

Supplemental Material for Betts et al. Synergistic Effects of Climate and Land-Cover Change on Long-Term Bird Population Trends of the Western USA: A Test of Modeled Predictions

Table S1. Variables used in boosted regression trees to model bird abundance. All variables were summarized at the 1-km scale surrounding BBS routes.

Variable	Category
June maximum temperature	Climate-temperature
June minimum temperature	Climate-temperature
July maximum temperature	Climate-temperature
January minimum temperature	Climate-temperature
June precipitation	Climate-precipitation
July precipitation	Climate-precipitation
December precipitation	Climate-precipitation
NDVI	Land cover
NDVI standard deviation	Land cover
Landsat reflectance band 1	Land cover
Landsat reflectance band 2	Land cover
Landsat reflectance band 3	Land cover
Landsat reflectance band 4	Land cover
Landsat reflectance band 5	Land cover
Landsat reflectance band 7	Land cover
Landsat reflectance band 1 standard deviation	Land cover
Landsat reflectance band 2 standard deviation	Land cover
Landsat reflectance band 3 standard deviation	Land cover
Landsat reflectance band 4 standard deviation	Land cover
Landsat reflectance band 5 standard deviation	Land cover
Landsat reflectance band 7 standard deviation	Land cover

Table S2. Parameter estimates of top AIC-ranked generalized linear mixed-effects model for the influence of life history and ecological traits on abundance change model prediction success. Model type shows the model improvement as a function of including land-cover predictor variables in climate models (“Model Type C x L”). Prediction success also improved for declining species (BBS trend; see Fig. 3).

	$\hat{\beta}$	SE	t	P
(Intercept)	0.287	0.023	12.352	0.0000
BBS Trend	-0.019	0.007	-2.575	0.0121
Model type: C x L	0.096	0.029	3.351	0.0013
Foraging (seeds)	-0.079	0.028	-2.793	0.0067

Table S3. American Ornithologists' Union (AOU) code, common and scientific names of all 108 species considered in analysis.

AOU CODE	Common Name	Scientific Name
KILL	Killdeer	<i>Charadrius vociferus</i>
MOUQ	Mountain Quail	<i>Oreortyx pictus</i>
CAQU	California Quail	<i>Callipepla californica</i>
RNEP	Ring-necked Pheasant	<i>Phasianus colchicus</i>
BTPI	Band-tailed Pigeon	<i>Patagioenas fasciata</i>
ROPI	Rock Pigeon	<i>Columba livia</i>
MODO	Mourning Dove	<i>Zenaida macroura</i>
TUVU	Turkey Vulture	<i>Cathartes aura</i>
NOHA	Northern Harrier	<i>Circus cyaneus</i>
COHA	Cooper's Hawk	<i>Accipiter cooperii</i>
AMKE	American Kestrel	<i>Falco sparverius</i>
HAWO	Hairy Woodpecker	<i>Picoides villosus</i>
DOWO	Downy Woodpecker	<i>Picoides pubescens</i>
NUWO	Nuttall's Woodpecker	<i>Picoides nuttallii</i>
RBSA	Red-breasted Sapsucker	<i>Sphyrapicus ruber</i>
PIWO	Pileated Woodpecker	<i>Dryocopus pileatus</i>
ACWO	Acorn Woodpecker	<i>Melanerpes formicivorus</i>
VASW	Vaux's Swift	<i>Chaetura vauxi</i>
WTSW	White-throated Swift	<i>Aeronautes saxatalis</i>
ANHU	Anna's Hummingbird	<i>Calypte anna</i>
RUHU	Rufous Hummingbird	<i>Selasphorus rufus</i>
WEKI	Western Kingbird	<i>Tyrannus verticalis</i>
ATFL	Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>
SAPH	Say's Phoebe	<i>Sayornis saya</i>
BLPH	Black Phoebe	<i>Sayornis nigricans</i>
OSFL	Olive-sided Flycatcher	<i>Contopus cooperi</i>
WEWP	Western Wood-Pewee	<i>Contopus sordidulus</i>
PSFL	Pacific-slope Flycatcher	<i>Empidonax difficilis</i>
WIFL	Willow Flycatcher	<i>Empidonax traillii</i>
HAFL	Hammond's Flycatcher	<i>Empidonax hammondi</i>
DUFL	Dusky Flycatcher	<i>Empidonax oberholseri</i>
HOLA	Horned Lark	<i>Eremophila alpestris</i>
BBMA	Black-billed Magpie	<i>Pica hudsonia</i>
STJA	Steller's Jay	<i>Cyanocitta stelleri</i>
WESJ	Western Scrub-Jay	<i>Aphelocoma californica</i>
AMCR	American Crow	<i>Corvus brachyrhynchos</i>

EUST	European Starling	<i>Sturnus vulgaris</i>
RWBL	Red-winged Blackbird	<i>Agelaius phoeniceus</i>
WEME	Western Meadowlark	<i>Sturnella neglecta</i>
BUOR	Bullock's Oriole	<i>Icterus bullockii</i>
BRBL	Brewer's Blackbird	<i>Euphagus cyanocephalus</i>
EVGR	Evening Grosbeak	<i>Coccothraustes vespertinus</i>
PUFI	Purple Finch	<i>Carpodacus purpureus</i>
CAFI	Cassin's Finch	<i>Carpodacus cassinii</i>
HOFI	House Finch	<i>Carpodacus mexicanus</i>
RECR	Red Crossbill	<i>Loxia curvirostra</i>
AMGO	American Goldfinch	<i>Carduelis tristis</i>
LEGO	Lesser Goldfinch	<i>Carduelis psaltria</i>
PISI	Pine Siskin	<i>Carduelis pinus</i>
VESP	Vesper Sparrow	<i>Pooecetes gramineus</i>
SAVS	Savannah Sparrow	<i>Passerculus sandwichensis</i>
GRSP	Grasshopper Sparrow	<i>Ammodramus savannarum</i>
LASP	Lark Sparrow	<i>Chondestes grammacus</i>
WCSP	White-crowned Sparrow	<i>Zonotrichia leucophrys</i>
CHSP	Chipping Sparrow	<i>Spizella passerina</i>
BRSP	Brewer's Sparrow	<i>Spizella breweri</i>
DEJU	Dark-eyed Junco	<i>Junco hyemalis</i>
SAGS	Sage Sparrow	<i>Amphispiza belli</i>
SOSP	Song Sparrow	<i>Melospiza melodia</i>
FOSP	Fox Sparrow	<i>Passerella iliaca</i>
SPTO	Spotted Towhee	<i>Pipilo maculatus</i>
GTTO	Green-tailed Towhee	<i>Pipilo chlorurus</i>
CALT	California Towhee	<i>Pipilo crissalis</i>
BHGR	Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>
LAZB	Lazuli Bunting	<i>Passerina amoena</i>
WETA	Western Tanager	<i>Piranga ludoviciana</i>
CLSW	Cliff Swallow	<i>Petrochelidon pyrrhonota</i>
BARS	Barn Swallow	<i>Hirundo rustica</i>
TRES	Tree Swallow	<i>Tachycineta bicolor</i>
VGSW	Violet-green Swallow	<i>Tachycineta thalassina</i>
BANS	Bank Swallow	<i>Riparia riparia</i>
NRWS	Northern Rough-winged Swallow	<i>Stelgidopteryx serripennis</i>
CEDW	Cedar Waxwing	<i>Bombcilla cedrorum</i>
LOSH	Loggerhead Shrike	<i>Lanius ludovicianus</i>
WAVI	Warbling Vireo	<i>Vireo gilvus</i>
CAVI	Cassin's Vireo	<i>Vireo cassinii</i>

HUVI	Hutton's Vireo	<i>Vireo huttoni</i>
NAWA	Nashville Warbler	<i>Vermivora ruficapilla</i>
OCWA	Orange-crowned Warbler	<i>Vermivora celata</i>
YEWA	Yellow Warbler	<i>Dendroica petechia</i>
BTYW	Black-throated Gray Warbler	<i>Dendroica nigrescens</i>
HEWA	Hermit Warbler	<i>Dendroica occidentalis</i>
MGWA	MacGillivray's Warbler	<i>Oporornis tolmiei</i>
COYE	Common Yellowthroat	<i>Geothlypis trichas</i>
YBCH	Yellow-breasted Chat	<i>Icteria virens</i>
WIWA	Wilson's Warbler	<i>Wilsonia pusilla</i>
HOSP	House Sparrow	<i>Passer domesticus</i>
NOMO	Northern Mockingbird	<i>Mimus polyglottos</i>
CATH	California Thrasher	<i>Toxostoma redivivum</i>
ROWR	Rock Wren	<i>Salpinctes obsoletus</i>
BEWR	Bewick's Wren	<i>Thryomanes bewickii</i>
HOWR	House Wren	<i>Troglodytes aedon</i>
PAWR	Pacific Wren	<i>Troglodytes troglodytes</i>
BRCR	Brown Creeper	<i>Certhia americana</i>
WBNU	White-breasted Nuthatch	<i>Sitta carolinensis</i>
RBNU	Red-breasted Nuthatch	<i>Sitta canadensis</i>
OATI	Oak Titmouse	<i>Baeolophus inornatus</i>
BCCH	Black-capped Chickadee	<i>Parus atricapillus</i>
MOCH	Mountain Chickadee	<i>Parus gambeli</i>
CBCH	Chestnut-backed Chickadee	<i>Parus rufescens</i>
WREN	Wrentit	<i>Chamaea fasciata</i>
BUSH	Bushtit	<i>Psaltiriparus minimus</i>
GCKI	Golden-crowned Kinglet	<i>Regulus satrapa</i>
BGGN	Blue-gray Gnatcatcher	<i>Polioptila caerulea</i>
TOSO	Townsend's Solitaire	<i>Myadestes townsendi</i>
SWTH	Swainson's Thrush	<i>Catharus ustulatus</i>
HETH	Hermit Thrush	<i>Catharus guttatus</i>
WEBL	Western Bluebird	<i>Sialia mexicana</i>
MOBL	Mountain Bluebird	<i>Sialia currucoides</i>

Table S4. AIC values and weights for life history and ecological trait predictors of model predictions for bird abundance changes from 1985 to 2010. The top model included long-term bird population trends, model predictor variable set (climate, land-cover versus both), and foraging preference (seeds, insects).

Model	K	AIC _c	Delta AIC _c	AIC _c Weight
Trend + predictor type + foraging	7	-103.68	0	0.96
Trend + predictor type	6	-97.39	6.29	0.04
Trend	4	-87.61	16.07	0
Foraging	4	-87.31	16.37	0

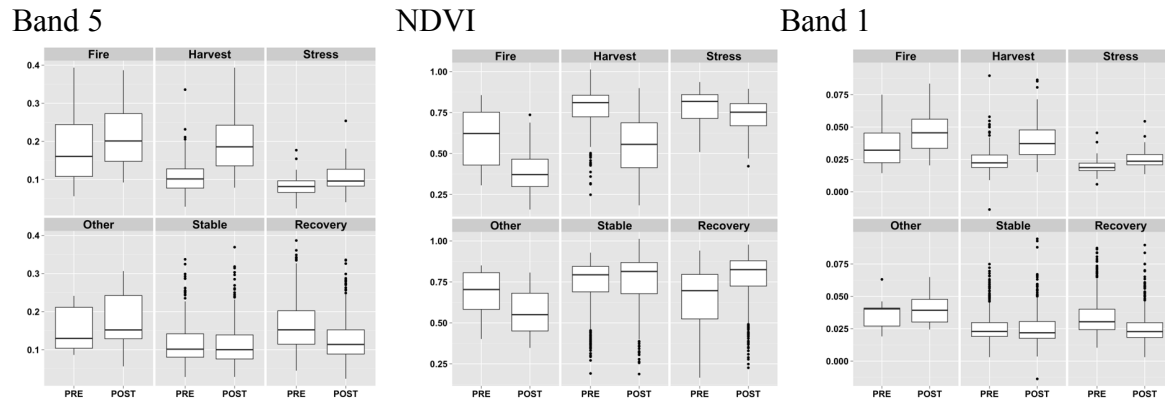


Figure S1. Examples of the effect of disturbance types on reflectance of Landsat TM band 5, band 1 and NDVI. Note that timber harvest (clearcutting) has a strong influence on reflectance on both band 5 and NDVI from pre-harvest (“PRE”) to post-harvest (“POST”). Similarly, regeneration (“recovery”) is correlated with NDVI. Sites that experienced no disturbance during the course of our study (“Stable”) showed little variation in reflectance, despite substantial climate change in some locations of our study area. Landsat reflectance changes therefore are indicative of land-cover changes at relatively fine spatial resolutions (30 m x 30 m pixels). All locations were manually labeled by expert observers using high-resolution Google Earth imagery (i.e., timber harvest [N=462], fire [N=126], insect damage [N=58]) or non-disturbance (undisturbed ‘control’ sites [N=880]) or sites where the forest has regrown following stand-replacing disturbance [N=1460]. Landsat signatures were taken in the year of disturbance in all cases and all years following disturbance until 2010 for forest regrowth.

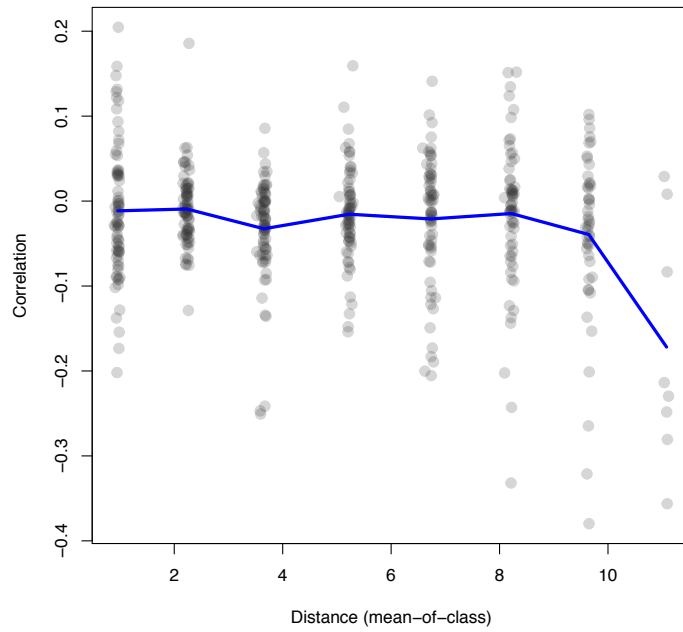


Figure S2 Moran's I values for the residuals of all 108 species models that combined land-cover and climate data. Note that values of I cluster around zero across all spatial lags; maximum values of I were typically <0.2 . Distance is measured in degrees of latitude and longitude.