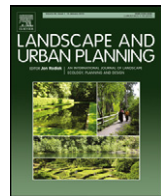




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Habitat associations and survey effort for shrubland birds in an urban pine barrens preserve

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ABSTRACT

Inland pine barrens offer the rarest type of shrubland habitat in the northeastern United States and may contribute disproportionately to the regional diversity and conservation of shrubland birds. Testing local habitat specialization and estimating survey effort is needed to inform management of pine barrens for this rapidly declining avian group. We evaluated shrubland bird habitat associations in a heavily urbanized pine barrens of the northeastern United States, and used occupancy-detection sampling and analysis to estimate the number of sample points and surveys for point-based monitoring of shrubland birds in pine barrens. Although forest area was significantly greater than shrubland area, 8 of 11 reliably modeled species showed evidence of association for shrubland, and are thus potentially useful as indicators of pine barrens shrubland quality and management to avert succession. From the analysis of survey effort, we suggest two design options for point-based monitoring of shrubland birds in pine barrens: (1) include enough points to cover at least ~3% of the study area and survey each point ≥ 5 times preferably during 05:00–08:00 hr, or (2) reduce the point sample, to no less than about 2% of study area, and increase the survey replication to ≥ 10 surveys. Three surveys, as suggested by shrubland bird experts for anthropogenic early-successional habitats (e.g., utility corridors) and by others as a general rule, may require too many sample points to feasibly monitor shrubland birds in pine barrens.

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1. Introduction

Clear identification of species–habitat relationships is paramount to effective habitat-based wildlife management. General preconceptions about habitat requirements at broad spatial scales or in natural areas may not hold at smaller scales (George and Zack, 2001; Lawler and Edwards, 2006) or in urbanized landscapes (Adams and Lindsey, 2009; Croci et al., 2008). Indeed, broadly classified ecological groups of avifauna may unreliably indicate local habitat specialization and show poor predictive power with regards to how birds respond to fragmentation (Ruiz-Gutiérrez et al., 2010; Schlossberg and King, 2008). Although research on avifauna in urban landscapes has increased (e.g., Chace and Walsh, 2006; Schlesinger et al., 2008; Sorace and Gustin, 2010), few studies have explored whether

generally accepted habitat associations hold in a local urban context.

Shrubland birds of the northeastern United States commonly exploit or inhabit anthropogenic early-successional habitats such as abandoned agriculture, utility corridors, regenerating clearcuts, and wildlife management openings (Askins et al., 2007; Chandler et al., 2009; Confer and Pascoe, 2003; King et al., 2009a,b). With fewer than 20 remnant sites worldwide (Barnes, 2003; Noss et al., 1995), inland pine barrens offer the rarest type of shrubland habitat in the northeastern US. These pyrogenic systems are characterized by early-successional shrub communities and sandy, acidic soils (Barnes, 2003; Finton, 1998). Though many remnants are fragmented and some exist in a heavily urbanized landscape matrix, inland pine barrens may contribute disproportionately to the regional diversity and conservation of shrubland birds. In a heavily urbanized site shrubland birds (including species of conservation concern) were observed more frequently in the limited and patchy shrubland habitat than in the more extensive forest area (Beachy and Robinson, 2008; Gifford et al., 2010), suggesting site conservation value despite drastic modification of the historical pine barrens landscape. Although these studies provided useful insight on species diversity and the strongest habitat relationships, they neglected to account for detection probability and

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thus may have overlooked more subtle patterns of habitat specialization.

Efforts to correct for detection probability will strengthen inferences on species–habitat associations and generate more accurate habitat-use maps and habitat suitability models (DeWan et al., 2009; Gu and Swihart, 2004; Tyre et al., 2003). Because detection of animals often varies among habitat types and structural characteristics (Chandler et al., 2009; Chace et al., 2009; Darrah and Krementz, 2009; Gonzalo-Turpin et al., 2008; Mitchell and Donovan, 2008; Ruiz-Gutiérrez et al., 2010), neglecting to correct for detection probability may lead to erroneous conclusions based on a species' detectability in different habitats rather than its actual habitat preferences. Recent bird studies have incorporated an occupancy-detection modeling approach to rigorously test hypotheses about habitat associations (Betts et al., 2008; DeWan et al., 2009; Hennemen and Andersen, 2009; Kroll et al., 2007; Pagano and Arnold, 2009; Richmond et al., 2008), but such analyses have not been done for shrubland birds in pine barrens. Grand and Cushman (2003) suggested that species-level habitat models of birds commonly associated with pine barrens will help managers create the appropriate mix of pine barrens successional communities (i.e., tree- vs. shrub-dominated habitat).

In response to the alarming rate of decline of shrubland birds in the northeastern United States (Askins, 2000; Dettmers, 2003), scientists and managers from nearly two dozen agencies, nature reserves, and universities across the region recently formed the Northeast Shrubland Bird Workgroup. The Workgroup's main objective is to develop and implement a monitoring program that both tracks population trends and assesses species' response to habitat management. At its September 2009 meeting, the Workgroup began evaluating effort requirements for shrubland bird point-based surveys in anthropogenic habitats (e.g., power-line rights-of-way, old fields) and pine barrens. Although experts reached general agreement on a sampling design for shrubland birds in anthropogenic habitats (e.g., conduct three surveys per sample point per season), lack of data prevented development of survey recommendations specific for pine barrens (P. Hunt, New Hampshire Audubon and Workgroup leader, personal communication). Additional empirical work is needed to identify a sampling framework that will reliably infer absence and estimate occupancy of shrubland birds in pine barrens habitat.

In an occupancy-detection framework (MacKenzie et al., 2006), the need for replicate surveys of each spatial unit (points, plots, sites, etc.) to estimate detection probability creates a tradeoff between the number of units and the number of surveys at each unit (Bailey et al., 2007; MacKenzie and Royle, 2005). The key challenge is finding an optimal and feasible balance between these two main components of survey design. Detection-based studies of survey effort exist for woodland birds (Field et al., 2005; Tyre et al., 2003; Watson et al., 2008) and other taxa (Bailey et al., 2007; Jackson et al., 2006; Krejca and Weckerly, 2007; Pellet and Schmidt, 2005; Tyre et al., 2003) but those results likely are not applicable to birds of open barrens and shrubland.

The goal of this paper was to use an occupancy-detection modeling approach (MacKenzie et al., 2006) to test habitat associations and develop survey guidelines for shrubland birds in pine barrens. Specifically our objectives were to: (1) assess whether shrubland birds show local specialization for shrubland habitat in a heavily urbanized pine barrens landscape, (2) compare detection-corrected and uncorrected habitat associations, and (3) use parameter values from occupancy-detection modeling to determine the number of sample points and surveys for point-based monitoring in pine barrens. We assumed that better survey design for measuring occupancy (habitat use) across a patchy landscape typical of contemporary pine barrens will lead to better understanding of local

habitat associations; a prerequisite for restoring urban landscapes for birds (Marzluff and Ewing, 2001).

2. Methods

2.1. Study site

The Albany Pine Bush (42°42'N, 73°52'W; elevation 79–110 m) is located in the densely populated capital region of east-central New York State, USA. The 1255 ha preserve is best known for its globally rare inland pitch pine (*Pinus rigida*)–scrub oak (*Quercus ilicifolia*, *Q. prinoides*) communities, parabolic sand dune formations, and as the type locality of the endangered Karner blue butterfly (*Lycaeides melissa samuelis*) (Barnes, 2003). Urbanization threatens shrubland birds at this site via direct effects such as housecat predation (Kays and DeWan, 2004) and indirectly by causing wildfire suppression, increased spread of fire-sensitive invasive trees, and reduced cover of early-successional, pyrogenic vegetation (Beachy and Robinson, 2008; Malcolm et al., 2008; Milne, 1985).

Wildlife management in the preserve is focused on thinning forest area, promoting early-successional habitat dominated by scrub oaks, and reducing the area of overgrown scrub oak thicket (Bried and Gifford, 2010). Mowing, prescribed fire, invasive plant control, and native planting has restored over 500 ha of preserve land since the early 1990s, enhancing refuge value for numerous rare and declining fauna (Barnes, 2003). In 2008, over 600 ha (nearly 50% of preserve land) was designated a Bird Conservation Area by state agencies for meeting criteria of high migratory concentrations, diverse species concentrations, individual species concentrations, and species at risk (<http://www.dec.ny.gov/animals/48815.html>, accessed 13 August 2009). At present the preserve contains over 150 ha of core habitat for regionally declining shrubland birds (Gifford et al., 2010).

2.2. Bird survey

Two trained observers with similar experience levels conducted standard point count surveys (Ralph et al., 1993) during the breeding season from 23 May to 14 June 2005. They conducted counts in a 50 m fixed-radius at 54 points dispersed at approximately 300 m intervals across protected lands including most of the pine barrens vegetation cover. Total search area was ~43 ha (54 points × 0.79 ha each), or about 3.4% of preserve area (1255 ha). Each point count survey lasted 10 min and started between 05:05 and 11:35 h. Each point was surveyed on 4–7 occasions ($\bar{x} = 6.2$) with most dates spread at least 2 days apart. The two observers rotated among randomly assigned sets of points for each sampling occasion, completing a total of 324 point counts over the study (146 by observer 1 and 178 by observer 2). Both auditory and visual observations were recorded, with traffic noise limiting audible range to approximately 50 m at most points.

We report on 11 shrubland species (Table 1) with sufficient detections (>10 sample points). Thirteen other shrubland species recorded over the study were too rare or poorly detected, or excluded because of inefficient parameter estimates and model convergence failure.

2.3. Habitat association analysis

Albany Pine Bush land cover in 2003 was classified into nine primary cover types and quantified using ArcMap v9.2. Three types accounted for 80% of cover (in a 50-m radius) on average across sample points: (1) pine barrens shrubland (~145 ha of preserve land) dominated by scrub oak, (2) pine barrens forest (~255 ha) dominated by pitch pine, and (3) upland forest (~620 ha) dominated by aspen (*Populus grandidentata*, *P. tremuloides*), black locust

Table 1

Uncorrected mean abundance per sample point (Index) of shrubland birds in the Albany Pine Bush Preserve, New York, USA, and analogous density estimates ($\hat{\lambda}$) from presence/absence (1/0) and count-based mixture models that account for imperfect detection.^a CI = confidence interval.

Species	Index	1/0 data $\hat{\lambda}$ (95% CI)	Count data $\hat{\lambda}$ (95% CI)
Eastern Towhee (<i>Pipilo erythrophthalmus</i>)	0.71	2.26 (1.37–3.15)	3.07 (2.07–4.08)
Chestnut-sided Warbler (<i>Dendroica pensylvanica</i>)	0.42	1.49 (0.91–2.07)	1.63 (1.08–2.18)
Gray Catbird (<i>Dumetella carolinensis</i>)	0.31	1.71 (0.74–2.68)	1.65 (0.94–2.36)
Common Yellowthroat (<i>Geothlypis trichas</i>)	0.29	1.58 (0.69–2.47)	1.93 (0.90–2.95)
Prairie Warbler (<i>Dendroica discolor</i>)	0.27	0.60 (0.34–0.87)	0.81 (0.52–1.10)
Northern Cardinal (<i>Cardinalis cardinalis</i>)	0.21	1.76 (0.24–3.28)	2.59 (0.00–5.19)
Chipping Sparrow (<i>Spizella passerina</i>)	0.17	Inestimable ^b	Inestimable
Pine Warbler (<i>Dendroica pinus</i>)	0.14	0.93 (0.36–1.49)	0.82 (0.38–1.26)
Song Sparrow (<i>Melospiza melodia</i>)	0.10	0.42 (0.15–0.70)	0.61 (0.23–0.99)
Field Sparrow (<i>Spizella pusilla</i>)	0.07	0.46 (0.11–0.81)	0.49 (0.18–0.80)
Brown Thrasher (<i>Toxostoma rufum</i>)	0.05	0.52 (0.00–1.25)	0.78 (0.00–2.12)

^a The 1/0 and count-based $\hat{\lambda}$ are highly correlated across species (Pearson's $r = 0.95$, $P < 0.001$). The 1/0 model exploits the fact that detection probability varies by sample point largely according to the number of animals available for detection (Royle and Nichols, 2003). The count-based model assumes that observed count data arise from a binomial distribution with parameters for point-specific abundance and the probability of detecting that abundance on a single survey (Royle, 2004). For both models we assumed that point-specific abundances for each species were Poisson distributed, and estimated λ from the data using maximum likelihood in PRESENCE.

^b Unreasonably large $\hat{\lambda}$ and standard errors.

(*Robinia pseudoacacia*), white pine (*Pinus strobus*), or mixed tree oaks (*Quercus alba*, *Q. coccinea*, *Q. rubra*, *Q. velutina*). These cover types form a successional gradient from open barrens and dense thicket (pine barrens shrubland) to the less disturbance-dependent forest communities. Area of each cover type within the 50-m radius was used to model the effect of habitat on detection/non-detection at each point. In this landscape, pine barrens forest and shrubland communities share the same dominant taxa (pitch pine and scrub oaks) but pitch pine cover is generally low (10–30%) in early-successional shrublands compared to 60–100% in forest areas.

We ran six occupancy-detection models for each species using an increasingly popular likelihood-based estimation framework (MacKenzie et al., 2002, 2006) and PRESENCE v2.4 (Patuxent Wildlife Research Center, United States Geological Survey, Laurel, MD; MacKenzie et al., 2002). Models included: (1) $\psi(\text{HABITAT})p(\cdot)$, (2) $\psi(\text{HABITAT})p(t)$, (3) $\psi(\text{HABITAT})p(\text{OBSERVER})$, (4) $\psi(\text{HABITAT})p(\text{STARTTIME})$, (5) $\psi(\text{HABITAT})p(\text{OBSERVER} + \text{STARTTIME})$, (6) $\psi(\text{HABITAT})p(\text{HABITAT})$, where occupancy (ψ) was defined as the fraction of sample points used at least once, given imperfect detection, and detection (p) was the probability of successfully recording the species on a particular survey, given its presence at the sample point. The models assumed that sample points were closed with respect to movement and mortality over the study period (MacKenzie et al., 2002, 2006). We interpret “occupancy” as habitat use, under the assumption that species established their breeding territories but randomly moved in and out of point areas over the study period.

The reference model, $p(\cdot)$, assumes that detection probability is imperfect ($p < 1$) but constant across points and surveys. In the $p(t)$ model, a unique detection probability was estimated for each survey date to account for potential breeding season changes in singing behavior and other territorial activities (Selmi and Boulinier, 2003). This was the most parameterized (about four sample points per model parameter) of the six models. We also modeled the influence of habitat type ($p(\text{HABITAT})$), observer identity ($p(\text{OBSERVER})$), and time of day ($p(\text{STARTTIME})$) on detection probability, as all of these factors can influence the potential detectability of numerous bird species (Chandler et al., 2009; Darrah and Krementz, 2009; Gonzalo-Turpin et al., 2008; King et al., 2009a,b; Mitchell and Donovan, 2008; Pagano and Arnold, 2009; Ruiz-Gutiérrez et al., 2010; Skirven, 1981). We converted habitat cover and point count start times into standard normal deviates (z-scores) to help facilitate convergence of the numerical optimization algorithm, and modeled observers as categories (observer 1 vs. 2). We inferred habitat association from the estimated occupancy probabilities and maximum likelihood coefficients in each cover type. We grouped the sample points by their dominant cover (>33% pine barrens

shrubland, pine barrens forest, or other forest) and averaged the occupancy estimates across points. Sample size was small in pine barrens forest (11 points) and shrubland (9 points) due to limited availability of these habitats.

We ranked models using the adjusted Akaike's Information Criterion (AIC_c) for small samples, comparing each model to the one with minimum achieved AIC_c (Burnham and Anderson, 2002). We tested for overdispersion in the most parameterized model, $\psi(\text{HABITAT})p(t)$, using a parametric bootstrapping method (1000 iterations) devised by MacKenzie and Bailey (2004). In species (eastern towhee, pine warbler) whose data appeared overdispersed ($\hat{c} > 1.0$), we used the quasi- AIC_c ($QAIC_c$) procedure for model selection and multiplied standard errors by $\sqrt{\hat{c}}$ (MacKenzie et al., 2006:112). We used model averaging to combine parameter estimates and errors of competing models, defined as those < 2.0 AIC_c or $QAIC_c$ units of the top model (Burnham and Anderson, 2002).

2.4. Survey effort analysis

The primary tradeoff in occupancy-detection study design is between the number of sample points and the number of surveys at each point (Bailey et al., 2007; MacKenzie and Royle, 2005). Allowing a 5% chance of not detecting a species after T surveys with detection probability p , the minimum number of surveys (T_{\min}) needed to be 95% certain of absence at a sample point is solved by $\log(0.05)/\log(1 - p)$ (Pellet and Schmidt, 2005). We calculated T_{\min} directly from estimated detection probabilities (\hat{p}) in the best supported STARTTIME model or, when ΔAIC_c or $\Delta QAIC_c < 2.0$, the model weighted-average between $p(\text{STARTTIME})$ and $p(\text{OBSERVER} + \text{STARTTIME})$. For reference we included the constant occupancy model, denoted $\psi(\cdot)$, in each evaluation. Modeling STARTTIME heterogeneity on detection probabilities accounted for likely biases (there were 152 different start times in the study) and provided diel-specific survey effort recommendations. We assume that diel-specific recommendations are necessary because detection of birds varies strongly with time of day (e.g., Skirven, 1981; King et al., 2009b). The \hat{p} and consequently T_{\min} were uniquely estimated from the average start time (nearest minute) in each 1-h interval (05:00–05:59 hr, 06:00–06:59 hr, ..., 10:00–11:35 hr; the last hour includes additional point counts that started at 11:04, 11:20, and 11:35 hr) of the study. For the $p(\text{OBSERVER} + \text{STARTTIME})$ model, the hourly \hat{p} were averaged across the two observers prior to model-averaging.

We used the following equation for standard survey designs to determine the number of sample points (S_{\min}) needed to estimate occupancy with standard errors (SE) of 0.05, 0.10, and 0.20

Table 2
Single best habitat model or competing habitat models (ΔAIC_c or $\Delta QAIC_c < 2.0$), where K =number of parameters, w = model weight, H =HABITAT covariate, O =OBSERVER covariate, and S =STARTTIME covariate.

Species	Model	<i>K</i>	<i>w</i>
Brown Thrasher	$\psi(H)p(\cdot)$	5	0.47
	$\psi(H)p(S)$	6	0.28
Chestnut-sided Warbler	$\psi(H)p(O+S)$	7	0.99
Chipping Sparrow	$\psi(H)p(H)$	8	0.26
	$\psi(H)p(O)$	6	0.24
	$\psi(H)p(\cdot)$	5	0.22
	$\psi(H)p(O+S)$	7	0.15
	$\psi(H)p(S)$	6	0.13
Common Yellowthroat	$\psi(H)p(O)$	6	0.73
	$\psi(H)p(O+S)$	7	0.27
Eastern Towhee	$\psi(H)p(O+S)$	7	0.48
	$\psi(H)p(O)$	6	0.35
Field Sparrow	$\psi(H)p(O)$	6	0.78
Gray Catbird	$\psi(H)p(S)$	6	0.95
Northern Cardinal	$\psi(H)p(O)$	6	0.62
	$\psi(H)p(O+S)$	7	0.37
Pine Warbler	$\psi(H)p(O+S)$	7	0.48
Prairie Warbler	$\psi(H)p(H)$	8	0.75
Song Sparrow	$\psi(H)p(O+S)$	7	0.78

(MacKenzie and Royle, 2005):

$$S_{\min} = \frac{\hat{\psi}}{SE(\hat{\psi})^2} \left[(1 - \hat{\psi}) + \frac{1 - p^*}{p^* - T_{\min} \times p \times (1 - p)^{T_{\min} - 1}} \right]$$

where

$$p^* = 1 - (1 - p)^{T_{\min}}$$

is the probability of detecting a given species at least once among T_{\min} surveys, and $\hat{\psi}$ is the estimated probability of occupancy. We populated $\hat{\psi}$ using the mean of the point-specific occupancy probability estimates from $\psi(\text{HABITAT})$, or by holding occupancy constant ($\psi(\cdot)$) when model selection indicated that a single probability was sufficient. We coupled $\psi(\text{HABITAT})$ and $\psi(\cdot)$ with each parameterization of detection probability described in the habitat analysis for a total of 12 models. We used the same information-theoretic approach as described in the habitat analysis for model selection and averaging. Values for T_{\min} included the $\log(0.05)/\log(1 - p)$ requirement and a tentative recommendation by the Northeast Shrubland Bird Workgroup to use three surveys. In each species we report S_{\min} for the 1-h interval that the species is most detectable. The detection-based sample sizes were almost identical across time because they were adjusted for the time-specific detection probability.

3. Results

3.1. Detection factors and habitat associations

Models that incorporated observer identity as a source of heterogeneity in detection had the most support (Table 2). The $p(\text{OBSERVER})$ model outperformed the $p(\text{STARTTIME})$ model in seven species by $\bar{x} = 0.40$ AIC_c or $QAIC_c$ weight, whereas the $p(\text{STARTTIME})$ model outperformed the $p(\text{OBSERVER})$ model in the remaining species by $\bar{x} = 0.05$ AIC_c or $QAIC_c$ weight. Observer 2 seemed to have a greater ability to detect the species (Fig. 1). The $p(\text{OBSERVER} + \text{STARTTIME})$ model fit as the single best description of the data for the chestnut-sided warbler, pine warbler, and song

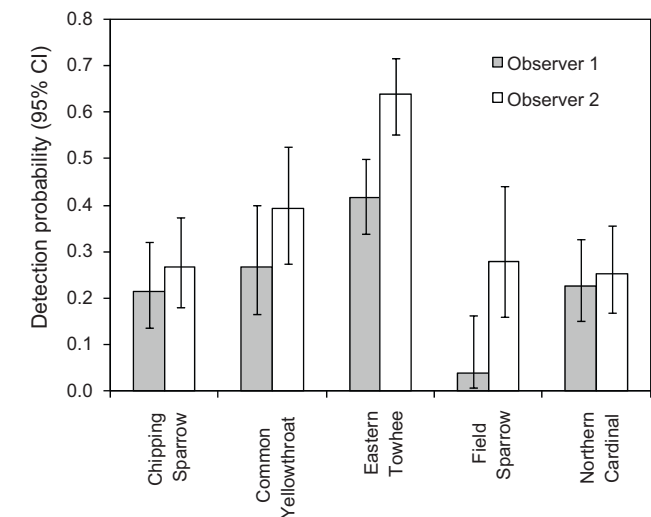


Fig. 1. Observer differences in estimated detection probability for shrubland birds showing evidence of a $p(\text{OBSERVER})$ model effect (see Table 2). CI = confidence interval.

sparrow (Table 2). There was no support for the $p(t)$ model in any species (ΔAIC_c and $\Delta QAIC_c \geq 17.74$).

About two-thirds of species showed a clear association with shrubland habitat (Fig. 2A) and a potential negative relationship to pitch pine forest (Table 3). The data did not support evidence of shrubland associations for chestnut-sided warbler, northern cardinal, and pine warbler (Fig. 2A and Table 3). Although sample size was small in pine barrens habitat, the variation across points in the shrubland category was low or even zero in many species, suggesting a representative sample of this landscape. Habitat type was an important factor for detection with the prairie warbler (Table 2), but there was insufficient evidence to conclude that shrubland birds as a group were more detectable in shrubland than in forest (Fig. 2B).

3.2. Recommended survey effort

Completing three surveys per sample point as suggested by the Northeast Shrubland Bird Workgroup for anthropogenic shrublands appears insufficient in the Albany Pine Bush, regardless of species or time of day. For most species, 10 surveys per point during 05:00–07:00 hr would be appropriate to infer absence, although five surveys during 05:00–08:00 hr may be sufficient for chestnut-sided warbler, eastern towhee, and prairie warbler (Fig. 3). Five early morning surveys (05:00–06:00 hr) are needed to infer absence for gray catbird, pine warbler, and song sparrow. Except for prairie warbler, detection probability decreased,

Table 3
Best-model or model-averaged (when ΔAIC_c or $\Delta QAIC_c < 2.0$) habitat parameter coefficients and standard errors (SE). PPSOB=pitch pine–scrub oak barrens and thicket (pine barrens shrubland); PPSOF=pitch pine–scrub oak forest (pine barrens forest); OF=other upland forest types (aspen, black locust, white pine, tree oaks).

Species	PPSOB (SE)	PPSOF (SE)	OF (SE)
Brown Thrasher	11.91 (9.84)	0.12 (1.77)	7.64 (6.73)
Chestnut-sided Warbler	−0.07 (0.37)	0.23 (0.37)	0.26 (0.38)
Chipping Sparrow	1.14 (1.11)	−0.16 (0.63)	−0.28 (1.17)
Common Yellowthroat	5.64 (23.51)	−0.32 (0.99)	0.40 (1.03)
Eastern Towhee	2.87 (2.01)	−0.32 (0.62)	0.39 (0.81)
Field Sparrow	1.36 (1.31)	−0.86 (0.74)	0.06 (1.06)
Gray Catbird	19.46 (8.97)	−3.21 (1.34)	0.05 (1.12)
Northern Cardinal	−0.35 (0.81)	0.00 (0.63)	−0.01 (1.01)
Pine Warbler	0.35 (0.66)	0.56 (0.46)	0.22 (0.75)
Prairie Warbler	9.54 (5.69)	−1.40 (1.33)	0.44 (1.29)
Song Sparrow	1.15 (1.31)	−3.05 (1.32)	−1.96 (1.22)

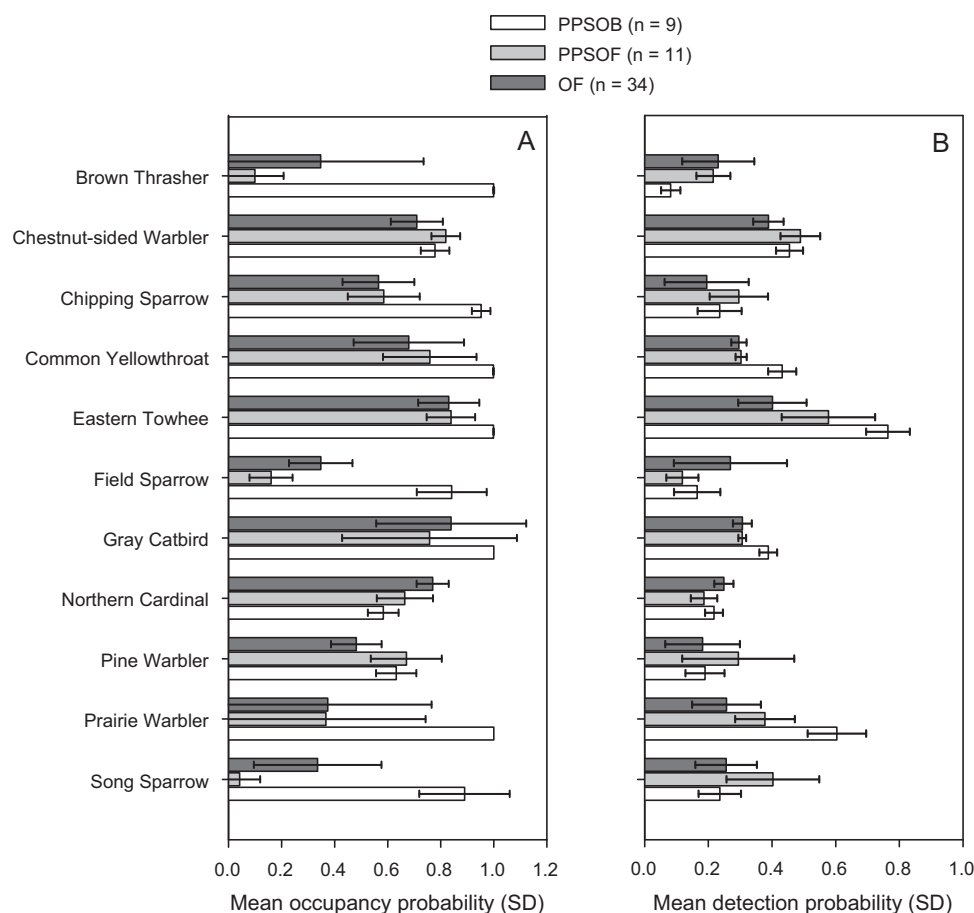


Fig. 2. Shrubland bird habitat preferences based on the chance of occupancy (habitat use) at each sample point (A), and variation in detection probability by habitat type (B). Points were categorized by their dominant vegetation cover type (>33% relative cover). PPSOB = pitch pine–scrub oak barrens and thicket (pine barrens shrubland); PPSOF = pitch pine–scrub oak forest (pine barrens forest); OF = other upland forest types (aspen, black locust, white pine, tree oaks); n = number of sample points; SD = standard deviation.

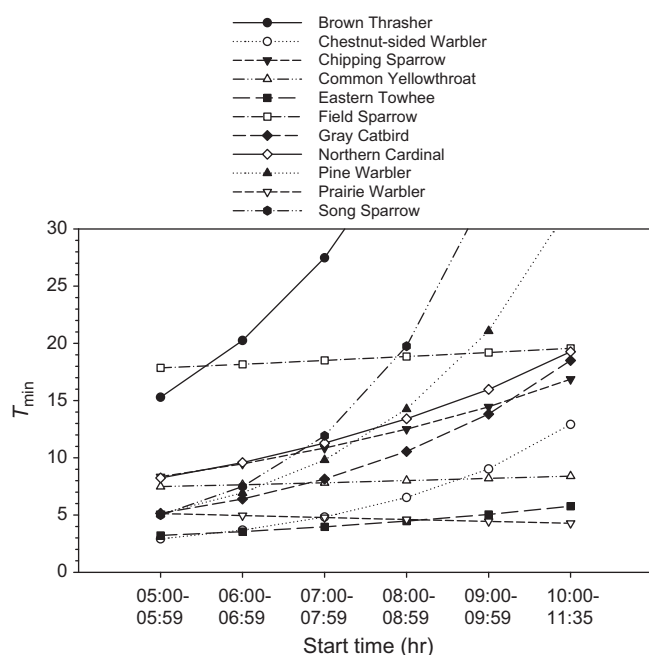


Fig. 3. Minimum number of surveys needed to be 95% confident of species' absence at a sample point (T_{min}) for different times of day (point count start times). The 10:00–11:35 hr interval includes 16 point counts during 10:00–10:59 hr along with counts at 11:04, 11:20, and 11:35 hr.

and thus minimum number of surveys increased, with time of day (Fig. 3). Results for field sparrow and prairie warbler are potentially less reliable because observer and habitat were stronger effects than time of day (Table 2).

Assuming enough surveys to be 95% certain of absence, the current sample size of 54 point count stations is sufficient to estimate occupancy with 0.05–0.10 SE in each species (Table 4, top row in each species). Having only three repeat surveys per point drastically increases the required sample size (Table 4, bottom row in each species). Importantly, the sample sizes in Table 4 correspond to the hour in which the species is most detectable (see Fig. 3), meaning these are the *minimum* required sample sizes. For a fixed effort of three surveys, Table 4 values may increase dramatically depending on species, time of day, and desired precision level. In the most extreme case for example, estimating occupancy with <0.05 SE from three surveys during 10:00–11:35 hr would require over 30,800 sample points (Fig. 4). In contrast, required sample size for each species varied little (by ≤ 5 points) with time of day for the detection-based T_{min} .

4. Discussion

4.1. Habitat associations

Urbanization has a strong local effect on birds and can modify primary habitat gradients, limit individual fitness, and ultimately restructure communities (Chace and Walsh, 2006; Croci et al., 2008; Marzluff et al., 2001; Schlesinger et al., 2008). Heavily urban-

Table 4
Minimum number of sample points (S_{\min}) for estimating shrubland bird occupancy at different levels of standard error in the Albany Pine Bush Preserve, New York, USA. In each species, the top row S_{\min} assumes enough surveys to be 95% certain of absence from a sample point (T_{\min} ; see Fig. 3), and the bottom row S_{\min} assumes $T = 3$ surveys as recommended by the Northeast Shrubland Bird Workgroup, at the ideal time of day for detection (Fig. 3). The modeled occupancy rate (ψ) was presumed constant or varying as a function of habitat, depending on information-theoretic support for $\psi(\cdot)$ vs. $\psi(\text{HABITAT})$.

Species	$\hat{\psi}$	S_{\min}		
		0.05 SE	0.10 SE	0.20 SE
Brown Thrasher	0.406	107	27	7
		1174	293	73
Chestnut-sided Warbler	0.753	96	24	6
		94	23	6
Chipping Sparrow	0.644	108	27	7
		495	124	31
Common Yellowthroat	0.753	94	24	6
		611	153	38
Eastern Towhee	0.885	66	17	4
		74	18	5
Field Sparrow	0.432	109	27	7
		1725	431	108
Gray Catbird	0.800	85	21	5
		200	50	12
Northern Cardinal	0.725	99	25	6
		519	130	32
Pine Warbler	0.553	114	28	7
		174	44	11
Prairie Warbler	0.464	112	28	7
		140	35	9
Song Sparrow	0.364	102	26	6
		144	36	9

ized pine barrens could reasonably be expected to have minimal attraction for shrubland birds, especially if shrubland birds are not actually edge-dependent as traditionally assumed (Schlossberg and King, 2008). In the small and fragmented Albany Pine Bush Preserve, 8 of 11 reliably modeled species showed evidence of association for the patchy shrubland habitat. In a detection-naïve analysis (Gifford et al., 2010), the clearest evidence of shrubland specialization and therefore indicator value was found in brown thrasher,

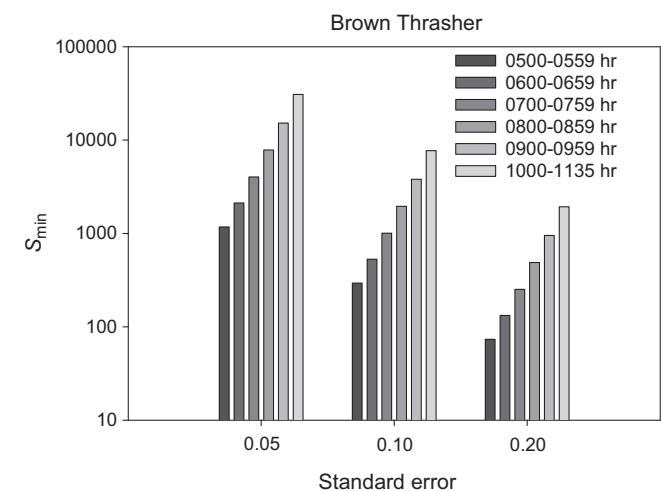


Fig. 4. Minimum number of sample points (S_{\min} , note the logarithmic scale) for estimating brown thrasher occupancy when using three surveys. This species required the largest sample sizes and showed dramatic variation in S_{\min} over time of day.

field sparrow, and prairie warbler. As that analysis did not account for false-absence errors, it may have over- or underestimated habitat associations from differences in species’ detectability among observers, start times, cover types, and other factors (Gu and Swihart, 2004; MacKenzie and Royle, 2005; Tyre et al., 2003).

The current analysis confirms brown thrasher, field sparrow, and prairie warbler as indicators, but also finds that chipping sparrow, common yellowthroat, eastern towhee, gray catbird, and song sparrow were more likely to use shrub-dominated areas. All of these species additionally showed possible negative coefficients (except for brown thrasher) and lower occupancy probabilities in pitch pine forest, consistent with field sparrow, prairie warbler, and other shrubland species avoiding mature forest adjacent to regenerating clearcuts in southern Ohio (Rodewald and Vitz, 2005). We say “possible” negative relationship because the coefficient standard errors were often large, which may have resulted from over-parameterization and/or sparse data. We suggest these eight species are all potentially useful for tracking management efforts to avert succession in the world’s few remaining inland pitch pine–scrub oak landscapes; Grand and Cushman (2003) made a similar recommendation in a coastal pitch pine–scrub oak landscape. Follow up studies that focus on effects of vegetation structure (e.g., height, forb vs. shrub cover) and plant species composition may help in developing more specific management guidelines (Schlossberg et al., 2010).

Chestnut-sided warbler, northern cardinal, and pine warbler each lacked evidence of shrubland association. The chestnut-sided warbler and northern cardinal tend to forage and nest in a variety of anthropogenic early-successional habitat (DeGraaf and Yamasaki, 2001). As generalists these species are less likely to differentiate land cover created by humans from natural land cover (Marzluff and Ewing, 2001), thereby mitigating the potential effects of fragmentation on habitat usage. The pine warbler is typically a woodland species. It did, however, reveal a similar occupancy rate in pine barrens forest and shrubland communities. This may be explained by pine warbler using small stands of pitch pine surrounded by large areas of scrub oak (authors’ observations), analogous to shrub-dependent birds that show area-insensitivity and use small forest openings (Askins et al., 2007; Lehen and Rodewald, 2009). Contrary to the findings of Ruiz-Gutiérrez et al. (2010), our study suggests that commonly perceived habitat associations were upheld in a fragmented landscape.

4.2. Survey effort

Our analysis suggests that occupancy-based sampling of shrubland birds in the Albany Pine Bush and possibly other pine barrens may require at least 10 surveys ideally, although five appears sufficient for some species. Watson et al. (2008) recommended nine surveys to estimate occupancy of the endangered golden-cheeked warbler (*Dendroica chrysoparia*) with a 20% coefficient of variation. Royle and Nichols (2003) suggested that 10 surveys can produce good model abundance estimates even for bird species with low detection probability. An effort of three surveys, as suggested by the Northeast Shrubland Bird Workgroup and elsewhere (Field et al., 2005; MacKenzie and Royle, 2005; Pagano and Arnold, 2009; Tyre et al., 2003) as a general rule, may be insufficient for shrubland birds in pine barrens. Note, however, that because detectability tends to vary by habitat type or structural characteristics (Chandler et al., 2009; Chace et al., 2009; Darrah and Krementz, 2009; Gonzalo-Turpin et al., 2008; Mitchell and Donovan, 2008; Ruiz-Gutiérrez et al., 2010), sample points located in habitat where a species is more detectable may require fewer surveys. In most species we did not find an effect of habitat on detection probability, possibly because of inherent limitations in sample size, or because traffic noise may have interfered with habitat-based detection dif-

ferences. The unique ecology of urban landscapes may limit the applicability of our results, but currently these are the only empirically based guidelines for point-based surveys of shrubland birds in pine barrens.

We found little evidence for an effect of habitat on detection probability but strong evidence for an effect on occupancy probability, which may in turn influence the required sample size. In a majority of species the habitat models had more support than constant models, suggesting that variegated landscapes will generate heterogeneous occupancy probabilities, and that the results of one study may not transfer to a different landscape. The ideal number of points and surveys for an urbanized landscape may change in a setting that contains less noise interference and more contiguous natural vegetation cover. Effort requirements could also vary depending on the scale of measured habitat features and the type of vegetation data. Developing a robust set of effort guidelines for shrubland bird monitoring in pine barrens may require analyzing more than one site along a gradient of landscape context (Schlossberg et al., 2010).

Time of day strongly influences bird detection probability and therefore survey effort. Leavelle (2008) reported that detection probability of blue-headed quail-dove (*Starnoenas cyanocephala*) dropped by more than half after 1000 hr. The present study found similar decreases in detection over time during a ~6-hr sampling interval. Chance of detection in most bird species is greater in early morning when vocalization activity is more frequent (Skirven, 1981), but optimal times of day to detect and therefore survey shrubland birds may vary with time of breeding season (King et al., 2009b). Modeling time of day as a quadratic effect with a well-defined peak could be more ecologically appropriate than assuming a linear change in detection probability over the breeding season. We presumed the sample size was inadequate to model date and time of day interaction. Lack of support for the $p(t)$ model could be an artifact of its relatively small sample to variable ratio (54 sample points to 14 model parameters), or may reflect minimal changes in singing behavior and other detection-related activity over the short (3 weeks) sampling period.

The urbanizing Albany Pine Bush landscape contains extremely patchy shrubland cover (Gifford et al., 2010) and only the 1255 ha protected land base is available for research. The latter fact precludes any large increase in sample size, such as required to achieve a 0.05 standard error. The current sample size (54 points, ~3.4% of preserve area) should provide acceptable errors (0.05–0.10 SE) in each species analyzed, assuming there are enough surveys to permit a less than 5% chance of false absence, and provided the equation inputs for occupancy and detection were reasonable. Using two observers for 10-min point counts, assuming ~5-min travel time between points, and restricting surveys to the ideal time for detection (05:00–08:00 hr), it should take between 2 and 3 days to cover all points on a sampling occasion. Using more than two observers is allowable, but given that we and others (e.g., Chandler et al., 2009; Darrah and Krementz, 2009; King et al., 2009a; Pagano and Arnold, 2009) have documented clear differences in observers' ability to detect birds, it is important to model detection probability as a function of observer heterogeneity. Alternatively, we found that reducing sample size to as few as ~30 points (~2% of preserve area) may retain 0.05–0.10 SE on occupancy estimates, at least if 10 or more surveys are conducted. Interestingly, this latter scenario is similar to the effort recommended for occupancy-based monitoring of an endangered woodland bird (Watson et al., 2008); note however that Tyre et al. (2003) found reasonable estimates for woodland birds by visiting 34 sites only three times each. Our analysis indicates that for reliable estimation of shrubland bird occupancy and habitat use in the Albany Pine Bush and possibly other pine barrens, three surveys may require a much larger point sample size than required by detection-based survey replication.

4.3. Conclusions

Our analysis suggests two competing design options for shrubland bird point-based surveys in the Albany Pine Bush and possibly other pine barrens of the northeastern United States: (1) include enough points to cover at least ~3% of the study area and survey each point ≥ 5 times preferably during 05:00–08:00 hr, or (2) reduce the point sample, to no less than about 2% of study area, and increase the survey replication to ≥ 10 surveys. The first scenario is recommended because: (1) adding surveys outstrips the reduced effort benefits of removing sample points in small landscapes like inland pine barrens, and 10 surveys probably is not feasible even for 30 points; (2) more sites and fewer surveys is typically a better strategy for species with low occupancy rate (Field et al., 2005; MacKenzie and Royle, 2005) – 13 shrubland species were too rare or poorly detected for the current analysis; (3) more sample points will facilitate building more informative models, such as incorporating habitat management covariates (e.g., managed vs. unmanaged, time since prescribed fire) and interactions with land cover at multiple scales; (4) larger point to survey ratio could mean less difficulty modeling effects of survey date on detection probability. To help compensate for fewer surveys, easily monitored shrubland habitat indicators (e.g., prairie warbler) could be tested as spatial or trend surrogates of hard-to-monitor species of interest (e.g., regionally rare brown thrasher), such as using species indicator power (Halme et al., 2009) and detection-based joint distribution modeling (Bailey et al., 2009) to evaluate spatial surrogacy.

Understanding local-scale habitat associations, and developing regionally coordinated site-specific conservation strategies for the few remaining inland pine barrens, may aid in the regional conservation of shrubland birds. Our habitat analysis supports the conclusion that landscape-level management to promote the scrub oak-dominated early-successional stage is essential in pine barrens sites looking to benefit shrub-dependent birds (Beachy and Robinson, 2008; Grand and Cushman, 2003). Dense and variable shrub cover may be especially important in urban ecosystems to mitigate rates of parasitism and nest predation (Burhans and Thompson, 2006; Marzluff and Ewing, 2001; Rodewald, 2009). Currently in the Albany Pine Bush the relative amount of forest to shrub cover is approximately 80 to 20%, even taking into account ~100 ha of aspen, black locust, and white pine removal since the 2003 ArcMap land cover analysis. This is opposite the ratio that we think will most benefit shrub-dependent wildlife. As managers work to reverse this ratio and control overabundant scrub oak thicket (Bried and Gifford, 2010), it will be necessary to continually assess how shrubland birds and other rare and declining fauna respond. Assessments corrected for detection probability are expected to help curb wasteful spending of management resources by showing that species may be more common than observed (e.g., Table 1) and by providing a more accurate baseline of species–habitat relationships.

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