Ecography

ECOG-04487

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Supplementary material

Appendix 1

Study area and diagnostic species of ecological landtypes

We sampled the taxonomic composition of bird (species) and plant (species and/or genera of woody stems in two size classes) assemblages from point samples distributed among five study sites in an actively managed, mixed-use forest landscape (~1300-km^2 area), dominated by deciduous hardwoods, in southeastern Ohio's Central Hardwoods (Fig. A1). A wide floristic and physiognomic spectrum was sampled to capture the broad variation in forest-associated habitat types encountered in the study area, maximizing the ecological coverage and comprehensiveness of the final data set, proven to be an important decision as many of the bird species have been shown to utilize a variety of forest types and growth stages throughout the breeding period (Vitz and Rodewald 2007).

Ecological landtypes (ELT) are used as a framework for generalizing forest community type and for the restoration of desired species assemblages due to the strong correlation of tree and shrub species to the topographic contours of the unglaciated Allegheny Plateaus physiographic region (Iverson et al. 2018). The ELTs recognized in this study are the following:

1. Ridgetops and southwestern hillslopes
2. Northeastern hillslopes
3. Bottomlands

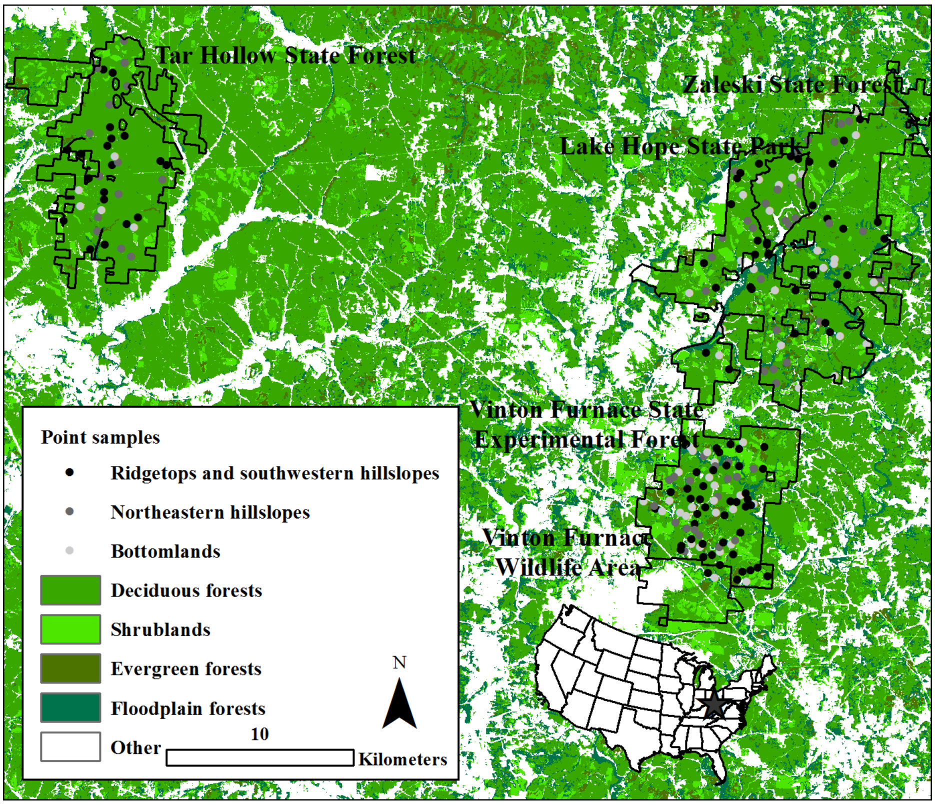

Figure A1. Study area. Locations of the five forest study sites and 210 point samples (shaded by ecological landtype) used to sample the composition of bird and plant assemblages in a forested landscape in southeastern Ohio's Central Hardwoods.

The ELT data help to generalize the complexity in forest assemblages, assisting the interpretation of patterns in the co-correspondence of avian and plant assemblages in this study. An indicator species analysis (Dufrêne and Legendre 1997) was further conducted to determine diagnostic plant taxa of the three ELTs using the labdsv package (Roberts 2016) in the R statistical environment (<https://cran.r-project.org/>). Diagnostic plant taxa of relatively dry ridgetops and southwestern hillslopes featured *Quercus spp*, *Smilax spp*, *Acer rubrum* and *Vaccinium spp* (Table A1, Fig. A2). Mixed-mesophytic species, *Lindera benzoin*, *Acer saccharum*, *Ulmus rubra*, and *Fraxinus pennsylvanica*, were indicative of northeastern hillslopes. For bottomlands, *Rosa multiflora*, *Toxicdendron radicans*, *Betula nigra* and *Acer saccharinum* were examples of some indicator species, highlighting the range in past disturbances and ecological conditions (e.g. previously settled flat inlands and riparian zones) unique to this ELT.

Table A1. Indicator species table. Indicator species of the ecological landtypes, including indicator value (IV) and frequency of occurrence (*f*) out of the 210 point locations sampled in this study.

SPECIES/GENERA	ECOLOGICAL LANDTYPE	IV	P	F
Rosa_multiflora	bottomlands points	31.74	0.004	81
Toxicodendron_radicans	bottomlands points	22.26	0.019	48
Ulmus_americana	bottomlands points	18.47	0.007	31
Betula_nigra	bottomlands points	11.85	0.004	10
Viburnum_dentatum	bottomlands points	10.76	0.047	18
Acer_saccharinum	bottomlands points	8.82	0.004	6
Cornus_amomum	bottomlands points	7.18	0.006	5
Lindera_benzoin	northeastern hillslopes points	45.27	0.001	125
Acer_saccharum	northeastern hillslopes points	36.68	0.016	138
Ulmus_rubra	northeastern hillslopes points	28.99	0.005	73
Fraxinus_pennsylvanica	northeastern hillslopes points	16.89	0.006	29
Quercus_montana	ridgetops and southwestern hillslopes points	55.53	0.001	105
*Smilax*_spp	ridgetops and southwestern hillslopes points	54.4	0.001	200
Acer_rubrum	ridgetops and southwestern hillslopes points	50.64	0.001	195
Quercus_velutina	ridgetops and southwestern hillslopes points	46.18	0.001	147
Oxydendrum_arboreum	ridgetops and southwestern hillslopes points	45.27	0.001	116
Sassafras_albidum	ridgetops and southwestern hillslopes points	41.91	0.001	105
Nyssa_sylvatica	ridgetops and southwestern hillslopes points	39.53	0.018	171
Quercus_alba	ridgetops and southwestern hillslopes points	38.91	0.043	159
Amelanchier_arborea	ridgetops and southwestern hillslopes points	31.44	0.003	96
Quercus_coccinea	ridgetops and southwestern hillslopes points	29.78	0.001	60
*Vaccinium*_spp	ridgetops and southwestern hillslopes points	29.46	0.002	48
Populus_grandidentata	ridgetops and southwestern hillslopes points	18.04	0.007	35
Rhus_copallinum	ridgetops and southwestern hillslopes points	12.95	0.009	15
Rhus_glabra	ridgetops and southwestern hillslopes points	11.6	0.019	18

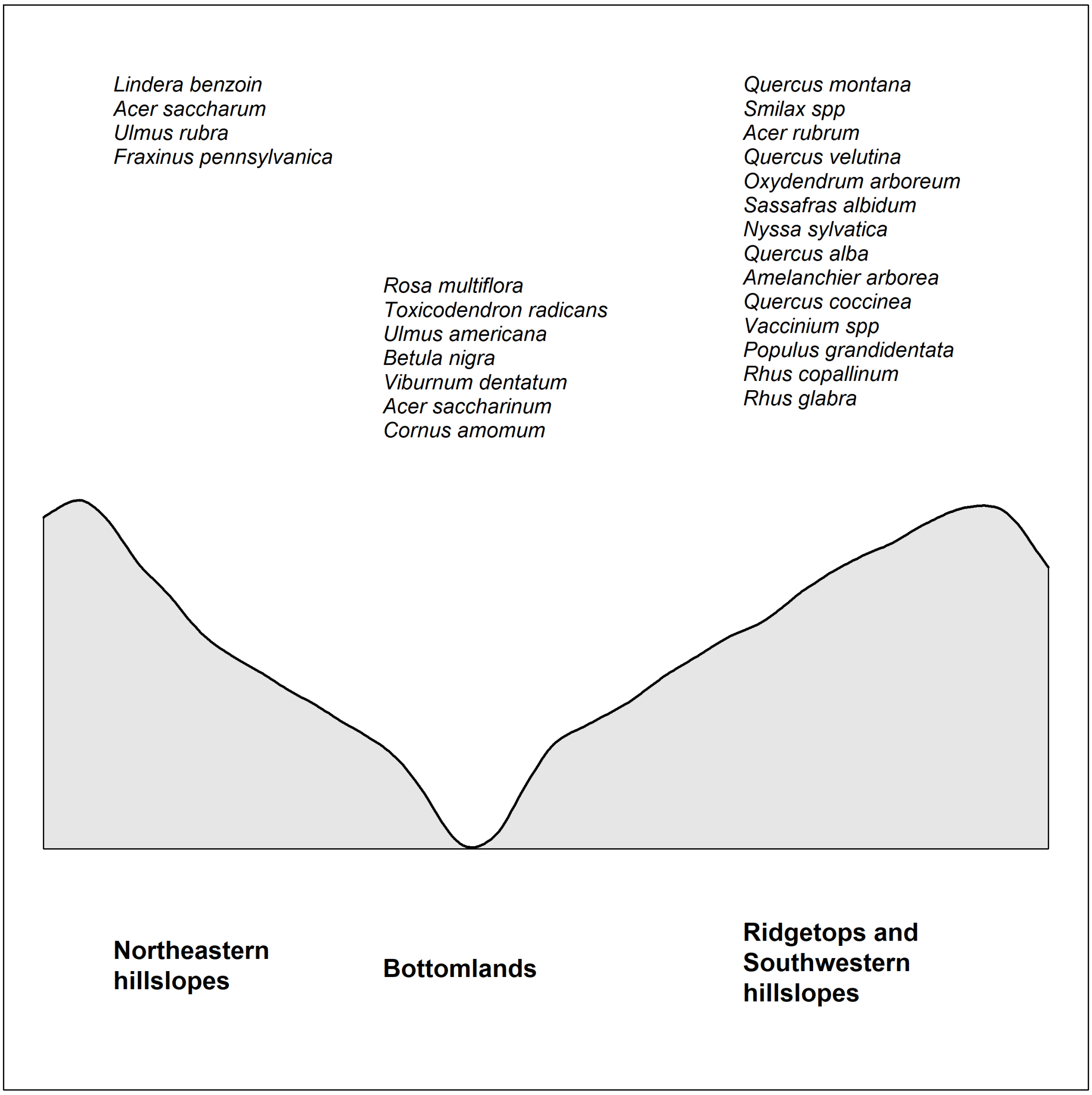

Figure A2. Diagnostic taxa (species/genera) of ecological landtypes. Schematic of ecological landtypes with lists of the corresponding indicator taxa, according to the indicator species analysis.

References

Dufrêne, M., and Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. – Ecol. Monogr. 67: 345–366.

Iverson, L. R. et al. 2018. Spatial modeling and inventories for prioritizing investment into oak-hickory restoration. – For. Ecol. Manage. 424: 355–366.

Roberts, D. W. 2016. labdsv: ordination and multivariate analysis for ecology. – R package ver. 1.8-0. <https://cran.r-project.org/package=labdsv>.

Vitz, A. C. and Rodewald, A. D. 2007. Vegetative and fruit resources as determinants of habitat use by mature-forest birds during the postbreeding period. – Auk 124: 494–507.

Appendix 2

Structural variable description

Field-derived ([F]) vegetation structural variables were generated using the data collected at the vegetation plots among the point locations. LiDAR-derived ([L]) structural variables were generated from publicly-available airborne discrete return LiDAR data from the Ohio Geographically Referenced Information Program (OGRIP; <http://ogrip.oit.ohio.gov/Home.aspx>; accessed 13 October 2014). The study area was scanned during the months of March–May (roughly leaf-out phenological phase) in 2007 using the Leica ALS50 digital LiDAR system at 2225 m above mean terrain, a targeted flight speed of 170 knots, and an approximate 30% overlap in flight lines. Collection protocol were designed to meet an approximate vertical accuracy of 0.15 m root mean square error and a 2.13-m point spacing with a maximum of two returns pulse^{-1}. Points were quality assessed and classified by the vendor. Point clouds were downloaded in LAS format in county sets, consisting of multiple 1524 × 1524 m tiles, in NAD 83 Ohio State Plane South Zone and NAVD 88 horizontal and vertical datums, respectively. The final LiDAR data set of filtered ground and vegetation returns had an average spacing and density of 1.27 m and 0.27 points m^{-2}, respectively. We developed a canopy height model by subtracting a terrain model, utilizing interpolated mean elevation values of ground returns, from a surface model, utilizing interpolated maximum elevation values of either ground or vegetation returns. A total of seven and four variables were quantified to predict bird species composition in this study from the LiDAR and field data (Table A1).

Table A1. Vegetation structural variables. Variables of the LiDAR- ([L]) and field-derived ([F]) vegetation structural predictor sets, including summary statistics of the 210 point samples used in the analysis to predict the species composition of avian assemblages.

Domain	Variable	Abbreviation	Mean	SD
LIDAR, [L]	Canopy max (CHM)	chm_max	34.15	7.44
	Canopy mean (CHM)	chm_mea	21.20	6.89
	Canopy SD (CHM)	chm_std	7.00	2.55
	Penetration ratio 0-2/0-50 m	pen2_50	0.53	0.09
	Penetration ratio 0-2/0-10 m	pen2_10	0.88	0.07
	Penetration ratio 0-1/0-5 m	pen1_5	0.97	0.02
	Foliage height diversity	vegDiv	0.89	0.15
	LiDAR returns 0-5 m (no.)*	...	146174.00	193559.17
	LiDAR returns 5-25 m (no.)*	...	45574.00	12388.79
	LiDAR returns > 25 m (no.)*	...	11929.00	18601.69
FIELD, [F]	All stem density (stems ha^{-1})	all_stem_den	13370.09	7240.55
	Tree basal area (m^2 ha^{-1})	big_stem_bas	24.95	9.78
	Canopy cover mean	can_covr_mea	86.75	15.08
	Canopy height mean	can_heig_mea	22.52	5.79

*Used in the computation of foliage height diversity and not directly as a predictor variable.

Appendix 3

Lists of bird species and plant taxa used in this study

Table A1. Field sampled list of bird species considered in the analysis. List of 48 passerine bird species considered in the analysis (detected in ≥5 point samples), including the frequency of occurrence (*f* – number of point samples detected; n = 210 total point samples) in which each species was recorded.

Common name	Scientific name	*f*
Acadian flycatcher	*Empidonax virescens*	181
American crow	*Corvus brachyrhynchos*	43
American goldfinch	*Spinus tristis*	34
American redstart	*Setophaga ruticilla*	81
American robin	*Turdus migratorius*	78
Baltimore oriole	*Icterus galbula*	16
Black-and-white warbler	*Mniotilta varia*	149
Blue-gray gnatcatcher	*Polioptila caerulea*	136
Brown-headed cowbird	*Molothrus ater*	133
Blackburnian warbler	*Setophaga fusca*	12
Blue jay	*Cyanocitta cristata*	102
Brown thrasher	*Toxostoma rufum*	9
Black-throated green warbler	*Setophaga virens*	18
Blue-winged warbler	*Vermivora cyanoptera*	28
Carolina chickadee	*Poecile carolinensis*	54
Carolina wren	*Thryothorus ludovicianus*	32
Cedar waxwing	*Bombycilla cedrorum*	23
Cerulean warbler	*Setophaga cerulea*	61
Chipping sparrow	*Spizella passerina*	5
Common yellowthroat	*Geothlypis trichas*	25
Eastern phoebe	*Sayornis phoebe*	32
Eastern towhee	*Pipilo erythrophthalmus*	141
Eastern wood-pewee	*Contopus virens*	127
Eastern tufted titmouse	*Baeolophus bicolor*	147
Field sparrow	*Spizella pusilla*	6
Great crested flycatcher	*Myiarchus crinitus*	37
Gray catbird	*Dumetella carolinensis*	24
Hooded warbler	*Setophaga citrina*	187
Indigo bunting	*Passerina cyanea*	52

Continued

Table S1. Continued

Common name	Scientific name	*f*
Kentucky warbler	*Geothlypis formosa*	62
Louisiana waterthrush	*Parkesia motacilla*	35
Northern cardinal	*Cardinalis cardinalis*	70
Northern parula	*Setophaga americana*	12
Ovenbird	*Seiurus aurocapilla*	196
Pine warbler	*Setophaga pinus*	10
Prairie warbler	*Setophaga discolor*	26
Rose-breasted grosbeak	*Pheucticus ludovicianus*	24
Red-eyed vireo	*Vireo olivaceus*	208
Red-winged blackbird	*Agelaius phoeniceus*	6
Scarlet tanager	*Piranga olivacea*	172
Summer tanager	*Piranga rubra*	20
White-breasted nuthatch	*Sitta carolinensis*	157
White-eyed vireo	*Vireo griseus*	48
Worm-eating warbler	*Helmitheros vermivorum*	157
Wood thrush	*Hylocichla mustelina*	173
Yellow-breasted chat	*Icteria virens*	24
Yellow-throated vireo	*Vireo flavifrons*	95
Yellow-throated warbler	*Setophaga dominica*	14

Table A2. Field sampled list of plant taxa considered in the analysis. List of 65 woody plant taxa by stem size class considered in the analysis (detected in ≥5 point samples), including the frequency of occurrence (*f* – number of point samples detected; n = 210 total point samples) in which each taxon was recorded.

	f		
Scientific name	Small stems (<8 cm DBH)	Large stems (≥8 cm DBH)	Combined*
Acer negundo	6	0	7
Acer rubrum	163	180	195
Acer saccharinum	0	5	6
Acer saccharum	88	122	138
Aesculus flava	46	22	49
Ailanthus altissima	6	5	8
Amelanchier arborea	95	11	96
Asimina triloba	25	0	25
Betula nigra	0	9	10
Carpinus caroliniana	99	17	101
Carya spp	162	149	191
Castanea dentata	22	0	23
Celtis occidentalis	6	0	6
Cercis canadensis	37	11	43
Cornus alternifolia	8	0	9
Cornus amomum	5	0	5
Cornus florida	90	31	105
Corylus americana	62	0	62
Crataegus spp	29	0	30
Elaeagnus umbellata	16	0	16
Fagus grandifolia	146	107	159
Fraxinus americana	132	47	143
Fraxinus pennsylvanica	28	6	29
Hamamelis virginiana	30	0	31
Hypericum spathulatum	6	0	6
Juglans nigra	6	10	14
Lindera benzoin	125	0	125
Liriodendron tulipifera	85	133	153

Continued

Table S2. Continued

Scientific name	*f* Small stems (<8 cm DBH)	Large stems (≥8 cm DBH)	Combined*
Lonicera japonica	24	0	24
Lonicera maackii	7	0	7
Nyssa sylvatica	143	137	171
Ostrya virginiana	34	12	36
Oxydendrum arboreum	105	79	116
Parthenocissus quinquefolia	69	0	69
Pinus rigida	0	12	12
Pinus strobus	10	14	17
Platanus occidentalis	7	18	22
Populus grandidentata	22	28	35
Prunus serotina	54	63	103
Quercus alba	100	134	159
Quercus coccinea	33	48	60
Quercus imbricaria	0	5	9
Quercus montana	67	93	105
Quercus rubra	124	110	159
Quercus velutina	115	85	147
Rhus copallinum	15	0	15
Rhus glabra	18	0	18
Rhus typhina	5	0	5
Robinia pseudoacacia	0	10	13
Rosa multiflora	81	0	81
Rubus allegheniensis	80	0	80
Rubus occidentalis	85	0	85
Sambucus canadensis	5	0	5
Sassafras albidum	100	25	105
Smilax spp	200	0	200
Spiraea tomentosa	6	0	6
Tilia americana	12	26	31
Toxicodendron radicans	48	0	48
Ulmus americana	18	22	31
Ulmus rubra	49	41	73
Vaccinium spp	48	0	48
Viburnum acerifolium	121	0	121

Continued

Table S2. Continued

Scientific name	*f* Small stems (<8 cm DBH)	Large stems (≥8 cm DBH)	Combined*
Viburnum dentatum	18	0	18
Viburnum prunifolium	34	0	34
Vitis spp	94	0	97

*Note that combined total does not necessarily equal the sum of small and large stems because each taxon (by stem size class) matrix was generated first before rare species were eliminated from analysis (i.e. each matrix was treated independently).

Appendix 4

Randomization test results

Simple two-sided randomization *t*-tests (van der Voet 1994) were used to examine the equality of predictive performance between pairs of models (Table A1). Residual difference (cross-validated sum of squared prediction error) was used as a test statistic, and site prediction errors were rearranged and swapped for random sites over 999 permutations. The probability for the observed difference be due to random chance was computed as the proportion of times a random set was greater than or equal to the observed difference – also by including the original value. As indicated by Schaffers et al. (2008), instances can emerge where the difference for one pair be significant while insignificant for another because of the effect of the often-skewed distribution of the combined residuals. Statistical significance was assigned to cases where $p < 0.05$.

Table A1. Randomization test results for the prediction of avian species composition. Probabilities (p-values) of the equality of predictive performance between pairs of models for the prediction of bird species composition (Birds, [B]) determined by simple two-sided randomization *t*-tests (999 permutations).

	$\text{Structure}_{\textit{Field}}$, [F]	Tree composition, [T]	Shrub composition, [S]	Total composition, [A]
$\text{Structure}_{\textit{LiDAR}}$, [L]	0.474	0.248	0.385	0.048
$\text{Structure}_{\textit{Field}}$, [F]		0.448	0.122	0.015
Tree composition, [T]			0.014	0.001
Shrub composition, [S]				0.001

References

van der Voet, H. 1994. Comparing the predictive accuracy of models using a simple randomization test. – Chemometrics and Intelligent Laboratory Systems 25: 313–323.

Schaffers, A. P. et al. 2008. Arthropod assemblages are best predicted by plant species composition. – Ecology 89: 782–794.