

APPENDIX 1

Additional Details on Time-of-Day Adjustment

Data source and filtering

We downloaded the raw BBS 50-stop data for each species for the period 1997-2014 (Pardieck et al. 2015). During the model testing and development phase we found that limiting the dataset to 500 BBS routes for widespread species (i.e. species that occurred on > 500 routes) greatly increased computational time without significantly altering model results. For these species, we applied two data quality filters to preferentially include route-level data that was representative of species: 1) we excluded BBS routes where the mean number of counts (across years) was an extreme outlier (defined as $3x$ the interquartile distance) relative to all other BBS routes, and 2) we preferentially included BBS routes if they were either run more than once with peak counts at different stop numbers in different years (unless the peak count occurred at the first stop), or had a large number of stops (defined as $\geq 75\%$ percentile) where the species was observed. We applied these filters to limit variability due to differences in habitat suitability along the 50 stops of the survey being incorrectly attributed as changes in time-of-day detectability.

Model

We fit generalized additive models (GAMs) to the raw BBS 50-stop data for each species to relate the time of day (i.e., stop number) to the number of birds observed at each stop while accounting for route-level effects and trends through time. We modeled the number of birds counted at each stop with a negative binomial distribution to allow for overdispersion of counts. The stop number acts as a proxy for the time-of-day since survey volunteers are instructed to begin the survey at a set time relative to dawn (30 minutes before local sunrise). The model finds a smoothed nonlinear function to relate stop number to the number of birds counted using a penalized cubic regression spline. The model included a random

effect for each BBS route and a linear fixed effect for survey year. All models were fit in the R language and environment (R Core Team 2017), using the package ‘mgcv’ (Wood 2011).

The ‘mgcv’ package has a GAM function that is optimized for efficiently fitting models to large datasets (bam; Wood et al. 2015). However, for the negative binomial family, the ‘bam’ function cannot handle fitting the *theta* (θ) parameter, and a fixed value is required. The parameter θ , in a negative binomial distribution, specifies the variance such that $var(y) = \mu + \mu^2/\theta$, where $\mu = E(y)$. To take advantage of this optimized GAM function, we fit the models using a two-step process. First, to estimate θ we specified a model using a subset of the data and the ‘gam’ function. For this step, we randomly selected 50 BBS routes from the set of suitable routes (see Data source and filtering above), fit a GAM model as described above, and recorded the θ parameter. We repeated this 10 times for each random draw of 50 BBS routes for each species. To make sure the estimation of θ was not overly influenced by the number of routes included in the random draw, we tested models with random draws 40, 60, 80, or 100 BBS routes on a subset of species. No pronounced pattern emerged with θ changing as a function of the number of routes included in the set. Once the first step was complete, we fit the full model using the mean θ value from the previous step as a fixed term in the negative binomial distribution using the ‘bam’ function.

Time-of-day adjustment

We then used the fitted time-of-day curves to calculate a time-of-day adjustment distribution for each species by resampling the fitted curve at each stop and re-calculating the maximum count divided by the mean count for each iteration. We parameterized the time-of-day distributions based on 1000 iterations. For species recorded on < 100 BBS routes, we calculated an average weighted by number of routes from all species in the same taxonomic (genus or family) and/or temporal (diurnal/nocturnal) group with > 100 routes (Table A1). Previous PIF population size estimates used averaging for species with > 50 routes

(Blancher et al. 2007). The decision to increase this to 100 routes was based on an examination of the coefficient of variation of the time of day adjustment statistic as a function of the number of routes.

Literature Cited

Blancher, P. J., K. V. Rosenberg, A. O. Panjabi, B. Altman, J. Bart, C. J. Beardmore, G. S. Butcher, D. D.

Demarest, R. Dettmers, E. H. Dunn, W. E. Easton, W. C. Hunter, E. E. Iñigo-Elias, D. N. Pashley, C. J.

Ralph, T. D. Rich, C. M. Rustay, J. M. Ruth, and T. C. Will. 2007. *Guide to the Partners in Flight*

Population Estimates Database. North American Landbird Conservation Plan 2004. Partners in Flight Technical Series No 5.

Pardieck, K. L., D. J. Ziolkowski, M.-A. R. Hudson, and K. Campbell. 2016. *North American Breeding*

Bird Survey Dataset 1966 - 2015, version 2015.1. U.S. Geological Survey, Patuxent Wildlife Research

Center, Laurel, MD, USA. <https://www.pwrc.usgs.gov/BBS/RawData>

R Core Team. 2017. *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria.

Wood, S. N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B)* 73:3–36.

Wood, S. N., Y. Goude, and S. Shaw. 2015. Generalized additive models for large data sets. *Journal of the Royal Statistical Society: Series C (Applied Statistics)* 64:139–155.

Table A1. Species present on < 100 BBS routes for which a weighted mean by number of BBS routes from the same taxonomic (genus or family) and/or temporal (diurnal/nocturnal) group with > 100 routes was used to estimate the time-of-day adjustment.

Genus mean	
Greater Prairie-Chicken (<i>Tympanuchus cupido</i>)	Long-billed Thrasher (<i>Toxostoma longirostre</i>)
Allen's Hummingbird (<i>Selasphorus sasin</i>)	Bendire's Thrasher (<i>Toxostoma bendirei</i>)
Rough-legged Hawk (<i>Buteo lagopus</i>)	California Thrasher (<i>Toxostoma redivivum</i>)
Western Screech-Owl ^a (<i>Megascops kennicottii</i>)	Le Conte's Thrasher (<i>Toxostoma lecontei</i>)
Lewis's Woodpecker (<i>Melanerpes lewis</i>)	Crissal Thrasher (<i>Toxostoma crissale</i>)
Gila Woodpecker (<i>Melanerpes uropygialis</i>)	Bohemian Waxwing (<i>Bombycilla garrulus</i>)
Golden-fronted Woodpecker (<i>Melanerpes aurifrons</i>)	American Pipit (<i>Anthus rubescens</i>)
Nuttall's Woodpecker (<i>Picoides nuttallii</i>)	Hoary Redpoll (<i>Acanthis hornemanni</i>)
White-headed Woodpecker (<i>Picoides albolarvatus</i>)	Lawrence's Goldfinch (<i>Spinus lawrencei</i>)
Gilded Flicker (<i>Colaptes chrysoides</i>)	Lapland Longspur (<i>Calcarius lapponicus</i>)
Gyr Falcon (<i>Falco rusticolus</i>)	Abert's Towhee (<i>Melospiza aberti</i>)
Gray Vireo (<i>Vireo vicinior</i>)	Black-chinned Sparrow (<i>Spizella atrogularis</i>)
Black-whiskered Vireo (<i>Vireo altiloquus</i>)	American Tree Sparrow ^b (<i>Spizelloides arborea</i>)
Mexican Jay (<i>Aphelocoma wollweberi</i>)	Bell's Sparrow (<i>Artemisiospiza belli</i>)
Northwestern Crow (<i>Corvus caurinus</i>)	Seaside Sparrow (<i>Ammodramus maritimus</i>)
Cave Swallow (<i>Petrochelidon fulva</i>)	Hooded Oriole (<i>Icterus cucullatus</i>)
Bridled Titmouse (<i>Baeolophus wollweberi</i>)	Bronzed Cowbird (<i>Molothrus aeneus</i>)
Black-crested Titmouse (<i>Baeolophus atricristatus</i>)	Lucy's Warbler (<i>Oreothlypis luciae</i>)
Black-tailed Gnatcatcher (<i>Poliophtila melanura</i>)	Grace's Warbler (<i>Setophaga graciae</i>)
Gray-cheeked Thrush (<i>Catharus minimus</i>)	Red-faced Warbler (<i>Cardellina rubrifrons</i>)
Family mean	
Chukar (<i>Alectoris chukar</i>)	Northern Hawk Owl ^c (<i>Surnia ulula</i>)
Willow Ptarmigan (<i>Lagopus lagopus</i>)	Elf Owl ^a (<i>Micrathene whitneyi</i>)
Rock Ptarmigan (<i>Lagopus muta</i>)	Great Gray Owl ^c (<i>Strix nebulosa</i>)
Mexican Whip-poor-will ^a (<i>Antrostomus arizonae</i>)	Long-eared Owl ^a (<i>Asio otus</i>)
Black Swift (<i>Cypseloides niger</i>)	Flammulated Owl ^a (<i>Deltarhynchus flammulatus</i>)
Costa's Hummingbird (<i>Calypte costae</i>)	McCown's Longspur (<i>Rhynchophanes mccownii</i>)
Harris's Hawk (<i>Parabuteo unicinctus</i>)	
All Diurnal	
Arctic Warbler (<i>Phylloscopus borealis</i>)	
Northern Wheatear (<i>Oenanthe oenanthe</i>)	

^a Summarizing group is further subset to only nocturnal species.

^b Summarized by genus *Spizella*.

^c Summarizing group is further subset to only diurnal species.