stated (ERG). Finally, we predicted no relationship with conifer dominance because Hairy Woodpeckers are described as occupying "both deciduous and coniferous forest habitats" (ERG).

Although we only predicted particular relationships with canopy composition for 2 species, we expected species' abundance could generally vary with canopy composition, which could affect statistical power for estimating population trends in different forest types. For example, in habitats where a species is less common, infrequent detections could limit power for estimating population change (Roberts et al. 2016). In such cases, estimated trends for a given species may primarily reflect changes occurring in forest types where the species is relatively common, making it less useful for informing management in other forest types. We therefore analyzed relationships with canopy composition for all species.

Table 4. Predicted relationships with covariates for focal species (negative [‘-’], positive [‘+’], quadratic with maximum population size or prevalence at intermediate covariate level [‘∩’]). Predictions reflect habitat descriptions in the KIPZ monitoring plan and Ecosystem Research Group (2012) report, or the broader scientific literature. Relationships described only in the literature (not in the monitoring plan or ERG report) are in parentheses. Focal species are Chipping Sparrow (CHSP), Dusky Flycatcher (DUFL), Hammond’s Flycatcher (HAFL), Olive-sided Flycatcher (OSFL), and Hairy Woodpecker (HAWO). Complete covariate names and descriptions are in Table 2. Superscripts indicate predictions that were supported ([S]), received mixed support ([MS]), or were contradicted ([NS]) (see footnotes for further definitions; compare with relationships in Table 6 and Figures 2–6). Lack of a superscript indicates where we found no statistically supported relationship with a covariate.

Habitat feature	Covariate(s)	Predicted relationships				
		CHSP	DUFL	HAFL	OSFL	HAWO
Tree size	TreeSiz10, TreeSiz15	-[S]	-[S]	+[MS]	-[MS]	+[NS]
Canopy cover	CanCov[a]	-[S]	∩[S]	+ or ∩ (max abundance predicted at >70% CanCov)[NS]	∩[S]	
Snags, standing dead	percDead, NumSnags	(+)[S]		(+[NS],-[S])[b]	+	+[S]
Conifer dominance	Conifer[a]	+[S]	+	+[NS]	+	0[NS]
Riparian	Ripar[a]		+[S]	+[S]	+[NS]	
Shrubs	ShrubLnd, ShrubCov	+	+[S]			
Canopy composition[c]	PIPO, SpFir, PICO, PSME	PIPO	PSME, PIPO			

[a] Represent VMAP and IMBCR versions ([name]_VMAP or [name]_IMBCR in Table 2).

[b] We found both positive and negative relationships with standing dead described for Hammond’s Flycatcher in the literature.

[c] Covariates are listed with which predicted relationships are positive

[S] The estimated covariate relationship matched the prediction and was statistically supported.

[NS] The estimated covariate relationship was statistically supported but was opposite in direction to the prediction.

[MS] We considered support to be mixed for predicted tree size relationships with HAFL and OSFL populations because we found contradictory relationships at different scales (see Table 6).

Data analysis

We initially modeled abundance for all focal species, but abundance models performed poorly (poor convergence and precision) for the 2 least frequently detected species, Olive-sided Flycatcher and Hairy Woodpecker. We therefore modeled occupancy (presence-absence) for these 2 species instead. We assumed a close relationship between abundance and occupancy (Joseph et al. 2006, Clare et al. 2015, Latif et al. 2018) and therefore applied the above predictions to occupancy for Olive-sided Flycatcher and Hairy Woodpecker. We provide details on abundance and occupancy models here.

We modeled abundance for Chipping Sparrow, Dusky Flycatcher, and Hammond's Flycatcher using Bayesian hierarchical distance sampling (Royle 2004, Royle et al. 2004, Buckland et al. 2015, Kéry and Royle 2016) with a separate model for each species. Abundance models described 4 levels of information relating ecological parameters (abundance related with habitat) with observed data (counts and distances). In the notation below, '[…]' denote probability distributions, and '[…|…]' denote conditional probability distributions (Gelfand and Smith 1990). We modeled point level local abundance as Poisson distributed,

$$[N_{it}] \sim Poisson(\lambda_{it}) \text{ (Equation 1a),}$$

where mean abundance at point *i* within grid *j* in year *t* varied log-linearly as a function of point-level covariates:

$$log(\lambda_{it}) = \beta_{0jt} + \boldsymbol{\beta} \times \boldsymbol{X_{it}} \text{ (Equation 1b).}$$

The intercept (mean abundance) for point *i* varied according to a grid-level normal random effect (i.e., the distribution of intercepts across grids was governed by a Normal distribution estimated as part of the model) and grid-level covariates:

$$\beta_{0jt} = \delta_{0jt} + \boldsymbol{\delta} \times \boldsymbol{X_{jt}} \text{ (Equation 2).}$$

The total number of individuals detected during a point survey (n_{it}) was modeled as a binomial distribution with the number of trials equal to the imperfectly observed latent abundance (N_{it}) at point *i* in year *t* and probability of success (integrated across all distances) p_{it}:

$$[n_{it}|N_{it}] \sim Binomial(N_{it}, p_{it}) \text{ (Equation 3).}$$

We modeled the number of individuals detected at site *i* in year *t* within binned distance class *k* (y_{itk}) as multinomially distributed conditional on the total number of individuals detected at site *i* in year *t* (n_{it}):

$$[y_{itk}|n_{it}] \sim Multinomial(n_{it}, \boldsymbol{\pi}_{it}) \text{ (Equation 4a),}$$

where $\boldsymbol{\pi}_{it}$ is a vector of multinomial distance cell probabilities of length 10. Each element of $\boldsymbol{\pi}_{it}$ is the product of the probability of detecting an individual in a given distance class and the proportionate area ($\pi_{itk} = g_{itk} \times A_k$). Detection probability declines with distance following a hazard function ($g_{itk} = 1 - exp(-(dist_d/a_{it})^b)$, where a_{it} and b are estimated parameters; Buckland et al. 2015). For all species, we modeled heterogeneity in detection probability by allowing the decline with distance, a_{it}, to vary as a log-linear function of covariates survey day-of-year (*DOY*), canopy cover (*CanCov_IMBCR*), and shrub cover (*ShrubCov*):

$$log(a_{it}) = \alpha_0 + \alpha_{DOY} \times DOY_{it} + \alpha_{DOY^2} \times DOY_{it}^{\ 2} + \alpha_{CanCov} \times CanCov\_IMBCR_{it} + \alpha_{ShrubCov} \times ShrubCov_{it} \text{ (Equation 4b).}$$

We also modeled occupancy for Hairy Woodpecker and Olive-sided Flycatcher using hierarchical (Nichols et al. 2008, Pavlacky et al. 2012) Bayesian state-space (Royle and Kéry 2007) approach. Occupancy models represented 3 levels of information: grid-level occupancy, point-level occupancy, and detection probability. We modeled latent grid-level occupancy as Bernoulli distributed,

$$\left[z_{jt}|\psi_{jt}\right] \sim Bernoulli\left(\psi_{jt}\right) \text{ (Equation 5a),}$$

where ψ_{it} is the grid-level occupancy probability and is modeled as a logit-linear function of grid-level covariates,

$$log\left(\psi_{jt}\right) = \delta_0 + \boldsymbol{\delta} \times \boldsymbol{X_{jt}} \text{ (Equation 5b).}$$

We modelled point occupancy as Bernoulli distributed:

$$\left[u_{it}|\theta_{it}, z_{jt}\right] \sim Bernoulli\left(\theta_{it} \times z_{jt}\right) \text{ (Equation 6a),}$$

where θ_{it} is the probability of point occupancy when grid *j* containing point *i* in year *t* was occupied ($z_{jt} = 1$). We modeled the probability of point occupancy (within occupied grids) as a logit-linear function of point-level covariates:

$$log(\theta_{it}) = \beta_0 + \boldsymbol{\beta} \times \boldsymbol{X_{it}} \text{ (Equation 6b).}$$

Finally, we modeled species detections at point *i* in year *t* as binomially distributed:

$$\left[y_{it}|p_{it}, u_{it}\right] \sim Binomial\left(SInt_{it}, p_{it} \times u_{it}\right) \text{ (Equation 7),}$$

where p_{it} is the probability of detection given point occupancy ($u_{it} = 1$) and $SInt_{it}$ is the minute within the survey period when the species was first detected. Detection data represented whether the species was detected at a given point in a given year ($y_{it} \in \{0, 1\}$). Where detections were recorded, we considered sampling to only extend up until the first detection was recorded ($SInt_{it} \in [0,1,\ldots,6] \mid y_{it} = 1$). Where the species was not detected, we assumed sampling extended for the entire length of the survey period ($SInt_{it} = 6 \mid y_{it} = 0$). This approach follows a removal sampling design, which uses the timing of detections to inform detection probability (Farnsworth et al. 2002). We modelled detection probability, p_{it}, as a logit-linear function of survey day-of-year (*DOY*), canopy cover (*CanCov_IMBCR*), and shrub cover (*ShrubCov*) for both species as represented in Equation 4b.

For each species, we fitted models with covariates for which we had predictions (Table 4). We related coarse-scale covariates (776 ac) with grid-level abundance or occupancy

(Equations 2, 5b), and finer scale covariates (2 ac, 12 ac) with point-level abundance or occupancy (Equations 1b, 6b). We considered covariate relationships supported or strongly supported, respectively, if their 90% or 95% Bayesian credible intervals (BCIs) excluded zero. For habitat features represented by both VMAP and IMBCR covariates, we initially favored the VMAP versions because of their particular relevance for forest management, and subsequently switched these out for IMBCR versions where relationships with VMAP covariates were not statistically supported. Because of the fine scale resolution of IMBCR covariates, we only considered relationships with these at the point level (Equations 1b, 6b). Models reported here represent those with maximum utility for testing our predictions, i.e., those with the most statistically supported covariate relationships relevant to our predictions.

We fitted models in JAGS (Plummer 2003) programmed from R (Su and Yajima 2014). For each model, we sampled parameter distributions using 3 chains of length ≥10000 iterations with ≥1000 burn-in, and adjustments to chain length, burn-in, and thinning as needed to reach convergence ($\hat{R} \leq 1.1$) and sufficient sampling ($n_{\text{effective}} \geq 100$) for all parameters (Gelman and Hill 2007). For 3 covariates with missing values (identified in Table 3), we implemented missing data imputation using priors that represented the distributions of observed values (Gelman and Hill 2007).

Results

Over the analysis period, we recorded 149–1,958 detections per species (Table 1). Chipping Sparrows were detected most frequently, and Hairy Woodpeckers least frequently. Bird surveys sampled a substantial range of covariate values at point- and grid-levels (Table 5). We found statistically supported habitat relationships for all species (Table 6, Figures 2–6). Estimated relationships were consistent with most but not all of our predictions (Table 4). All statistically supported relationships were consistent with habitat descriptions for Chipping Sparrow and Dusky Flycatcher, but we were unable to corroborate all predictions for these species. Furthermore, we either could not corroborate or found relationships contradicting predictions for the remaining 3 species – Hammond’s Flycatcher, Olive-sided Flycatcher, and Hairy Woodpecker. We also found supported relationships with canopy composition for 4 focal species (all except Hairy Woodpecker), suggesting course-scale differences in population density among forest types (Table 6, Figures 2–5). Models corrected for spatial and temporal variation in detectability when estimating species habitat relationships. Statistically supported detectability patterns consisted of seasonal variation for 3 species and relationships with canopy cover for 4 species (all except Hairy Woodpecker; Table 6).

Chipping Sparrow

Consistent with the Chipping Sparrow habitat description, point-level abundance related positively with conifer dominance, and negatively with tree size and canopy cover (Tables 4, 6, Figure 2). Additionally, consistent with the literature but not in species habitat descriptions, Chipping Sparrow abundance related positively with standing dead canopy at the point scale. We were unable to definitively corroborate predicted association with ponderosa pine forest. Instead, Chipping Sparrow abundance was higher in lodgepole pine (*Pinus contorta*) and Douglas fir forests compared other forest types (Table 6, Figure 2).

Dusky Flycatcher

Consistent with their habitat description, Dusky Flycatcher abundance related positively with riparian and shrublands both at the point scale, related negatively with tree size at both scales, reached a maximum level with intermediate levels of canopy cover at both scales (Tables 4, 6, Figure 3). We were unable to corroborate an expected positive relationship with conifer dominance or associations with ponderosa pine and Douglas fir forests. Dusky Flycatcher abundance was lowest in lodgepole pine and spruce-fir forests, and highest in forest types other than those explicitly represented in our models.

Hammond's Flycatcher

Most of our predictions for Hammond's Flycatcher received mixed support or were contradicted by the data. Consistent with our prediction, Hammond's Flycatcher abundance related positively with riparian (Tables 4, 6, Figure 4). Contradicting our predictions, however, abundance was negatively related with conifer dominance and was maximized at ≈40–45% canopy cover, well below the predicted desirability of at least 70% canopy cover. We found opposite relationships with tree size at different spatial scales; a positive point-level relationship was consistent with our prediction, but a negative relationship contradicted our prediction and was greater in magnitude. We also found a positive relationship for Hammond's Flycatcher with snags described in the literature but not represented in the species habitat description. Hammond's Flycatcher abundance was higher in spruce-fir and Douglas fir compared to lodgepole and ponderosa pine forests, but was highest in forest types other than those represented explicitly in our analysis (e.g., Western Red Cedar [*Thuja plicata*], Mountain Hemlock [*Tsuga mertensiana*], Western Larch [*Tsuga mertensiana*], or shade-intolerant conifer mix; Table 6, Figure 4).

Olive-sided Flycatcher

Consistent with our prediction, Olive-sided Flycatcher occupancy decreased with increasing tree size at the point scale, and reached maxima at relatively low levels of canopy cover at both scales (Tables 4, 6, Figure 5). We found the opposite relationship with tree size at the grid scale, however, contradicting our prediction. Additionally, the grid-scale relationship with tree size had greater implications for point occupancy than the point-scale relationship (Figure 5). Also contradicting our predictions, occupancy related negatively with riparian at the point scale. We were unable to corroborate predicted relationships with snags and conifer dominance. Olive-sided Flycatcher abundance was higher in spruce-fir, lodgepole pine, and Douglas fir forests compared to other forest types (Table 6, Figure 5).

Hairy Woodpecker

Consistent with our prediction, Hairy Woodpecker occupancy increased with prevalence of dead canopy (Tables 4, 6, Figure 6). Contradicting our predictions, however, Hairy Woodpecker related negatively with tree size at the point scale. We also found a positive point-level relationship with conifer dominance, contradicting our prediction of no relationship.

Table 5. Covariate summary statistics and sample sizes.

Covariate	Point-level		Grid-level	
	Mean (SD, range)	*n*	Mean (SD, range)	*n*
TreeSiz10	71.01 (34.75, 0-100)	3530	66.33 (22, 5.1-99.82)	74
TreeSiz15	42.55 (37.68, 0-100)	3530	39.43 (20.6, 0-86.36)	74
CanCov_IMBCR	23.44 (14.69, 1-95)	3530	--	
CanCov_VMAP	58.51 (18.47, 0-92.78)	3530	56.49 (14.58, 22.33-81.74)	74
percDead	15.56 (6.44, 0-38.28)	3528	15.31 (4.59, 7.24-24.1)	74
NumSnags	3.89 (7.62, 0-304)	3503	--	
Conifer_VMAP	89.03 (19.78, 0-100)	3530	86.02 (9.64, 51.16-99.82)	74
Conifer_IMBCR	80.76 (26.12, 0-110)	3530	--	
PIPO	--		5.35 (13.48, 0-58.64)	74
SpFir	--		24.42 (30.64, 0-95.42)	74
PICO	--		5.71 (12.04, 0-79.03)	74
Ripar_VMAP	0.24 (2.06, 0-38.78)	3530	--	
Ripar_IMBCR	2.96 (8.86, 0-85)	3530	--	
Shrublnd	2.91 (11.79, 0-100)	3530	2.47 (5.21, 0-38.6)	74
ShrubCov	20.29 (16.59, 0-90)	3529	--	

[a] When fitting models, missing values for these covariates were imputed using a vague priors.

Table 6. Model parameter (posterior median and 95% Bayesian credible intervals [BCIs]) estimates quantifying habitat relationships for focal species. Models for Chipping Sparrow (CHSP), Dusky Flycatcher (DUFL), and Hammond's Flycatcher (HAFL) estimate abundance. Models for Olive-sided Flycatcher (OSFL) and Hairy Woodpecker (HAWO) estimate occupancy. Parameters quantify relationships with grid-level abundance or occupancy (δ), point-level abundance or occupancy (β), and detection probability (α). Parameter subscripts refer to covariates in Table 2.

Parameter	Posterior median estimates (95% BCIs)				
	CHSP	DUFL	HAFL	OSFL	HAWO
$\delta_{\text{TreeSiz10}}$	-0.03(-0.18,0.12)	-0.32(-0.57,-0.09)**	--	1.4(0.48,3.32)**	--
$\beta_{\text{TreeSiz10}}$	-0.11(-0.19,-0.04)**	-0.49(-0.62,-0.36)**	--	-0.25(-0.45,-0.05)**	-0.33(-0.58,-0.15)**
$\delta_{\text{TreeSiz15}}$	--	--	-0.49(-0.79,-0.2)**	--	--
$\beta_{\text{TreeSiz15}}$	--	--	0.15(0.01,0.29)**	--	--
$\delta_{\text{CanCov\_VMAP}}$	-0.03(-0.24,0.17)	-0.09(-0.42,0.25)	-0.55(-0.96,-0.17)**	-0.79(-2.3,0.13)*	--
$\delta_{\text{CanCov\_VMAP2}}$	--	-0.43(-0.66,-0.22)**	-0.25(-0.44,-0.06)**	0.46(-0.04,2.22)*	--
$\beta_{\text{CanCov\_VMAP}}$	-0.24(-0.32,-0.15)**	-0.34(-0.52,-0.16)**	-0.35(-0.54,-0.15)**	-1.01(-1.32,-0.73)**	--
$\beta_{\text{CanCov\_VMAP2}}$	--	-0.14(-0.23,-0.05)**	-0.23(-0.33,-0.12)**	-0.27(-0.43,-0.1)**	--
$\delta_{\text{Conifer\_VMAP}}$	0.08(-0.09,0.24)	0.13(-0.18,0.45)	0.26(-0.05,0.57)	0.07(-0.54,0.73)	--
$\beta_{\text{Conifer\_VMAP}}$	0.07(0.01,0.13)**	0.03(-0.08,0.15)	-0.15(-0.26,-0.03)**	0.07(-0.13,0.26)	0.26(0.06,0.5)**
δ_{ShrubLnd}	0.06(-0.06,0.19)	-0.06(-0.34,0.2)	--	--	--
β_{ShrubLnd}	--	0.11(0.01,0.21)**	--	--	--
$\beta_{\text{Ripar\_VMAP}}$	--	0.04(-0.01,0.08)	--	-0.29(-0.8,-0.04)**	--
$\beta_{\text{Ripar\_IMBCR}}$	--	--	0.16(0.09,0.23)**	--	--
δ_{percDead}	-0.05(-0.19,0.1)	--	0.01(-0.23,0.24)	-0.53(-1.39,0.25)	1.26(0.38,2.89)**
β_{percDead}	0.12(0.05,0.18)**	--	-0.28(-0.43,-0.14)**	0.02(-0.15,0.18)	--
δ_{PIPO}	0.07(-0.05,0.2)	0(-0.21,0.21)	-0.56(-0.82,-0.31)**	0.07(-0.43,0.53)	-0.46(-1.45,1.91)
δ_{SpFir}	-0.03(-0.18,0.1)	-0.24(-0.49,0.01)*	-0.53(-0.79,-0.27)**	1.05(0.32,2.88)**	-0.29(-1.33,0.73)
δ_{PICO}	0.13(0.02,0.24)**	-0.28(-0.52,-0.07)**	-0.55(-0.82,-0.31)**	0.8(0.17,2.25)**	0.03(-0.71,1.9)
δ_{PSME}	0.18(0.05,0.31)**	-0.12(-0.35,0.11)	-0.23(-0.48,0.01)*	0.48(0.02,1.15)**	-0.51(-1.65,0.27)
α_{Date}	-0.05(-0.1,0)**	-0.2(-0.3,-0.11)**	-0.09(-0.19,-0.01)**	0.28(-0.34,0.86)	-0.13(-0.39,0.13)
α_{Date2}	0.06(0.01,0.11)**	0.01(-0.08,0.1)	0.08(-0.01,0.17)*	-0.22(-0.62,0.2)	0.11(-0.14,0.34)
$\alpha_{\text{CanCov\_IMBCR}}$	-0.14(-0.19,-0.1)**	-0.14(-0.2,-0.07)**	0.09(0.03,0.15)**	-0.32(-0.66,0.02)*	0.07(-0.2,0.33)
α_{ShrubCov}	0.01(-0.03,0.05)	-0.01(-0.05,0.04)	-0.03(-0.1,0.03)	0.18(-0.06,0.43)	0.11(-0.17,0.43)

*Covariate relationships whose 90% BCI excludes zero.

**Covariate relationships whose 95% BCI excludes zero.

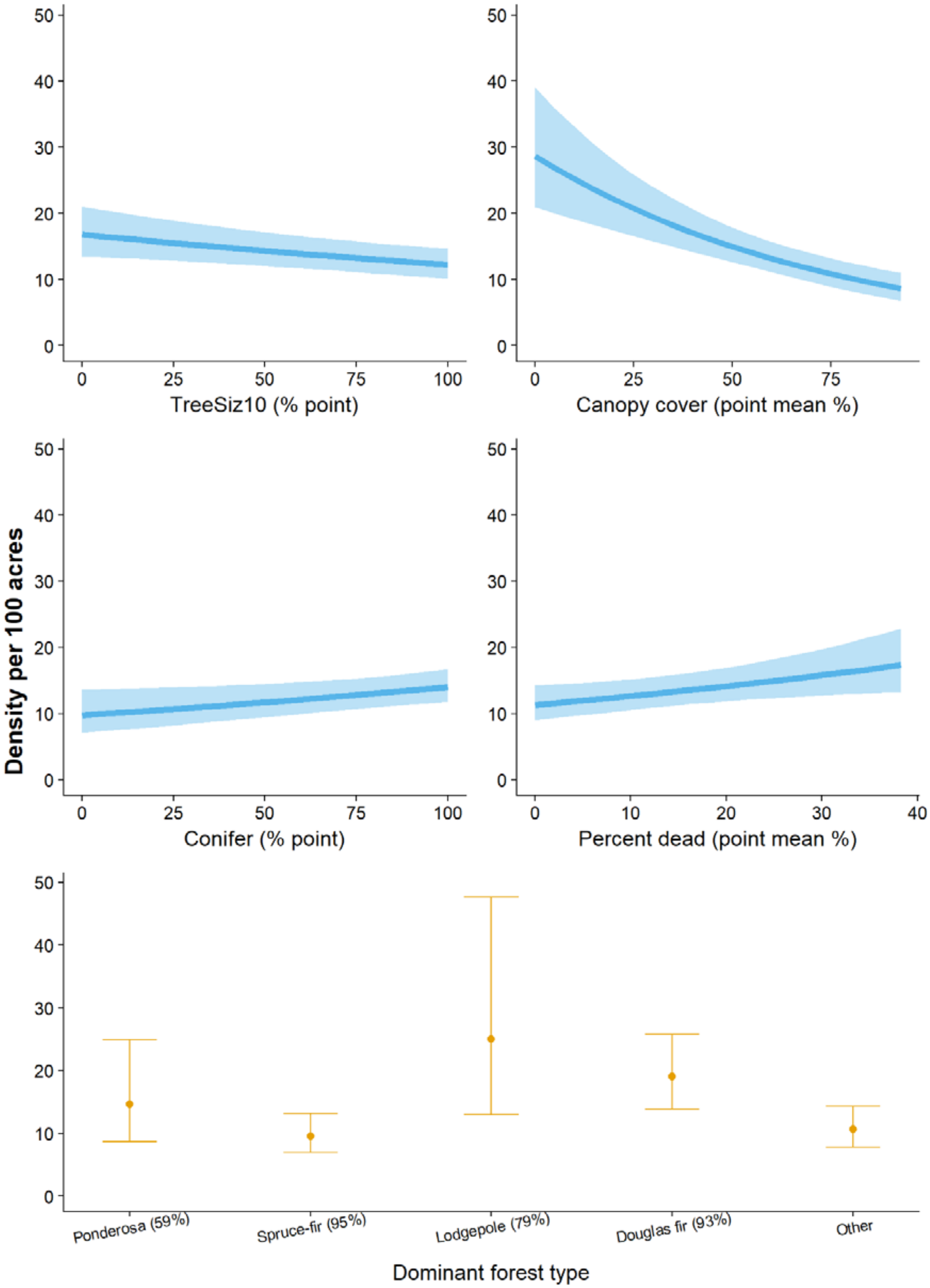

Figure 2. Statistically supported habitat relationships with abundance for Chipping Sparrow. For canopy composition, we display abundance estimates at maximum relative cover values (in parentheses) for each species dominance group.

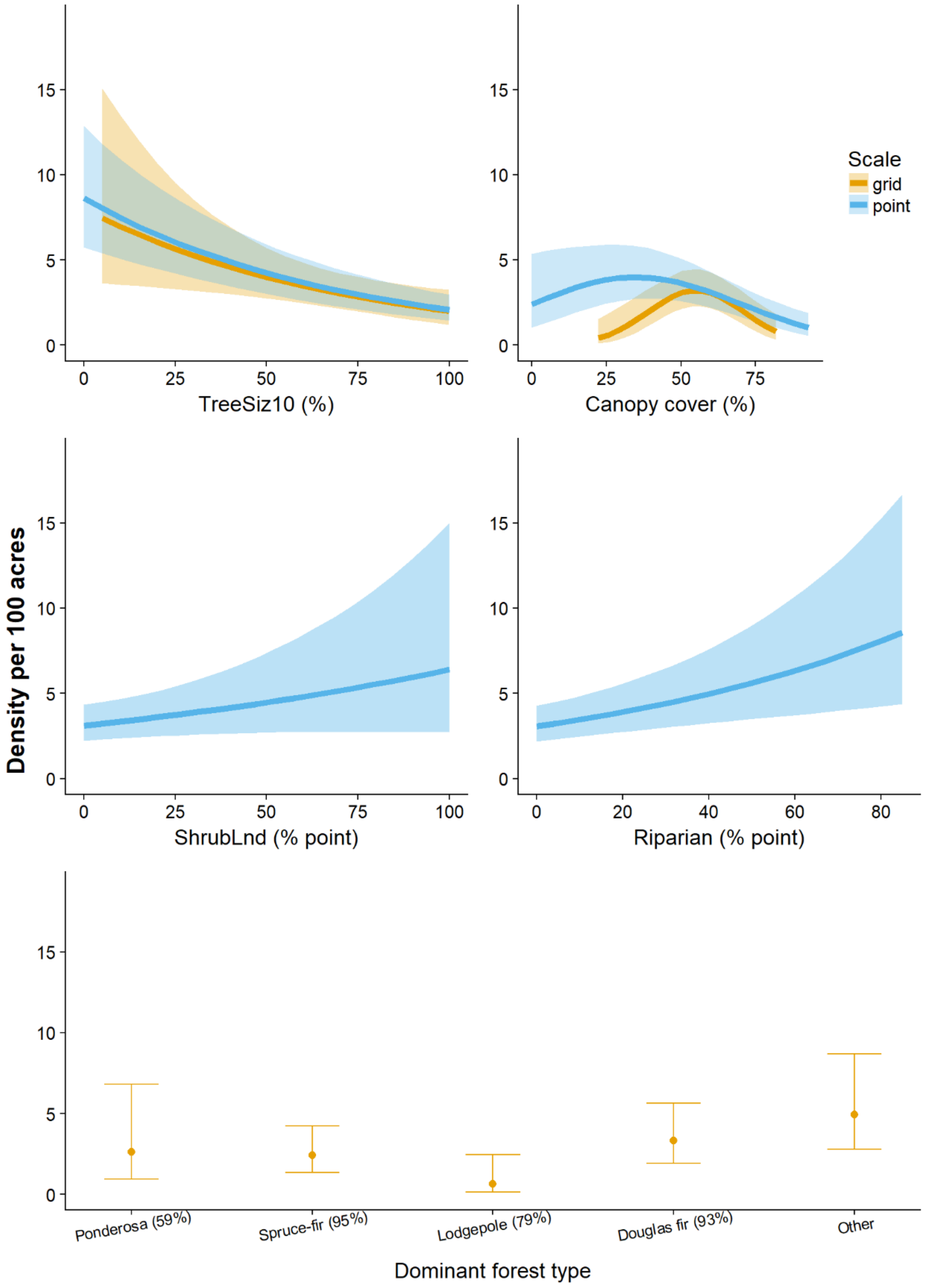

Figure 3. Statistically supported habitat relationships with abundance for Dusky Flycatcher. Blue and orange relationships are at the point and grid levels, respectively. For canopy composition, we display abundance estimates at maximum relative cover values (in parentheses) for each species dominance group.

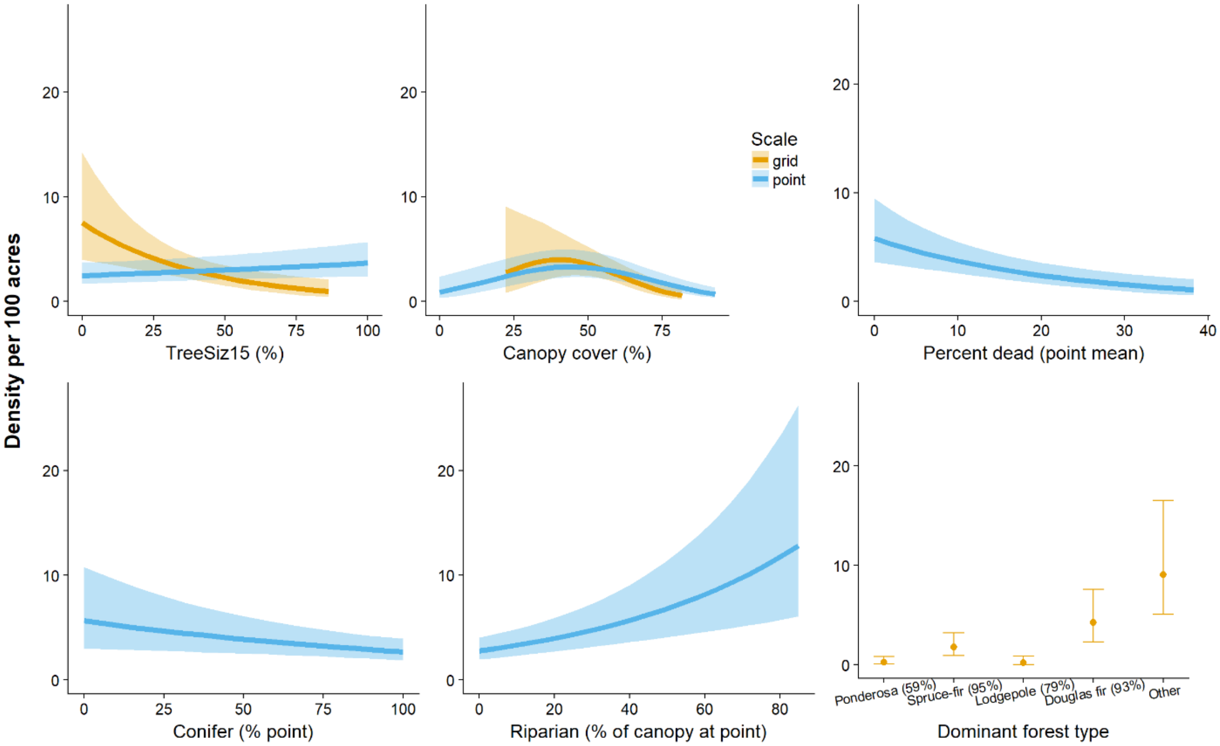

Figure 4. Statistically supported habitat relationships with abundance for Hammond's Flycatcher. Blue and orange relationships are at the point and grid levels, respectively. For canopy composition, we display abundance estimates at maximum relative cover values (in parentheses) for each species dominance group.

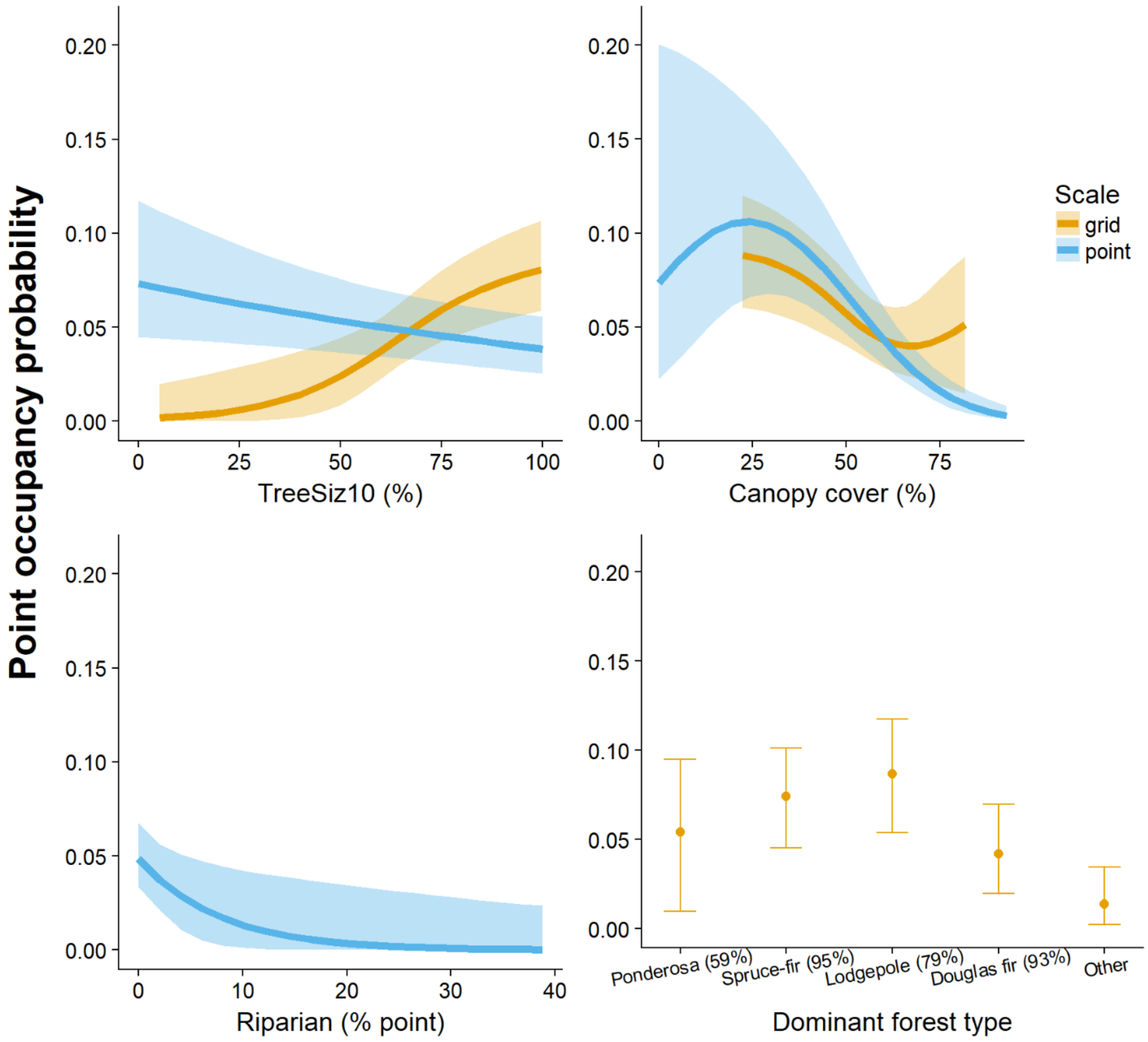

Figure 5. Statistically supported habitat relationships with species occupancy for Olive-sided Flycatcher. Blue and orange relationships are at the point and grid levels, respectively. To allow comparison of the magnitude of relationships exhibited at different spatial scales, we plotted both on a common y-axis, which represents the unconditional probability of point occupancy ($\psi \times \theta$). For canopy composition, we display occupancy estimates at maximum relative cover values (in parentheses) for each species dominance group.

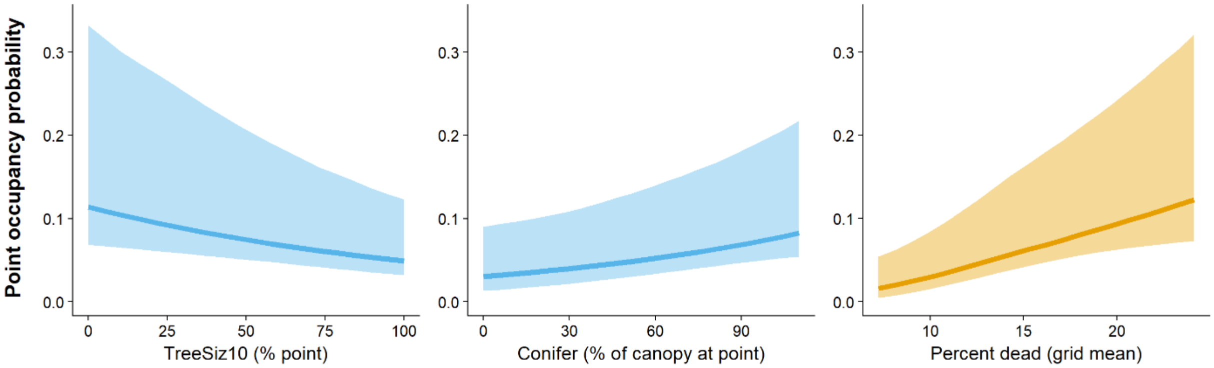

Figure 6. Statistically supported habitat relationships with species occupancy for Hairy Woodpecker. Blue and orange relationships are at the point and grid levels, respectively. To allow comparison of the magnitude of relationships exhibited at different spatial scales, we plotted both on a common y-axis, which represents the unconditional probability of point occupancy ($\psi \times \theta$).

Discussion

Our results largely corroborated focal species habitat descriptions for KIPZ forest monitoring, but nevertheless reveal potential gaps or inaccuracies for all 5 focal species. To the extent evaluated here, habitat descriptions for Chipping Sparrow and Dusky Flycatcher appear accurate, although the Chipping Sparrow description potentially misses snags as a valuable habitat component. We found potential inaccuracies in habitat descriptions for Hammond’s Flycatcher, Olive-sided Flycatcher, and Hairy Woodpecker. Hammond’s Flycatcher related negatively with tree size and conifer dominance, and associated with moderate levels of canopy cover, in contrast with “mature coniferous forest” described as their habitat. Additionally, live canopy cover with relatively few snags represents a potentially overlooked habitat component for this species. Considering the complex relationships exhibited by Olive-sided Flycatcher with tree size and canopy cover, and a lack of any clear relationship with conifer dominance, we cannot confidently corroborate habitat descriptions for this species (Table 3, Appendix A). Finally, although only marginally supported, a negative relationship with tree size contradicts the supposed importance of mid and large trees for Hairy Woodpecker.

Gaps and inaccuracies in habitat descriptions identified by our analysis suggest potential revisions to these descriptions and raise the need to re-evaluate these particular species as foci for monitoring. For example, species other than Hammond’s Flycatcher may be needed to adequately represent “mature coniferous forests” to the extent that this condition is of interest for monitoring. Indeed, none of the species considered here could definitively represent large trees, a key component of mature forests, although focal species may be less important for informing management of tree size because tree size can be measured directly. Comprehensive analysis of species habitat relationships using IMBCR data might suggest other species useful for representing desired conditions.

The focal species monitoring approach planned for KIPZ involves assessing and comparing forest-level trends with regional population trends estimated from IMBCR. Statistically supported regional trends for all species and forest-level trends for all species except Dusky Flycatcher are already apparent with IMBCR (Figure 7; Green et al. 2019). KIPZ forests began implementing new management strategies under their current plans in 2015. Our data therefore only include the initial 2 years following the shift in management approach, wherein realized management-related changes to forest condition were necessarily limited. Statistical power for distinguishing variation in trends across geographic or temporal units, alternative management regimes, or environmental conditions may increase with additional years of monitoring or increased spatial extent of sampling units. More accurate and comprehensive habitat descriptions for focal species would better inform interpretation of focal species trends, and thus, effectiveness of forest management plans.

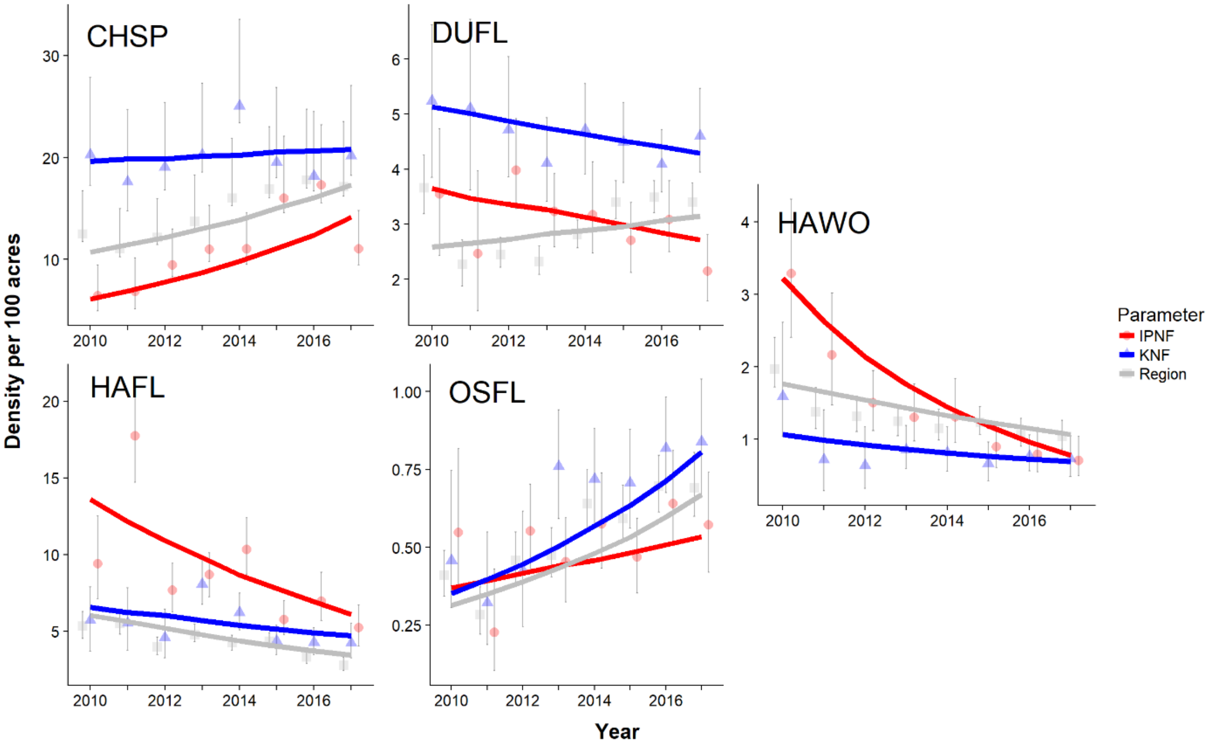

Figure 7. Regional and forest-level population trends (lines) and year-specific abundance estimates with 95% credible intervals (points and error bars) for KIPZ focal species in 2010–2017. Focal species are Chipping Sparrow (CHSP), Dusky Flycatcher (DUFL), Hammond's Flycatcher (HAFL), Olive-sided Flycatcher (OSFL), and Hairy Woodpecker (HAWO). All regional trends (gray) are statistically supported (95% credible intervals exclude zero). Trends for CHSP, HAFL, and HAWO in Idaho Panhandle National Forest (IPNF; red), and OSFL in Kootenai National Forest (KNF; blue) were also statistically supported. Trends are those reported by Green et al. (2019).

Variation in focal species' abundances among forest types should be considered when interpreting population trends and potentially when planning sampling. Even if management is affecting populations, trends may primarily reflect management regimes in forest types where focal species are most abundant. For example, Olive-sided Flycatcher population dynamics may primarily reflect conditions in higher elevation spruce-fir and lodgepole pine forests, making them less informative for assessing management-related improvements in lower elevation forests. Trends for species more closely associated with ponderosa pine and Douglas fir forests may be more informative for evaluating management of those forests. *A priori* power analyses could be a prudent way to gauge whether sampling is sufficient within forest types of interest for meaningful inference to inform management of those forest types.

For managers to use bird population trends to inform movement towards desired conditions, they need to know the particular conditions with which focal species most strongly relate. So far, we have primarily discussed statistical support and direction (positive or negative) for habitat relationships, but the magnitude of these relationships (slope of lines in Figures 2–6) informs which habitat components are most relevant for understanding population trends. For example, we saw the largest changes in Chipping Sparrow abundance in relation to canopy cover compared to other covariates. Thus, managers may pay particular attention to activities with implications for canopy cover to understand population trends for this species.

Although our predictions did not specify spatial scale, our results suggest some scale-specificity for focal species habitat relationships. Chipping Sparrow abundance relationships were primarily apparent at a relatively fine scale among survey points, whereas other species also exhibited some coarser scale relationships among grids. The spatial scale of habitat relationships can provide clues for understanding underlying mechanisms and population drivers. Point scale relationships may reflect finer scale selection of sites for nesting or foraging, whereas grid-scale relationships more likely reflect factors that operate at coarser scales, such as disturbance regimes (Latif et al. 2016b, Tingley et al. 2018). Species that use different habitat conditions for different needs can exhibit contrasting habitat relationships across scales. For example, White-headed Woodpeckers in the Inland Northwest favor open-canopy nest sites but forage in relatively closed-canopy forests, so nest sites relate negatively at a fine scale but positively at a coarse scale with canopy cover (Hollenbeck et al. 2011, Latif et al. 2015). Dusky Flycatcher, Hammond’s Flycatcher, and Olive-sided exhibited such cross-scale differences in relationships with canopy cover and tree size (Figures 3, 4, 5). These relationships potentially reflect associations with edges or canopy openings within forested landscapes, features that appear in habitat descriptions for these species (Table 3, Appendix A).

Focal species’ monitoring could particularly inform management of heterogeneity, a key habitat feature of management interest that is difficult to measure directly. Disturbance maintains heterogeneity by generating forest canopy openings. Homogenization via loss of openings is widely attributed to anthropogenic impacts that alter natural disturbance processes (Schoennagel et al. 2004, Saab and Powell 2005). The importance of heterogeneity for biodiversity is also widely recognized (Saab et al. 2005, Fontaine and Kennedy 2012), but metrics of heterogeneity that are both broadly applicable and ecologically meaningful remain elusive. The KIPZ monitoring plan provides rough, broad targets for forest patch size and structure for different forest types, but without clear links to ecological function. Most KIPZ focal species relate functionally with canopy openings, so we expect management activities that reintroduce openings to the landscape to benefit these species. In particular, flycatcher species associated with intermediate levels of canopy cover and exhibiting contrasting habitat associations across scales, may be particularly informative for verifying ecologically relevant improvements to heterogeneity and associated processes in the Northern Region (see also Latif et al. 2015).

Study limitations

This analysis relies on informative translation of species habitat descriptions into predicted covariate relationships. We recognize some subjectivity in these translations, however. In many cases, habitat descriptions described a range of conditions where species could occur, which are not readily represented as predicted covariate relationships. For example, we could not definitively interpret the expected importance of large trees and conifer forests in the habitat description for Hairy Woodpecker. Moreover, species habitat descriptions do not clearly identify how habitat components related with desired conditions, and thus which ones were particularly important for focal species to inform management (ERG). We consider our evaluation to represent the best possible effort at evaluating species’ habitat descriptions, with the ultimate goal of spurring more rigorous thinking regarding how these species could inform forest-level management.

We recognize several additional limitations to this study. For species with fewer detections (e.g., Hairy Woodpecker), information and thus statistical power may be limited for estimating habitat relationships, so additional data could reveal more. To focus on testing *a priori* predictions to assess assumed habitat relationships, we did not comprehensively consider all possible covariates or covariate combinations of potential interest. The spatial scales for habitat relationships primarily reflected sampling design rather than species ecology. We lacked data on tree densities and inadequately sampled aspen-dominated habitats to evaluate expected relationships with these features. We also need to examine population dynamics and fitness to fully understand species' habitat requirements. For example, selective harvest might generate habitat that attracts Olive-sided Flycatcher without necessarily providing resources for reproductive success (Robertson and Hutto 2007). In short, we would need further analysis of existing monitoring data combined with additional focused sampling to investigate comprehensively focal species' habitat relationships. Nevertheless, our analysis identifies gaps in knowledge needed to implement the focal species concept in KIPZ forests.

Future directions

We suggest reevaluating KIPZ focal species for monitoring desired conditions in light of our study. Reevaluation could include reexamining which focal species adequately represent desired habitat conditions, and which conditions are of interest for focal species monitoring (e.g., which conditions are difficult to measure directly). Leveraging existing data (e.g., IMBCR, VMAP) could facilitate a more rigorous selection of focal species (or guilds) informed by empirically determined habitat relationships along with published habitat descriptions.

Biologists may want to estimate focal species' population trends to evaluate management actions being implemented within particular forest types. Statistical power for estimating population trends depends in part on information in the analyzed data (i.e., degrees of freedom) for species of interest, which for abundance and occupancy, depends heavily on the frequency at which detections are recorded (Roberts et al. 2016). Detections are recorded more frequently where species are more abundant and occupancy is relatively high. Thus, statistical power may vary among forest types with different focal population densities. We therefore suggest *a priori* power analyses to evaluate levels of sampling for assessing management within forest types of interest. Monitoring could then include supplemental sampling or switch the focus to species that provide more power within forest types of interest.

Predictive models could supplement focal species monitoring to assess landscape-wide forest management. Habitat models presented here can predict focal species distributions (abundance or occupancy) across the KIPZ. To have confidence in these predictions, however, we need to measure and compare predictive performance for a more comprehensive set of covariates and covariate values (see discussion above and also Latif et al. 2016a). After verifying predictive performance, we could inform forest planning by relating changes in model-predicted habitat and populations with management and other environmental or demographic changes. We noticed that habitat queries developed for ERG's (2012) simulations did not fully or accurately represent focal species' habitat descriptions. To the extent that predictive habitat models provide more accurate representations of species habitat, replacing habitat queries with predictive models could improve projections of focal species' population trends under alternative management regimes.

Ultimately, focal species for KIPZ were selected because they have expected ecological ties to desired conditions for management. Reintroduction of fire on the landscape as currently planned is expected to benefit or maintain habitat for these species. In addition to habitat relationships, we need to examine relationships with fire to fully evaluate how focal species can inform various management practices. Continued monitoring, targeted studies, and additional data mining may facilitate incorporation of fire relationships into evaluation of focal species for USFS management.

References

Altman, B., and R. Sallabanks. 2012. Olive-sided Flycatcher (*Contopus cooperi*), version 2.0. *in* A. F. Poole and F. B. Gill, editors. The Birds of North America. Cornell Lab of Ornithology, Ithica, N.Y., USA. https://doi.org/10.2173/bna.502.

Berglund, D., R. Bush, J. Barber, and M. Manning. 2009. R1 multi-level vegetation classification, mapping, inventory, and analysis system. Region 1 Vegetation Classification, Inventory, and Analysis Report #09-01 v2.0. Available at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5363894.pdf.

Buckland, S. T., E. A. Rexstad, T. A. Marques, and C. S. Oedekoven. 2015. Distance sampling: methods and applications. Springer International Publishing, Switzerland.

Clare, J. D. J., E. M. Anderson, and D. M. MacFarland. 2015. Predicting bobcat abundance at a landscape scale and evaluating occupancy as a density index in central Wisconsin. The Journal of Wildlife Management 79:469-480.

Covert-Bratland, K. A., W. M. Block, and T. C. Theimer. 2006. Hairy woodpecker winter ecology in ponderosa pine forests representing different ages since wildfire. The Journal of Wildlife Management 70:1379-1392.

ERG. 2012. Wildlife habitat assessment for the Kootenai and Idaho Panhandle plan revision zone (KIPZ). Ecosystem Research Group, Missoula, MT. completed in 2012 for U.S. Forest Service.

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. Auk 119:414-425.

Fontaine, J. B., and P. L. Kennedy. 2012. Meta-analysis of avian and small-mammal response to fire severity and fire surrogate treatments in U.S. fire-prone forests. Ecological Applications 22:1547-1561.

Gelfand, A. E., and A. F. M. Smith. 1990. Sampling-based approaches to calculating marginal densities. Journal of the American Statistical Association 85:398-409.

Gelman, A., and J. Hill. 2007. Data analysis using regression and multilevel/ hierarchical models. Cambridge University Press, New York, NY.

Green, A. W., J. M. Timmer, and C. Staab. 2019. Population Trends and the Effects of Fire on Avian Species of Interest in the U.S. Forest Service Northern Region: A Preliminary Analysis. Bird Conservancy of the Rockies. Brighton, Colorado, USA.

Hanni, D. J., C. M. White, N. J. V. Lanen, J. J. Birek, J. M. Berven, and M. F. McLaren. 2018. Integrated Monitoring in Bird Conservation Regions (IMBCR): Field protocol for spatially-balanced sampling of land bird populations. Unpublished report. Bird Conservancy of the Rockies, Brighton, Colorado, USA.

Hansen, A. J., W. C. McComb, R. Vega, M. G. Raphael, and M. Hunter. 1995. Bird habitat relationships in natural and managed forests in the West Cascades of Oregon. Ecological Applications 5:555-569.

Hollenbeck, J. P., V. A. Saab, and R. W. Frenzel. 2011. Habitat suitability and nest survival of White-headed Woodpeckers in unburned forests of Oregon. Journal of Wildlife Management 75:1061-1071.

Hutto, R. L., and J. S. Young. 1999. Habitat relationships of landbirds in the Northern Region, USDA Forest Service. Gen. Tech. Rep. RMRS-GTR-32. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 pp.

Jackson, J. A., H. R. Ouellet, and B. J. Jackson. 2018. Hairy Woodpecker (*Dryobates villosus*), version 1.1.*in* P. G. Rodewald, editor. The Birds of North America. Cornell Lab of Ornithology, Ithica, N.Y., USA. https://doi.org/10.2173/bna.109.

Joseph, L. N., S. A. Field, C. Wilcox, and H. P. Possingham. 2006. Presence-absence versus abundance data for monitoring threatened species. Conservation Biology 20:1679-1687.

Kéry, M., and J. A. Royle. 2016. Applied hierarchical modeling in ecology. Elsevier, Inc.

Latif, Q. S., M. M. Ellis, V. A. Saab, and K. Mellen-McLean. 2018. Simulations inform design of regional occupancy-based monitoring for a sparsely distributed, territorial species. Ecology and Evolution 8:1171-1185.

Latif, Q. S., V. A. Saab, J. P. Hollenbeck, and J. G. Dudley. 2016a. Transferability of habitat suitability models for nesting woodpeckers associated with wildfire. The Condor 118:766-790.

Latif, Q. S., V. A. Saab, K. Mellen-Mclean, and J. G. Dudley. 2015. Evaluating habitat suitability models for nesting white-headed woodpeckers in unburned forest. The Journal of Wildlife Management 79:263-273.

Latif, Q. S., J. S. Sanderlin, V. A. Saab, W. M. Block, and J. G. Dudley. 2016b. Avian relationships with wildfire at two dry forest locations with different historical fire regimes. Ecosphere 7:e01346.

Marks, J. S., P. Hendricks, and D. Casey. 2016. Birds of Montana. Buteo Books, Arlington, VA.

Middleton, A. L. 1998. Chipping Sparrow (*Spizella passerina*), version 2.0. *in* A. F. Poole and F. B. Gill, editors. The Birds of North America. Cornell Lab of Ornithology, Ithica, N.Y., USA. https://doi.org/10.2173/bna.334.

MTBS. 2018. Monitoring Trends in Burn Severity. https://www.mtbs.gov/. accessed 2018.

Nichols, J. D., L. L. Bailey, A. F. O'Connell Jr, N. W. Talancy, E. H. Campbell Grant, A. T. Gilbert, E. M. Annand, T. P. Husband, and J. E. Hines. 2008. Multi-scale occupancy estimation and modelling using multiple detection methods. Journal of Applied Ecology 45:1321-1329.

Pavlacky, D. C., J. A. Blakesley, G. C. White, D. J. Hanni, and P. M. Lukacs. 2012. Hierarchical multi-scale occupancy estimation for monitoring wildlife populations. The Journal of Wildlife Management 76:154-162.

Pavlacky, D. C., Jr., P. M. Lukacs, J. A. Blakesley, R. C. Skorkowsky, D. S. Klute, B. A. Hahn, V. J. Dreitz, T. L. George, and D. J. Hanni. 2017. A statistically rigorous sampling design to integrate avian monitoring and management within Bird Conservation Regions. PLoS ONE 12.

Pereyra, J. A., and J. A. Sedgwick. 2015. Dusky Flycatcher (*Empidonax oberholseri*), version 2.0. *in* A. F. Poole, editor. The Birds of North America. Cornell Lab of Ornithology, Ithica, N.Y., USA. https://doi.org/10.2173/bna.78.

Plummer, M. 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. *in* Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20-22, Vienna, Austria.

Roberts, D. L., L. Taylor, and L. N. Joppa. 2016. Threatened or Data Deficient: assessing the conservation status of poorly known species. Diversity and Distributions 22:558-565.

Robertson, B. A., and R. L. Hutto. 2007. Is selectively harvested forest an ecological trap for olive-sided flycatchers? The Condor 109:109-121.

Royle, J. A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108-115.

Royle, J. A., D. K. Dawson, and S. Bates. 2004. Modeling abundance effects in distance sampling. Ecology 85:1591-1597.

Royle, J. A., and M. Kéry. 2007. A Bayesian state-space formulation of dynamic occupancy models. Ecology 88:1813-1823.

Saab, V. A., and H. D. W. Powell. 2005. Fire and avian ecology in North America: process influencing pattern. Studies in Avian Biology 30:1-9.

Saab, V. A., H. D. W. Powell, N. B. Kotliar, and K. R. Newlon. 2005. Variation in fire regimes of the Rocky Mountains: implications for avian communities and fire management. Studies in Avian Biology 30:76-96.

Schoennagel, T., T. T. Veblen, and W. H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience 54:661-676.

Sedgwick, J. A. 1994. Hammond's Flycatcher (*Empidonax hammondii*), version 2.0. *in* A. F. Poole and F. B. Gill, editors. The Birds of North America. Cornell Lab of Ornithology, Ithica, N.Y., USA. https://doi.org/10.2173/bna.109.

Su, Y.-S., and M. Yajima. 2014. R2jags: A package for running jags from R. R package version 3.3.0. http://CRAN.R-project.org/package=R2jags.

Tingley, M. W., A. N. Stillman, R. L. Wilkerson, C. A. Howell, S. C. Sawyer, and R. B. Siegel. 2018. Cross-scale occupancy dynamics of a postfire specialist in response to variation across a fire regime. Journal of Animal Ecology 87:1484-1496.

U. S. Forest Service. 2016a. Monitoring guide for the 2015 Forest Plan (V2). Idaho Panhandle National Forests, Coeur d’Alene, Idaho. 104pp.

U. S. Forest Service. 2016b. Monitoring guide for the 2015 Forest Plan (V2). Kootenai National Forest, Libby, Montana. 112pp.

Appendix A. Habitat descriptions compiled by the Ecosystem Research Group (ERG 2012). These descriptions formed the basis for selecting avian focal species for KIPZ forest monitoring, and for habitat queries used in simulations to project expected population trends with forest management. Condensed versions of these descriptions also appear in KIPZ forest monitoring plans (Table 3). The reference list for citations in these descriptions appears in ERG (2012).

Chipping Sparrow and Dusky Flycatcher

The dusky flycatcher (Empidonax oberholseri) and chipping sparrow (Spizella passerine) habitat assessments were combined due to their similar habitat preferences. In the 13 national forests in the USFS Northern Region, both species are mainly found in ponderosa pine forests, cottonwood/aspen forests, and forests that are open through post-fire or timber harvesting activities (Hutto and Young 1999).

Dusky flycatchers occupy relatively open habitats, including mixed coniferous forests, willow riparian zones, and open ecotonal woodlands of Douglas-fir, ponderosa pine, sagebrush, mountain juniper, and aspen groves (Sedgwick 1993). Habitats often include forest edges, agricultural borders, and shrub habitats (Kelly 1993). In central Idaho, dusky flycatchers responded positively to increases in shrub cover and density and number of vegetation height classes, and negatively to increases in overstory conifer density (Kroll 2007).

In northern or montane regions, chipping sparrows breed in open, early successional or low-growth woodlands with shrubby vegetation, and have a strong preference for conifers (Middleton 1998).

Hammond's Flycatcher

Hammond's flycatchers (*Empidonax hammondii*) prefer dense, mature, coniferous or mixed forests ranging from cool and moist to warm and dry sites up to timberline (Sedgwick 1994). Hutto and Young (1999) found them most frequently in relatively uncut conifer forests, as well as in riparian areas, which may be closely associated with conifer forests.

Hammond's flycatchers build open cup nests in tall, large-diameter trees and tend to avoid young stands and stands with openings of scattered large trees (Sakai and Noon 1991). They are likely to be negatively affected by the conversion of mature and old-growth stands into younger age classes.

Since Hammond's flycatchers are aerial foragers, they require openings and airspace in the canopy. It is assumed that in dense forests (70–100% canopy cover), fly-catching opportunities are found in breaks that exist naturally such as riparian sites.

Olive-sided Flycatcher

Olive-sided flycatchers (Contopus cooperi) are found in montane and northern coniferous forests, most often in forest openings, forest edges near natural openings (meadows, canyons, rivers) or human-made openings, and in open to semi-open forest stands (Altman and Sallabanks 2000). They can be found in dry to moist sites across a range of elevations. Occurrence of olive-sided flycatchers is influenced by relatively open canopies and the presence of tall trees for aerial flycatching/foraging, and perches for singing (Altman and Sallabanks 2000).

In mixed conifer forests and in redcedar-western hemlock forests in Idaho, they were found to be significantly more abundant in a matrix of clearcuts than in landscapes of old-growth forest (Evans and Finch 1994; Hejl and Paige 1994). Olive-sided flycatchers have also been found to be more abundant in early post-fire communities than in other major cover types in the Northern Rocky Mountains (Hutto 1995).

Hairy Woodpecker

Hairy woodpeckers (*Picoides villosus*) are year-round resident primary cavity nesters, which subsequently provide nest cavities for a myriad of other small birds and mammals. Hairy woodpeckers nest and forage in mid- and large-sized snags. Nests can occur within fairly short, small diameter snags, although like pileated woodpeckers, they often locate nest cavities near the top of snags (Bull 1987; Thomas 1979).

The hairy woodpecker occupies both deciduous and coniferous forest habitats, as well as forest edges and openings (Jackson et al. 2002).

In the Northern Region, Hutto and Young (1999) found hairy woodpeckers in most forest types, including aspen forests and associated wetlands. They were found more often in cut than in uncut forests, and detected most frequently within early post-fire stands. Because they utilize snags that are often fairly short and of small diameter, hairy woodpeckers, along with northern flickers, are generally not considered at risk in most locales.