Assessment of early successional arthropod and breeding bird response to intercropping switchgrass within an intensively managed loblolly pine forest

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By

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Loblolly pine (*Pinus taeda*) plantations are a common land use of the southeastern United States that have the potential to function as a source of cellulosic biomass for biofuel production. A novel land use practice of intercropping switchgrass (*Panicum virgatum*) between planted loblolly pines has been developed as a potential method of cellulosic biomass production. I evaluated response of arthropods and breeding birds to intercropping switchgrass within loblolly pine plantations compared to typically managed pine plantations. I detected 13 arthropod orders and 44 breeding bird species during 2014 – 2015. Intercropping switchgrass reduced arthropod diversity and evenness, with richness not affected. Arthropod abundance response to intercropping switchgrass varied among orders. Breeding bird species did not respond differently to intercropping switchgrass compared to typically managed pine. Continued assessment is needed to provide greater insight regarding potential effects of this land use practice throughout a rotational period.

DEDICATION

To my father, whose guidance and love molded me into the man I am today. To Sam Riffell and Scott Rush, for your support, guidance, and patience. To the love of my life, Jenny Foggia. And finally, to Miko, for your unwavering loyalty, support, and love.

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CHAPTER I

NOVEL LAND USE PRACTICE FOR PRODUCTION OF SWITCHGRASS BIOMASS, A REVIEW

Introduction

Finite reserves of fossil fuels, concerns regarding energy security, and environmental costs associated with fossil fuel production and use have led to an increased interest in renewable energy sources (McLaughlin et al. 1999, Koh and Ghazoul 2008). In particular, production of biofuels from cellulosic biomass, such as willows (*Salix* spp.), giant miscanthus (*Miscanthus x giganteus*), agricultural residues, and switchgrass (*Panicum virgatum*), have garnered considerable attention (Sanderson et al. 2006, Heaton et al. 2008). Depending on how they are cultivated and refined, biofuels produced from cellulosic biomass can serve as an alternative energy source to fossil fuels, which may reduce greenhouse gas emissions and contribute to conserving biological diversity (Fargione et al. 2008, Koh and Ghazoul 2008, Fletcher et al. 2011). However, the raw materials involved in biofuel production require either a significant redirection of land used for agricultural production or conversion of land currently in a natural state (Hoekman 2008, Broch et al. 2013). Novel land use practices and techniques, such as producing biofuels from biomass grown on marginal land or from waste biomass, must be developed for biofuels to significantly contribute to current and future energy needs (Fargione et al. 2008).

Loblolly pine (*Pinus taeda*) plantations are a common landscape in the southeastern United States and are a potential source of cellulosic biomass to produce biofuels (Riffell et al. 2011, Verschuyl et al. 2011, Wear and Greis 2012). A recently developed land use practice for cellulosic biomass production within loblolly pine plantations is intercropping switchgrass between young pine trees (Riffell et al. 2012). Switchgrass intercropping within loblolly pine plantations potentially reduces the amount of land required for cellulosic biomass production. This practice also creates a system that produces an annual source of switchgrass biomass during early rotation and marketable forest products from mature pines (Riffell et al. 2012). A secondary benefit associated with this land use practice is using native perennial grass, as opposed to its non-native counterparts, such as giant miscanthus and reed canary grass (*Phalaris arundinaceae*; Casler et al. 2009). Research has shown that planting switchgrass in North America is a potentially viable land use practice for producing cellulosic biomass, while maintaining biological diversity (Riffell et al. 2012, Robertson et al. 2012), whereas minimal knowledge currently exists on how introduction of a non-native, potentially invasive species, such as miscanthus, for producing cellulosic biomass will impact native flora and fauna (Robertson et al. 2012).

Loblolly pine plantations of the southeastern United States support a diverse array of flora and fauna, including species of conservation concern (Miller et al. 2009, Riffell et al. 2011). Maintaining biological diversity, among other things, within these systems is an integral aspect of forest management requirements set by sustainable forestry certification programs, such as the Sustainable Forestry Initiative (Miller et al. 2009, Sustainable Forestry Initiative Inc. 2010). Limited knowledge currently exists on how intercropping switchgrass affects floral and faunal communities associated with loblolly pine plantations (e.g. Riffell et al. 2012, Homyack et al. 2013, Homyack et al. 2014, Loman et al. 2014, King et al. 2014). Further, no study has yet to evaluate response of arthropod communities to intercropping switchgrass within loblolly pine plantations at any point throughout a rotational period.

With these research needs in mind, my objectives were to quantify response of arthropods and breeding birds to intercropping switchgrass within loblolly pine plantations, four and five years post-stand establishment. This study sheds light on how arthropods, an underrepresented taxonomic group within switchgrass intercropping research, and breeding birds respond to within-stand alterations to vegetative communities resulting from intercropping switchgrass. This study also adds to the current body of literature evaluating effects of switchgrass intercropping on multiple taxonomic groups, improving our overall understanding of this novel land use practice, and providing necessary information for informed sustainable forestry management decisions.

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CHAPTER II

ARTHROPOD RESPONSE TO INTERCROPPING SWITCHGRASS WITHIN LOBLOLLY PINE PLANTATIONS

Introduction

Forests cover approximately 245 million acres in the southern United States, with 44 million acres comprised of planted loblolly pine (*Pinus taeda*: USDA Forest Service 2007, USDA Forest Service 2012). Within Mississippi, loblolly pine covers an estimated 5 million acres (USDA Forest Service 2007). Loblolly pine plantations are economically beneficial to society by producing wood and wood fiber, while also providing other societal benefits through ecosystem services, such as protecting water quality, carbon sequestration, providing wildlife habitat, conservation of biological diversity, and recreation (Wigley et al. 2000, Miller et al. 2009). These benefits are derived from current management practices resulting in a heterogeneous landscape of varying successional stages and diverse plant communities at the landscape and patch level (Miller et al. 2009).

With increased global interest in alternative energy sources, forest managers have implemented a novel land use practice of intercropping switchgrass within loblolly pine plantations (Koh and Ghazoul 2008, Riffell et al. 2012). This practice is aimed to produce a renewable source of cellulosic biomass for biofuel production alongside production of timber products. Implementing switchgrass intercropping within loblolly pine plantations will result in changes to current management practices to facilitate switchgrass cultivation (Loman et al 2013). With regards to stand establishment, intercropping requires a more extensive removal of coarse woody debris from inter-bed rows and application of herbicide to facilitate switchgrass establishment (Loman et al. 2013, Wheat 2015). Congregation, addition, or loss of coarse woody debris due to switchgrass establishment may affect species associated with these fossorial microhabitat structures (Ulyshen and Hanula 2009, Riffell et al. 2011, Loman et al. 2013). The prevention of early successional and scrub-shrub vegetation establishment within inter-bed rows through herbicide application and its replacement with switchgrass may alter the structure and composition of the vegetative community at the stand level, resulting in changes in biological diversity (Tews et al. 2004, Iglay et al. 2012a, Wheat 2015).

Past studies reveal that intercropping switchgrass within loblolly pine plantations resulted in observed differences in ecological patterns, depending on the taxonomic group and temporal scale studied (e.g. Homyack et al. 2013, Loman et al. 2014, Wheat 2015). Wheat (2015) observed an initial reduction in plant community richness and diversity after stand and switchgrass establishment, whereas, Iglay et al. (2012a) found that intercropping switchgrass diversified the plant community in stands ≥ 5 years post-establishment. Homyack et al. (2013) observed no short-term effects on herpetofauna diversity or relative abundance from intercropping switchgrass within loblolly pine plantations. Switchgrass intercropping research has covered multiple vertebrate taxa (e.g. small mammals) and plants; however, research assessing response of arthropods to switchgrass intercropping is lacking (e.g. Iglay et al. 2012a, Homyack et al. 2014).

Arthropods are well-suited for diversity studies, as they fulfill a variety of functional roles (e.g. pollinators, herbivores, predators, and decomposers) and are sensitive to changes in environmental conditions (bioindicators; e.g. Kremen et al. 2002, Rainio and Niemela 2003, Rand and Louda 2006, Nummelin et al. 2007). Alterations to arthropod community structure may have direct and indirect effects on trophic dynamics, as arthropods are an important food resource for other organisms (Hamilton 1941, Holmes and Schultz 1988, McCracken and Tallowin 2004, Landis and Werling 2010). Observing how ecological patterns of arthropods are affected will provide a basis for future research aimed at assessing implications of intercropping switchgrass within loblolly pine plantations. Because arthropods are sensitive to environmental changes and because limited knowledge currently exists regarding arthropods and switchgrass intercropping, I investigated arthropod community responses to intercropping switchgrass within loblolly pine plantations. My objective was to assess responses of arthropod diversity, richness, evenness, and abundance to intercropping switchgrass within loblolly pine stands, four and five years post-establishment. I hypothesized that switchgrass intercropping would decrease arthropod diversity, richness, evenness, and abundance compared to loblolly pine stands, following typical management practices. Switchgrass establishment in inter-bed rows would result in less available habitat for arthropods associated with scrub-shrub vegetative communities, which is a common vegetative assemblage of loblolly pine stands four and five years post-establishment (Iglay et al. 2012a, Foggia 2015, Wheat 2015).

Materials and Methods

Study Area

I collected arthropod data in Kemper County, Mississippi, USA (32 51' N, 88 33' W) within the Interior Flatwoods Area of the Upper Coastal Plain (Petty 1977) on property owned and managed by Weyerhaeuser Company, and within research sites established and maintained by Weyerhaeuser Company and Catchlight Energy LLC (CLE), a joint venture between Chevron and Weyerhaeuser. The climate of the region was subtropical with mean annual temperatures of 16° C – 18° C (minimum and maximum) and a mean annual precipitation of 140 cm (National Oceanic and Atmospheric Administration 2013). The study area consisted of 9,600 ha of loblolly pine stands of various ages (70%), mature pine-hardwoods (17%), hardwoods (10%), and non-forested areas (3%; Iglay 2010).

Study Design

My study followed a complete randomized block design consisting of five sampling blocks. Within each block, there were three; 10-ha experimental stands with randomly assigned treatments (pine control, switchgrass intercropped, and switchgrass monoculture). Each experimental stand was previously a mature loblolly pine stand clearcut harvested during 2009 and 2010. Pine control treatments used Weyerhaeuser standards for site preparation, competition control, tree planting, and tree spacing. Site preparation included a V-blade plow, bedding plow, and subsoil ripper to establish pine beds. Planted pine seedlings were spaced 1.5×6.1 m resulting in pine beds and inter-bed rows having widths of 1.2 m and 4.9 m, respectively. A banded application of imazapyr (0.29 L/ha; Arsenal® AC, BASF Corp., Research Triangle Park, NC) and sulfometuron-methyl (0.15 L/ha; Oust®, E. I. du Pont de Nemours and Company, Wilmington, DE) was applied during the first growing season to pine beds to reduce woody and herbaceous competition. Switchgrass intercropped treatments had similar site preparation as pine control stands, with the addition of more extensive coarse woody debris removal. Once pine beds were established, a V-blade plow was used to remove coarse woody debris from inter-bed rows into pine bed edges. Upon clearing inter-bed rows, a banded application of glyphosate (2.34 – 4.68 L/ha; Accord®XRT, Dow AgroSciences, Indianapolis, IN) was applied to inter-bed rows. Inter-bed rows were then disked and broadcast seeded with switchgrass. Switchgrass intercropped stands were seeded in spring 2011 and reseeded again in 2012, due to poor establishment after initial seeding. Inter-bed rows were sprayed with a banded application of glyphosate and disked a second time during the reseeding event in 2012. Site preparation for switchgrass monoculture treatments included complete removal of coarse woody debris using a V-blade plow and broadcast application of glyphosate (2.34 – 4.68 L/ha; Accord®XRT, Dow AgroSciences, Indianapolis, IN). Glyphosate was applied to reduce plant competition prior to disking and broadcast seeding of switchgrass.

Three permanent sampling points, generated during previous studies conducted on these experimental stands (e.g. Loman et al. 2014), were located along the southeastern to northwestern corners of the experimental stands, with end points ≥ 50 m from edges to reduce edge effects. Permanent points were also arranged to maximize distances from streamside management zones (pine/hardwood and hardwood corridors maintained along waterways). I randomly generated four paired points within a 50 m radius of the three permanent sampling points per treatment (24 points per treatment). Paired points allowed stratification of sampling points by beds (planted pines) and inter-bed rows (either scrub-shrub vegetation or switchgrass). Monocultures lacked beds and inter-bed rows, with sampling instead conducted at four unpaired points (12 points per treatment). I sampled arthropods three times annually from late May to late June, 2014 – 2015, with one sampling event occurring in May and two in June. This period was selected as it coincided with breeding and nesting period of avian species.

I sampled arthropods using heavy duty, 38.1cm diameter sweep-nets with a 91.4cm handle (BioQuip Products, Rancho Dominguez, California, USA), as this is the optimal method for collecting arthropods associated with medium height vegetation (e.g. shrubs and saplings; Ozanne 2005), which was typical of my study sites. I collected arthropod samples when the vegetation was dry and wind speeds were < 20km/h, as these are optimal conditions for effective capture of arthropods using sweep-nets (Doxon et al. 2011). Only one person collected samples during each sampling event to reduce bias associated with using multiple observers (Buffington and Redak 1998). Sweeps of the net were consistent among treatment types, with the net reaching a maximum height of 3 m with the arc (approx. 2 m wide) ending at ground level. At the end of each sweep, I twisted the net 180° to prevent escapes (Doxon et al. 2011). I placed collected samples into a re-sealable plastic bag and left them in a kill bucket (i.e. five gallon bucket containing sponges soaked in acetone) until storage by freezing was available (Doxon et al. 2011). I identified all arthropods to order using the dichotomous key of Triplehorn and Johnson (2005).

Statistical Analysis

I calculated Shannon's Diversity Index, richness, and evenness to assess arthropod community responses to intercropping and planting monocultures of switchgrass within loblolly pine plantations compared to loblolly pine stands following standard management practices (R package "vegan"; R Core Team 2013, Oksanen et al. 2011). I used linear mixed effects models following a normal distribution to compare community metrics among treatments. Models consisted of a fixed effect of treatment and un-nested random effects of year, plot, and visit. I assessed community metrics for 11 of 13 detected arthropod orders, which included Acari, Araneae, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepitoptera, Mantodea, Neuroptera, Opiliones, and Orthoptera. I did not include Decapoda and Phasmatodea in diversity analyses due to minimal detections of these orders throughout the study (n = 2 and n = 1, respectively). I conducted a post-hoc Tukey test (R package "multcomp") with one degree of freedom linear contrasts to compare mean diversity, richness, and evenness among treatments (Hothorn et al. 2008).

I used generalized linear mixed effects models (R package "lme4") following a poisson distribution to assess response of arthropod general abundance to intercropping and planting monocultures of switchgrass compared to loblolly pine stands following standard management practices (R Core Team 2013, Douglas et al. 2015). The models consisted of a fixed effect of treatment and un-nested random effects of year, plot, and visit. I used a post-hoc Tukey test (R package "multcomp") with one degree of freedom linear contrasts to compare mean abundance of arthropods across treatments (Hothorn et al. 2008). I selected five arthropod orders (Araneae, Coleoptera, Diptera, Hemiptera, and

Orthoptera) for analyses to assess general abundance response to treatments, based on the criteria that each order had a sufficient number of detections (n = > 50) across all treatments. I considered all tests significant at $\alpha = 0.05$.

Results

I detected 2,913 individuals (n = 1,172 and 1,741 in 2014 and 2015, respectively), encompassing 13 orders over the 2-year sampling period (2014 – 2015; Table 2.1). Diversity significantly differed between switchgrass intercropped and pine control treatments (z-value = -2.62, P = 0.023), and between switchgrass monoculture and pine control treatments (z-value = -4.92, P = <0.001). Diversity did not significantly differ between switchgrass monoculture and switchgrass intercropped treatments (z-value = -2.30, P = 0.055). Richness significantly differed between switchgrass monoculture and pine control treatments (z-value = -4.13, P = <0.001), and between switchgrass monoculture and switchgrass intercropped treatments (z-value = -3.18, P = 0.004). Richness did not differ between switchgrass intercropped and pine control treatments (z-value = 0.94, P = 0.61). Evenness significantly differed between switchgrass intercropped and pine control treatments (z-value = -2.49, P = 0.033), and between switchgrass monoculture and pine control treatments (z-value = -2.35, P = 0.049). Evenness did not significantly differ between switchgrass monoculture and switchgrass intercropped treatments (z-value = 0.029, P = 0.98; see Table 2.2).

Araneae and Coleoptera general abundance followed a similar pattern, with abundances differing significantly between switchgrass monoculture and pine control treatments and between switchgrass monoculture and switchgrass intercropped treatments (Table 2.3). Diptera general abundance differed significantly between switchgrass intercropped and pine control treatments (z-value = -2.60, P = 0.024) and between switchgrass monoculture and pine control treatments (z-value = -3.85, P = <0.001), but not between switchgrass monoculture and switchgrass intercropped treatments (z-value = -1.32, P = 0.38). Hemiptera general abundance differed significantly between switchgrass intercropped and pine control treatments (z-value = 2.49, P = 0.034), with no significant differences being observed among the remaining treatment comparisons. Orthoptera general abundance was significantly different between switchgrass monoculture and pine control treatments (z-value = 3.65, P = 0.00083), with no significant differences being observed among the remaining treatment comparisons (Table 2.3).

Discussion

Results of my study indicated that cultivation of switchgrass, whether intercropped or planted in a monoculture within loblolly pine plantations, led to a significant reduction in arthropod diversity and evenness. My results also indicate that arthropod richness was significantly reduced in switchgrass monoculture treatments as compared to switchgrass intercropped and pine control treatments. Responses of arthropod diversity, richness, and evenness to intercropping and planting monocultures of switchgrass indicated that arthropod communities responded negatively to these treatments as compared to pine control treatments, four and five years post-stand establishment. Furthermore, general abundance responses to treatments varied across arthropod orders. For example, I detected higher (Orthoptera and Hemiptera) and lower (Diptera) abundances in treatments containing switchgrass, compared to treatments without switchgrass.

Multiple taxonomic groups respond to changes in the structural and compositional diversity of vegetative communities (MacArthur and MacArthur 1961, Tews et al. 2004 and citations therein). Iglay et al. (2012a) hypothesized that intercropping switchgrass may increase diversity by providing a heterogeneous plant community consisting of a herbaceous component in inter-bed rows and a woody, shrub component in pine beds. However, my study indicated that structural and compositional diversity of the plant community in switchgrass intercropped treatments reduced arthropod community metrics. I hypothesize that the decline in arthropod community metrics had less to do with structural and compositional heterogeneity of the plant community of switchgrass intercropped treatments, but instead was influenced by specific habitat requirements of the arthropods detected (Tews et al. 2004).

Separately, loblolly pine plantations and switchgrass plantings are able to support diverse arthropod communities (e.g. Bird et al. 2004, Gardiner et al. 2010, Landis and Werling 2010, Iglay et al. 2012b). However, specific habitat requirements of certain arthropods associated with loblolly pine plantations may inhibit their use of switchgrass plantings, and vice-versa (e.g. Martin and Major 2001). My assessment of arthropods was conducted across two structurally and compositionally differing vegetative communities (e.g. grassland-forest matrix; Iglay et al. 2012a). These differences in the vegetative community provide habitat conditions for a different suite of arthropods, resulting in a shift in the community as amount of available switchgrass changes across treatments. The observed increase in general abundance of Hemiptera and Orthoptera in switchgrass intercropped and switchgrass monoculture treatments, respectively, compared to pine control treatments suggests that some members of these orders may be generalists.

Therefore, they may be able to exploit resources available in vegetative communities associated with switchgrass intercropped and switchgrass monoculture treatments, whereas, other orders detected may have strict habitat requirements, limiting their use of switchgrass plantings (e.g. Rand and Louda 2006).

The inferences made in my study regarding arthropod community response to intercropping switchgrass within loblolly pine plantations are limited. My study does not capture how the entire arthropod community is responding to implementing this novel land use practice. To better elucidate response of the overall arthropod community, future research should incorporate multiple sampling techniques. Sweep-net sampling is the optimal technique used to assess arthropods associated with medium-height vegetation, such as grasses and small shrubs (Ozanne 2005). However, sweep-net sampling may not be the optimal technique for sampling large, dense thickets of thorny shrubs (e.g. *Rubus argutus*), which dominated my study site (e.g. Iglay et al. 2012a, Wheat 2015). Coupling multiple sampling techniques, such as sweep-nets, pit-fall traps, and branch clipping, would allow for a more extensive sampling of the arthropod community (Ozanne 2005, Woodcock 2005). Additionally, a sampling period encompassing a large portion of the year should be implemented to evaluate effects of switchgrass intercropping on seasonal patterns exhibited by some arthropods (e.g. Pinheiro et al. 2002, Danks 2007). Lastly, future studies should evaluate how intercropping switchgrass affects arthropods identified to a lower taxonomic level, such as family. This would allow for greater delineation of arthropod functional roles and habitat requirements, improving our understanding of arthropod response to intercropping switchgrass.

Arthropods provide valuable ecosystem services, such as pest control, pollination, and decomposition, with the annual value of these services estimated to be worth $57 billion (Lousey and Vaughan 2006). Arthropods are also important food resources for other taxonomic groups, such as amphibians, small mammals, and birds (e.g. Hamilton 1941, Holmes and Schultz 1988, Moseley et al. 2005, Horn and Hanula 2008). Therefore, it is vital to understand how forest management practices influence arthropod communities and, in turn, limit or enhance ecosystem services and biodiversity. Arthropod communities respond differently to the implementation of novel forestry practices across different geographic regions and forest types (e.g. Bird et al. 2004, Horn and Hanula 2008, Ulyshen and Hanula 2009). It is currently unknown how intercropping switchgrass within forest stands of differing ages, other forests types, and different geographic regions will impact arthropod communities. Comparative and more extensive studies are needed to provide greater insight regarding the impacts of this novel land use practice.

Management Implications

Observations made from my study indicate that intercropping switchgrass within loblolly pine plantations may negatively affect arthropod diversity and evenness as compared to pine stands following typical management practices. It is also clear that abundance responses to intercropping switchgrass varies across orders, with positive responses detected in switchgrass intercropped treatments compared to pine control treatments, and vice-versa. Although past research reveals that certain management practices within loblolly pine plantations can benefit arthropods, it appears that, overall, intercropping switchgrass provides no additional benefits (e.g. Ulyshen and Hanula 2009, Iglay et al. 2012b). In fact, it appears that switchgrass intercropping may negatively affect the arthropod community associated with loblolly pine stands following typical silviculture practices, four and five years post-stand establishment. However, inferences drawn from this study are limited due to its temporal scope, but it does provide a basis for continued research aimed at addressing arthropod responses to intercropping switchgrass within loblolly pine plantations.

Negative impacts of switchgrass establishment to arthropod communities could have important ramifications on the ecosystem services provided by arthropods and on wildlife species dependent on arthropods as a prey base. Additional research is needed to evaluate potential negative effects of switchgrass intercropping on arthropod communities. Continued research is also needed regarding effects of intercropping switchgrass from stand establishment to three years post stand establishment and beyond five years post stand establishment. Lastly, additional research is needed to address how different establishment practices, such as coarse woody debris removal associated with intercropping switchgrass, affects arthropod communities compared to establishment practices currently implemented on non-intercropped pine. Addressing the aforementioned gaps in research regarding arthropod community response to intercropping switchgrass is needed before a recommendation can be made regarding viability of intercropping switchgrass within loblolly pine plantations.

Table 2.1 Mean and standard deviation of arthropod abundance among treatments established within an intensively managed loblolly pine forest and summed across years (2014 – 2015) in Kemper County, Mississippi, USA.

Order	Switchgrass Intercropped	Switchgrass Monoculture	Pine Control
Acari	0.20 ± 0.60	NP	0.70 ± 1.63
Araneae	15.10 ± 8.27	8.90 ± 2.55	14.70 ± 9.31
Coleoptera	7.70 ± 3.02	3.10 ± 2.23	5.70 ± 3.88
Decapoda	NP	NP	0.20 ± 0.63
Diptera	5.20 ± 4.78	3.70 ± 3.77	9.10 ± 5.42
Hemiptera	46.40 ± 17.62	38.70 ± 24.26	28.50 ± 9.69
Hymenoptera	1.20 ± 0.78	0.50 ± 0.70	1.40 ± 1.35
Lepidotpera	0.80 ± 0.91	0.20 ± 0.42	1.00 ± 0.66
Mantodea	0.10 ± 0.31	NP	1.00 ± 1.33
Neuroptera	0.60 ± 0.84	0.10 ± 0.31	0.20 ± 0.42
Opiliones	0.60 ± 0.96	NP	0.70 ± 1.05
Orthoptera	8.20 ± 2.65	11.20 ± 6.92	5.70 ± 3.49
Phasmatodea	NP	0.10 ± 0.31	NP

NP: Not Present

Table 2.2 Linear tests of hypotheses of arthropod diversity, richness, and evenness among treatments established within a loblolly pine plantation in Kemper County, Mississippi, USA, 2014 – 2015.

Linear Hypotheses	Effect Size	CI Lower	CI Upper	z-value	P-value
Diversity					
IC --- PC	-0.16	-0.30	-0.01	-2.63	0.02
M --- PC	-0.31	-0.45	-0.16	-4.92	<0.001
M --- IC	-0.14	-0.28	0.002	-2.30	0.06
Richness					
IC --- PC	-0.26	-0.92	0.39	-0.94	0.61
M --- PC	-1.16	-1.82	-0.50	-4.13	<0.001
M --- IC	-0.90	-1.56	-0.23	-3.18	0.004
Evenness					
IC --- PC	-0.07	-0.14	-0.004	-2.49	0.03
M --- PC	-0.06	-0.13	-0.0002	-2.35	0.04
M --- IC	-0.004	-0.06	0.07	0.14	0.98

IC: Switchgrass intercropped
PC: Pine control
M: Switchgrass monoculture
---: Signifies a comparison between treatments

Table 2.3 Linear tests of hypotheses of Araneae, Coleoptera, Diptera, Hemiptera, and Orthoptera abundance among treatments within a loblolly pine plantation in Kemper County, Mississippi, USA, 2014 – 2015.

Linear Hypotheses	Effect Size	CI Lower	CI Upper	z-value	P-value
Araneae					
IC --- PC	0.02	-0.33	0.39	0.17	0.98
M --- PC	-0.49	-0.89	-0.09	-2.91	0.009
M --- IC	-0.52	-0.92	-0.12	-3.09	0.005
Coleoptera					
IC --- PC	0.31	-0.20	0.82	1.42	0.32
M --- PC	-0.60	-1.20	-0.0004	-2.34	0.04
M --- IC	-0.91	-1.49	-0.33	-3.67	<0.001
Diptera					
IC --- PC	-0.57	-1.08	-0.05	-2.60	0.02
M --- PC	-0.90	-1.45	-0.35	-3.85	<0.001
M --- IC	-0.33	-0.92	0.25	-1.32	0.38
Hemiptera					
IC --- PC	0.48	0.02	0.93	2.49	0.03
M --- PC	0.23	-0.22	0.69	1.21	0.44
M --- IC	-0.24	-0.69	0.20	-1.27	0.41
Orthoptera					
IC --- PC	0.36	-0.08	0.81	1.89	0.14
M --- PC	0.67	0.24	1.10	3.65	<0.001
M --- IC	0.30	-0.08	0.70	1.82	0.16

IC: Switchgrass intercropped
PC: Pine control
M: Switchgrass monoculture
---: Signifies a comparison between treatments

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CHAPTER III

BREEDING BIRD RESPONSE TO INTERCROPPING SWITCHGRASS WITHIN A LOBLOLLY PINE PLANTATION

Introduction

Cellulosic biomass production may exacerbate current conservation threats to agricultural and grassland associated bird species (Fargione et al. 2008, Robertson et al. 2012). Switchgrass plantings have been shown to support diverse avian communities, however, studies have focused mainly on switchgrass plantings within regions historically dominated by grasslands and not on cultivating switchgrass within a forest-dominated landscape (Murray and Best 2003, Murray et al. 2003, Roth et al. 2005, Robertson et al. 2012). With increased global interest in biofuels as a renewable, alternative energy source, a novel land use practice of intercropping switchgrass within loblolly pine plantations has been developed for producing cellulosic biomass (Koh and Ghazoul 2008, Riffell et al. 2012). This land use practice allows for the co-production of an annual crop of cellulosic biomass and forest products, while circumventing competition for land that is already in production and reducing conversion of natural land to biomass production.

Loblolly pine plantations are a ubiquitous landscape cover of the southeastern United States, with approximately 5 million acres present within Mississippi (USDA Forest Service 2007, Wear and Greis 2012). These plantations are able to support a diverse avian community throughout an entire rotation, from establishment to harvest (e.g. Childers et al. 1986, Wilson and Watts 2000, Lohr et al. 2002, Iglay 2010, Owens et al. 2014). More specifically, loblolly pine plantations provide habitat conditions for scrub-shrub associated avian species, which have experienced steep population declines (Brawn et al. 2001, Loman et al. 2014, Ownes et al. 2014). Intercropping switchgrass within loblolly pine plantations results in the removal of inter-bed row scrub-shrub vegetation and replaces it with switchgrass. Limited knowledge currently exists on how alterations to the vegetative assemblage due to intercropping switchgrass will affect scrub-shrub associated avian species within loblolly pine plantations (e.g. Riffell et al. 2012, Loman et al. 2014).

A past study revealed that intercropping switchgrass within loblolly pine plantations supported an avian community as diverse as one associated with loblolly pine managed under standard silviculture practices. However, intercropping switchgrass resulted in a one to two year lag in avian abundance (Loman et al. 2014). Loman et al. (2014) provides some insight regarding scrub-shrub associated avian species responses to intercropping switchgrass, however, inferences were limited due to the temporal scope of the study (conducted from establishment to three years post establishment). No study has yet to assess response of scrub-shrub associated avifauna to within stand alterations due to intercropping switchgrass within loblolly pine stands four and five years post establishment.

Acting as indicators of ecosystem integrity, the diversity of species and habitat conditions used, and ease of monitoring make birds well suited for evaluation and assessment of forest management practices (Maurer 1993, Bibby et al. 2000, Nuttle et al.

2003). Because birds can help elucidate effects of novel forest management practices and because limited knowledge currently exists regarding birds and intercropping switchgrass, I investigated scrub-shrub associated breeding bird responses to intercropping switchgrass within loblolly pine plantations. My objective was to assess patterns of breeding bird abundance and diversity to intercropping switchgrass within loblolly pine stands, four and five years post establishment. A secondary objective was to compare the Conservation Value (CV) of treatments to quantify their value to breeding birds. I hypothesized that switchgrass intercropping would decrease breeding bird abundance and diversity compared to loblolly pine stands following typical management practices. Switchgrass establishment in the inter-bed rows would result in less available habitat for birds associated with scrub-shrub vegetative communities, which is a common vegetative assemblage of loblolly pine stands four and five years post establishment (Iglay et al. 2012a, Foggia 2015).

Materials and Methods

Study Area

I collected bird data in Kemper County, Mississippi, USA (32 51' N, 88 33' W) within the Interior Flatwoods Area of the Upper Coastal Plain (Petty 1977) on property owned and managed by Weyerhaeuser Company and within research sites established and maintained by Weyerhaeuser Company and Catchlight Energy LLC (CLE), a joint venture between Chevron and Weyerhaeuser. The climate of the region was subtropical with mean annual temperatures of 16° C – 18° C (mean for minimum and maximum) and a mean annual precipitation of 140 cm (National Oceanic and Atmospheric Administration 2013). The study area consisted of 9,600 ha of loblolly pine stands of various ages (70%), mature pine-hardwoods (17%), hardwoods (10%), and non-forested areas (3%; Iglay 2010).

Study Design

My study followed a complete randomized block design consisting of five sampling blocks. Within each block, there were three; 10-ha experimental stands with randomly assigned treatments (pine control, switchgrass intercropped, and switchgrass monoculture). Each experimental stand was previously a mature loblolly pine stand clearcut harvested during 2009 and 2010. Pine control treatment, used Weyerhaeuser standards for site preparation, competition control, tree planting, and tree spacing. Site preparation included a V-blade plow, bedding plow, and subsoil ripper to establish pine beds. Planted pine seedlings were spaced 1.5×6.1 m resulting in pine beds and inter-bed rows having widths of 1.2 m and 4.9 m, respectively. A banded application of imazapyr (0.29 L/ha; Arsenal® AC, BASF Corp., Research Triangle Park, NC) and sulfometuron-methyl (0.15 L/ha; Oust®, E. I. du Pont de Nemours and Company, Wilmington, DE) was applied during the first growing season to pine beds to reduce woody and herbaceous competition. Switchgrass intercropped treatment had similar site preparation as pine control stands with the addition of more extensive coarse woody debris removal. Once pine beds were established, a V-blade plow was used to remove coarse woody debris from inter-bed rows into pine bed edges. Upon clearing inter-bed rows, a banded application of glyphosate (2.34 – 4.68 L/ha; Accord®XRT, Dow AgroSciences, Indianapolis, IN) was applied to inter-bed rows. Inter-bed rows were then disked and broadcast seeded with switchgrass. Switchgrass intercropped stands were seeded in spring 2011 and reseeded again in 2012 due to poor establishment after initial seeding.

Inter-bed rows were sprayed with a banded application of glyphosate and disked a second time during the reseeding event in 2012, Site preparation for switchgrass monoculture treatment included complete removal of coarse woody debris using a V-blade plow and broadcast application of glyphosate (2.34 – 4.68 L/ha; Accord®XRT, Dow AgroSciences, Indianapolis, IN). Glyphosate was applied to reduce plant competition prior to disking and broadcast seeding of switchgrass.

Three permanent sampling points, generated during previous studies conducted on these experimental stands (e.g. Loman et al. 2014), were located along the southeastern to northwestern corners of the experimental stands with end points ≥ 50 m from edges to reduce edge effects. Permanent points were also arranged to maximize distances from streamside management zones (pine/hardwood and hardwood corridors maintained along waterways) and minimize overlap of detections from other survey locations. I conducted ten minute point transect surveys for breeding birds at each of the three permanent points. For each survey, I recorded all detections made, identified species, method of detection (visual or auditory), time of detection during the survey, distance from the observer at time of detection, and number of individuals detected. I recorded distances of detected individuals using the consistent spacing (1.5×6.1 m) of planted loblolly pines as a reference for distance estimation. I recorded distances in exact distances and not binned distances. I conducted surveys between sunrise and 3.5 – 4 hours after sunrise. I did not conduct surveys in inclement weather conditions (e.g. high winds ((≥ 16.09 kph), rain, and heavy fog) that could influence ability of individuals to be detected or reduce observer's ability to detect birds. I surveyed all treatment plots five times annually between May and mid-June, 2014 – 2015, coinciding with the avian breeding period, with a minimum of seven days and a maximum of ten days between surveys of the same treatment plot. This sampling time frame reduced detection of late staying wintering birds and allowed for migrating individuals to reach breeding grounds and establish territories. Multiple observers were used and rotated evenly among treatment plots to minimize bias associated with multiple observers conducting point transect surveys (MacKenzie et al. 2003). Observers received similar training prior to conducting surveys, which consisted of mock point transects. Training continued until observers were proficient with bird identification and distance estimation.

Statistical Analysis

I used the statistical package "Unmarked" in R to analyze breeding bird abundances obtained from point transect surveys. Within "Unmarked", I used the distance sampling model "gdistsamp". I used this statistical package because it accounts for imperfect detections of individuals across treatments and counts (Fisk and Chandler 2011, R Core Team 2013). Abundance estimates were obtained for species that met the specific criteria for analyses, which included having approximately 40 – 50 detections for model convergence and an accurate distance estimate obtained, with this condition excluding coursing birds such as Turkey Vultures (*Cathartes aura*) and Barn Swallows (*Hirundo rustica*) from analysis (Loman et al. 2014). I also excluded species that were solely confined to streamside management zones or associated with adjacent forest stands (e.g. Tufted Titmouse [*Baeolophus bicolor*] and Pine Warbler [*Setophaga pinus*]). Lastly, switchgrass monocultures did not have an adequate number of detections for model convergence of any breeding bird species, and so, I excluded these from analyses.

I created a no-covariate model for each breeding bird species and selected the best key function, which describes the shape of detection function based on observed distances, using AIC. Once a key function was selected, I built a candidate model for each species using treatment as an abundance covariate and observer as a detection covariate. I then used abundance estimates to calculate Shannon's Diversity Index for treatments ("vegan" package in R; Oksanen et al. 2011). I used a linear mixed effects model ("lme4" package in R) to compare breeding bird diversity between switchgrass intercropped and pine control treatments (Douglas et al. 2015). The model consisted of a fixed effect of treatment and un-nested random effects of plot and year. I then performed a post-hoc Tukey test ("multcomp" package in R) with one degree of freedom linear contrast to compare mean diversity between switchgrass intercropped and pine control treatments (Hothorn et al. 2008).

I calculated a Conservation Value Index (CV) for each treatment following the recommendations of Nuttle et al. (2003) and using Partners in Flight (PIF) ranks for the Southeastern Coastal Plain Conservation Region to calculate weighted means of bird abundance. Partners in Flight is a partnership of stakeholders, including government agencies, non-governmental organizations, and industry, interested in avian conservation. Partners in Flight ranks are derived from the relative extinction risk of each species, and are used to prioritize conservation for species of the United States, Canada, and Mexico, with a higher PIF rank indicating a species of higher priority. Partners in Flight rank is assigned based on scores given to assessment factors that include population size and trend (increasing, decreasing, or stable), breeding distribution, non-breeding distribution, and discerned threats to breeding and threats to non-breeding populations (Panjabi et al.

2012). To calculate CV, I multiplied PIF ranks by species abundances, with weighted abundances added across each treatment. I used a linear mixed effects model ("lme4" package in R) with a fixed effect of treatment and un-nested random effects of plot and year to compare CV between switchgrass intercropped and pine control treatments (Douglas et al. 2015). I performed a post-hoc Tukey test ("multcomp" package in R) with one degree of freedom linear contrasts to compare mean CV between treatments (Hothorn et al. 2008). I considered tests significant at $\alpha = 0.05$.

Results

I detected 5,462 individuals of 44 different species, 12 of which I used for analyses based on the aforementioned criteria (Table 3.1). Breeding bird abundance did not significantly differ between switchgrass intercropped and pine control treatments for any of the 12 species. No significant differences were found among observers and their ability to detect each species. I had minimal to no detections of the 12 breeding birds assessed on switchgrass monoculture treatments, with most detections on these treatments being flyovers. I calculated a Shannon's Diversity Index for the same 12 species and found that diversity did not significantly differ between pine control and switchgrass intercropped treatments (z-value = -0.437, P = 0.972). I calculated Conservation Value (CV) using abundance estimates of the same 12 species, and I found no significant difference in CV between pine control and switchgrass intercropped treatments (z-value = -2.325, P = 0.093). General abundance of Gray Catbirds (*Dumetella carolinensis*) differed greatly between 2014 and 2015 (n = 2 and n = 62, respectively), and for Orchard Orioles (*Icterus spurius*) between 2014 and 2015 (n = 4 and n = 20, respectively). General abundances of each species were summed across pine control and switchgrass intercropped treatments.

Discussion

Intercropping switchgrass within loblolly pine plantations did not influence the breeding bird community associated with scrub-shrub vegetation. Intercropping switchgrass did not reduce breeding bird abundance and diversity compared to pine control treatments as predicted. There are several possible explanations for why breeding bird abundance and diversity did not differ between switchgrass intercropped and pine control treatments. First, the dense scrub-shrub vegetation maintained within pine beds of switchgrass intercropped treatments was analogous to the scrub-shrub vegetation maintained within pine control treatments. Patches of thickets consisting of sawtooth blackberry (*Rubus argutus*), Japanese honeysuckle (*Lonicera japonica*), and other woody plant species were maintained within switchgrass intercropped beds (Iglay et al. 2012a, Wheat 2015). Retaining these patches of thickets provided habitat conditions to support scrub-shrub associated breeding birds. Second, implementation of adjacency constraints to meet forest certification standards produces a heterogeneous landscape that provided a diversity of habitat conditions (Miller et al. 2009, SFI 2015). Availability of diverse habitat conditions in adjacent edges and stands within these managed systems may have offset potential resource limitations associated with switchgrass intercropped treatments (Zanette et al. 2000, Fahrig et al. 2011).

Though supporting a similar breeding bird community in my study, this trend may not continue as stands age (Loman et al. 2014). Intercropping switchgrass creates more open understory conditions, potentially maintaining scrub-shrub habitat conditions longer throughout the rotational period than pine stands following typical silviculture practices (Riffell et al. 2012). As stands age, breeding bird community structure of switchgrass intercropped treatments may diverge from that of pine control treatments, similar to the findings of Loman et al. (2014). As loblolly pine stands age, the canopy closes and understory vegetation becomes more homogeneous, being dominated by woody shrubs, such as sawtooth blackberry (Iglay et al. 2012a, Foggia 2015). This results in a reduction in avian diversity until the understory is re-opened through thinning, prescribed fire, or herbicide application (Dickson et al. 1993, Wilson and Watts 1999, Iglay 2010). Intercropping switchgrass may maintain a more open understory and diverse vegetative community for a longer timeframe than loblolly pine stands of a similar age, following typical silviculture practices, and thus, support a more diverse breeding bird community (MacArthur and MacArthur 1961, Tews et al. 2004, Iglay et al. 2012a). Maintaining scrub-shrub habitat conditions in switchgrass intercropped treatments may create a potential conservation benefit to scrub-shrub associated birds, which have experienced population declines (Brawn et al. 2001).

Breeding bird responses to switchgrass monoculture treatments suggests that these small grasslands provide few resources for breeding scrub-shrub associated birds. Riffell et al. (2012) hypothesized that switchgrass cultivation within loblolly pine plantations could serve as a potential conservation benefit to grassland associated breeding birds. However, detections suggesting a local population of grassland associated breeding birds were not observed on switchgrass monoculture treatments. Lack of grassland breeding bird detections may be a result of the small size of the grasslands (~10 ha) and their placement within a forest-dominated landscape (Johnson and Igl 2001, Robertson et al. 2012). There was one exception, a singing Eastern Meadowlark (*Sturnella magna*), a grassland species (Lanyon 1995), was detected throughout the 2015 season. A potential reason for presence of this Eastern Meadowlark is that grassland associated breeding birds are locating these grasslands within the forest-dominated landscape, and are starting to use them. Despite a lack of use of these grasslands by grassland-associated breeding birds, switchgrass monocultures may be important stopover sites for migrating species, or be used as overwintering areas. Thus, continued assessment throughout the breeding season and additional assessment outside of the breeding season of switchgrass monocultures is needed.

It is currently unknown what caused annual variation in abundance of Gray Catbirds, as this species used habitat conditions readily abundant across the landscape during both years of this study. The difference detected in abundance of Orchard Orioles could be attributed to young hardwoods reaching a size and shape that provides adequate nest sites (Scharf and Kren 2010). Orchard Orioles nest in the forks of trees away from the main trunk, a condition that is available in a few scattered young hardwoods of the sampled treatments (e.g. *Acer rubrum* [red maple] and *Liquidambar styraciflua* [sweetgum]). Availability of these trees may relate more to stand age, with more hardwoods available as stands mature, and less so with the treatment being implemented (e.g. switchgrass intercropped or pine control), but further study is needed before a definitive answer can be drawn.

Avian communities respond differently to implementing novel forestry management practices within loblolly pine plantations (e.g. Wilson and Watts 1999, Lohr et al. 2002, Iglay 2010, Iglay et al. 2012b, Loman et al. 2014, Owens et al. 2014).

Additional research on effects of intercropping switchgrass should evaluate movement of individuals within treatment plots and within adjacent forest stands. This would provide insight into territory size between treatments and if it is influenced by potential differences in resource availability (Myers et al. 1979, Marshall and Cooper 2004). Also, this would make clear whether individuals are using adjacent edges and stands to offset resource limitations in switchgrass intercropped treatments (Zanette et al. 2000, Fahrig et al. 2011). It is currently unknown how intercropping switchgrass within older forest stands, other forests types, and different geographic regions will affect breeding bird communities. Comparative and more extensive studies are also needed to provide greater insight regarding these effects.

Management Implications

Observations made from my study indicate that intercropping switchgrass within loblolly pine plantations supported a scrub-shrub associated breeding bird community similar to one present in pine stands following typical silviculture practices. If co-producing forest products and cellulosic biomass, while conserving scrub-shrub breeding bird habitat are management goals, forest managers should implement switchgrass intercropping within loblolly pine plantations. However, this recommendation is limited to stands four and five year post establishment, given the scope of my study. Due to the limited temporal scope of this study, it is unknown how intercropping switchgrass affects breeding bird communities as stands age. Continued research is needed in this regard. Also, an assessment of intercropping switchgrass during the non-breeding period is needed before a holistic recommendation can be made. Switchgrass monocultures did support a diverse breeding bird community in my study.

Table 3.1 Mean and standard deviation of breeding birds detected per treatment and summed across years (2014 – 2015) within a loblolly pine plantation in Kemper County, Mississippi, USA.

Species	Switchgrass Intercropped	Pine Control
Brown-headed Cowbird *Molothrus ater*	5.60 ± 2.80	6.80 ± 4.47
Common Yellowthroat *Geothlypis trichas*	16.70 ± 6.25	17.90 ± 6.10
Eastern Towhee *Pipilo erythrophthalmus*	13.60 ± 3.57	13.20 ± 5.01
Gray Catbird *Dumetella carolinensis*	2.70 ± 2.91	3.70 ± 4.69
Indigo Bunting *Passerina cyanea*	24.60 ± 5.82	19.20 ± 7.12
Northern Bobwhite *Colinus virginianus*	1.60 ± 2.12	1.60 ± 2.41
Northern Cardinal *Cardinalis cardinalis*	4.40 ± 1.96	5.90 ± 3.04
Northern Mockingbird *Mimus polyglottos*	2.40 ± 1.90	1.60 ± 1.35
Orchard Oriole *Icterus spurius*	0.90 ± 1.37	1.50 ± 1.35
Prairie Warbler *Setophaga discolor*	31.40 ± 4.30	34.40 ± 7.92
White-eyed Vireo *Vireo griseus*	12.00 ± 4.88	17.30 ± 6.46
Yellow-breasted Chat *Icteria virens*	47.80 ± 6.16	48.00 ± 3.46

Switchgrass monocultures had no detections, and therefore, are not included.

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CHAPTER IV

GENERAL CONCLUSIONS

Under current silviculture practices, loblolly pine (*Pinus taeda*) plantations of the southeastern United States are biologically diverse, supporting species associated with a wide range of habitat conditions (e.g. Wilson and Watts 2000, Horn and Hanula 2008, Miller et al. 2009, Iglay 2010, Riffell et al. 2012). Maintenance of biological diversity within these systems is an integral aspect of forest management targeted to meet biodiversity measures set by sustainable forestry programs, such as the Sustainable Forestry Initiative (Miller et al. 2009, Sustainable Forestry Initiative Inc. 2010). Development of a novel land use practice of intercropping switchgrass (*Panicum virgatum*) within loblolly pine plantations presents a unique opportunity to evaluate effects of further land use intensification on floral and faunal communities (Riffell et al. 2012). Minimal literature currently exists regarding floral and faunal responses to this novel land use practice (e.g. Iglay et al. 2012, Homyack et al. 2013, Homyack et al. 2014, Loman et al. 2014, Wheat 2015). The literature that currently exists is limited by its temporal scope, with most research focused on young stands (1 – 3 years post establishment). This study adds to the current body of literature regarding floral and faunal responses to intercropping switchgrass by evaluating arthropod, an underrepresented taxonomic group with regards to intercropping switchgrass research, and breeding bird responses to intercropping switchgrass within older stands (four and five years post establishment).

In my study, intercropping switchgrass provided habitat for breeding bird species associated with scrub-shrub vegetative communities. However, this land use practice negatively impacted arthropods, an important prey base for some wildlife, including breeding birds (e.g. Hamilton 1941, McCracken and Tallowin 2004, Horn and Hanula 2008, Moseley et al. 2008). Breeding birds detected in this study included insectivores, such as Yellow-breasted Chat (*Icteria virens*), Common Yellowthroat (*Geothlypis trichas*), Prairie Warbler (*Setophaga discolor*), Gray Catbird (*Dumetella carolinensis*), and White-eyed Vireo (*Vireo griseus*; Cimprich and Moore 1995, Hopp et al. 1995, Guzzy and Ritchison 1999, Nolan et al. 1999, Eckerle and Thompson 2001), yet no decline in abundance of these species was detected despite potential prey base reductions, with the caveat that the arthropod community was not entirely sampled due to limitations of sweep-netting scrub-shrub vegetation. Some breeding birds may be able to supplement their diet with fruit available within intercropped stands, such as Yellow-breasted Chats and Gray Catbirds; however, species that are strictly insectivores (i.e. Prairie Warblers) do not have an alternate food source (Cimprich and Moore 1995, Nolan et al. 1999, Eckerle and Thompson 2001).

This suggests that arthropods preyed upon are not reduced to a level within intercropped switchgrass that negatively affected insectivorous breeding birds, or that breeding birds were able to obtain resources in adjacent edges and stands to offset resource limitations within switchgrass intercropped stands (Zanette et al. 2000, Fahrig et al. 2011). Additional research should address movement of breeding birds within treatment plots and within adjacent forest stands, which would provide insight into effects of resource availability on territory size and use of adjacent forest edges and stands (Myers et al. 1979, Marshall and Cooper 2004). Additionally, future research should examine relationships between arthropod community structure and ecosystem services (i.e. pollination) and wildlife (e.g. amphibians, other arthropods, small-mammals) dependent on arthropods as a prey base within intercropped stands (e.g. Moseley et al. 2008, Losey and Vaughan 2006).

To provide a holistic evaluation of intercropping switchgrass within loblolly pine, continued study throughout an entire rotational period is needed. Current research is limited temporally, with research only conducted from stand establishment to five years post establishment, and taxonomically, with some taxa not represented throughout entirety of stand existence (e.g. arthropods). Sampling outside of the breeding season for birds is needed to understand how intercropping switchgrass affects migrating and overwintering birds. Arthropods should also be studied outside of the avian breeding period as community structure fluctuates throughout the year (Danks 2007). It is currently unknown how intercropping switchgrass within older forest stands, other forests types, and different geographic regions will impact arthropod and breeding bird communities. Comparative and more extensive studies are needed to provide greater insight regarding effects of intercropping switchgrass, as this land use practice has potential to provide economic (e.g. co-production of biomass for biofuels and wood products) and ecological benefits to society (e.g. carbon sequestration and protection of water quality; Wigley et al. 2000, Miller et al. 2009).

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