

Alternative biomass strategies for bioenergy: implications for bird communities across the southeastern United States

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Abstract

Concerns over energy demands and climate change have led the United States to set ambitious targets for bioenergy production in the coming decades. The southeastern United States has had a recent increase in biomass woody pellet production and is projected to produce a large portion of the nation's cellulosic biofuels. We conducted a large-scale, systematic comparison of potential impacts of two types of bioenergy feedstocks – corn (*Zea mays*) and pine (*Pinus* spp.) – on bird communities across the southeastern United States. In addition, we evaluated three biomass alternatives for woody biomass from pine plantations: thinning, residue harvest, and short-rotation energy plantations (SREPs). We conducted transect counts for birds in eight different land uses across the region (85 sites), including corn fields, reference forest, and plantation forests, 2013–2015. We then used hierarchical occupancy models to test the effect of these biomass alternatives on 31 species. Across all species, birds had lower rates of occupancy in corn fields compared to pine stands. Thinning had positive effects on the average occupancy across species, while residue harvest and the potential conversion of conventional plantations to SREPs had negative effects. Cavity nesters and species with bark-gleaning foraging strategies tended to show the strongest responses. These results highlight the potential negative effects of corn as an energy crop relative to the use of pine biomass. In addition, harvesting biomass via thinning was a bird-friendly harvest method in comparison with other alternatives. While SREPs may negatively impact some bird species, previously reported yields emphasize that they may provide an order of magnitude greater yield per unit area than other alternatives considered, such that this land-use practice may be an important alternative to minimize the bioenergy impacts across the landscape.

Keywords: biofuels, corn, land-use change, occupancy, pine plantations, residue harvest, short-rotation energy plantations, songbird, thinning

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Introduction

Concerns over rising energy demands, climate change, and the economics and politics surrounding crude oil production have created global interest in diversifying and growing domestic energy portfolios (Klass, 2003). In 2007, the U.S. Congress adopted the Renewable Fuel Standard Provision (RFS2) as a part of the Energy Independence and Security Act (EISA), which set a goal for the United States to produce 36 billion gallons of liquid biofuels per year by 2022 (Sissine, 2007). This ambitious goal was scaled back with the RFS2 mandate of 2013, yet long-term, renewable fuel goals remain high. These and other policies collectively (e.g., Biomass Crop

Assistance Program of the 2014 Farm Bill) emphasize a diverse potential portfolio for biomass and bioenergy production across the United States, where different crops and harvesting methods may be used to extract biomass for bioenergy.

The USDA and DOE project that a major portion of the national production of biofuels and bioenergy will come from the southeastern United States (USDA, 2010, DOE, 2016). In addition, there has been a recent increase in woody biomass production in the southeast for bioenergy in the form of woody pellet production (Galik & Abt, 2016; Dale *et al.*, 2017). As a consequence, large-scale land-use change may occur (Fargione *et al.*, 2010), such as the conversion of plantation stands for timber production to that of short-rotation stands dedicated to biomass (Munsell & Fox, 2010). Understanding the potential impacts that land-use changes for bioenergy

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may have on wildlife communities is needed to encourage use of best management practices that limit impacts on biodiversity on a local and regional scale.

Two primary biomass feedstocks being considered in the southeast include corn (*Zea mays*) row crops and pine (*Pinus* spp.) plantations (DOE, 2011, 2016). Corn is the dominant row crop grown for ethanol production in the United States and could be grown as either a first-generation (i.e., ethanol derived from sugars extracted from the fruit) or second-generation (i.e., ethanol derived from cellulose) biofuel crop in the southeast (Gonzalez *et al.*, 2012). Loblolly (*Pinus taeda*) and slash pine (*Pinus elliottii*) plantations are likely to be a primary source of biomass in the southeast and are already widely cultivated across the region for other purposes (Nesbit *et al.*, 2011; DOE, 2016, Costanza *et al.*, 2017). Three major harvest methods for extracting biomass from pine plantations include (i) biomass from thinning conventional pine plantations ('thinning'); (ii) the harvest of coarse woody debris (CWD) residues from clear-cuts ('residue harvest'); and (iii) the conversion of conventional timber stands to short-rotation energy plantations ('SREP') (Munsell & Fox, 2010). Meta-analyses and scenario modeling have provided key insights regarding effects of these crops and potential wildlife responses (Fletcher *et al.*, 2011; Riffell *et al.*, 2011a,b; Verschuyt *et al.*, 2011; Tarr *et al.*, 2017) and some recent investigations have provided useful information for specific alternatives (Homyack *et al.*, 2014; Fritts *et al.*, 2016; Grodsky *et al.*, 2016a). Yet the extent to which these harvest methods differentially impact wildlife is largely unknown, as a systematic land-use comparison across each of these land uses has not yet been done to allow formal comparison among these alternatives. Such a comparison is essential for policymakers and the bioenergy industry to be able to make informed decisions about environmental issues related to land management practices for bioenergy production.

Our objective was to conduct a systematic comparison of the conservation implications of potential bioenergy alternatives for bird communities in the southeast. We contrasted two primary bioenergy feedstocks – corn and pine biomass (Fig. 1a). Within pine plantations, we contrasted three major harvest methods: (i) thinning, (ii) residue harvest, and (iii) SREPs. We also contrasted bird communities in corn field and plantations to reference longleaf pine (*Pinus palustris*) savanna forests. We chose to study the response of birds to land management for bioenergy development because they are a highly diverse taxon that can be sampled rapidly to determine patterns of occupancy across a landscape (Ralph *et al.*, 1995). We focused on changes in occupancy of birds across land uses reflecting these bioenergy conditions (Fig. 1b–h). We focused on occupancy because this

parameter can be estimated for dozens of species across several land uses in a standardized way that rigorously accounts for observation error (i.e., imperfect detection; Kery & Royle, 2016; Mackenzie *et al.*, 2002), which can impact inferences and predictions regarding occurrence in birds (e.g., Rota *et al.*, 2011).

We expected that while birds would occur at the highest rates of occupancy in reference forests, bird occupancy would be higher in pine plantations than in corn (Fargione *et al.*, 2010; Fletcher *et al.*, 2011). Few bird species are known to consistently breed in corn fields (Best *et al.*, 1997), whereas a greater diversity of birds has been reported in pine plantations (Brockerhoff *et al.*, 2008), presumably because of greater habitat heterogeneity than in corn fields (Fletcher *et al.*, 2011). Within the pine plantations, we predicted that plantation thinning would have a positive or neutral effect on species occupancy by creating more heterogeneity and providing more open habitats needed for some bird species (Verschuyt *et al.*, 2011). In contrast, we predicted that residue removal and SREPs alternatives would have, on average, negative effects on occupancy by reducing cover from residue and via reduced heterogeneity in tree age and spacing for SREPs (Riffell *et al.*, 2011a,b). Yet we expected that the effect of SREPs would be greater than that of residue removal because of greater structural changes in vegetation. We end by contrasting these effects with reported potential biomass yields generated by these alternatives (Varvel *et al.*, 2008; Eisenbies *et al.*, 2009; Evans & Cohen, 2009; Guo *et al.*, 2010; Munsell & Fox, 2010; Gonzalez *et al.*, 2012).

Materials and methods

Study area

We sampled birds at 85 sites across three breeding seasons, April–July, 2013–2015 (Fig. 2). Sampling occurred in mature, naturally regenerated longleaf pine savannas, slash and loblolly pine plantations, and corn fields evenly distributed among three geographic regions (Fig. 1, Table S1) within the Southeastern Plains and Southern Coastal Plains ecoregions in the key bioenergy states of Florida, Georgia, and Alabama (USDA, 2010).

We compared bird species occurrence among reference forest, two crop types – corn and pine – and three pine harvest methods: thinning, residue harvest, and SREPs. We identified eight relevant land-use conditions that enabled us to estimate effects of alternatives for biomass production (Fig. 1b–i; and see below). For each of these crop types and harvesting methods, existing relevant land uses occur across the region where biomass was being removed or altered. However, biomass at some of these sites was not being used for bioenergy at the time. We located 7–12 sites of each type (Table S1) by consulting with local extension specialists and industry partners, which were stratified among three geographic regions (Fig. 2).

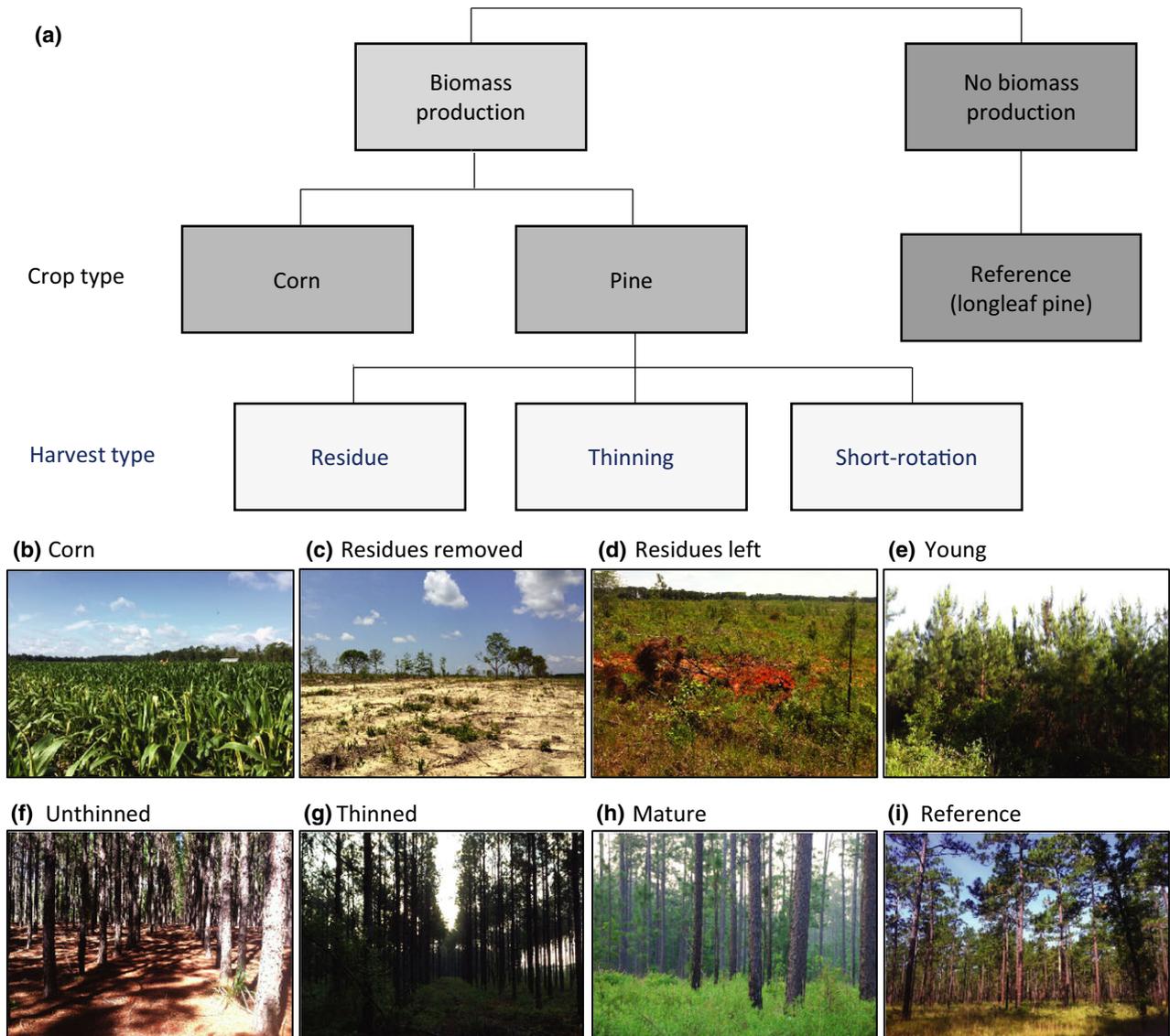


Fig. 1 (a) We considered the effects of several biomass alternatives on bird communities in the southeast United States. We considered two crop types, pine and corn, and three biomass harvesting alternatives for pine, contrasting these alternatives to reference longleaf forest. (b–i) To interpret these biomass alternatives, we surveyed eight land-use types that are relevant to alternative biomass strategies, including (b) corn fields, (c) clear-cut pine forests with residues removed and (d) with residues left (≤ 3 years), (e) young pine plantations (8–10 years), (f) unthinned and (g) thinned plantations (12–16 years), (h) mature plantations (20–32 years), and (i) reference longleaf forests (>40 years).

We selected corn fields in each region to contrast corn with pine biomass alternatives. Cornfields are currently used for biomass as a first-generation biofuel, although corn stover could be an alternate source of cellulosic biomass. Although corn is not currently produced in the study region at levels similar to the midwestern United States, corn yields can be high in many areas of the southeast (Evans *et al.*, 2010). To interpret the effects of residue harvest, we sampled loblolly and slash pine plantations that had been clear-cut within the past two years where CWD was left on the ground (clear-cut debris left, CCDL, $n = 11$) and compared them to clear-cuts where CWD was removed from the plot (clear-cut residues removed, CCRR,

$n = 10$). When timber is harvested within the context of traditional forestry, a substantial amount of nonmerchantable coarse woody debris (CWD) is often left on site and is a potential source of biomass for biofuel production (Riffell *et al.*, 2011a). To interpret effects of thinning, we compared unthinned loblolly and slash pine plantations aged 12–16 years (unthinned, $n = 11$) to recently thinned stands of similar age (thinned, $n = 12$). This comparison attempts to control for stand age while contrasting stands that have been thinned to those of similar age that have not been thinned. In a conventional pine production system, plantations are typically first thinned between ages 12 and 15 to promote the health and growth of

remaining trees. To examine a short-rotation effect, we focused on comparing sites around 8–10 years of age ('young') (Gonzalez *et al.*, 2011) to conventional timber production, in which trees are frequently harvested on 24- to 25-year rotations and thinned at least once. See *Methods: Analysis* for more details on this comparison. Late successional or old-growth longleaf pine savannas ('reference') were considered to represent historic forest conditions. These sites allowed for understanding how general pine production for biofuels and other timber purposes may impact bird communities relative to historic conditions.

Survey design

We identified field sites primarily in patches >16 ha ($n = 83$) and established two, 200 × 100 m transects. To control for potential edge effects that can be common in bird distributions (Ries *et al.*, 2004), in all sites we sampled both at the edge and in the interior of sites. An edge transect was placed 50 m from, and parallel to, the edge of the stand with the greatest contrast to adjacent habitat. An interior transect was placed ≥150 m from any edge, with at least 100 m between the two transects. Two sites were <16 ha but >4.5 ha, and a single-edge transect was established in these stands.

Bird surveys

We conducted line transect surveys for birds between April 1 and June 30 of each year. Trained observers walked at a standard pace down the center line of each 200 × 100 m transect and recorded all birds observed by sight or sound within the boundaries of the transect. Each transect was surveyed on three sampling occasions separated by approximately 4 weeks. During these three sampling occasions, each transect was surveyed twice in the same morning to account for variation in imperfect detection, between sunrise and 9:30 AM. Each site was surveyed only during one of the three years in order to maximize the spatial coverage of the study. Surveys were postponed if weather conditions (wind or rain) compromised an observer's ability to detect birds.

Vegetation sampling

We sampled vegetation to contrast differences in our management land-use categories. At the midpoint of each transect, we established a vegetation plot following the protocol described by the Forest Inventory and Analysis program of the USDA Forest Service (Woudenberg *et al.*, 2010) to characterize the vegetation structure under the eight management conditions. Each vegetation plot consisted of four, 7.3-m-radius subplots in which the diameter at breast height (DBH) and species of all trees >12.7 cm DBH were recorded. In the center of each subplot within a radius of 2.1 m, we also recorded the abundance of shrubs in each of the following height classes: a. 0–1 m; b. >1–2 m; c. >2–3 m, d. >3 m. Radiating from the center of each subplot were three 7.3-m transects along which we measured the length and diameter of each piece of coarse woody debris (CWD) that intersected the transect. We estimated the percent groundcover of woody, forb, graminoid, and bare/litter

cover within a 1-m² ground cover plot located at the end of each CWD transect.

Statistical analyses

Testing effects of biomass production alternatives on bird occurrence. To estimate effects of bioenergy options on birds, we used a single-species, single-season occupancy modeling approach developed by Mackenzie *et al.* (2002) in which presence-absence (or more appropriately, detection-nondetection) data from independent, repeated surveys were used to account for errors in species detection. We based our analysis on the Bayesian occupancy model of Royle & Dorazio (2008) because of its ability to estimate uncertainty surrounding point estimates of occupancy, include random effects into the models, and quantify appropriate *a priori* contrasts among land uses. We modeled occupancy for bird species that were detected in at least 20% of the field sites ($n = 31$ species). For each species, we estimated the probability of occurrence (ψ) across the 85 field sites as a function of management condition (eight land uses) as a covariate on ψ , and we included site as a random effect. Although we were primarily interested how ψ varied across land uses, we also initially considered effects of patch size because occupancy is widely known to vary with patch size in birds (Prugh *et al.*, 2008) and our sites varied in patch size. Yet we found no evidence of patch size effects altering our estimates of how ψ varied across land uses (*unpublished analysis*), so we removed this covariate from models to reduce model complexity. Because the breeding population could be potentially 'open' during the 3-month survey period (Rota *et al.*, 2009), where occupancy could change over time from dispersal into or out of the site, we formatted our model to account for this potential issue, while focusing on average occupancy (rather than local colonization-extinction parameters; McCarthy *et al.*, 2012). To do so, we used the two surveys from a site (pooling edge and interior transects within sites) in a single morning to produce a detection history from which we estimated species-specific detection probabilities (Mackenzie *et al.*, 2002). These paired detection histories were repeated three times (one/visit) for each site, and we used site as a random effect on ψ to account for within-site dependence and site-level variation not captured by our land-use categories. This approach increases the likelihood of adequately addressing the assumption of closure in occupancy models, because closure was only assumed within visits (Rota *et al.*, 2009). To account for heterogeneity in detection probabilities, we included survey-specific covariates of Julian date (linear and quadratic terms) and time of day. For more details on the occupancy modeling framework, see Supporting Information.

For each species, we calculated the probability of occurrence ψ in each land-use condition. To isolate potential effects of land-use changes associated with biomass production scenarios, we also focus on the change in the probability of species occurrence, $\Delta\psi$, associated with each harvest method for bioenergy production using *a priori* contrasts based on posterior distributions from models for each species. Contrasts included residue effect, thinning effect, two types of short-rotation effect, and corn effect. The contrast for residue harvest effect was

quantified as:

$$\Delta\psi_{\text{residue}} = \psi_{\text{CCRR}} - \psi_{\text{CCDL}} \quad (1)$$

The thinning effect contrast compared occupancy in thinned vs. unthinned plots of similar age:

$$\Delta\psi_{\text{thin}} = \psi_{\text{thin}} - \psi_{\text{unthinned}} \quad (2)$$

For the short-rotation effect, we decomposed it into two separate parts, the first related to the harvest of CWD and the second related to the difference in the length of the plantation rotation. Therefore, to assess the impact of a SREP compared to conventional timber production, we used the 'residue harvest effect' described above, as well as the 'short-rotation' effect, which describes the downward shift in the age of the plantation. We compared occupancy data from young stands, representative of SREPs at the maximum stage of their rotation, and compared them to the average occupancy of unthinned, thinned, and mature. The rationale for this comparison is that a shift to short-rotation production will eliminate older age classes from the life cycle of a plantation stand and the comparison is most representative of how this management change would manifest over the course of a timber rotation. This contrast can be formalized as:

$$\Delta\psi_{\text{SREP}} = \psi_{\text{young}} - (\psi_{\text{unthin}} + \psi_{\text{thin}} + \psi_{\text{mature}})/3 \quad (3)$$

We combined these two issues as:

$$\Delta\psi_{\text{SREPTOTAL}} = (\psi_{\text{CCRR}} + \psi_{\text{young}})/2 - (\psi_{\text{CCDL}} + \psi_{\text{unthin}} + \psi_{\text{thin}} + \psi_{\text{mature}})/4 \quad (4)$$

Finally, for the corn effect contrast, we tested for differences in occupancy of corn fields compared to timber stands by combining occupancy data from all timber land-use conditions and comparing them as a group to corn fields:

$$\Delta\psi_{\text{corn}} = \psi_{\text{corn}} - (\psi_{\text{CCDL}} + \psi_{\text{CCRR}} + \psi_{\text{young}} + \psi_{\text{unthinned}} + \psi_{\text{thin}} + \psi_{\text{mature}})/6 \quad (5)$$

In addition to species-specific results, we provide average effects across all species and considered relationships between the changes in ψ and species traits, including foraging guild (Degraaf *et al.*, 1985) and nest type (Martin, 1993), and we also identified regional conservation status of species as defined by Partners in Flight and local state agencies (Carter *et al.*, 2000, FWC, 2012; GDNr, 2014, ADCNR, 2015). To do so, we used posterior distributions from contrasts (Eqns 1–5) to estimate pooled effects across all species considered and species groups, similar to the derivation of community parameters from an 'N-fold single-species occupancy model' (Kery & Royle, 2016).

We estimated parameters using Markov chain Monte Carlo (MCMC) algorithm using JAGS 4.0.1 (Plummer, 2012) in program R (Team, 2016). We ran three chains for 100 000 iterations, using the first 50 000 samples as burn-in and using a thin factor of 5 to select samples. Convergence was assessed using the Rubin–Gelman statistic (all R -hat values < 1.1). We used vague priors for all fixed covariates ($N \sim (0,100)$) and used a uniform distribution for standard deviation parameters of the random site effects ($U \sim (0,10)$). We made inferences based on 95% credible intervals taken from the posterior distributions.

Differences in vegetation between land uses. To help interpret habitat variation across land uses, we determined whether there were quantifiable differences in vegetation among the land uses we considered. From our vegetation sampling, we summarized DBH based on the mean for each plot and the coefficient of variation (CV), tall (>1 m), and short (<1 m) shrub density (shrubs/m²), and we calculated the total volume (cm³) using length and diameter measurements and frequency (proportion of plots with CWD) of coarse woody debris, and the average ground cover (%) for woody, graminoid, forb, and bare/litter.

We first tested for a general effect of whether forest land use was structurally different using a multivariate analysis of variance (MANOVA). We then used *a priori* contrasts described above for bird communities (Eqns 1–4) to determine variation in each component vegetation structure described above between key land-use comparisons relevant for biomass production alternatives. For analyses, all vegetation variables were centered and scaled, but we provide effect sizes on the raw scale to aid in interpretation. We did not include corn sites in this comparison because of their extreme differences in vegetation from forested sites (e.g., no canopy, shrub cover).

Results

Avian responses to biomass alternatives

We collected a total of 6641 individual detections of 81 species of birds in the 85 study sites. Twenty-one of these species were categorized as 'of regional concern' in the Southeastern Coastal Plain by the Partners in Flight, or as a 'Species of Greatest Conservation Need' by the states of Florida, Georgia, or Alabama (Table S2). Seventy percent of bird observations were by sound only, 12% by sight only, and 18% by sight and sound. Consequently, we expected time of morning and date to be relevant covariates for detectability in occupancy models because singing behavior is greatly influenced by time and date (Brown & Handford, 2003). See Table S3 for parameter estimates of detectability based on time and date.

Across all 31 species considered for occupancy modeling, the average occupancy varied among land-use types (Fig. 3a), with low rates of occurrence in corn fields and in clear-cuts with residues removed and higher rates of occurrence in all other forests land uses (Fig. 3a; See Fig. S1 for occupancy of each species by land-use types). Based on contrasts from pooling across all species considered, thinning (Eqn. 2) tended to have positive effects, while residue harvest (Eqn. 1), the total short-rotation alternative (SREP_{total}; Eqn. 4), and corn (Eqn. 5) tended to have negative effects (Fig. 3b).

Yet there were many individual species that experienced significant increases or decreases in their probability of occurrence associated with each harvest

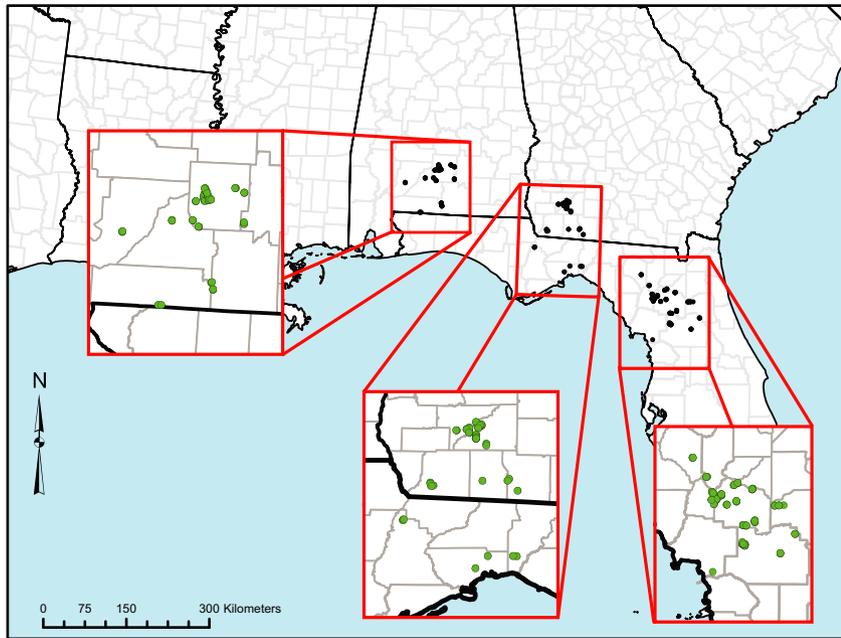


Fig. 2 (a) Our study area spanned core of the coastal plain in the southeastern United States. We sampled 85 sites spread across three geographic strata located in Alabama, Georgia, and northern Florida. For each geographic strata, we surveyed eight land uses, where we estimated occupancy of 31 bird species.

method (Fig. 4), which can be explained, in part, based on species traits and responses to specific vegetation variables (see Gottlieb, 2016 for analyses based on vegetation covariates rather than land-use types). All five species with significant responses to the thinning effect increased in the probability of occurrence with thinning. Groups that had the largest increases in occurrence associated with the thinning effect included cavity nesters and bark excavators/gleaners, two guilds with considerable species overlap (Fig. 5; Table S2). Nine species had significant residue harvest effects; each of these species decreased in occurrence with residue harvest. All foraging and nesting guilds tended to have negative responses to residue harvest, although the most sensitive groups were lower canopy foragers and cavity nesters (Fig. 5). For the SREP scenario, seven species decreased in occurrence related to the short-rotation effect (loss of older age stands). Only the white-eyed vireo (*Vireo griseus*) increased in occupancy in response to the short-rotation effect. Again, bark excavators/gleaners and cavity nesters were the most sensitive groups to the short-rotation effect (Fig. 5). The SREP_{total} scenario that included both residue harvest and a loss of older plantation stages had 14 species with significant effects, all of which decreased in occurrence (Fig. 4). For the corn scenario, 20 species had significant effect sizes (Fig. 4), all of which decreased in occurrence in corn relative to managed pine.

Vegetation differences across land uses

Overall, vegetation structure of the seven land uses considered (corn not considered; see Methods) was different based on MANOVA (Pillai's trace = 1.67; df = 6, 71; $P < 0.0001$; Table 1). Sites with residues removed had lower DBH, basal area, less woody cover, lower frequency of coarse woody debris, and a tendency for lower volume coarse woody debris than sites with residues retained (4.1 ± 2.7 vs. 8.6 ± 4.4 , SE, respectively). While the volume of coarse woody debris was not significantly different in this comparison, we note that volume had a highly skewed distribution and that this difference was significant when assessed with a rank-based test (Kruskal–Wallis test: $\chi^2 = 6.43$, df = 1, $P = 0.011$). Thinned sites had lower basal area than unthinned sites of similar age. For the SREP effect, we found lower DBH, basal area, woody cover, and a lower frequency of CWD. For the SREP_{total} effect, we found lower DBH, lower coefficient of variation of DBH, basal area, woody cover, and a lower frequency of CWD (Table 1).

Discussion

Interpreting the potential effects of an expansion in biofuel and bioenergy production on biodiversity requires systematic comparisons regarding potential alternative biomass strategies being considered. To date, most comparisons on the biodiversity within bioenergy crops

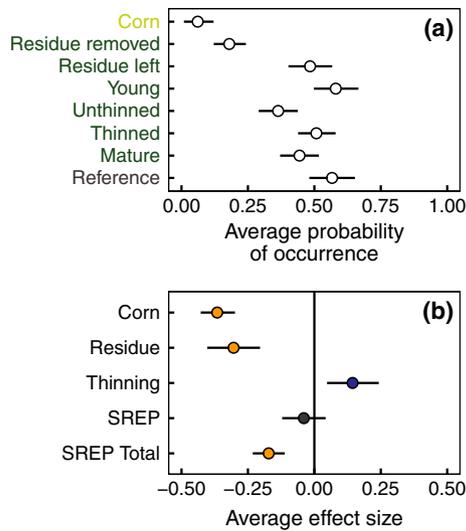


Fig. 3 Average occupancy rate (with 95% credible intervals) for 31 bird species surveyed at 85 sites in Alabama, Georgia, and northern Florida. (a) Average occupancy for each land-use type considered, and (b) effect sizes taken from land-use contrasts for each biomass alternative (with 95% credible intervals, CRI). For (a), plantation land-use labels are shown in green, longleaf forest in gray, and corn field in yellow. For effect sizes shown in (b), ‘corn’ compared the average occupancy rate in all timber stands to corn fields, ‘residue’ compared clear-cuts where the residues were left on site to clear-cuts where the residues were harvested, ‘thinning’ compared unthinned stands to recently thinned stands of similar stand age, short-rotation, ‘SREP’ compared young stands (8–10 years) at the maximum age of a short-rotation plantation (SREP) to the average occupancy rate of a conventional pine plantation stages >12 years that may be absent in a SREP scenario, and ‘SREP Total’ combined the SREP and residue effect sizes.

compare these stands to native, natural habitats or only consider single harvest methods (Fritts *et al.*, 2016; Grodsky *et al.*, 2016a). While such comparisons are useful, these comparisons do not allow a formal assessment of relative impacts to biodiversity of biomass alternatives being considered across regions. Our results allow formal contrast between both key crop types and biomass harvest alternatives relevant to biofuel and bioenergy expansion in the southeast United States. In addition, these general alternatives are being considered in other portions of the United States (DOE, 2016) and could provide insight into general trade-offs in regarding to bioenergy production and biodiversity.

Crop type

When contrasting potential effects of pine vs. corn biomass, timber stands, regardless of whether they are managed as conventional or short-rotation plantations, supported far greater occurrence of birds than corn fields. Every nesting and foraging guild examined had

lower occupancy rates in corn sites than in timber sites, with lower canopy foragers, cavity nesters, and bark excavators/gleaners showing the strongest negative responses (Fig. 4, 5). Most of the species found in corn fields were detected only once or twice, and only in one or two sites, suggesting that their use of corn fields for breeding is likely limited. Further, only one species of conservation concern (northern bobwhite; *Colinus virginianus*) occurred in a corn field (cf. Robertson *et al.*, 2012), while all seven species of conservation concern we considered in our study (Table S2) occurred widely across timber plantations, suggesting that timber plantations can provide habitat for these species, whereas cornfields do not. These results add to a growing consensus that only few bird species persist in corn fields (Christian *et al.*, 1997; Fletcher & Koford, 2003; Fargione *et al.*, 2010; Robertson *et al.*, 2011; Blank *et al.*, 2016), and our results demonstrated that birds occurred at higher rates in pine plantations than in corn fields.

Alternative pine biomass harvest options

While there were clear differences in avian communities between corn and pine stands, the bird response to pine biomass harvest methods varied widely among species. The positive impact of thinning in plantation forests on wildlife biodiversity has been well documented. The proposed mechanism is that thinning the dense, closed canopy allows light to penetrate to the forest floor, facilitating an increase in complexity of vertical structure in the understory, and subsequently, the abundance and diversity of birds and other species. Indeed, thinning was the only biomass harvest method with a net positive impact on avian occupancy rates (Fig. 3b). Most guilds benefitted from the thinning effect, although the strongest responses were observed in bark gleaners, cavity nesters, tree nesters, and upper canopy foragers (Fig. 5) such as the downy woodpecker (*Picoides pubescens*) and the tufted titmouse (*Baeolophus bicolor*).

As hypothesized, the harvest of logging residues from clear-cut plantations had consistently negative effect on avian occupancy across all nesting and foraging guilds in the study, but the magnitude of the effect was surprising. In addition, a recent experiment on residue removal found little effects on breeding and wintering birds (Grodsky *et al.*, 2016a,b); rather, Grodsky *et al.* (2016a,b) and instead suggested that the successional trajectory of vegetation (e.g., sapling growth/tree successional stage) was more critical than residue retention per se. Similarly, the understory of clear-cuts where debris was retained varied substantially in our study area, and some had a well-developed understory and vertical structure (e.g., snags and nontarget trees), which was reflected by variation

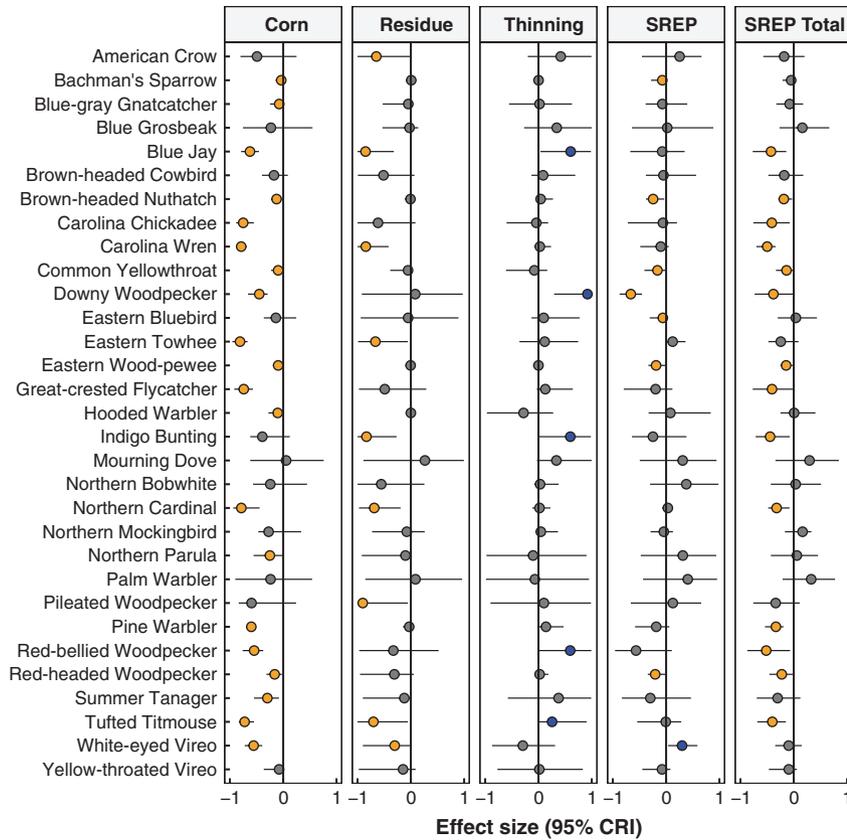


Fig. 4 Species-specific effect sizes taken from land-use contrasts for each biomass alternative (with 95% credible intervals, CRI) for 31 species surveyed at 85 sites in Alabama, Georgia, and northern Florida. For effect sizes, corn compared the probability of occurrence in all timber stands to corn fields, residue compared clear-cuts where the residues were left on site to clear-cuts where the residues were harvested, thinning compared unthinned stands to recently thinned stands of similar stand age, short-rotation (SREP) compared young stands (8–10 years) at the maximum age of a short-rotation plantation (SREP) to the average occupancy rate of a conventional pine plantation stages >12 years that may be absent in a SREP scenario, and SREP Total combined SREP and residue effect sizes. Blue points highlight significant positive effect sizes, while orange points highlight significant negative effect sizes, based on 95% CRIs. See Supporting Information for scientific names.

in basal area and DBH of remaining trees (Table 1). We hypothesize that this structure, rather than solely the retention of CWD, provided habitat for summer tanager (*Piranga rubra*), pileated woodpeckers, and red-headed woodpeckers (*Melanerpes erythrocephalus*), which were never observed in clear-cuts where the residues had been removed. In stands where the residues were removed, much of the substrate for perching, foraging, and cover was removed, and very few birds remained. This uniform pattern of low occupancy across the taxa is consistent with a recent meta-analysis reporting that both cavity and open-nesting birds consistently decline in response to residue harvest (Riffell *et al.*, 2011a). Cavity nesters and lower canopy foragers were the most sensitive groups to this harvest method (Fig. 5). Retention of selected live trees, snags, and CWD on clear-cut sites may increase the ability of many birds to persist in clear-cuts (Hansen *et al.*, 1995).

The SREP alternative had the largest overall negative effect on the bird community of the three woody biomass harvest methods considered, in terms of the number of species showing negative effects, because of the combined effects of the residue harvest and the short-rotation effect (loss of older age stands). Between the two effects, 14 of the 31 species considered were negatively affected by management for SREPs. The species negatively affected by the short-rotation effect show a strong pattern: Seven of the nine species were cavity nesters, and five were either bark gleaners or air salliers that require large trees and an open canopy and/or understory in which to forage. Four species of conservation concern (Bachman's sparrow, *Peucaea aestivalis*; brown-headed nuthatch; Eastern towhee, *Pipilo erythrophthalmus*; red-headed woodpecker) showed a negative response to the residue harvest effect or short-rotation effect, supporting previous findings that while short-rotation energy plantations may provide habitat

Table 1 Summary of vegetation variables by land use (mean (SE)) and *a priori* contrasts that indicate whether there are significant differences in each vegetation variable among biomass production alternatives (*a priori* contrasts; see Eqns 1–4 of main text)

Vegetation Variable	Land use							Biomass alternative				
	Residue left	Residue removed	Young	Unthinned	Thinned	Mature	Reference	Residue	Thin	SREP	SREP total	
DBH (mean)	14.4 (4.53)	5.4 (3.71)	16.1 (0.52)	19.1 (0.40)	21.7 (0.72)	29.9 (1.56)	29.3 (1.91)	-8.98***	2.61	-7.45***	-10.50***	
DBH (CV)	0.2 (0.09)	0.0 (0.04)	0.1 (0.01)	0.2 (0.03)	0.2 (0.02)	0.2 (0.02)	0.4 (0.03)	-0.12	-0.01	-0.08	-0.11*	
Basal area (m ² /ha)	0.9 (0.28)	0.1 (0.04)	11.7 (2.14)	12.8 (1.87)	7.9 (0.75)	8.0 (1.42)	5.3 (0.47)	-0.85***	-4.91**	2.15***	-1.51***	
Tall shrub density (m ²)	0.3 (0.05)	0.1 (0.03)	0.2 (0.03)	0.2 (0.03)	0.1 (0.03)	0.3 (0.05)	0.2 (0.06)	-0.17	-0.04	-0.01	-0.07	
Short shrub density (m ²)	2.4 (0.51)	2.0 (0.44)	1.8 (0.28)	0.9 (0.18)	2.0 (0.54)	2.6 (0.46)	2.8 (0.92)	-0.37	1.08	-0.03	-0.05	
CWD volume (cm ³)	8.6 (4.40)	4.1 (2.67)	0.9 (0.80)	18.2 (12.89)	4.2 (3.49)	21.8 (14.09)	6.7 (4.91)	-4.50	-13.92	-13.85	-10.72	
CWD frequency	0.6 (0.06)	0.3 (0.07)	0.1 (0.02)	0.2 (0.04)	0.3 (0.06)	0.4 (0.08)	0.2 (0.05)	-0.35***	0.13	-0.23***	-0.20***	
Woody	21.8 (4.63)	14.4 (3.41)	11.1 (3.05)	10.0 (2.00)	11.8 (2.00)	14.8 (3.12)	13.0 (5.14)	-7.37*	1.87	-1.10*	-1.85*	
Forbs	21.3 (4.12)	17.8 (2.99)	13.4 (4.32)	15.7 (5.74)	15.6 (5.74)	28.3 (5.09)	18.8 (4.88)	-3.46	-0.07	-6.49	-4.61	
Graminoid	13.6 (3.51)	13.1 (2.84)	8.9 (2.38)	11.3 (2.02)	15.9 (2.02)	17.0 (3.85)	22.9 (5.61)	-0.49	4.66	-5.90	-3.49	
Bare/litter	43.4 (5.89)	54.7 (5.52)	66.7 (5.93)	63.1 (6.74)	56.7 (6.74)	39.9 (5.00)	45.3 (8.08)	11.32	-6.42	13.48	9.94	

P* < 0.05, *P* < 0.01, ****P* < 0.001, *****P* < 0.0001.

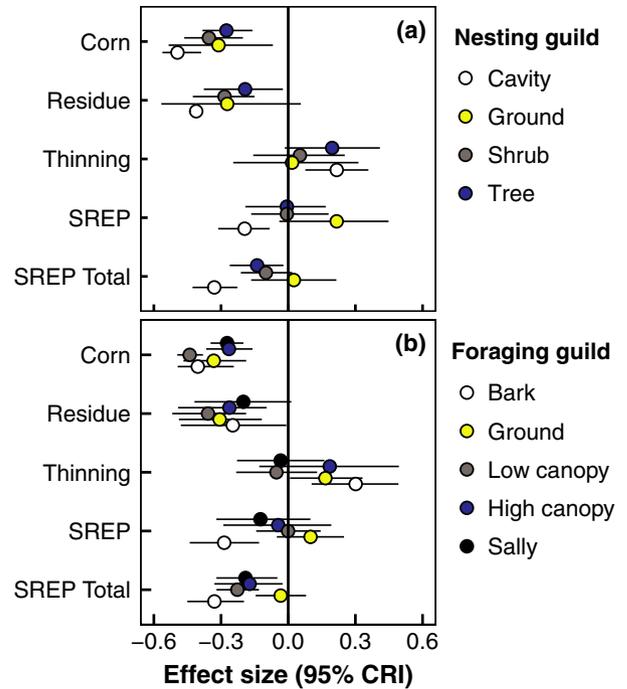


Fig. 5 Effect sizes (with 95% credible intervals, CRI) taken from land-use contrasts for each biomass alternative as a function of species traits: (a) nesting guild and (b) foraging guild. For effect sizes, corn compared the probability of occurrence in all timber stands to corn fields, residue compared clear-cuts where the residues were left on site to clear-cuts where the residues were harvested, thinning compared unthinned stands to recently thinned stands of similar stand age, short-rotation (SREP) compared young stands (8–10 years) at the maximum age of a short-rotation plantation (SREP) to the average occupancy rate of a conventional pine plantation stages >12 years that may be absent in a SREP scenario, and SREP Total combined SREP and residue effect sizes.

for many common for early successional birds and other wildlife, they were not valuable for protecting rare species of conservation concern that depend on mature pine savannas (Campbell *et al.*, 2012). The white-eyed vireo was the single species that showed a significant positive response to the short-rotation effect. These findings are concordant with Riffell *et al.*'s (2011b) meta-analysis, which found mostly negative responses to SREPs from cavity nesters, but an increase in some species of shrub-associated birds.

Limitations

Our results provide new empirical information on bird communities across land uses relevant to several biomass alternatives. However, there were some limitations to our study. First, we did not consider the population demography of species and instead focused on community structure. Avian demography (e.g., nest success,

survival) can vary considerably across landscapes and can be important information for interpreting habitat quality for birds (e.g., Bock & Jones, 2004; Fletcher *et al.*, 2006). This issue is particularly relevant when assuming that an increase in occurrence reflects habitat quality, such as assuming that thinning and retention of residues on clear-cuts increase habitat quality for some species. Although evidence suggests that occupancy and related count-based indices may often correlate with measures of habitat quality (Sergio & Newton, 2003; Bock & Jones, 2004), notable exceptions exist (Chalfoun & Schmidt, 2012). In such cases, ecological traps may occur (Robertson & Hutto, 2006), which can have detrimental impacts on populations (Fletcher *et al.*, 2012). Yet demographic information is difficult to collect on several species and across many different land uses, and demographic rates cannot be collected when species do not occur in certain land uses, often limiting demographic estimation to more abundant species. Second, our sampling was limited to a single breeding season in each site. We chose to focus sampling on as many sites as possible across field seasons, rather than repeat sampling at the same sites across years to both capture more variation across land uses and because for some sites, conditions changed across years (e.g., an unthinned site sampled in one year may be thinned in the following year). Yet our design limited the ability to make inferences regarding changes in bird communities over time with land-use change (e.g., colonization rates of species to bioenergy land uses). Third, we targeted land-use conditions where biomass was removed or altered and have been emphasized as being potential pathways for generating biomass (DOE, 2011, 2016), although biomass at some of these sites was not being used for bioenergy at the time. As bioenergy production expands, subtle differences in land use for bioenergy and currently land uses may occur, such as changes in planting densities for SREPs (Munsell & Fox, 2010). Finally, our results only apply to bird communities. Effects on other taxa could differ from birds. For instance, less mobile taxon (e.g., some small mammals) or species that require multiple habitats (e.g., some amphibians) may have very different responses than birds. Further research on other taxa, particularly those that provide critical ecosystem services (e.g., bats, bees; Boyles *et al.*, 2011; Brosi *et al.*, 2008), would be useful.

Context for the landscape – yield and net energy benefit

Short-rotation energy plantations had an overall negative effect on the bird community, but the energy yield from these intensively managed plantations has been estimated to be more than an order of magnitude greater than the yield per hectare per year acquired

through thinning, residue harvest, or corn production (Varvel *et al.*, 2008; Eisenbies *et al.*, 2009; Evans & Cohen, 2009; Guo *et al.*, 2010; Munsell & Fox, 2010; Gonzalez *et al.*, 2012). Consequently, minimizing the industry's impact on the landscape could mean choosing the most intensive management regime, because far less land would be required to meet the bioenergy production goals by relying on short-rotation energy plantations instead of acquiring biomass through other methods (cf. Heaton *et al.*, 2008). The specific context of land change for short-rotation energy plantations will be important for bioenergy, regardless of region or feedstock (Efroymsen *et al.*, 2013). Converting a conventional plantation to a short-rotation energy plantation may result in negative impacts on the bird community, whereas converting a corn field or degraded agricultural land to a short-rotation energy plantation could result in a net increase in the occurrence of several bird species.

Residue removal has been estimated to have the lowest yield of biomass per hectare of the woody biomass harvest methods considered here (Eisenbies *et al.*, 2009; Guo *et al.*, 2010; Munsell & Fox, 2010), and it had a large negative impact on the bird community. However, the time period during which a clear-cut exists on the landscape before it is treated and replanted is typically only 1–3 years, so the negative effect of removing residues from these stands is somewhat ephemeral over the typical 25-year rotation of a conventional pine plantation. Thinning has a higher biomass yield than residue removal (Guo *et al.*, 2010; Munsell & Fox, 2010), but it is still modest in comparison with SREPs. Thinning was the only biomass harvest method in the study that benefited avian biodiversity, so despite its modest yield, thinning may be a good choice for a wildlife-friendly biomass harvest method for southeastern bird communities. Harvesting plantation thinnings for bioenergy production may also provide economic gains for nonindustrial private landowners, who may benefit from competitive prices from the biomass industry compared to current prices for pulpwood and roundwood (Gruchy *et al.*, 2012).

Although corn is not as widely cultivated as pine in the southeast, it is currently the primary bioenergy feedstock in the United States with millions of acres currently in production for corn ethanol, primarily in the midwest. Corn grain and stover can yield similar amounts of ethanol compared to plantation thinning and residue harvest (Hill *et al.*, 2006; Gibbs *et al.*, 2008; Varvel *et al.*, 2008; Don *et al.*, 2012; Gonzalez *et al.*, 2012); however, the Net Energy Balance (NEB) is less. The NEB of corn has been estimated as 0.56–1.26, and in some cases, the energy input for production may exceed ethanol yield (Pimentel & Patzek, 2006; Pimentel *et al.*, 2007; Evans & Cohen, 2009). In contrast, the NEB from

pine biomass has been estimated as 2.2–2.97, approximately 50–300% higher than first-generation corn, increasing its feasibility as a major feedstock in the southeast (Dwivedi *et al.*, 2009; Evans & Cohen, 2009).

Bioenergy production has the potential to alter land use across broad regions, and may potentially impact larger areas than some other energy alternatives (McDonald *et al.*, 2012; Trainor *et al.*, 2016). Consequently, it is essential to evaluate potential land-use alternatives that can arise from an increase in the emerging bioenergy economy (Fargione *et al.*, 2010). We provide one of the first systematic assessments that contrasts several biomass alternatives identified by the DOE and USDA across the southeastern United States (USDA, 2010, DOE, 2016) and use advanced statistical models that account for key issues of imperfect detection that can bias results from wildlife surveys. Our results emphasize two key results. First, corn biomass has greater negative effects on average than that of pine biomass in this region. Second, for pine biomass, thinning tended to be a bird-friendly way to acquire biomass while the removal of residue from clear-cuts and potential conversion to short-rotation energy plantations tended to have negative effects on bird communities. Because these pine alternatives can generate different amounts of biomass, landscape-scale planning is needed to balance potential land-use change alternatives for bioenergy production and the intensity of potential effects that may arise from different biomass alternatives.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Description, distribution, and sample sizes of management conditions in each region: Alabama (AL), Panhandle (PH), and Gainesville (GV).

Table S2. Information on each bird species included in the occupancy models.

Table S3. Parameter estimates* (\pm 95% credible intervals, LCL = lower credible interval, UCL = upper credible interval) of detectability parameters for each species.

Figure S1. Estimated occurrence probability ($\psi \pm$ 95% credible intervals) for 31 bird species in eight land uses considered, 2013–2015. See Table S1 for land-use codes. Yng = Young; Mat = Mature, and Ref = Reference categories in Table S1.