Avian community relationships with recreation and human mobility in Colorado: analysis and preliminary results

Report

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Connecting People, Birds and Land

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Bird Conservancy of the Rockies

Connecting people, birds and land

Mission: Conserving birds and their habitats through science, education and land stewardship

Vision: Native bird populations are sustained in healthy ecosystems

Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education, and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship, and sustained through partnerships. Together, we are improving native bird populations, the land, and the lives of people.

Core Values:

1. **Science** provides the foundation for effective bird conservation.
2. **Education** is critical to the success of bird conservation.
3. **Stewardship** of birds and their habitats is a shared responsibility.

Goals:

1. Guide conservation action where it is needed most by conducting scientifically rigorous monitoring and research on birds and their habitats within the context of their full annual cycle.
2. Inspire conservation action in people by developing relationships through community outreach and science-based, experiential education programs.
3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

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Introduction and methods

Land management agencies must increasingly navigate potentially conflicting demands of intensifying recreational land use with mandates for conserving biological resources, including wildlife habitat. Colorado Parks and Wildlife (CPW) contracted Bird Conservancy of the Rockies (hereafter Bird Conservancy) to evaluate recreation and trail use impacts on bird communities. Sampling leveraged the Integrated Monitoring in Bird Conservation Regions (IMBCR) program, whereby ongoing background sampling was supplemented in 2021–2023 with focused sampling of popular recreation areas within the Routt and White River National Forests, and in several Bureau of Land Management Field Offices (Glenwood Springs, Gunnison, Kremmling, Royal Gorge, Saguache, and Uncompahgre). To provide a meaningful contrast to sampled areas impacted by recreation, we included samples from background strata within which focused sampling occurred (i.e., National Forests and BLM field offices listed above). Thus, focused and background sampling together represented both high and low intensities of recreational land use to allow inference of recreation effects on avian populations and communities.

IMBCR sampling units are 1km grid cells each consisting of a 4×4 array of evenly (250 m) spaced survey points. We included data from 285 grid cells representing both recreation-impacted and background strata in our analysis. Not all grid cells were surveyed every year, but the IMBCR design allows variability in sampling intensity while maintaining spatially balanced sampling within strata in any given year. Available data represented 500 grid cell surveys. Surveyors visited points within each sampled grid cell in any given year once per breeding season (May–July) during morning hours to conduct a 6 min count of all birds seen or heard along with the time (min) to detection and the distance to each detected individual. Detected individuals could be either a single bird or a cluster of non-independent members of the same species.

Here, we provide results from a preliminary analysis of data from this monitoring effort using a hierarchical community model formulated to estimate species abundance relationships with covariates quantifying environmental attributes subject to management, human mobility metrics derived from anonymized cell phone data, and habitat metrics derived from field classifications (Table 1). The hierarchical model includes sub-models for each species that estimate components of detectability by modeling time to detection within the survey and distance from the surveyor. Thus, we corrected for both spatial and temporal components of detection probability to better estimate true abundance. Additionally, all species parameters are derived from community-level hyper-parameters to improve estimation for sparsely detected species. The model presented here is not fully converged (max $\hat{R}$ = 1.3), so final relationships may differ slightly from those presented here. We follow a summary of preliminary results from the analysis reported here with a plan for final analysis, including questions and hypotheses to be evaluated.

To abide by model assumptions, we treated clusters of non-independently detected individuals (e.g., members of a mated pair or small groups of interacting individuals detected together) as a single detection in this analysis. Thus, our model describes abundance of independent clusters, which we need to multiply by mean cluster size (< 1.5 for all except 8 species) to estimate abundance. For the remainder of this report, we refer to clusters as individuals and leave derivation of actual abundance for future final analysis.

Table 1. Covariates included in analysis of avian abundance relationships with recreation intensity and human mobility. Management covariates were extracted from COTREX and human mobility covariates from cell phone data. Habitat covariates were based on field classifications of points when surveyed (individual points were sometimes classified differently in different years). Habitat classes are defined in the IMBCR field protocol (see "primary habitats"). Detectability covariates were related with components of detection probability (see text for details).

Type	Covariate	Description
Management	Trail density	Total length (m) of trails within grid cell
	Road density	Total length (m) of roads within grid cell
	Proportion no horses	Proportion of total trail length where horses are prohibited
	Proportion no OHVs	Proportion of total trail length where OHVs are prohibited
Human mobility	Human presence	Binary indicator of whether any cell phone pings were recorded in May–July, 2021–2023
	Traffic volume (no zeros)	Number of cell phone pings × mean residency time per day where humans were present (log transformed for analysis)
	Traffic speed	Mean speed of recorded human movements where humans were present and >1 pings were recorded for at least one unique user
	Mean traffic date	Mean day-of-year of cell phone pings where humans were present
	Mean traffic time	Mean time of day (hours) of cell phone pings where humans were present
Habitat	Shrubland	Proportion of point surveys classified as shrubland (including sage, desert, and semi-desert shrublands)
	Pinyon-juniper	Proportion of point surveys classified as pinyon-juniper forest
	Conifer forest	Proportion of point surveys classified as spruce-fir, mixed conifer, lodgepole pine, or ponderosa pine forest
	Aspen	Proportion of point surveys classified as aspen woodland
	Oak woodland	Proportion of point surveys classified as oak woodland
	Grassland or meadow	Proportion of point surveys classified as grassland, montane meadow, or herbaceous meadow
	Mesic	Proportion of point surveys classified as riparian, open water, or wetland
	Alpine	Proportion of point surveys classified as alpine tundra

Type	Covariate	Description
Detectability	Traffic volume (with zeros)	Same as above except zeros are included to represent grid cells where humans were (apparently) absent, and 0.1 is added to all values before log transformation
	Survey date	Day of year survey was conducted
	Survey time since sunrise	Number of minutes since sunrise (negative values represent pre-sunrise times) when the survey was conducted.

Results, discussion, and plan for final analysis

We recorded 56,096 detections of 152 bird species during the study period (Table 2). We estimated statistically supported abundance relationships with all covariates of abundance (Figures 1–3). We estimated predominantly positive supported relationships with trail density, proportion no OHVs, traffic volume, and traffic speed, predominantly negative relationships with proportion no horses, human presence, and mean traffic date, and similar numbers of positive and negative relationships with road density and mean traffic time (Table 3). Forty-eight species exhibited supported relationships with quadratic terms for mean traffic date or mean traffic time, indicating somewhat non-linearity in relationships with these covariates. Relationships with habitat covariates were consistent with species life histories (Figure 3).

Pearson's correlation coefficients relating management with human mobility metrics showed positive relationships of trail density with human presence, traffic volume, and traffic time, a negative relationship between trail density and traffic date, and a negative relationship between OHV restriction and traffic speed. These relationships are largely consistent with how we might expect management to influence human mobility. Trails increase access by the recreating public, increasing the presence and volume of human traffic. Restriction of motorized vehicles reduces traffic speed because non-motorized traffic (i.e., hiking, biking, and horses) is slower on average than motorized traffic. Other relationships are less intuitive and may reflect coincidences of circumstance rather than management effects *per se*. For example, trails may be denser in areas more accessible to families, visitors, and tourists, who may recreate later in the day, pushing the mean of diel timing later.

Results from this preliminary analysis indicate available data could be used to evaluate various hypotheses for recreation effects on birds. Hypotheses that could be evaluated include 1) more negative impacts of recreation on habitat specialists compared to generalists (Divictor et al 2008), 2) more negative effects for migratory compared to resident species (Miller et al 2020), 3) relatively negative effects for ground nesting and foraging species (Thompson 2015, Larson et al. 2019, but see Botsch et al. 2018), 4) relatively negative effects for small-bodied birds (Larson et al 2019), 5) positive effects for species habituated to disturbance or that benefit from human subsidies (e.g., corvids; Walker and Marzluff 2015), 6) reduced species diversity with increasing recreation intensity (Reed and Merenlender 2008, Larson et al. 2019, Botsch et al. 2018), 7) relatively negative effects on insectivorous species (Miller et al 2020), 8) more negative effects of foot traffic compared to horseback or motorized traffic, and 9) more negative effects of bikers and runners compared to hikers (Hennings 2017, Miller et al 2020). To evaluate hypothesis 6, we can derive a metric of diversity by summarizing across species abundance estimates (Iknayan et al. 2014) and derive relevant covariate relationships with overall diversity. Remaining hypotheses (1-5 and 7-9) describe potential ways in which species life history may modulate recreation effects. To evaluate these, we could consult available literature (e.g., Billerman et al. 2022) and group species based on their life history (e.g., specialists vs generalists) and derive and compare within-group diversity relationships with relevant recreation covariates.

In addition to evaluating hypotheses about recreation impacts, we have data for evaluating mechanisms by which management could influence human impacts, potentially informing management action. By including regression models that relate management with human mobility covariates, we can use path analytic approaches to derive direct, indirect, and total effects of management variables on species abundance and diversity. From there, we can calculate the contribution of human mobility effects to overall management effects, which can help elucidate underlying mechanisms (see also Latif et al. 2023). Evidence for mechanisms provides relatively strong support for potential management actions that leverage documented mechanisms. Moreover, we could use a path analytic model to predict the magnitude of potential management actions to clarify their expected value.

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Table 2. Species recorded and included in analysis of avian relationships with recreation management and human mobility. Four-letter codes are referenced in subsequent figures. The sum of all counts of individuals are reported for each species. Nineteen of detected species are species of greatest conservation need (SGCN) for Colorado.

Code	Species	Sum of counts	SGCN
AGOL	American Goldfinch	15	
AMCR	American Crow	200	
AMDI	American Dipper	1	
AMKE	American Kestrel	34	
AMPI	American Pipit	70	
AMRO	American Robin	2440	
ATFL	Ash-throated Flycatcher	642	
ATTW	American Three-toed Woodpecker	41	
BANS	Bank Swallow	8	
BARS	Barn Swallow	3	
BBMA	Black-billed Magpie	510	
BCCH	Black-capped Chickadee	209	
BCHU	Black-chinned Hummingbird	73	
BCRF	Brown-capped Rosy-Finch	7	x
BEKI	Belted Kingfisher	1	
BEWR	Bewick's Wren	185	
BGGN	Blue-gray Gnatcatcher	626	
BHCO	Brown-headed Cowbird	185	
BHGR	Black-headed Grosbeak	530	
BLGR	Blue Grosbeak	5	
BLJA	Blue Jay	1	
BRBL	Brewer's Blackbird	77	
BRCR	Brown Creeper	37	
BRSP	Brewer's Sparrow	2879	x
BTHU	Broad-tailed Hummingbird	814	
BTPI	Band-tailed Pigeon	11	x
BTSP	Black-throated Sparrow	62	
BTYW	Black-throated Gray Warbler	1134	
BUOR	Bullock's Oriole	14	
BUOW	Burrowing Owl	3	x
BUSH	Bushtit	159	
CACR	Cassia Crossbill	1	
CAFI	Cassin's Finch	86	
CAJA	Canada Jay	183	
CANT	Canyon Towhee	3	
CANW	Canyon Wren	16	

Code	Species	Sum of counts	SGCN
CEDW	Cedar Waxwing	22	
CHSP	Chipping Sparrow	1179	
CHUK	Chukar	20	
CLNU	Clark's Nutcracker	264	
CLSW	Cliff Swallow	46	
COGR	Common Grackle	47	
COHA	Cooper's Hawk	9	
CONI	Common Nighthawk	144	
COPO	Common Poorwill	34	
CORA	Common Raven	1488	
COYE	Common Yellowthroat	5	
DEJU	Dark-eyed Junco	1809	
DOWO	Downy Woodpecker	43	
DUFL	Dusky Flycatcher	1188	
DUGR	Dusky Grouse	29	
EAKI	Eastern Kingbird	1	
EAPH	Eastern Phoebe	1	
EUCD	Eurasian Collared-Dove	40	
EUST	European Starling	13	
EVGR	Evening Grosbeak	93	
FEHA	Ferruginous Hawk	1	x
FOSP	Fox Sparrow	65	
GCKI	Golden-crowned Kinglet	66	
GHOW	Great Horned Owl	2	
GOEA	Golden Eagle	7	x
GRCA	Gray Catbird	15	
GRFL	Gray Flycatcher	568	
GRSG	Greater Sage-Grouse	1	x
GRVI	Gray Vireo	213	x
GTTO	Green-tailed Towhee	4668	
GUSG	Gunnison Sage-Grouse	17	x
HAFL	Hammond's Flycatcher	68	
HAWO	Hairy Woodpecker	210	
HETH	Hermit Thrush	1417	
HOFI	House Finch	442	
HOLA	Horned Lark	1149	
HOSP	House Sparrow	1	
HOWR	House Wren	1110	
JUTI	Juniper Titmouse	178	x
KILL	Killdeer	10	

Code	Species	Sum of counts	SGCN
LARB	Lark Bunting	3	x
LASP	Lark Sparrow	378	
LAZB	Lazuli Bunting	131	x
LEFL	Least Flycatcher	4	
LEGO	Lesser Goldfinch	64	
LISP	Lincoln's Sparrow	510	
LOSH	Loggerhead Shrike	29	x
MGWA	MacGillivray's Warbler	430	
MOBL	Mountain Bluebird	735	
MOCH	Mountain Chickadee	1608	
MODO	Mourning Dove	1434	
NOFL	Northern Flicker	686	
NOHA	Northern Harrier	2	
NOMO	Northern Mockingbird	108	
NRWS	Northern Rough-winged Swallow	21	
NSWO	Northern Saw-whet Owl	3	
OCWA	Orange-crowned Warbler	664	
OSFL	Olive-sided Flycatcher	100	x
OVEN	Ovenbird	2	
PEFA	Peregrine Falcon	3	
PIGR	Pine Grosbeak	84	
PIJA	Pinyon Jay	712	x
PISI	Pine Siskin	980	
PLVI	Plumbeous Vireo	410	
PRFA	Prairie Falcon	6	x
PUMA	Purple Martin	20	x
PYNU	Pygmy Nuthatch	22	
RBNU	Red-breasted Nuthatch	472	
RCKI	Ruby-crowned Kinglet	840	
RECR	Red Crossbill	437	
RNSA	Red-naped Sapsucker	133	
ROPI	Rock Pigeon	36	
ROWR	Rock Wren	1257	
RTHA	Red-tailed Hawk	52	
RWBL	Red-winged Blackbird	80	
SABS	Sagebrush Sparrow	298	
SAPH	Say's Phoebe	46	
SATH	Sage Thrasher	919	
SAVS	Savannah Sparrow	3	
SCOR	Scott's Oriole	1	

Code	Species	Sum of counts	SGCN
SCQU	Scaled Quail	1	
SOSP	Song Sparrow	122	
SPSA	Spotted Sandpiper	2	
SPTO	Spotted Towhee	2179	
SSHA	Sharp-shinned Hawk	7	
STGR	Sharp-tailed Grouse	10	
STJA	Steller's Jay	319	
SWHA	Swainson's Hawk	13	x
SWTH	Swainson's Thrush	182	
TOSO	Townsend's Solitaire	146	
TRES	Tree Swallow	158	
TUVU	Turkey Vulture	60	
VEER	Veery	2	x
VESP	Vesper Sparrow	1916	
VGSW	Violet-green Swallow	869	
VIWA	Virginia's Warbler	705	
WAVI	Warbling Vireo	1602	
WBNU	White-breasted Nuthatch	154	
WCSP	White-crowned Sparrow	820	
WEBL	Western Bluebird	8	
WEFL	Western Flycatcher	171	
WEKI	Western Kingbird	22	
WEME	Western Meadowlark	1196	
WETA	Western Tanager	1522	
WEWP	Western Wood-Pewee	489	
WIFL	Willow Flycatcher	6	
WISA	Williamson's Sapsucker	49	
WISN	Wilson's Snipe	7	
WITU	Wild Turkey	9	
WIWA	Wilson's Warbler	23	
WOSJ	Woodhouse's Scrub-Jay	289	
WTPT	White-tailed Ptarmigan	10	
WTSW	White-throated Swift	63	
YBCH	Yellow-breasted Chat	17	
YEWA	Yellow Warbler	280	
YRWA	Yellow-rumped Warbler	997	

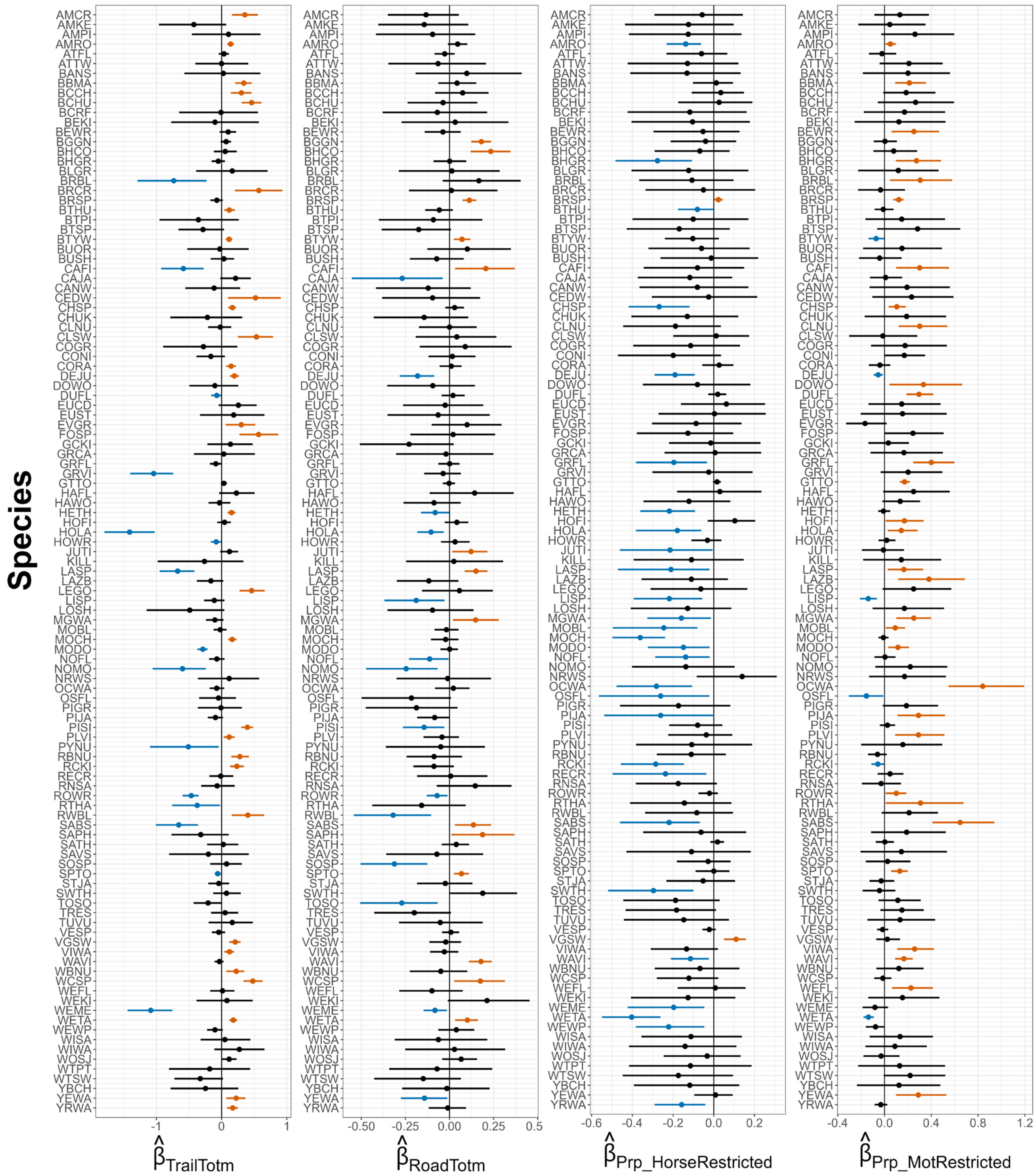

Figure 1. Species abundance relationships with management covariates Trail Density (TrailTotm), Road density (RoadTotm), proportion no horses (Prp_HorseRestricted), and proportion no OHVs (Prp_MotRestricted). Dots and error bars are posterior median and 95% Bayesian credible intervals. Statistically supported positive and negative relationships are orange and blue, respectively.

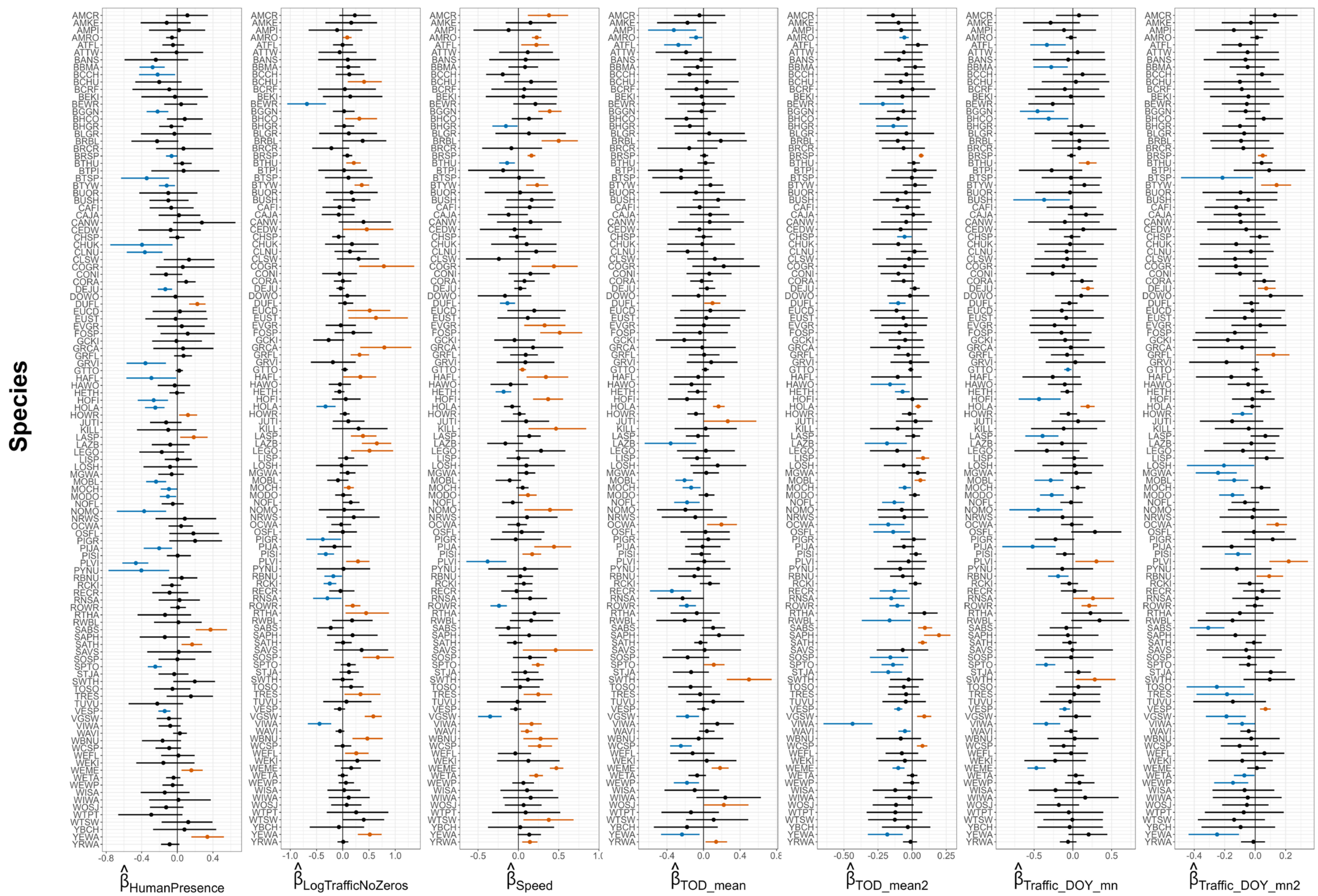

Figure 2. Species abundance relationships with human mobility covariates human presence (HumanPresence), traffic volume (LogTrafficNoZeros), traffic speed (Speed), mean traffic date (Traffic_DOY_mn), and mean traffic time (TOD_mean), along with quadratic terms for the latter two (Traffic_DOY_mn2 and TOD_mean2). Dots and error bars are posterior median and 95% Bayesian credible intervals. Statistically supported positive and negative relationships are orange and blue, respectively.

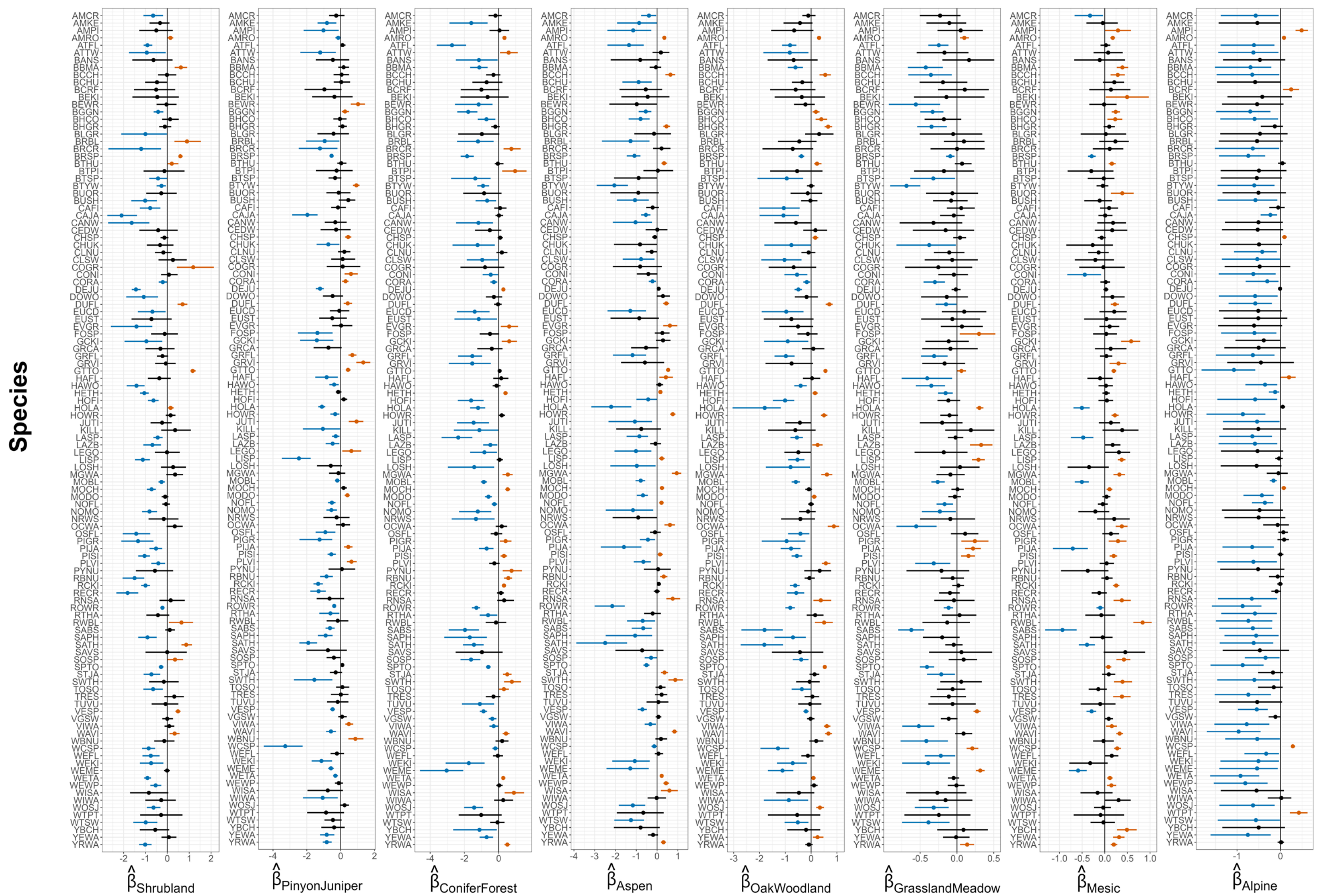

Figure 3. Species abundance relationships with habitat covariates (see Table 1 for full names). Dots and error bars are posterior median and 95% Bayesian credible intervals. Statistically supported positive and negative relationships are orange and blue, respectively.

Table 3. Number of supported species abundance relationships with management and human mobility covariates. Supported relationships are those for which the 95% credible interval excludes zero. Supported relationships for species designated as greatest conservation need (SGCN) in the state of Colorado are also summarized.

Covariate type	Covariate	Number of supported relationships			
		positive	negative	positive SGCN	negative SGCN
Management	Trail density	30	15	0	1
	Road density	14	14	2	0
	Proportion no OHVs	31	6	3	1
	Proportion no horses	2	28	1	3
Human mobility	Human presence	7	22	0	3
	Traffic volume	25	8	1	0
	Mean traffic date	7	17	0	1
	Traffic speed	29	7	2	0
	Mean traffic time	9	13	1	1

Table 4. Pearson's correlation coefficients relating management with human mobility metrics. Asterisks indicate correlations that were statistically supported ($p < 0.01$). Sample sizes (n) are the number of grid cell × year occasions represented by each value.

Human mobility metrics	Correlations with management metrics (n)			
	Trail density	Road density	Proportion no OHVs	Proportion no horses
Human presence	0.139** (500)	0.014 (500)	0 (500)	0.046 (500)
Traffic volume	0.559** (331)	0.021 (331)	0.073 (331)	0.017 (331)
Traffic speed	-0.078 (242)	0.013 (242)	-0.194** (242)	-0.057 (242)
Traffic date	0.222** (242)	-0.108 (242)	0.039 (242)	0.084 (242)
Traffic time	0.239** (331)	0.089 (331)	-0.033 (331)	-0.032 (331)