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EFFECTS OF NON-CONSUMPTIVE RECREATION AND ENVIRONMENTAL
FACTORS ON ARKANSAS STATE PARK BIODIVERSITY

By

BENNETT P. GROOMS

Submitted to the Faculty of the Graduate College of
Arkansas Tech University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE IN FISHERIES AND WILDLIFE SCIENCE
December 2016

EFFECTS OF NON-CONSUMPTIVE RECREATION AND ENVIRONMENTAL
FACTORS ON ARKANSAS STATE PARK BIODIVERSITY

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Program: Fisheries and Wildlife Science

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Abstract

State parks serve a dual conservation role by offering protected habitat to many species while also promoting recreational use of natural resources. Non-consumptive recreation activities, however, have long-term negative effects on the behavior, physiology, and reproductive success of state park biotic communities. The purpose of my research was to investigate the possible synergistic effects of non-consumptive trail use, environmental factors, and trail design factors on avian, mesocarnivore, and woody vegetation communities in Arkansas state parks. During 18 May – 7 August 2015, I conducted avian point counts, trail user counts, set camera traps, and sampled vegetation at 227 points on the main trail systems of 4 Arkansas state parks. I quantified community richness, evenness, and diversity for each taxon and used a series of 1-way ANOVAs and Kruskal-Wallis tests to examine differences in communities at regional and local scales. I also created 3 candidate model sets (e.g., richness, evenness, and diversity) for each taxonomic community in each park and used AICc and regression analyses to determine whether synergistic effects influenced biotic communities in the parks. These data were further used to create detection maps of flagship avifauna and to evaluate the efficacy of a pilot citizen science program in the parks. Differences in communities were predominantly restricted to the local scale and found in evenness and diversity values of avian ($F_{3,22} = 9.57 - 17.8$ $P = 0.001 - 0.003$) and understory vegetation communities ($F_{3,22} = 7.38 - 9.41$ $P \leq 0.001$). Non-consumptive trail use was a strong predictor for avian richness (relative Akaike weight $\omega = 0.85$) and diversity ($\omega = 0.70 - 0.84$), however, vegetation communities and attributes were stronger determinants of the other biotic communities. Detection probabilities (0.00 – 0.99) for the 5 focal avifauna varied

in response to a spectrum of trail use rates and response rates were low (2%) for the citizen science and human dimension surveys. In general, my results indicate the need for a holistic management strategy that addresses the collective anthropogenic and local environmental effects that influence park taxonomic communities while actively incorporating the public in those conservation goals.

TABLE OF CONTENTS

ABSTRACT.....	vii
LIST OF TABLES.....	xiv
LIST OF FIGURES	xix
THESIS INTRODUCTION.....	1
LITERATURE CITED	5
CHAPTER I: COMPARISON OF AVIAN, MESOCARNIVORE, AND WOODY VEGETATION COMMUNITY METRICS ACROSS LOCAL AND REGIONAL LANDSCAPES.....	9
METHODS	11
Study Area	11
Taxa Data Collection	15
Data Analyses	18
RESULTS	19
Avian Community Metrics	19
Mesocarnivore Community Metrics	20
Understory Woody Vegetation Community Metrics	21
Overstory Woody Vegetation Community Metrics	22
DISCUSSION.....	25

Regional Scale Comparisons	26
Local Scale Comparisons.....	29
Management Recommendations.....	34
LITERATURE CITED	34
CHAPTER II: EFFECTS OF NON-CONSUMPTIVE TRAIL USE, ENVIRONMENTAL, AND TRAIL DESIGN FACTORS ON STATE PARK TAXONOMIC COMMUNITIES	68
METHODS	74
Study Area	74
Taxa Data Collection	74
Non-Consumptive Trail Use Rates	74
Environmental Data Collection.....	75
Trail Design Data Collection	76
Data Analyses	76
RESULTS	79
Variable Summary Results	79
Effects of Anthropogenic, Environmental, and Trail Design Factors on Taxonomic Community Metrics	82
DISCUSSION	89

Avian Community Metrics	90
Mesocarnivore Community Metrics	95
Understory Woody Vegetation Community Metrics	99
Overstory Woody Vegetation Community Metrics	103
Management Recommendations	108
LITERATURE CITED	108
CHAPTER III: MAPPING DETECTION PROBABILITIES OF STATE PARK	
AVIFAUNA TO ENCOURAGE VISITOR CONSERVATION ATTITUDES.....	
	143
METHODS	148
Study Area	148
Avian Data Collection.....	148
Visitor Use of Trails.....	148
Occupancy Models.....	148
Detection Maps	153
RESULTS	154
Avian Data Collection.....	154
Visitor Use of Trails.....	154
Species Occupancy and Detectability Models	154
DISCUSSION	158

Species-Specific Occupancy Models	160
Management Recommendations	170
LITERATURE CITED	171
CHAPTER IV: EFFICACY OF A PILOT CITIZEN SCIENCE PROGRAM FOR ARKANSAS STATE PARKS.....	204
METHODS	209
Study Area	209
Standard Taxa Data Collection	209
Citizen Science Taxa Data Collection	209
Citizen Science Human Dimensions Survey	210
Data Analyses	211
RESULTS	214
Citizen Science Taxa Data	215
Citizen Science Human Dimensions Survey	215
DISCUSSION	219
Citizen Science Taxa Data	220
Citizen Science Human Dimensions.....	223
Management Recommendations	226
LITERATURE CITED	227

APPENDICES	236
Appendix A. Arkansas Division of State Parks (ADP) Natural Resource Inventory Database (NRID) Citizen Science Survey	236
Appendix B. Arkansas Division of State Parks (ADP) Natural Resource Inventory Database (NRID) Citizen Science Survey Display Poster.....	238
Appendix C. Human Dimensions Participant Survey.....	239

LIST OF TABLES

Table 1.1. Community metrics (± 1 SD) for avian, mesocarnivore, understory woody vegetation, and overstory woody vegetation communities in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and taxon, different letters indicate differences among parks ($P < 0.05$).	42
Table 1.2. Avian community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).	44
Table 1.3. Bray-Curtis similarity values for avian species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.....	46
Table 1.4. Bray-Curtis similarity values for avian species composition in Mount Magazine State Park trails, Arkansas, 2015.....	47
Table 1.5. Bray-Curtis similarity values for avian species composition in Mount Nebo State Park trails, Arkansas, 2015.	48
Table 1.6. Bray-Curtis similarity values for avian species composition in Petit Jean State Park trails, Arkansas, 2015.	49
Table 1.7. Bray-Curtis similarity values for avian species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.....	50
Table 1.8. Mesocarnivore community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Species richness, evenness, and diversity did not differ between trails at any park ($\chi^2_5 = 5.47 - 7.58$ $P = 0.181 - 0.602$).	51
Table 1.9. Bray-Curtis similarity values for mesocarnivore species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.....	53
Table 1.10. Understory woody vegetation community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).	54
Table 1.11. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.....	56

Table 1.12. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Magazine State Park trails, Arkansas, 2015.	57
Table 1.13. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Nebo State Park trails, Arkansas, 2015.	58
Table 1.14. Bray-Curtis similarity values for understory woody vegetation species composition in Petit Jean State Park trails, Arkansas, 2015.	59
Table 1.15. Bray-Curtis similarity values for understory woody vegetation species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.	60
Table 1.16. Overstory woody vegetation community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).	61
Table 1.17. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.	63
Table 1.18. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Magazine State Park trails, Arkansas, 2015.	64
Table 1.19. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Nebo State Park trails, Arkansas, 2015.	65
Table 1.20. Bray-Curtis similarity values for overstory woody vegetation species composition in Petit Jean State Park trails, Arkansas, 2015.	66
Table 1.21. Bray-Curtis similarity values overstory woody vegetation species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.	67
Table 2.1. Mean daily rate of trail use per 30min per trail calculated from bootstraps of structured and opportunistic trail counts at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks or trails within parks ($P < 0.05$).	116
Table 2.2. Average environmental variables of minimum temperature ($^{\circ}\text{C}$), maximum temperature ($^{\circ}\text{C}$), precipitation totals (mm), canopy cover (%), slope (%), mean trail depth (mm), mean trail width (m; mean ± 1 SD for all environmental data) from daily recordings of climatic data and trail sampling point recordings for Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks for each variable ($P < 0.05$).	119

Table 2.3. Average vegetative attributes and trail design data of cover (%), slope (%), trail incision depth (mm), and trail width (m; mean \pm 1 SD for all data) from data recorded at sampling points for Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks trails for each variable ($P < 0.05$).....	120
Table 2.4. Description and abbreviations of variables used included in models to determine the effects of non-consumptive trail use, environmental factors, and trail design on taxonomic community metrics in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.....	123
Table 2.5. Selected variables from cluster analyses for stepwise regression models to examine effects of non-consumptive trail use, environmental factors, and trail design on taxonomic communities in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Descriptions and abbreviations of variables are found in Table 2.2.	125
Table 2.6. Most parsimonious models for estimating avian community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized parameter estimates, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.....	127
Table 2.7. Competing models for estimating avian community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.....	128
Table 2.8. Competing models for estimating avian community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.....	129
Table 2.9. Competing models for estimating mesocarnivore community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.....	131

Table 2.10. Competing models for estimating mesocarnivore community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	133
Table 2.11. Competing models for estimating mesocarnivore community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	135
Table 2.12. Competing models for estimating understory vegetation community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	137
Table 2.13. Competing models for estimating understory vegetation community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	138
Table 2.14. Competing models for estimating understory vegetation community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	139
Table 2.15. Competing models for estimating overstory vegetation community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	140

Table 2.16. Competing models for estimating overstory vegetation community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	141
Table 2.17. Competing models for estimating overstory vegetation community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.	142
Table 3.1. Occupancy probabilities ($\pm 1SE$) for ovenbirds (<i>Seiurus aurocapilla</i>), Carolina wrens (<i>Thryothorus ludovicianus</i>), blue-gray gnatcatchers (<i>Polopptila caerulea</i>), northern cardinals (<i>Cardinals cardnalis</i>), and scarlet tanagers (<i>Piranga olivacea</i>) in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.....	179
Table 3.2. Detection probabilities ($\pm 1SE$) for ovenbirds (<i>Seiurus aurocapilla</i>), Carolina wrens (<i>Thryothorus ludovicianus</i>), blue-gray gnatcatchers (<i>Polopptila caerulea</i>), northern cardinals (<i>Cardinals cardnalis</i>), and scarlet tanagers (<i>Piranga olivacea</i>) at Mount Magazine State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.....	180
Table 3.3. Detection probabilities ($\pm 1SE$) for ovenbirds (<i>Seiurus aurocapilla</i>), Carolina wrens (<i>Thryothorus ludovicianus</i>), blue-gray gnatcatchers (<i>Polopptila caerulea</i>), northern cardinals (<i>Cardinals cardnalis</i>), and scarlet tanagers (<i>Piranga olivacea</i>) at Mount Nebo State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.	181
Table 3.4. Detection probabilities ($\pm 1SE$) for ovenbirds (<i>Seiurus aurocapilla</i>), Carolina wrens (<i>Thryothorus ludovicianus</i>), blue-gray gnatcatchers (<i>Polopptila caerulea</i>), northern cardinals (<i>Cardinals cardnalis</i>), and scarlet tanagers (<i>Piranga olivacea</i>) at Petit Jean State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.	182
Table 3.5. Detection probabilities ($\pm 1SE$) for ovenbirds (<i>Seiurus aurocapilla</i>), Carolina wrens (<i>Thryothorus ludovicianus</i>), blue-gray gnatcatchers (<i>Polopptila caerulea</i>), northern cardinals (<i>Cardinals cardnalis</i>), and scarlet tanagers (<i>Piranga olivacea</i>) at Pinnacle Mountain State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.....	183

LIST OF FIGURES

Figure 3.1. Detectability of ovenbirds (<i>Seiurus aurocapilla</i>) in relation to rate of trail use within trails at Mount Magazine State Park, Arkansas, 2015.....	184
Figure 3.2. Detectability of Carolina wrens (<i>Thryothorus ludovivianus</i>) in relation to rate of trail use within trails at Mount Magazine State Park, Arkansas, 2015.....	185
Figure 3.3. Detectability of northern cardinals (<i>Cardinals cardnalis</i>) in relation to rate of trail use within trails at Mount Magazine State Park, Arkansas, 2015.	186
Figure 3.4. Detectability of blue-gray gnatcatchers (<i>Polopptila caerulea</i>) in relation to rate of trail use within trails at Mount Magazine State Park, Arkansas, 2015.....	187
Figure 3.5. Detectability of scarlet tanagers (<i>Piranga olivacea</i>) in relation to rate of trail use within trails at Mount Magazine State Park, Arkansas, 2015.	188
Figure 3.6. Detectability of ovenbirds (<i>Seiurus aurocapilla</i>) in relation to rate of trail use within trails at Mount Nebo State Park, Arkansas, 2015.....	189
Figure 3.7. Detectability of Carolina wrens (<i>Thryothorus ludovivianus</i>) in relation to rate of trail use within trails at Mount Nebo State Park, Arkansas, 2015.....	190
Figure 3.8. Detectability of northern cardinals (<i>Cardinals cardnalis</i>) in relation to rate of trail use within trails at Mount Nebo State Park, Arkansas, 2015.	191
Figure 3.9. Detectability of blue-gray gnatcatchers (<i>Polopptila caerulea</i>) in relation to rate of trail use within trails at Mount Nebo State Park, Arkansas, 2015.....	192
Figure 3.10. Detectability of scarlet tanagers (<i>Piranga olivacea</i>) in relation to rate of trail use within trails at Mount Nebo State Park, Arkansas, 2015.....	193
Figure 3.11. Detectability of ovenbirds (<i>Seiurus aurocapilla</i>) in relation to rate of trail use within trails at Petit Jean State Park, Arkansas, 2015.	194
Figure 3.12. Detectability of Carolina wrens (<i>Thryothorus ludovivianus</i>) in relation to rate of trail use within trails at Petit Jean State Park, Arkansas, 2015.....	195
Figure 3.13. Detectability of northern cardinals (<i>Cardinals cardnalis</i>) in relation to rate of trail use within trails at Petit Jean State Park, Arkansas, 2015.	196
Figure 3.14. Detectability of blue-gray gnatcatchers (<i>Polopptila caerulea</i>) in relation to rate of trail use within trails at Petit Jean State Park, Arkansas, 2015.....	197
Figure 3.15. Detectability of scarlet tanagers (<i>Piranga olivacea</i>) in relation to rate of trail use within trails at Petit Jean State Park, Arkansas, 2015.	198

Figure 3.16. Detectability of ovenbirds (<i>Seiurus aurocapilla</i>) in relation to rate of trail use within trails at Pinnacle Mountain State Park, Arkansas, 2015.....	199
Figure 3.17. Detectability of Carolina wrens (<i>Thryothorus ludovicianus</i>) in relation to rate of trail use within trails at Pinnacle Mountain State Park, Arkansas, 2015.....	200
Figure 3.18. Detectability of northern cardinals (<i>Cardinals cardnalis</i>) in relation to rate of trail use within trails at Pinnacle Mountain State Park, Arkansas, 2015.	201
Figure 3.19. Detectability of blue-gray gnatcatchers (<i>Polopptila caerulea</i>) in relation to rate of trail use within trails at Pinnacle Mountain State Park, Arkansas, 2015.....	202
Figure 3.20. Detectability of scarlet tanagers (<i>Piranga olivacea</i>) in relation to rate of trail use within trails at Pinnacle Mountain State Park, Arkansas, 2015.....	203
Figure 4.1. Top 3 ranked purposes for park visit of survey participants at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016.....	233
Figure 4.2. Percent of responses designating the primary location of survey participant wildlife viewing experiences per park visit at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016.....	234
Figure 4.3. Primary motivations of survey participants for participating in the Arkansas Division of State Parks Natural Resource Inventory Database survey at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016....	235

THESIS INTRODUCTION

Recreation ecology is focused on balancing the conservation of flora and fauna while simultaneously promoting human recreation in protected areas such as wildlife reserves and national parks (Knight and Gutzwiller 1995, Reed and Merenlender 2008, Hammitt et al. 2015, Kays et al. 2016). Data typically consists of the frequency, concentration, and duration of human activities collected through in-person counts or electronic counters and surveys (Reynolds et al. 2007, Torn et al. 2009, Pettebone et al. 2010) which are then used to detect disturbances in distribution and behavior of biotic communities (Miller et al. 1998, Leung and Marion 2000, Miller and Hobbs 2000, Fortin et al. 2016). Recreation ecology has the potential to serve as a valuable tool in protected area management by conserving biotic communities while simultaneously promoting participation in wildlife conservation and sustainable area use by the visiting public.

Outdoor recreation activities can be broadly classified into 2 main factions; consumptive use and non-consumptive use (Boyle and Samson 1985, Flather and Cordell 1995, Reed and Merelender 2008). Consumptive-use activities are organism-dependent activities that have an immediate and direct impact on a species (Flather and Cordell 1995, Knight and Cole 1995). These activities include hunting, fishing, or firewood collection on trails and result in the removal of an organism from the habitat. Conversely, non-consumptive use, such as hiking and wildlife observation, encompasses a broader spectrum of organism-dependent and independent effects that may act on species either directly or indirectly (Cole 1993, Flather and Cordell 1995, Monz et al. 2013). While consumptive activities have an obvious direct impact on the health of individuals and entire populations (i.e., alterations to resource availability, culling, hunter avoidance),

these activities are regulated so that the removal of individuals is conducted sustainably (Knight and Cole 1995). Non-consumptive use, though initially considered to be innocuous to the surrounding biota compared to consumptive use, has been shown to have greater, more widespread ecological impacts as a result of its inconsistent and repetitive nature (Anderson 1995, Taylor and Knight 2003, Hammitt et al. 2015). For example, continued hiking and cycling on the same trail may lead to physical alterations which consequently result in the temporal or permanent avoidance of that trail by disturbance-intolerant species. As such, non-consumptive activities may lead to long-term environmental degradation and a decline in biodiversity if left unmanaged (Leung and Marion 1999, Leung and Marion 2000). Additionally, these effects are of particular concern given the current increase in recreational outdoor use (Flather and Cordell 1995, Cordell et al. 2008).

Studies examining the impacts of non-consumptive use have focused on larger, higher-use areas such as national parks, urban recreation areas, and public forests (Monz et al. 2008, Larson 2015), with little focus on state parks. Comparatively, state parks witness a higher number of annual visitors that surpasses national park and federal land visitation (Flather and Cordell 1995, Cordell et al. 2008) and traditionally contain a series of interconnecting trails and campsites within natural habitats. Furthermore, residential and migratory species in state parks are subject to both regional and local influences of temperature, precipitation, and land use (Sekercioglu 2002). Thus, the goal of my study was to investigate the collective impacts of non-consumptive trail use, environmental factors, and trail design on biotic communities in state parks to better understand the potential influences acting on state park taxonomic communities. Additionally, these data

will facilitate comparisons of regional and local community metrics and be used to educate park visitors on wildlife conservation via understanding species detection and involving parks visitors in data collection.

Biotic communities may respond differently to external influences depending on the focal community and spatial scale of observation. However, analyses that simultaneously evaluate changes in communities across multiple spatial scales in multiple taxonomic groups are scarce (Harrison and Cornell 2008). In Chapter I, my goal was to quantify species richness, evenness, and diversity for avian, mesocarnivore, and woody vegetation communities in 4 state parks and compare these metrics at the regional (among parks) and local (within parks) scales. Observing differences in communities simultaneously over multiple spatial scales may enable a more holistic understanding on the collective effects on communities to assist park managers in mitigating short-term, local scale influences from daily park use on park biotic communities with respect to the long-term influences of land use and biogeography.

Understanding the combined effects on taxonomic communities from non-consumptive use, environmental factors, and trail design is essential in creating management strategies that fully address the variables influencing park communities (Cole 1993, Leung and Marion 2000, Marion and Leung 2001). Few studies have addressed effects of non-consumptive use in state parks on multiple taxonomic groups at once (Harrison and Cornell 2008). Additionally, fewer studies have extended their range of focus to synergistic effects of environmental factors, trail design, and non-consumptive use. Therefore, my goal in Chapter II was to examine the collective effects of non-consumptive trail use, environmental factors, and trail design on the avian,

mesocarnivore, and woody vegetation communities residing in Arkansas state parks. Such knowledge could provide state park managers a better understanding on where to delineate efforts to mitigate the potential effects of human disturbance and alterations to park habitat which will aid in maintaining their dual role in balancing conservation with recreation opportunities.

Visually demonstrating the relationship between recreationist's park use and behavior to species detectability may aid in wildlife conservation by showing visitors how different levels of use can affect avifaunal populations. Most approaches to mapping occurrence of species across a landscape focus on the abundance of individuals; however, individuals may go undetected even if they are present within an area due to observation timing and species' avoidance behaviors (MacKenzie et al. 2002, Fiske and Chandler 2011). This imperfect detection may complicate estimations of species occupancy as a result of measurement error. Occupancy modeling can accommodate for this error by using repeated detection and non-detection surveys paired with external covariates that influence detectability during a survey (MacKenzie et al. 2002, MacKenzie and Royle 2005, Fiske and Chandler 2011, Shannon et al. 2014). Therefore, in Chapter III my overall objective was to use a single season, single species occupancy model with covariates to calculate detection probabilities of 5 flagship avian species to facilitate sustainable trail use. Additionally, I visually displayed these species detections in a series of maps with respect to differing rates of park trail use to demonstrate how the rate of recreational trail use may influence the distribution of avifauna.

In Chapter IV, my objectives were to validate the quality of avian, mesocarnivore, and woody vegetation taxon data collected by participants in a pilot citizen science

program designed by the Arkansas Division of State Parks (ADSP). In 2014, the ADSP developed an experimental citizen science survey instrument in the form of a passive brochure with the goal of incorporating presence/absence data gathered by visitors on species within Arkansas state parks. I investigated the accuracy, precision, and potential bias in taxa observations from survey participants. Further, I analyzed participant demographics, scientific background, and participation motivations to examine possible differences in participation based on demographics and conservation attitudes (Trumbull et al. 2000, Crall et al. 2011, Dickinson et al. 2012). Citizen science programs that use park visitors may be another helpful tool to supplement the dual role of state parks in promoting both conservation and recreation. Additionally, addressing the potential observer errors encountered in previous citizen science research from participant variation may help establish guidelines for the future implementation of citizen science in Arkansas state parks.

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CHAPTER I:
COMPARISON OF AVIAN, MESOCARNIVORE, AND WOODY VEGETATION
COMMUNITY METRICS ACROSS LOCAL AND REGIONAL LANDSCAPES

Research in recreation ecology primarily seeks to determine the potential influences of anthropogenic and environmental factors on the biodiversity within protected areas (Flather and Cordell 1995, Knight and Temple 1995, Steidl and Powell 2006, Monz et al. 2009, Monz et al. 2013). As such, recreation ecology has provided insight on the direct and indirect influences of outdoor recreation activities such as hiking and camping on wildlife communities (Monz et al. 2013). However, it may be difficult to observe the influences of anthropogenic and environmental variables on biotic community structure unless biodiversity can be thoroughly quantified and done so across varying spatial scales (Buckland et al. 2005). Biodiversity can be measured within a mosaic of spatial scales, with taxonomic communities often governed by a mix of both local and regional processes (Turner et al. 1989, Noss 1990, Huston 1999, Atauri and de Lucio 2001, Agrawal et al. 2007, Harrison and Cornell 2008). Further, patterns of biodiversity may depend on the spatial scale of observation (Scrosati and Heaven 2007, Marsh and Trenham 2008). Thus, understanding not only the influences acting on taxonomic community structure but how those communities and influences change across spatial scales is imperative for the management of flora and fauna in protected areas.

Research on the influence of external factors on biotic communities has been conducted primarily at 2 spatial perspectives: the local scale and the regional scale (Caley and Schluter 1997, Hillebrand and Bleckner 2002, Harrison and Cornell 2008, Hillebrand et al. 2008). Studies at the local scale typically focus on community influences to the

extent of an individual site or cluster of sites (Huston 1999, Harrison and Cornwell 2008). Changes in community structure at the local scale tend to be primarily influenced by local environmental processes such as food availability and predator-prey interactions, as well as short-term alterations to habitat structure by park management (Hillebrand and Bleckner 2002, Harrison et al. 2006). Studies at the regional scale vary in extent, but typically apply to areas such as national parks, forests, and biogeographic regions (Ricklefs 2004, Harrison and Cornwell 2008). Regional scale changes in community structure are attributed more to gradients of topography, geology, climate, and patterns of land use (Böhning-Gaese 1997, Cueto and Casenave 1999, Rahbek and Graves 2001).

Metrics important at one perspective often react differently at another, with changes in community structure possible from influences at both the local and regional scales (Koskimies 1989, Noss 1990, Böhning-Gaese 1997, Scrosati and Heaven 2007). Additionally, local and regional processes may reciprocally influence one another (Noss 1990). Influences from regional scale processes such as climatic patterns and historic land usage, are likely to be important determinants of local community structures across patches of habitat within a region (Koskimies 1989, Huston 1999). Further, local ecological processes, such as predator-prey interactions and species competition, may influence community structure at the regional scale via alterations on the success of individual reproductive and foraging behaviors (Huston 1999, Harrison et al. 2006). These individual and reciprocal effects have been observed for species across various spatial scales (Noss 1990), but to my knowledge, little research has encompassed these influences on community structure at both spatial scales simultaneously or on taxonomic communities (Harrison and Cornell 2008, Galitsky and Lawler 2015).

State parks offer an ideal setting to observe environmental and anthropogenic effects on flora and fauna at multiple spatial scales. The likelihood of human-wildlife interactions changes throughout state parks, depending on the location and frequency of human activities and the distribution of wildlife (Cole 1993, Knight and Cole 1995, Leung and Marion 2000, Steidl and Powell 2006). For example, longer hiking trails that bisect a greater variety of natural habitats may increase human-wildlife interactions compared to shorter trails or trails that have a lower diversity of habitats (Torn et al. 2009). Differences in vegetation structure and resource availability may further change depending on the location within the park as well as the location of the park itself (Weaver and Dale 1978, Cueto and Casenave 1999, Cornwell and Grubb 2003). Therefore, by focusing research within a state park lens, it is possible to examine the influences on community biodiversity at both the local and regional scale simultaneously. My goal was to quantify and compare avian, mesocarnivore, and woody vegetation communities in 4 state parks at the regional (among parks) and local (within parks) scales. Evaluating differences in these communities simultaneously over multiple spatial scales may enable park managers to hierarchically mitigate short term, local scale influences from daily park management activities on park biotic communities while understanding the historical, regional scale processes that have shaped the species composition and communities in the area.

METHODS

Study Area

My study focused on 4 state parks located in Northwestern Arkansas: Mount Magazine State Park, Mount Nebo State Park, Petit Jean State Park, and Pinnacle

Mountain State Park. Mount Magazine, Mount Nebo, and Petit Jean State Parks are located in the Arkansas River Valley ecoregion and Pinnacle Mountain State Park is located in the Ouachita Mountain ecoregion (USEPA 2016).

Mount Magazine State Park is located in Logan County, south of Paris, Arkansas (15 S 442199, 38952229) and encompasses 904ha surrounded by the Ozark National Forest. The park is positioned on top of the Magazine mountain (839m), a flat-topped plateau rimmed by sandstone bluffs which supports a diverse collection of wildlife and vegetation species adapted to the mountain ecosystem such as Ozark chinquapin (*Castanea ozarkensis*) and maple-leaf oak (*Quercus acerifolia*). The park area has a Linker fine sandy loam dominant soil type with small portions of gravelly clay loam surrounding the mountain (USDA and NRCS 2015). Mount Magazine had a mean minimum temperature of $18.3 \pm 5.80^{\circ}\text{C}$ (mean \pm 1 SD for all statistics hereafter) and a mean maximum temperature of $27.7 \pm 5.80^{\circ}\text{C}$ during the study (Weather Underground 2015). Mean precipitation for the park during the study was $7.27 \pm 6.54\text{mm}$ (Weather Underground 2015). The park included 8 trails spanning 22.5km in length, 13 cabins, and 18 campsites.

Mount Nebo State Park is located in Yell County, west of Dardanelle, Arkansas (15 S 476945, 3897552) and encompasses 1,246ha of habitat. The park is centered on top of Mount Nebo, which measures 411m in elevation. The habitat is mostly comprised of thick oak (*Quercus* spp.) and hickory (*Carya* spp.) dominated forests, characteristic of the Ozark Plateau region, with mixes of sweetgum (*Liquidambar styraciflua*) and red maple (*Acer rubra*) stands throughout the park. The park is dominantly a Nella-Enders stone fine sandy loam soil type with 8 – 20% slopes, with much of the mountain covered in

Linker-Mountainburg complex soil type (USDA and NRCS 2015). Mount Nebo had a mean minimum temperature of $21.4 \pm 2.62^{\circ}\text{C}$ and a mean maximum temperature of $32.1 \pm 3.23^{\circ}\text{C}$ during the study. Mean precipitation for the park during the study was $8.33 \pm 5.08\text{mm}$. The park included 6 trails with a combined length of 22.5km, 15 cabins, and 44 campsites.

Petit Jean State Park is located in Conway County, west of Oppelo, Arkansas (15 S 505957, 3886563). Petit Jean mountain (368m) lies between the Ozark and Ouachita mountain ranges in the Arkansas River Valley and serves as the midpoint for the 1,416ha park. The habitat is comprised mostly of forests dominated by a mix of oak, hickory, and pine (*Pinus* spp.) stands within a series of ponds, streams, and glades, also characteristic of the Ozark mountain ecoregion (USEPA 2016). The park has a dominantly Mountainburg stony fine sandy loam soil type with 12 – 40% slopes, with large patches of Linker fine sandy loam and Enders gravelly fine sandy loam surrounding the park (USDA and NRCS 2015). Petit Jean had a mean minimum temperature of $20.7 \pm 2.16^{\circ}\text{C}$ and a mean maximum temperature of $32.1 \pm 3.50^{\circ}\text{C}$ during the study. Mean precipitation for the park during the study was $1.87 \pm 3.06\text{mm}$. Eight trails traversing 37.0km, 33 cabins, and 125 campsites were available in the park.

Pinnacle Mountain State Park is located in Pulaski County, Northwest of Little Rock, Arkansas (15 S 547062, 3855665) and encompasses 809ha surrounding Pinnacle Mountain (308m). The park is composed of a mosaic of habitats including boulder fields, bald cypress (*Taxodium distichum*) swamps, bottomland hardwood forests, and upland forests composed of mixes of oak, hickory, and pine stands. The park supports a diverse variety of floral and faunal species as a result from the heterogeneity in habitat types

including the park's Arboretum that contains woody vegetation from across the state and from the Big and Little Maumelle rivers that run through the park. The park is primarily of Carnassial-Mountainburg association undulating soil type, surrounded by patches of Perry clay soil type (USDA and NRCS 2015). Pinnacle Mountain had a mean minimum temperature of $23.2 \pm 0.60^{\circ}\text{C}$ and a mean maximum temperature of $34.7 \pm 2.42^{\circ}\text{C}$ during the study. Mean precipitation for the park during the study was $0.49 \pm 0.84\text{mm}$. Pinnacle Mountain State Park included 10 trails stretching 30.0km; no camping sites or cabins existed at the time of this study.

I focused data collection on specific trails chosen within each state park based on 3 criteria: total trail length (m), diversity of habitat types that the trail traversed, and the area of the park that each trail encompassed (km). I chose trails $\leq 16\text{km}$ in length and split trails measuring 8 – 16km into 2 equal portions to accommodate temporal limitations of accessing trails during each visit. I then used ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA) to overlay the trails meeting these distance criteria onto park maps and chose trails that passed through the greatest diversity of habitat types (USEPA 2016) and that represented the greatest area of park use. Applying these criteria to the trails in each park resulted in 6 trails each at Mount Magazine State Park, Mount Nebo State Park, and Petit Jean State Park and 8 trails at Pinnacle Mountain State Park.

I then created sampling points on the selected trail systems of each park because most human-wildlife interactions should occur on trails that promote recreational activities such as hiking and wildlife observation (Boyle and Samson 1985, Marion and Leung 2001, Cordell et al. 2008). For each trail, I created an initial sampling point randomly within the first 250m of the trailhead by generating a random distance (m) via

the sample program in Program R (sample=x, size, replace=FALSE, prob=NULL; R Version 3.1.2., <http://www.r-project.org/>). Subsequent sampling points were then systematically located every 250m (Ralph et al. 1995, Torn et al. 2009). This methodology resulted in 227 sampling points for all 4 parks: Mount Magazine ($n = 60$); Mount Nebo ($n = 56$); Petit Jean ($n = 59$); Pinnacle Mountain ($n = 52$).

Taxa Data Collection

I collected data in 1-week sessions from 18 May 2015 – 7 August 2015. During this time, 2 technicians and I sampled each park for 3 weeks. The reoccurring 1-week sessions followed this order: Mount Magazine State Park, Mount Nebo State Park, Petit Jean State Park, and Pinnacle Mountain State Park.

Avian point counts.— I conducted fixed distance point counts (see Ralph et al. 1995). Each point was sampled independently 3 times/week (Monday – Friday), once each by 3 observers (Petit et al. 1995). This methodology resulted in 9 visits for each of the 227 points (i.e., 3 times/week at each point during 3 independent weeks), with 45 minutes of total observation time collected/point. By utilizing 3 observers throughout the week rather than 1, as is common in many avian surveys, I was able to diminish repeated observer bias and increase the detection probability at each point (Ralph et al. 1995, MacKenzie and Royle 2005). No point was visited at the same time throughout the week by any of the 3 observers. Travel time between point counts was <10 minutes which reduced potential bias by avoiding repeated counts of avian individuals at adjacent points (Ralph et al. 1993). Counts began ≤ 15 min of sunrise until 5 hours after sunrise (~0500 – 1000hr). Point counts lasted 5-min each and observers recorded both visual and auditory detections for birds within a 50m-radius. I identified birds to species level and used 4-

letter alpha codes to record visual and auditory bird detections at each sampling point (Pyle and Desante 2003). Point counts were conducted only during suitable weather conditions for avian activity, which I defined as: mornings with no rain or fog (although temperate, light drizzle can be tolerated by most species; Cyr et al. 1995, Martin et al. 1997), wind speeds <13km/hr (Freedmark and Rogers 1995, Petit et al. 1995), and temperatures ranging 18 – 23°C (Buskirk and McDonald 1995, Martin et al. 1997). If conditions did not meet these criteria or did not improve by 1000hr, counts were halted for that observation day and were continued during the next day or at the end of the sampling week to maintain independent samples (Ralph et al. 1993, Martin et al. 1997).

Mesocarnivore camera traps.— I used 8 Spypoint C4 camera traps (Spypoint, Swanton, Vermont) to collect community data for mesocarnivores in each park. Each camera was powered by 6 AA batteries and captured still photos via a motion-sensitive infrared trigger without the use of attractants (Shannon et al. 2014). I used a cable lock to mount cameras at a height of 30 – 50cm on trees parallel to the designated sampling point on the trail (Yasuda 2004, Gompper et al. 2006, TEAM 2011). Each camera was focused on the trail edge facing away from the trailhead to ensure captures of all individuals passing by (Harmsen et al. 2010). I adjusted the conical range of the camera sensors to a 5-m range resulting in a field of view of approximately 3.5-m to ensure photo clarity (TEAM 2011). I set cameras to a 3-min time delay between captures with 1 photo taken per trigger event to maximize photo amounts while balancing continuous sampling. This also avoided overfilling the 4GB SD card in each camera by waste footage caused by multiple records of a single animal or group of animals repeatedly triggering the trap (Yasuda 2004, Rowcliffe et al. 2008).

One camera was deployed at a randomly chosen sampling point on the Sunday of each sampling week between 1200 – 1500hrs and began recording photos by 1500hr that day. I programmed cameras to record 24-hours a day and to include the time and date when triggered until they were collected on Friday of the same week between 1200 – 1500hrs. After each sampling week, I identified captured mesocarnivore photos to the species level. I observed the time stamps of each photo capture to assure independent samples and to prevent the recording of multiple captures of the same animal during a single instance.

Woody vegetation subplots.— I used a nested subplot method to collect community data for understory and overstory woody vegetation similar to James and Shugart (1970) and the BBIRD monitoring program (Ralph et al. 1993, Martin et al. 1997). Vegetation data were collected at each sampling point once during the study. I centered circular subplots with 5-m and 11.3-m radii on adjusted sampling points established 16.3m away from each trail sampling point. This adjustment created a 5-m buffer between the edges of the trail and each vegetation plot to avoid immediate edge effects (Brown et al. 2009). I established these adjusted points randomly on either the left or right side of the trail; adjusted sampling points that were too dangerous to sample (e.g., close to the mountain edge or in a ravine) were either switched sides or conducted without the 5-m buffer offset from the trail. Of the 227 sampling points, this methodology resulted in 97 sampling points adjusted left, 106 adjusted right, and 24 sampled on the trails.

I quantified all understory woody vegetation (saplings measuring $\leq 1.4\text{m}$ tall) within the 5-m plot and all overstory vegetation (trees measuring $> 1.4\text{m}$ tall) in the 11.3-

m plot (Geldenhuys 1997, Rodewald and Brittingham 2004, Brown et al. 2009). I also recorded canopy cover, slope, and aspect within the 5-m subplot for further characterization of the vegetation community (Martin et al. 1997). I used a spherical densitometer to measure canopy cover by averaging cover recordings at 5m from center in all 4 cardinal directions at each sampling point. Percent slope was measured across the 5-m subplot from the top of the plot to bottom (facing downhill) with a clinometer and I recorded aspect in degrees with a compass at the top of the 5-m subplot facing downhill to record the azimuth of the slope.

Data Analyses

I calculated species composition, species richness, and Simpson's evenness and diversity (recorded as $1 - D$; Magurran 2004) for each taxonomic community at each sampling point for each visit. I summarized all community metrics per sampling point and later pooled metric data per trail or park for use in a series of 1 – way ANOVAs park (PROC GLM, $\alpha = 0.05$ for all statistical analyses; SAS Institute Cary, North Carolina) with Tukey's *HSD* (TUKEY in the means statement) to investigate differences in each taxonomic community among parks and between trails within each park. Data were transformed when found to violate the normality assumption and Kruskal Wallis tests with Dunn's multiple comparison tests [R Version 3.1.2., <http://www.r-project.org/>; `dunn.test`] were used when normality could not be attained. I also examined differences in species composition with the Bray-Curtis similarity index [R Version 3.1.2., <http://www.r-project.org/>; `vegdist (dataset, method = "bray")`] among parks at the regional scale and between trails at the local scale (Su et al. 2004). The Bray-Curtis similarity index compares the shared species abundances between 2 areas and provides a

percent value of similarity ranging from 0 – 100%, with 0% representing complete dissimilarity and 100% representing complete similarity (Summerville and Crist 2003).

RESULTS

Avian Community Metrics

I conducted 2,043 point counts and recorded 70 avian species among the 4 parks. Avian species richness did not differ among the parks at the regional scale ($F_{3,22} = 0.50$ $P = 0.685$; Table 1.1). At the local scale, avian species richness also did not differ between trails at Mount Magazine, Mount Nebo, and Petit Jean State Parks ($F_{5,50-54} = 1.71 - 2.21$ $P = 0.067 - 0.148$; Table 1.2). However, at Pinnacle Mountain, the East Summit trail had a lower avian richness ($F_{7,44} = 2.78$ $P = 0.017$) than the Kingfisher trail, with no differences in avian richness among the remaining trails (Table 1.2).

Mount Magazine had the lowest avian evenness ($F_{3,22} = 9.57$ $P = 0.003$) and diversity ($F_{3,22} = 17.8$ $P \leq 0.001$) at the regional scale among the parks (Table 1.1); the other parks had similar evenness and diversity values. Differences in avian evenness were found between trails within Mount Magazine ($F_{5,54} = 3.99$ $P = 0.011$), Mount Nebo ($\chi^2_5 = 11.8$ $P = 0.038$), and Petit Jean ($\chi^2_5 = 13.1$ $P = 0.023$; Table 1.2). The Mossback Ridge trail at Mount Magazine had a lower avian evenness than the Benefield and Will Apple' trails, with no differences evident among the Rim, Signal Hill, and Greenfield trails comparatively. There were subtle differences in avian evenness between trails at Mount Nebo: the Bench Road A trail had a lower evenness compared to the North Rim, Nebo Steps, and Summit Park trails, but was similar to the Bench Road B and Varnall Spring trails. Similarly, avian evenness values overlapped at Petit Jean between trails, however the Canyon trail had a lower evenness compared to all trails except the CCC Hike and

Bike trail. Additionally, the Cedar Creek trail had a greater evenness than all of the trails except both Seven Hollows trails. Avian evenness did not differ among trails at Pinnacle Mountain ($\chi^2_5 = 5.44$ $P = 0.606$; Table 1.2). Avian diversity did not differ at the local scale within any of the parks ($\chi^2_5 = 6.53 - 13.9$ $P = 0.053 - 0.258$; Table 1.2).

Avian species composition at the regional scale was most similar between Petit Jean and Pinnacle Mountain state parks while Mount Magazine and Pinnacle Mountain were the least similar in avian species composition (Table 1.3). At Mount Magazine, the Mossback Ridge and Rim trails were most similar and the Greenfield and Rim trails were least similar in avian composition (Table 1.4). Among Mount Nebo trails, the Bench Road A and B trails were most similar while the North Rim and Varnall Springs trails were least similar in species composition (Table 1.5). At Petit Jean, the Seven Hollows A and B trails had the greatest similarity while the Seven Hollows B and Cedar Creek trails had the lowest avian composition similarity (Table 1.6). At Pinnacle Mountain, the East Quarry and West Summit trails were most similar and the Base and West Summit trails were least similar in species composition (Table 1.7).

Mesocarnivore Community Metrics

I collected 18,653 camera trap photos capturing 6 mesocarnivore species among the 4 parks: coyotes (*Canis latrans*; 7), nine-banded armadillos (*Dasypus novemcinctus*; 1), bobcats (*Lynx rufus*; 3), raccoons (*Procyon lotor*; 4), American black bears (*Ursus americanus*; 2), and red foxes (*Vulpes vulpes*; 1). No differences were found among the parks at the regional scale for richness, diversity, or evenness ($\chi^2_3 = 0.31 - 1.62$, $P = 0.656 - 0.957$; Table 1.1). Species richness ($\chi^2_5 = 5.47 - 7.58$ $P = 0.181 - 0.602$), evenness ($\chi^2_5 = 5.47 - 6.07$ $P = 0.299 - 0.602$), and diversity ($\chi^2_5 = 5.47 - 6.07$ $P = 0.299$

– 0.602) also did not differ at the local scale within any park (Table 1.8). Mesocarnivore species composition at the regional scale was most similar between Mount Magazine and Mount Nebo and least similar between Mount Magazine and Pinnacle Mountain (Table 1.9). Due to inadequate counts of individuals per trail (≤ 1 individual per species), I could not calculate similarity comparisons at the local scale.

Understory Woody Vegetation Community Metrics

I recorded 65 understory woody vegetation species among the 4 parks. Understory vegetation richness did not differ at the regional scale ($F_{3,22} = 2.85$ $P = 0.060$; Table 1.1). Differences in understory vegetation richness were observed at the local scale only within Mount Nebo State Park ($\chi^2_5 = 30.1$ $P \leq 0.001$; Table 1.10). Both Bench Road trails had a greater understory vegetation richness than the North Rim, Nebo Steps, and Summit Park trails. Understory vegetation richness did not differ at the local scale between trails in Mount Magazine, Petit Jean, or Pinnacle Mountain State Parks ($F_{5-7,44-54} = 0.99 - 1.29$ $P = 0.279 - 0.432$; Table 1.10)

At the regional scale, Mount Magazine had the lowest understory vegetation evenness ($F_{3,22} = 9.41$ $P \leq 0.001$) and diversity ($F_{3,22} = 7.38$ $P = 0.001$) among the parks (Table 1.1), with no evidence of evenness or diversity varying among the remaining 3 parks. Differences in evenness at the local scale were found at Mount Nebo and Petit Jean State Parks ($F_{5,50-53} = 2.64 - 3.63$ $P = 0.007 - 0.035$) but not at Mount Magazine ($F_{5,54} = 2.31$ $P = 0.057$) or Pinnacle Mountain ($F_{7,44} = 1.87$ $P = 0.098$; Table 1.10). At Mount Nebo, the Nebo Steps trail had a greater understory vegetation evenness than all the trails except the North Rim trail. At Petit Jean, the Canyon trail had a lower evenness value

than the CCC Hike and Bike, Seven Hollows A, and Cedar Creek trails, with no differences in evenness evident among the remaining trails.

Differences in understory vegetation diversity were present among trails at Mount Magazine ($F_{5,54} = 3.58$ $P = 0.007$) and Petit Jean ($\chi^2_5 = 11.9$ $P = 0.035$), but not at Mount Nebo ($F_{5,50} = 1.22$ $P = 0.315$) or Pinnacle Mountain ($\chi^2_5 = 6.09$ $P = 0.530$; Table 1.10). The Signal Hill trail had a lower understory vegetation diversity than the Rim, Mossback Ridge, and Will Apple's trails at Mount Magazine, with no differences in diversity present between the remaining trails. At Petit Jean, the Canyon trail had the lowest understory diversity, but was similar to both Seven Hollows trails.

Understory vegetation species composition was most similar between Mount Nebo and Petit Jean at the regional scale and was least similar between Mount Magazine and Pinnacle Mountain (Table 1.11). At Mount Magazine, the Greenfield and Mossback Ridge trails were most similar while the Rim and Signal Hill trails were least similar (Table 1.12). At Mount Nebo, the Bench Road A and B trails were most similar and the Bench Road A and Varnall Springs trails were the least similar (Table 1.13). At Petit Jean, the Seven Hollows A and B trails were most similar and the Cedar Creek and Seven Hollows B trails were least similar (Table 1.14). The Ouachita and Rocky Valley trails were most similar and the Kingfisher and Ouachita trails were least similar (Table 1.15) in understory vegetation composition at Pinnacle Mountain.

Overstory Woody Vegetation Community Metrics

I recorded 83 overstory woody vegetation species among the 4 parks. Overstory vegetation richness did not differ at the regional scale ($F_{3,22} = 1.67$ $P = 0.202$; Table 1.1), but differences were observed at the local scale between Mount Magazine, Mount Nebo,

and Pinnacle Mountain trails ($F_{5-7,44-54} = 2.85 - 5.82$; $0.001 > P \leq 0.024$; Table 1.16). In general, the Mossback Ridge, Will Apple's, and Signal Hill trails at Mount Magazine had the lowest richness and the Benefield trail had the highest richness, but species richness values tended to overlap among any given trail. Similarly, at Mount Nebo, the North Rim trail had a lower overstory vegetation richness between all the trails, but species richness tended to overlap among the remaining trails. At Pinnacle Mountain, the East Summit trail had a lower overstory richness than the Arkansas, Ouachita, Rocky Valley, and West Summit trails, with the remaining trails having similar overlapping values observed in the other parks. Petit Jean did not have any local scale differences in richness ($F_{5,53} = 2.07$ $P = 0.084$; Table 1.16).

Evenness of overstory woody vegetation did not differ at the regional scale ($F_{3,22} = 0.71$ $P = 0.559$; Table 1.1). Evenness differed at the local scale among trails in Petit Jean and Pinnacle Mountain ($F_{5-7,44-53} = 2.36 - 3.74$ $P = 0.005 - 0.053$) with no differences observed for trails within Mount Magazine ($F_{5,54} = 2.36$ $P = 0.053$) and Mount Nebo ($F_{5,50} = 0.66$ $P = 0.654$; Table 1.16). At Petit Jean, the Seven Hollows A trail had a lower evenness than the CCC Hike and Bike trail; no other differences existed between the remaining trails. The East Quarry trail had a greater evenness than the Arkansas, Kingfisher, and West Summit trails at Pinnacle Mountain State Park and no other differences were evident.

Diversity in overstory vegetation also did not differ at the regional scale ($F_{3,22} = 1.61$ $P = 0.242$; Table 1.1). At the local scale, overstory vegetation diversity differed among trails in Mount Magazine, Mount Nebo, and Pinnacle Mountain State Parks ($\chi^2_5 = 18.6 - 20.0$ $P = 0.001 - 0.010$; Table 1.16) but not within Petit Jean State Park ($F_{5,53} =$

1.54 $P = 0.194$). The Rim trail had the greatest overstory vegetation diversity of all trails except compared to the Benefield trail. Further, the Mossback Ridge trail had the lowest overstory diversity of Mount Magazine trails. At Mount Nebo, the North Rim trail had the lowest diversity in overstory vegetation compared to all other trails within the park. At Pinnacle Mountain, the Arkansas, Kingfisher, and Base trails had the highest overstory vegetation diversity and the East Summit trail had the lowest overstory vegetation diversity. The Ouachita, East Quarry, West Summit, and Rocky Valley trails all had moderate values of overstory diversity compared to these trails.

At the regional scale, overstory vegetation composition was most similar between Mount Nebo and Mount Magazine and least similar between Mount Magazine and Pinnacle Mountain (Table 1.17). Overstory vegetation composition had lower similarity values between trails in all parks compared to the other taxonomic groups. At Mount Magazine, the Greenfield and Mossback Ridge trails had the greatest local similarity while the Benefield and Greenfield trails had the lowest local similarity (Table 1.18). At Mount Nebo, the North Rim and Summit Park trails had the greatest local similarity and the Bench Road A and Varnall Springs trails had the lowest similarity (Table 1.19). At Petit Jean, the Seven Hollows A and B trails had the greatest similarity and the Cedar Creek and Seven Hollows B trails had the lowest similarity (Table 1.20). The East Quarry and West Summit trails were most similar in local overstory vegetation composition and the Kingfisher and Ouachita trails were least similar in overstory vegetation composition at Pinnacle Mountain (Table 1.21).

DISCUSSION

Biotic communities are subject to both anthropogenic and environmental influences acting at the regional and local scales and community responses to these influences may differ depending on the spatial scale of observation and the specific taxon observed. I quantified and compared community metrics of avian, mesocarnivore, and woody vegetation communities in 4 state parks at the regional (among parks) and local scales (between trails within parks) to aid in understanding how taxonomic communities change across the landscape. I found that local scale differences were more pronounced than regional scale differences across each taxonomic community. Local scale differences were primarily observed for vegetative communities in all the parks, with fewer differences observed in avian communities and no differences for mesocarnivore communities. I observed no differences in regional community richness in any taxonomic community, but regional evenness and diversity for avian and understory vegetation communities was lower in Mount Magazine compared to the other 3 parks. No differences were observed for regional mesocarnivore or overstory vegetation community metrics. Regional and local scale differences in all metrics were typically confined to a select park or specific trails within each park across each taxonomic community. Additionally, similarities in local species composition for all taxa were also confined to specific trails within each park. Differences at the local scale were likely attributed to short-term, local processes such as daily anthropogenic disturbances (e.g., hiking, walking dogs [*Canis lupus familiaris*], camping) and variations in trail structure and management. Differences at the regional scale were likely attributed to historical, large-scale patterns in topography, climate, and land use. My results may indicate that biotic

communities may respond more rapidly to local scale processes compared to regional scale influences and thus lead to more notable differences observed in local communities. These results underscore the importance of spatial scale in relation to park management decisions and indicate the need for hierarchical management strategies that consider influences on taxonomic communities from both spatial scales.

Regional Scale Comparisons

I observed no differences in richness at the regional scale for any of the taxonomic communities. Harrison et al. (2006) demonstrated that regional communities are strongly influenced by historical and geological processes such as historic land use, climate, topography, and soil conditions. Four state parks may not have been a large enough scale to elicit regional differences in taxonomic richness because the species present have adapted to the same historical patterns of temperature, precipitation, and topography in Northwestern Arkansas. Additionally, all 4 state parks were mountainous parks that were of similar latitude and regional habitat conditions.

Historic land use and park management decisions both can affect taxonomic communities. The regional differences in evenness and diversity values of understory vegetation and avian communities may be related to responses to the historic layout of Mount Magazine. State parks are composed of a series of intersecting trails that often bisect natural habitat within each park (Leung and Marion 1999) and reflect decisions from the Civilian Conservation Corps and park managers (Paige 1985, Böhning-Gaese 1997). Historic changes in the park's structure could have influenced the regional composition of understory vegetation species present, which in turn, could have shaped the abundance of avian species present via the availability of habitat. Similarly, no

differences in regional community evenness or diversity were observed in overstory woody vegetation. State parks often do not allow for major timber removal within park boundaries and typically alter woody vegetation only in conjunction with park management decisions. Thus, overstory woody vegetation communities were also likely influenced by long-term patterns of climate, human land use, and topography within the region which may account for the lack of regional differences in overstory communities.

The lack of regional scale differences in mesocarnivores may have been attributed to the low number of camera trap captures of mesocarnivores species and the ability of mesocarnivores to adapt to anthropogenic changes in the environment. All of the species I documented represented common members of the Arkansas mesocarnivore guild. Notably, there were fewer captures of raccoons (*Procyon lotor*) compared to prior camera trap studies (Gompper et al. 2006) and I recorded no captures of striped skunks (*Mephitis mephitis*), Virginia opossums (*Didelphis virginiana*), and gray foxes (*Urocyon cinereoargenteus*), despite these species all being listed on each park's resident mammal composition lists.

Mesocarnivores are highly adaptable to changes in habitat (Roemer et al. 2009). For example, smaller mesocarnivores such as raccoons and red foxes are highly tolerant to human disturbance and generally are more abundant in areas of anthropogenic land use and forest fragmentation (Erb et al. 2012, Fischer et al. 2012, Lesmeister et al. 2015). Larger mesocarnivores may also adapt to the presence of anthropogenic structures via traveling along park trails as movement corridors (George and Crooks 2006). However, larger mesocarnivores favor habitats with lower probabilities of human interaction and respond negatively to forest fragmentation (Erb et al. 2012, Fischer et al. 2012, Fortin et

al. 2016). As such, while mesocarnivores communities were likely influenced by the same regional factors as avian and understory woody vegetation communities, the life history characteristics of the 6 mesocarnivore species observed may have aided in their possible adaptability to historical patterns of habitat availability and park land use (George and Crooks 2006, Thompson 2007, Fortin et al. 2016), thus resulting in a lack of differences in regional communities.

Mesocarnivore communities may have also been influenced by the presence of other mesocarnivores among the parks (George and Crooks 2006, Thompson and Gese 2007, Fortin et al. 2016). Lesmeister et al. (2015) reported that the co-occurrence of mesocarnivores broadly contributed to mesocarnivore community richness and evenness at regional scales. For example, large apex mesocarnivores such as the American black bear (*Ursus americanus*) and mountain lion (*Puma concolor*) can reduce populations of coyotes as a result of intraguild predation and competition for prey (Roemer et al. 2009, Lesmeister et al. 2015). My camera traps recorded only 2 observations of American black bear although park staff relayed to me anecdotal sightings of American black bears and mountain lions during the course of the study. Although this intraguild predation may explain the number of coyote captures in Petit Jean in the absence of American black bear captures (Fischer et al. 2012), the co-occurrences of the observed mesocarnivores also likely reflects historical patterns of species composition in Northwestern Arkansas.

The 3 parks located within the Arkansas River Valley ecoregion were the most similar in species composition which was probably due to historic topography and land use. Ecoregions are identified based on similarities in abiotic factors such as soil type, historic land use, and geology (USEPA 2016). Given that Mount Magazine, Mount Nebo,

and Petit Jean occurred in the same ecoregion, I expected the biotic community compositions to have high levels of similarity in species composition. For example, Mount Magazine and Mount Nebo were most similar in regional avian and overstory vegetation species composition while Petit Jean and Mount Nebo were most similar in regional understory vegetation species composition. Conversely, Mount Magazine and Pinnacle Mountain were the most dissimilar in species composition across all taxonomic communities at the regional scale. Of the 4 parks, Mount Magazine and Pinnacle Mountain were of greatest geographical distance from each other and existed in 2 different ecoregions. This distance may have translated into differing abiotic pressures acting on regional collections of species, resulting in dissimilarities in biotic community composition between the 2 parks (USEPA 2016).

Local Scale Comparisons

Differences in taxonomic communities were more pronounced at the local scale compared to the regional scale. Ricklefs (1987) demonstrated that influences acting on local taxonomic communities may be regulated more by local processes such as short-term disturbances from human recreation, species competition, and availability of habitat. These local scale processes could have resulted in the removal of woody vegetation along trails, to which avian and mesocarnivore communities may respond by temporary avoidance behaviors compared to the long-term adaptations to historic patterns of land use (Hillebrand and Blenckner 2002, Harrison and Cornell 2008, Hillebrand et al. 2008).

Prior research suggests that species richness at the local scale was best predicted by the overall heterogeneity in local vegetation community structure (MacArthur and MacArthur 1961, Böhning-Gaese 1997). Local scale alterations to trailside vegetation

communities can be caused by recreational activities along park trails, including different rates of trail use, direct removal of woody vegetation for campfires, and trampling effects on exposed roots and understory vegetation (Cole 1993, Cole and Landres 1995, Leung and Marion 1996, Leung and Marion 2000). These recreational activities typically promote disturbance-tolerant vegetation species resulting in changes to richness and evenness through the loss of disturbance-intolerant species (Hillebrand et al. 2008). For example, the North Rim trail at Mount Nebo had one of the highest rates of trail use in the park and passed through several sites that contained summer homes and cabins (Chapter II). The high rate of trail use and habitat fragmentation from human structures may have promoted disturbance-tolerant vegetation species along the trail, thus resulting in lower levels of understory vegetation evenness compared to other trails in the park. Similarly, the Signal Hill trail in Mount Magazine had the highest rate of use within the park and had corresponding low richness values in overstory vegetation compared to other trails in that park.

A positive relationship exists between vegetation community structure and avian and mesocarnivore communities at local scales via the availability of resources and the amount of protective vegetation cover (Böhning-Gaese 1997, Cueto and Casenave 1999, Gill et al. 2001, Rahbek and Graves 2001). As a result, changes to local woody vegetation communities from recreational use and park management may have led to cascading effects on the surrounding avian and mesocarnivore communities that depend on that vegetation for visual cover and resources (Gill et al. 2001). For example, the East Summit trail in Pinnacle Mountain had one of the highest rates of trail use within the park (Chapter II). Additionally, the East Summit trail also had some of the lowest values of

local avian and overstory woody vegetation richness in Pinnacle Mountain. The high rates of trail use could have resulted in the removal of overstory vegetation via trampling damage to exposed roots and removal of trees by park campers. Overstory vegetation adjacent to trails is an important resource to avian communities and provides visual cover for ground nesting species as well as longer alert distances to predator perception for canopy nesting species (Smith-Castro and Rodewald 2010). Therefore, the low levels of overstory richness and diversity along the East Summit trail may have also translated into low levels of avian richness.

Physical trail design and unsustainable trail use may serve as additional local scale influences on the evenness and diversity metrics of woody vegetation and avian communities (Leung and Marion 1996, Marion and Leung 2001). Daily decisions on trail upkeep, design, and the clearing of debris within state parks can promote unevenness in woody vegetation through the removal of disturbance-intolerant species. Differences in local avian evenness values in my study were primarily located along trails either managed for vegetation or designed to facilitate multiple trail use activities. To promote recreation in state parks, park managers will alter trail structure and vegetation with respect to the desired purpose of the trail (Marion et al 2011). This may explain why the Mossback Ridge trail in Mount Magazine had some of the lowest levels of local overstory vegetation richness and diversity as well as the lowest levels of local avian evenness in the park. The Mossback Ridge trail in Mount Magazine had a primarily grassy substrate and as such was regularly mowed and had branch trimming to allow for recreational use. These modifications to trailside vegetation may have resulted in the removal of overstory vegetation species adjacent to the trail, which could have lowered

overstory richness and increased the frequency of avoidance behaviors in disturbance-intolerant avian species. Similarly, the Bench Road trails at Mount Nebo, which experienced moderate levels of trail use and have campsites along the trail (Chapter II), had some of the lowest evenness values in local understory woody vegetation and avian evenness in the park. The wider trail paths, softer substrate, and moderate rates of trail use observed on the Bench Road trails may have promoted dominance of vegetation and avian species that were more tolerant to human disturbance resulting in the lower evenness values compared to other trails in the park.

Similar to the regional scale, I observed no differences in the local communities of mesocarnivores. Prior research has shown that differences in trail user activity, specifically walking dogs along park trails, may affect the detection and local communities of mesocarnivores (George and Crooks 2006, Reed and Merenlender 2011, Lesmeister et al. 2015). For example, chasing and barking dogs can disrupt wildlife species behavior (George and Crooks 2006, Miller et al. 2006). Further, the predictability of recreationist behavior may also influence local mesocarnivore communities (Erb et al. 2012, Coleman et al. 2013, Fortin et al. 2016). Predictable behaviors in park visitors, such as time of trail usage and location of campgrounds, can allow larger mesocarnivores to habituate to human presence and temporally avoid the effects of human recreation (Fortin et al. 2016). Therefore, the lack of local differences in mesocarnivore communities may be attributed to species adaptations to the predictability of daily recreationist behavior and to the presence of dogs within all the parks.

In general, similarities in local species composition occurred between trails that had similar lengths, trail structures, and habitat features. As expected, trails that had been

divided into 2 subparts to facilitate sampling had the greatest similarities in species composition. These included the Bench Road A and B trails in Mount Nebo and the Seven Hollows A and B trails in Petit Jean, which were most similar in avian and understory woody vegetation species composition at the local scale. Similarities in local species composition were also likely influenced by trail structure, such as vegetation density and trail surface substrate. The Greenfield and Mossback Rim trails in Mount Magazine had grassy trail structures, possibly explaining why the 2 trails were most similar in local understory and overstory woody vegetation species composition. Additionally, the positive relationship between woody vegetation and avian communities (Cueto and Casenave 1999, Gill et al. 2001) may have influenced similarities in species composition given that the West Summit and East Quarry trails in Pinnacle Mountain had the greatest similarities in both overstory vegetation and avian species composition.

Dissimilarities in local species composition were likely attributed to differences in trail length, slope, and trail placement within each park. For example, the Varnall Springs trail in Mount Nebo was least similar in understory and overstory vegetation species composition compared to the Bench Road A trail and most dissimilar in avian species composition compared to the North Rim trail. The Varnall Spring trail was the shortest trail in the park while the Bench Road A and North Rim trails were the longest and may have been able to sustain a greater number of species compared to the shorter Varnall Springs trail (Plotkin and Muller-Landau 2002). Similarly, the Seven Hollows B and Cedar Creek trails in Petit Jean were most dissimilar in species composition for all taxonomic communities. This may have been attributed to different trail lengths or to differences in trail structure (rockier substrate compared to grassy/soil substrate). Further,

trail slope and aspect can also influence species composition at the local scale (Leung and Marion 1996, Torn et al. 2009, Marion et al. 2011). For example, the Kingfisher and Ouachita trails in Pinnacle Mountain were located on the West and East sides of the mountain respectively, and likely were subject to differences in soil moisture and solar radiation, resulting in dissimilarities in understory and overstory vegetation composition.

Management Recommendations

Biotic communities within protected areas may respond differently to anthropogenic and natural influences depending on the spatial scale of observation. Differences in taxonomic communities were more pronounced at the local scale and were primarily observed in understory and overstory vegetation communities. Additionally, differences in local vegetation communities may have led to cascading effects on local avian and mesocarnivore communities (Hillebrand et al. 2008). These differences indicate a need for a hierarchical conservation management scheme (Noss 1990) that recognizes that the influences of anthropogenic and environmental stresses will be expressed differently depending on the spatial scale of observation. A hierarchical management framework that clearly defines richness, evenness, and diversity which also monitors taxonomic communities at multiple spatial scales may provide park managers a holistic understanding on how to mitigate local scale influences on biotic communities occurring within the parks with respect to the historical, regional scale processes that have shaped the species composition and communities across the landscape.

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Table 1.1. Community metrics (± 1 SD) for avian, mesocarnivore, understory woody vegetation, and overstory woody vegetation communities in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and taxon, different letters indicate differences among parks ($P < 0.05$).

Taxon and parks	Richness	Evenness	Diversity
<i>Avian</i>			
Mount Magazine	26.0 ± 3.63^a	0.49 ± 0.08^a	0.92 ± 0.01^a
Mount Nebo	29.0 ± 6.94^a	0.69 ± 0.11^b	0.95 ± 0.01^b
Petit Jean	30.0 ± 7.19^a	0.65 ± 0.06^b	0.95 ± 0.01^b
Pinnacle Mountain	29.0 ± 6.14^a	0.74 ± 0.10^b	0.95 ± 0.01^b
<i>Mesocarnivore</i>			
Mount Magazine	1.00 ± 0.75^a	0.50 ± 0.55^a	0.58 ± 0.50^a
Mount Nebo	1.00 ± 0.55^a	0.50 ± 0.55^a	0.50 ± 0.55^a
Petit Jean	1.00 ± 0.82^a	0.47 ± 0.52^a	0.56 ± 0.50^a
Pinnacle Mountain	1.00 ± 0.52^a	0.38 ± 0.52^a	0.63 ± 0.52^a
<i>Understory vegetation</i>			
Mount Magazine	25.0 ± 4.80^a	0.10 ± 0.03^a	0.55 ± 0.16^a
Mount Nebo	20.0 ± 6.50^a	0.27 ± 0.10^b	0.77 ± 0.10^b
Petit Jean	23.0 ± 3.33^a	0.27 ± 0.11^b	0.81 ± 0.08^b
Pinnacle Mountain	18.0 ± 5.54^a	0.28 ± 0.14^b	0.76 ± 0.07^b

Overstory vegetation

Mount Magazine	27.0 ± 6.12^a	0.35 ± 0.14^a	0.88 ± 0.04^a
Mount Nebo	23.0 ± 6.56^a	0.43 ± 0.14^a	0.89 ± 0.02^a
Petit Jean	23.0 ± 2.83^a	0.32 ± 0.14^a	0.83 ± 0.08^a
Pinnacle Mountain	21.0 ± 5.13^a	0.35 ± 0.15^a	0.84 ± 0.07^a

Table 1.2. Avian community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).

Park trails	Richness	Evenness	Diversity
<i>Mount Magazine</i>			
Benefield	12.0 ± 2.45^a	0.94 ± 0.04^a	0.91 ± 0.02^a
Greenfield	11.0 ± 2.07^a	0.88 ± 0.06^{ab}	0.89 ± 0.04^a
Mossback Ridge	10.0 ± 2.52^a	0.86 ± 0.06^b	0.87 ± 0.04^a
Rim	9.00 ± 1.55^a	0.92 ± 0.03^{ab}	0.88 ± 0.03^a
Signal Hill	9.00 ± 1.13^a	0.90 ± 0.01^{ab}	0.87 ± 0.02^a
Will Apple's Road	11.0 ± 2.84^a	0.93 ± 0.04^a	0.89 ± 0.03^a
<i>Mount Nebo</i>			
North Rim	14.0 ± 2.85^a	0.98 ± 0.03^{ac}	0.92 ± 0.02^a
Bench Road A	16.0 ± 3.00^a	0.95 ± 0.04^b	0.93 ± 0.02^a
Bench Road B	14.0 ± 3.64^a	0.96 ± 0.03^{ab}	0.92 ± 0.02^a
Summit Park	12.0 ± 3.37^a	0.98 ± 0.03^{ac}	0.91 ± 0.03^a
Nebo Steps/Springs	15.0 ± 2.12^a	1.00 ± 0.00^{ac}	0.93 ± 0.01^a
Varnall Springs	13.0 ± 2.83^a	0.97 ± 0.05^{abc}	0.92 ± 0.02^a
<i>Petit Jean</i>			
Canyon	14.0 ± 3.69^a	0.94 ± 0.06^a	0.92 ± 0.03^a
CCC Hike and Bike	15.0 ± 4.98^a	0.97 ± 0.04^{ab}	0.92 ± 0.02^a
Cedar Creek	13.0 ± 2.78^a	1.00 ± 0.00^c	0.92 ± 0.02^a

Cedar Falls	11.0 ± 2.43^a	0.99 ± 0.02^b	0.90 ± 0.02^a
Seven Hollows A	13.0 ± 3.23^a	0.99 ± 0.02^{bc}	0.91 ± 0.03^a
Seven Hollows B	14.0 ± 2.97^a	0.98 ± 0.05^{bc}	0.92 ± 0.02^a
<i>Pinnacle Mountain</i>			
Arkansas	14.0 ± 2.16^{ab}	1.00 ± 0.00^a	0.93 ± 0.01^a
Kingfisher	17.0 ± 4.58^a	1.00 ± 0.00^a	0.94 ± 0.02^a
Ouachita	16.0 ± 2.53^{ab}	0.99 ± 0.02^a	0.93 ± 0.01^a
Base	13.0 ± 3.01^{ab}	0.99 ± 0.01^a	0.92 ± 0.02^a
East Quarry	16.0 ± 3.51^{ab}	0.98 ± 0.03^a	0.94 ± 0.02^a
Rocky Valley	14.0 ± 2.69^{ab}	0.98 ± 0.03^a	0.92 ± 0.02^a
East Summit	10.0 ± 3.87^b	0.98 ± 0.03^a	0.88 ± 0.07^a
West Summit	16.0 ± 5.03^{ab}	0.98 ± 0.03^a	0.93 ± 0.02^a

Table 1.3. Bray-Curtis similarity values for avian species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Parks	Mount Magazine	Mount Nebo	Petit Jean	Pinnacle Mountain
Mount Magazine		64.8	53.8	51.3
Mount Nebo	64.8		77.6	78.8
Petit Jean	53.8	77.6		79.5
Pinnacle Mountain	51.3	78.8	79.5	

Table 1.4. Bray-Curtis similarity values for avian species composition in Mount Magazine State Park trails, Arkansas, 2015.

Trails	Benefield	Greenfield	Mossback Ridge	Rim	Signal Hill	Will Apple's Road
Benefield		66.3	65.6	61.4	64.2	74.2
Greenfield	66.3		59.6	54.0	67.1	61.5
Mossback Ridge	65.6	59.6		81.0	60.8	72.8
Rim	61.4	54.0	81.0		55.1	72.6
Signal Hill	64.2	67.1	60.8	55.1		62.7
Will Apple's Road	74.2	61.5	72.8	72.6	62.7	

Table 1.5. Bray-Curtis similarity values for avian species composition in Mount Nebo State Park trails, Arkansas, 2015.

Trails	North Rim	Bench Road A	Bench Road B	Summit Park	Nebo Springs/Steps	Varnall Springs
North Rim		63.4	65.1	56.4	36.5	18.7
Bench Road A	63.4		81.1	63.7	44.7	21.7
Bench Road B	65.1	81.1		65.5	49.2	24.7
Summit Park	56.4	63.7	65.5		54.7	33.3
Nebo Springs/Steps	36.5	44.7	49.2	54.7		52.3
Varnall Springs	18.7	21.7	24.7	33.3	52.3	

Table 1.6. Bray-Curtis similarity values for avian species composition in Petit Jean State Park trails, Arkansas, 2015.

Trails	Canyon	CCC Hike and Bike	Cedar Falls	Cedar Creek	Seven Hollows A	Seven Hollows B
Canyon		59.2	66.7	71.0	55.9	55.7
CCC Hike and Bike	59.2		67.2	56.8	67.9	71.0
Cedar Falls	66.7	67.2		70.5	57.4	57.0
Cedar Creek	71.0	56.8	70.5		53.9	51.8
Seven Hollows A	55.9	67.9	57.4	53.9		82.8
Seven Hollows B	55.7	71.0	57.0	51.8	82.8	

Table 1.7. Bray-Curtis similarity values for avian species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.

Trails	Arkansas	Kingfisher	Ouachita	Base	East Quarry	Rocky Valley	East Summit	West Summit
Arkansas		71.0	51.9	36.2	71.7	61.0	60.9	67.3
Kingfisher	71.0		51.1	34.7	79.2	53.7	60.2	78.8
Ouachita	51.9	51.1		65.4	55.9	73.1	63.7	50.8
Base	36.2	34.7	65.4		34.1	53.1	47.7	33.6
East Quarry	71.7	79.2	55.9	34.1		60.8	62.3	79.6
Rocky Valley	61.0	53.7	73.1	53.1	60.8		64.7	57.5
East Summit	60.9	60.2	63.7	47.7	62.3	64.7		61.7
West Summit	67.3	78.8	50.8	33.6	79.6	57.5	61.7	

Table 1.8. Mesocarnivore community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Species richness, evenness, and diversity did not differ between trails at any park ($\chi^2_5 = 5.47 - 7.58$ $P = 0.181 - 0.602$).

Park trails	Richness	Evenness	Diversity
<i>Mount Magazine</i>			
Benefield	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
Greenfield	1.00 \pm 0.58	0.33 \pm 0.58	0.67 \pm 0.58
Mossback Ridge	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
Rim	1.00 \pm 0.58	0.67 \pm 0.58	0.33 \pm 0.58
Signal Hill	1.00 \pm 0.58	0.33 \pm 0.58	0.67 \pm 0.58
Will Apple's Road	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
<i>Mount Nebo</i>			
North Rim	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
Bench Road A	1.00 \pm 0.58	0.67 \pm 0.58	0.33 \pm 0.58
Bench Road B	1.00 \pm 0.58	0.33 \pm 0.58	0.67 \pm 0.58
Summit Park	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
Nebo Steps/Springs	1.00 \pm 0.58	0.33 \pm 0.58	0.67 \pm 0.58
Varnall Springs	0.00 \pm 0.00	0.00 \pm 0.00	1.00 \pm 0.00
<i>Petit Jean</i>			
Canyon	1.00 \pm 0.58	0.67 \pm 0.58	0.33 \pm 0.58

CCC Hike and Bike	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
Cedar Creek	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
Cedar Falls	1.00 ± 0.58	0.33 ± 0.58	0.67 ± 0.58
Seven Hollows A	1.00 ± 0.58	0.33 ± 0.58	0.67 ± 0.58
Seven Hollows B	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00

Pinnacle Mountain

Arkansas	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
Kingfisher	1.00 ± 0.58	0.33 ± 0.58	0.67 ± 0.00
Ouachita	1.00 ± 0.58	0.33 ± 0.58	0.67 ± 0.58
Base	1.00 ± 0.58	0.33 ± 0.58	0.67 ± 0.58
East Quarry	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
Rocky Valley	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
East Summit	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00
West Summit	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00

Table 1.9. Bray-Curtis similarity values for mesocarnivore species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Parks	Mount Magazine	Mount Nebo	Petit Jean	Pinnacle Mountain
Mount Magazine		66.7	54.5	25.0
Mount Nebo	66.7		60.0	28.6
Petit Jean	54.5	60.0		44.4
Pinnacle Mountain	25.0	28.6	44.4	

Table 1.10. Understory woody vegetation community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).

Park trails	Richness	Evenness	Diversity
<i>Mount Magazine</i>			
Benefield	11.0 ± 1.63^a	0.18 ± 0.04^a	0.47 ± 0.11^{ab}
Greenfield	10.0 ± 2.32^a	0.21 ± 0.05^a	0.49 ± 0.16^{ab}
Mossback Ridge	9.00 ± 2.59^a	0.29 ± 0.14^a	0.54 ± 0.17^a
Rim	9.00 ± 2.41^a	0.35 ± 0.17^a	0.59 ± 0.20^a
Signal Hill	8.00 ± 2.44^a	0.17 ± 0.04^a	0.24 ± 0.22^b
Will Apple's Road	9.00 ± 2.30^a	0.29 ± 0.17^a	0.53 ± 0.20^a
<i>Mount Nebo</i>			
North Rim	4.00 ± 2.52^b	0.56 ± 0.30^{ab}	0.54 ± 0.27^a
Bench Road A	10.0 ± 2.15^a	0.37 ± 0.10^b	0.69 ± 0.10^a
Bench Road B	9.00 ± 1.70^a	0.47 ± 0.17^b	0.71 ± 0.18^a
Summit Park	5.00 ± 4.19^b	0.45 ± 0.35^b	0.70 ± 0.30^a
Nebo Steps/Springs	6.00 ± 2.50^b	0.61 ± 0.22^a	0.69 ± 0.13^a
Varnall Springs	7.00 ± 0.71^{ab}	0.48 ± 0.15^b	0.67 ± 0.07^a
<i>Petit Jean</i>			
Canyon	9.00 ± 1.51^a	0.29 ± 0.05^b	0.62 ± 0.07^a
CCC Hike and Bike	9.00 ± 4.35^a	0.45 ± 0.18^a	0.81 ± 0.10^{bc}

Cedar Creek	7.00 ± 1.85^a	0.60 ± 0.17^a	0.74 ± 0.12^{bc}
Cedar Falls	9.00 ± 3.08^a	0.47 ± 0.18^{ab}	0.70 ± 0.18^{bc}
Seven Hollows A	7.00 ± 3.04^a	0.52 ± 0.22^a	0.66 ± 0.17^{ac}
Seven Hollows B	9.00 ± 2.95^a	0.45 ± 0.20^{ab}	0.70 ± 0.11^{ac}
<i>Pinnacle Mountain</i>			
Arkansas	7.00 ± 2.22^a	0.37 ± 0.18^a	0.50 ± 0.30^a
Kingfisher	6.00 ± 3.06^a	0.47 ± 0.19^a	0.54 ± 0.14^a
Ouachita	7.00 ± 2.77^a	0.56 ± 0.13^a	0.72 ± 0.12^a
Base	7.00 ± 1.77^a	0.44 ± 0.16^a	0.61 ± 0.18^a
East Quarry	6.00 ± 3.46^a	0.66 ± 0.30^a	0.66 ± 0.14^a
Rocky Valley	8.00 ± 1.46^a	0.47 ± 0.18^a	0.69 ± 0.12^a
East Summit	6.00 ± 3.39^a	0.62 ± 0.17^a	0.66 ± 0.17^a
West Summit	10.0 ± 2.52^a	0.44 ± 0.30^a	0.69 ± 0.22^a

Table 1.11. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Parks	Mount Magazine	Mount Nebo	Petit Jean	Pinnacle Mountain
Mount Magazine		36.3	41.3	26.4
Mount Nebo	36.3		72.1	43.2
Petit Jean	41.3	72.1		50.0
Pinnacle Mountain	26.4	43.2	50.0	

Table 1.12. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Magazine State Park trails, Arkansas, 2015.

Trails	Benefield	Greenfield	Mossback Ridge	Rim	Signal Hill	Will Apple's Road
Benefield		83.9	76.7	61.9	69.8	71.2
Greenfield	83.9		85.3	67.6	65.5	73.9
Mossback Ridge	76.7	85.3		62.8	66.6	72.9
Rim	61.9	67.6	62.8		49.7	63.7
Signal Hill	69.8	65.5	66.6	49.7		75.4
Will Apple's Road	71.2	73.9	72.9	63.7	75.4	

Table 1.13. Bray-Curtis similarity values for understory woody vegetation species composition in Mount Nebo State Park trails, Arkansas, 2015.

Trails	North Rim	Bench Road A	Bench Road B	Summit Park	Nebo Springs/Steps	Varnall Springs
North Rim		37.3	48.4	66.2	18.4	30.9
Bench Road A	37.3		75.3	38.8	20.9	11.4
Bench Road B	48.4	75.3		43.3	14.4	13.2
Summit Park	66.2	38.8	43.3		30.2	31.9
Nebo Springs/Steps	18.4	20.9	14.4	30.2		31.6
Varnall Springs	30.9	11.4	13.2	31.9	31.6	

Table 1.14. Bray-Curtis similarity values for understory woody vegetation species composition in Petit Jean State Park trails, Arkansas, 2015.

Trails	Canyon	CCC Hike and Bike	Cedar Falls	Cedar Creek	Seven Hollows A	Seven Hollows B
Canyon		51.5	46.6	61.3	66.8	57.1
CCC Hike and Bike	51.5		60.3	48.8	55.4	49.6
Cedar Falls	46.6	60.3		46.0	45.8	38.1
Cedar Creek	61.3	48.8	46.0		38.3	32.9
Seven Hollows A	66.8	55.4	45.8	38.3		75.5
Seven Hollows B	57.1	49.6	38.1	32.9	75.5	

Table 1.15. Bray-Curtis similarity values for understory woody vegetation species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.

Trails	Arkansas	Kingfisher	Ouachita	Base	East Quarry	Rocky Valley	East Summit	West Summit
Arkansas		28.2	37.5	28.2	25.6	48.0	24.4	26.3
Kingfisher	28.2		0.07	15.4	9.90	11.0	10.4	19.1
Ouachita	37.5	0.07		52.2	25.3	67.3	22.3	19.9
Base	28.2	15.4	52.2		15.9	54.4	24.5	19.5
East Quarry	25.6	9.90	25.3	15.9		33.9	38.8	35.6
Rocky Valley	48.0	11.0	67.3	54.4	33.9		40.4	31.7
East Summit	24.4	10.4	22.3	24.5	38.8	40.4		28.3
West Summit	26.3	19.1	19.9	19.5	35.6	31.7	28.3	

Table 1.16. Overstory woody vegetation community metrics (± 1 SD) on trails in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Within each community metric and park, different letters indicate differences between trails ($P < 0.05$).

Park trails	Richness	Evenness	Diversity
<i>Mount Magazine</i>			
Benefield	13.0 ± 3.10^a	0.44 ± 0.10^a	0.80 ± 0.06^{ab}
Greenfield	10.0 ± 1.64^{ab}	0.48 ± 0.17^a	0.75 ± 0.11^b
Mossback Ridge	7.00 ± 2.18^b	0.49 ± 0.11^a	0.69 ± 0.09^c
Rim	10.0 ± 1.85^{ab}	0.58 ± 0.10^a	0.83 ± 0.03^a
Signal Hill	8.00 ± 1.95^b	0.52 ± 0.15^a	0.71 ± 0.16^b
Will Apple's Road	9.00 ± 2.73^b	0.43 ± 0.14^a	0.71 ± 0.11^b
<i>Mount Nebo</i>			
North Rim	6.00 ± 2.28^a	0.53 ± 0.19^a	0.61 ± 0.22^a
Bench Road A	9.00 ± 1.51^b	0.55 ± 0.15^a	0.78 ± 0.07^b
Bench Road B	9.00 ± 3.23^b	0.57 ± 0.14^a	0.79 ± 0.06^b
Summit Park	8.00 ± 3.05^{ab}	0.51 ± 0.08^a	0.72 ± 0.17^b
Nebo Steps/Springs	9.00 ± 2.00^b	0.58 ± 0.15^a	0.80 ± 0.03^b
Varnall Springs	8.00 ± 0.71^{ab}	0.70 ± 0.01^a	0.81 ± 0.01^b
<i>Petit Jean</i>			
Canyon	10.0 ± 2.16^a	0.54 ± 0.11^{ab}	0.80 ± 0.05^a
CCC Hike and Bike	13.0 ± 4.75^a	0.57 ± 0.21^a	0.76 ± 0.27^a

Cedar Creek	11.0 ± 1.77^a	0.56 ± 0.13^{ab}	0.82 ± 0.05^a
Cedar Falls	11.0 ± 1.51^a	0.57 ± 0.15^{ab}	0.81 ± 0.08^a
Seven Hollows A	11.0 ± 2.84^a	0.37 ± 0.16^b	0.66 ± 0.17^a
Seven Hollows B	11.0 ± 2.30^a	0.40 ± 0.15^{ab}	0.71 ± 0.17^a
<i>Pinnacle Mountain</i>			
Arkansas	10.0 ± 1.26^a	0.43 ± 0.19^b	0.71 ± 0.16^a
Kingfisher	9.00 ± 1.53^{ab}	0.43 ± 0.15^b	0.72 ± 0.12^a
Ouachita	10.0 ± 2.07^a	0.58 ± 0.11^{ab}	0.81 ± 0.05^b
Base	7.00 ± 2.03^{ab}	0.61 ± 0.14^{ab}	0.72 ± 0.16^a
East Quarry	7.00 ± 1.00^{ab}	0.75 ± 0.15^a	0.80 ± 0.03^b
Rocky Valley	10.0 ± 1.98^a	0.55 ± 0.09^{ab}	0.81 ± 0.05^b
East Summit	6.00 ± 2.15^b	0.48 ± 0.21^{ab}	0.54 ± 0.13^c
West Summit	10.0 ± 2.65^a	0.40 ± 0.13^b	0.73 ± 0.03^b

Table 1.17. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Parks	Mount Magazine	Mount Nebo	Petit Jean	Pinnacle Mountain
Mount Magazine		52.9	44.2	41.5
Mount Nebo	52.9		45.7	52.6
Petit Jean	44.2	45.7		45.5
Pinnacle Mountain	41.5	52.6	45.5	

Table 1.18. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Magazine State Park trails, Arkansas, 2015.

Trails	Benefield	Greenfield	Mossback Ridge	Rim	Signal Hill	Will Apple's Road
Benefield		30.6	34.8	33.8	54.3	33.9
Greenfield	30.6		60.0	43.9	50.4	37.1
Mossback Ridge	34.8	60.0		47.9	45.6	49.8
Rim	33.8	43.9	47.9		37.5	56.2
Signal Hill	54.3	50.4	45.6	37.5		32.6
Will Apple's Road	33.9	37.1	49.8	56.2	32.6	

Table 1.19. Bray-Curtis similarity values for overstory woody vegetation species composition in Mount Nebo State Park trails, Arkansas, 2015.

Trails	North Rim	Bench Road A	Bench Road B	Summit Park	Nebo Springs/Steps	Varnall Springs
North Rim		30.0	30.2	55.6	22.0	15.4
Bench Road A	30.0		49.0	39.5	35.1	13.2
Bench Road B	30.2	49.0		42.8	24.2	19.3
Summit Park	55.6	39.5	42.8		47.0	18.6
Nebo Springs/Steps	22.0	35.1	24.2	47.0		25.0
Varnall Springs	15.4	13.2	19.3	18.6	25.0	

Table 1.20. Bray-Curtis similarity values for overstory woody vegetation species composition in Petit Jean State Park trails, Arkansas, 2015.

Trails	Canyon	CCC Hike and Bike	Cedar Falls	Cedar Creek	Seven Hollows A	Seven Hollows B
Canyon		51.0	50.0	63.9	27.5	24.5
CCC Hike and Bike	51.0		69.2	39.8	45.6	40.9
Cedar Falls	50.0	69.2		34.3	37.2	34.3
Cedar Creek	63.9	39.8	34.3		18.7	16.4
Seven Hollows A	27.5	45.6	37.2	18.7		83.8
Seven Hollows B	24.5	40.9	34.3	16.4	83.8	

Table 1.21. Bray-Curtis similarity values overstory woody vegetation species composition in Pinnacle Mountain State Park trails, Arkansas, 2015.

Trails	Arkansas	Kingfisher	Ouachita	Base	East Quarry	Rocky Valley	East Summit	West Summit
Arkansas		17.8	35.2	20.7	20.9	26.0	17.8	26.1
Kingfisher	17.8		12.6	17.8	20.5	22.3	16.0	12.9
Ouachita	35.2	12.6		44.4	28.7	49.0	34.2	35.0
Base	20.7	17.8	44.4		17.4	48.2	49.0	16.7
East Quarry	20.9	20.5	28.7	17.4		32.3	21.3	50.0
Rocky Valley	26.0	22.3	49.0	48.2	32.3		43.9	35.4
East Summit	17.8	16.0	34.2	49.0	21.3	43.9		24.9
West Summit	26.1	12.9	35.0	16.7	50.0	35.4	24.9	

CHAPTER II:

EFFECTS OF NON-CONSUMPTIVE TRAIL USE, ENVIRONMENTAL, AND TRAIL DESIGN FACTORS ON STATE PARK TAXONOMIC COMMUNITIES

State parks offer protected habitat and resources to many resident and migratory animals, however, they may also serve as the only available location for many people to experience outdoor recreation and to observe wildlife (Reed and Merenlender 2008, Rodriguez-Prieto et al. 2014). As such, state parks demand management strategies that protect the plant and wildlife communities within the park while also promoting outdoor participation and recreation. This dual conservation role is accomplished through a mutually beneficial process in which state parks provide visitors the opportunity to participate in wildlife education, viewing, and guided outdoor activities which then provides park managers funding opportunities for conservation (e.g., visitor passes and workshops) and data on park flora and fauna (e.g., visitor sightings and participatory wildlife data collection).

Participation in outdoor recreation, ranging from national parks to public forests, has steadily increased over the past century (Duffus and Dearden 1990, Knight and Temple 1995, Monz et al. 2013). This trend is expected to continue to grow over the next several decades (Outdoor Foundation 2016). For example, a recent analysis found that 48.4% of Americans participated in some form of outdoor recreation in 2015 (Outdoor Foundation 2016). While many participation surveys highlight increases in outdoor recreation and visitation to federal lands, outdoor recreation and visitation to state parks was >80% higher than levels that occurred in all federal lands in which visitation had been recorded (Cordell 2012). Visitation to state parks specifically has

increased since the 1980's, likely due to state parks typically being more developed compared to national parks and being in closer proximity to large metropolitan areas, providing easier day access to outdoor use and recreation (Cordell 2012).

Outdoor recreation has commonly been viewed as an innocuous activity when compared to activities such as urban development and deforestation (Miller et al. 1998, Kays et al. 2016). However, outdoor recreation in state parks has been recognized as an important factor that can influence park faunal communities as well as the surrounding quality of habitat (Boyle and Samson 1985, Knight and Temple 1995, Leung and Marion 2000, Hammitt et al. 2015, Kays et al. 2016). These recreation activities can be categorized into 2 main types, consumptive and non-consumptive uses (Boyle and Samson 1985, Applegate and Clark 1987, Cole and Landres 1995, Reed and Merenlender 2008), which can affect park biota both directly and indirectly (Knight and Cole 1995). Consumptive use activities are those that directly affect biotic populations and result in the removal of plants and animals from the environment, such as hunting, fishing, and firewood collection (Cole 1993, Knight and Cole 1995, Leung and Marion 2000). Consumptive activities are often regulated to prevent unsustainable harvest and to weaken their effects on communities such as altering vegetative structure, influencing predator-prey relationships, and causing avoidance behaviors in response to noise pollution (Knight and Temple 1995). Comparatively, non-consumptive use activities do not actively remove organisms from the environment and incorporate a broader scale of activities including trail use (e.g., hiking, jogging, and dog [*Canis lupus familiaris*] walking), wildlife observation, and swimming. While these non-consumptive activities have been historically considered benign when compared to consumptive uses, there is a

growing body of evidence suggesting that non-consumptive activities have greater, more widespread negative effects on biological communities (Miller et al. 1998, Taylor and Knight 2003, Hammitt and Cole 2015) and may not be compatible with the dual role of balancing outdoor recreation with the conservation of state park communities (Reed and Merenlender 2008).

The direct and indirect effects of non-consumptive use on flora and fauna can be broken down into 3 primary routes of influence: 1) habitat modification; 2) effects on physiological health and behavior; and 3) effects on community structure (Cole and Landres 1995). Repeated use of park trails without managing the frequency or intensity of foot traffic can adversely alter habitat via clearing of near-trail vegetation for firewood (Cole 1993), reduction of seed production and biomass from trampling (Dale and Weaver 1974, Leung and Marion 1999, Leung and Marion 2000, Campbell and Gibson 2001), and reductions in carbohydrate reserves in the soil (Dale and Weaver 1974, Cole 1993). Recreational trail use also increases the amount of soil erosion that occurs in protected areas and increases the likelihood for the introduction of invasive plant species via hiking and horseback riding (e.g., seeds in manure; Dale and Weaver 1974). High rates of trail use have led to increased levels of temporary and permanent avoidance behaviors in birds and mammals, which may increase physiological stress through the interruption of courtship rituals and displacement from familiar territories (Riffell et al. 1996, Miller and Hobbs 2000). This avoidance can lead to declines in overall species productivity (Riffell et al. 1996, Juricic et al. 2005), reductions in reproductive success (Safina and Burger 1983, Gutzwiller et al. 1994, Riffell et al. 1996, Miller et al. 1998, Sekercioglu 2002), and displace migration and movement corridors (Knight and Swaddle 2007).

Furthermore, some wildlife species may become conditioned to human disturbances, resulting in high diversities and abundances of disturbance-tolerant species near trails (Knight and Gutzwiller 1995). This conditioning increases the likelihood of adverse human-wildlife interactions through dependence on human resources and promoting recreation activities which involve wildlife viewing (Cole 1993, Sekercioglu 2002, Knight and Swaddle 2007).

Recreation ecology research has primarily focused on the population dynamics of species, with less research conducted on communities (Campbell 2011, Steven et al. 2011). These single-species studies, though helpful in managing populations, may not adequately address all the possible influences acting on state park biota. Effects at the individual or population level may alter reproductive rates and foraging behaviors of several species at once, which then manifest into community-scale effects on metrics such as diversity, evenness, richness, and composition (Riffell et al. 1996, Rahbek and Graves 2001). Community richness and diversity generally have a negative relationship with environmental stressors such as high rates of trail use (Riffell et al. 1996), however this relationship can vary depending on the type of trail activity, focal taxon, and the spatial scale of observation (Torn et al. 2009, Rodriguez-Prieto et al. 2014, Larson 2015). Evenness of a community may also decrease as a result of high levels of disturbance if that community is composed of only a small number of disturbance-tolerant species (Scrosati and Heaven 2007, Hillebrand et al. 2008).

In addition to the potential influences of non-consumptive activities, natural dynamics of the environment, such as climate, geology, and topography, are also important determinants in the structure and dynamics of communities in protected areas

(Leung and Marion 1999, Camille and Willig 2000, Crick 2004). Aspects of an ecosystem's climate, such as the amount of precipitation and temperature range, can influence individual fitness, resource availability, and place selective morphological and behavioral pressures on individuals (Camille and Willig 2000) which can influence the community. Temperature can influence metabolic rates of wildlife which can indirectly affect foraging and reproductive behaviors (Knight and Temple 1995, Camille and Willig 2000) and more precipitation can result in greater vegetation growth and soil erosion, thus potentially improving or lowering the evenness and richness of floral communities (Leung and Marion 1999, Camille and Willig 2000). Aspects of topography, such as slope alignment and aspect, can also indirectly affect community structure through higher susceptibility to water runoff and soil erosion (Leung and Marion 1999, Miller et al. 2009).

Physical aspects of the environment, such as canopy cover and vegetation community metrics may further have considerable influences on communities. Canopy cover controls the quantity and distribution of light that reaches the forest floor, thus directly affecting understory vegetation growth (Naumberg and DeWald 1999, North et al. 2005). Changes to understory vegetation can have cascading effects on the structure of wildlife communities by influencing the abundance and availability of invertebrate populations and nest material, resulting in changes in foraging behavior (Galitsky and Lawler 2015). Additionally, attributes of woody vegetation such as composition, evenness, and diversity may affect animal communities within protected areas. Avian diversity, for example, has been related to the distribution and species composition of vegetative communities (Mason et al. 2007). High diversity and density of understory

vegetation can also act to restrict the lateral spread of trail users, possibly decreasing the total effects of non-consumptive use on deeper, forest interior communities (Marion and Leung 2001).

Trails serve as a useful management tool in providing recreationists access to wildlife viewing and to divert visitor use away from protected resources (Leung and Marion 1999). However, physical characteristics such as trail width, incision depth, and percentage of bare ground may additionally affect surrounding biotic communities (Dale and Weaver 1974). For example, increased trail width and depth resulting from poor trail design or overuse can result in the loss of understory vegetation located near the trail (Knight and Cole 1995, Torn et al. 2009, Hammitt et al. 2015) as well as serve as a corridor for introducing invasive species (Dale and Weaver 1974). Large amounts of bare ground on trails can lead to increased soil erosion and tree root exposure which can negatively affect overstory vegetation communities (Leung and Marion 1996). Furthermore, trails typically bisect natural habitats which introduce immediate edge effects and can result in avoidance behaviors in parks species, thus influencing community structure through the displacement of individuals (Yahner 1988, Knight and Temple 1995, Leung and Marion 2000).

Understanding the collective effects on communities from non-consumptive use, environmental factors, and trail design is essential in creating management strategies that fully encompass the diversity of variables influencing park flora and fauna. Although there is a growing pool of literature documenting the effects of non-consumptive recreation on organisms (Boyle and Samson 1985, Knight and Gutzwiller 1995, Hammitt et al. 2015), few studies have addressed the effects of non-consumptive use in state parks

(Knight and Gutzwiller 1995, Taylor and Knight 2003) on taxonomic communities (Fortin et al. 2016), or on multiple taxon groups at once (Rodriguez-Prieto et al. 2014, Larson 2015). Further, many studies have noted the possible synergistic effects of environmental factors and trail design with the effects of non-consumptive use, however, few researchers have encompassed all 3 sources of influence when examining state park communities (Cole 1993, Harrison and Cornell 2008, Monz et al. 2013). Therefore, my goal was to examine the collective effects of non-consumptive trail use, environmental factors, and trail design on the avian, mesocarnivore, and woody vegetation communities residing in Arkansas state parks. By utilizing a holistic approach, such knowledge then could provide state park managers a better understanding on the effects of non-consumptive use on state park taxonomic communities relative to the influences from the environment and improve management practices.

METHODS

Study Area

Please see the study area description in Chapter I.

Taxa Data Collection

Please see the taxa data collection methods in Chapter I.

Non-Consumptive Trail Use Rates

During the same time period as taxa data collection, I recorded the daily rate of non-consumptive use for each trail, measured as the number of trail users/30 min/trail. Trail user rates were calculated from an aggregation of structured and opportunistic in-person trail counts. The structured trail user data were collected 5 days a week with 30-min observations randomly scheduled per observer and per trail during varied timeslots

between 0900 – 1800hrs. Counts were observed at the second sampling point from the trailhead of each trail to ensure capture of total use on each trail (Torn et al. 2009). The number of users/trail/day was recorded; observers noted whether trail users were in a group or alone and if the individual was entering or leaving the trail during the observation period to avoid double-sampling the same individuals. This methodology resulted in 2.5 hours of structured observation for each trail each week (5 visits of 30 minutes each) and 7.5 hours of structured observation for each trail in each park by the end of the study.

Trail users were also opportunistically recorded during morning avian point counts from 0500 – 1000hrs and during vegetation sampling which occurred throughout the day. During avian and vegetation sampling, I would record the time that I detected a trail user, whether the user was in a group or alone, and the direction they were traveling relative to the trail head. Opportunistic trail use rates/day were calculated by dividing the total number of users recorded per day by the total number of 30-min increments that occurred during the hours of opportunistic observation to create user rates/30 min/trail/day.

Environmental Data Collection

I collected daily data on environmental conditions during each visit to a state park. Environmental variables were divided into 3 broad categories: climate, vegetation community metrics (Chapter I), and habitat structure. For climate data, I used the Weather Underground phone application (Weather Underground 2015) to record daily minimum and maximum temperatures (°C) and daily precipitation totals (mm) for each

park visit. To quantify habitat structure, I measured canopy cover and slope at each sampling point (Chapter I).

Trail Design Data Collection

I collected data on the trail incision depth (mm) and width (m) at each sampling point because both measures can influence both the rate and nature of trail use (Weaver and Dale 1978, Leung and Marion 1996). For example, wider trails may elicit larger groups of people while more narrow trails will force groups to walk single file, thus possibly increasing erosion from trampling (Marion et al. 2011). Trail width was recorded as one obvious edge of the trail to the other and trail depth was recorded as the change in height from the trail surface to the bordering rocks and vegetation (Torn et al. 2009).

Data Analyses

Taxa community metrics.— Please see the data analyses description in Chapter I.

Non-consumptive trail user rates.— In order to account for possible losses in data, such as trail users outside of observation hours, weekend trail users, and observer error (Pettebone 2010), I used bootstrapping methods to calculate a mean rate of trail use/visit for each trail from the combined daily structured and opportunistic trail use rates. I used a bootstrap with replacement and approximately 1,000 resamples (PROC SURVEYSELECT, rep = 150) to create a distribution of trail use rates/visit; the mean of these distributions was then used as the estimated mean rate of trail use/trail/visit (Table 2.1). I conducted 1 - way ANOVAs (PROC GLM, $\alpha = 0.05$ for all SAS analyses; SAS Institute, Cary, North Carolina, 2016) and Tukey's *HSD* (TUKEY in the means statement) on these trail use rates among the parks and between park trails to detect

possible differences in rates of trail use; data were log-transformed when found to violate normality or equal variances assumptions.

Environmental data.— I calculated minimum temperature, maximum temperature, and precipitation totals for each visit by averaging the daily measurements of each variable per visit (Table 2.2). I also calculated values for canopy cover and slope for each park (Table 2.2) and for trails within parks (Table 2.3) by averaging the canopy cover and slope recordings from each sampling point along a trail. Data were transformed when found to violate the normality or equal variances assumptions and then I conducted 1 - way ANOVAs and Tukey's *HSD* on the averaged environmental data to detect differences in climatic and vegetative attributes among the parks and between trails within each park. Kruskal-Wallis tests with Dunn's multiple comparison tests [$\alpha = 0.05$ for all R analyses; R Version 3.1.2., <http://www.r-project.org/>; `dunn.test`] were used when normality could not be attained.

Trail design data.— I calculated trail depth and width values for each park (Table 2.2) and for trails within each park (Table 2.3) by averaging the depth and width measurements recorded from each sampling point along a trail. I also conducted 1 - way ANOVAs and Tukey's *HSD* on the averaged trail design data to detect differences in average trail width and depth among the parks and between trails within each park. Data were again transformed when found to violate the normality or equal variances assumption and Kruskal-Wallis tests with Dunn multiple comparison tests were again used when normality could not be attained.

Models.— State park taxonomic communities are likely influenced by multiple variables, yet few non-consumptive use studies have included observations on the

potential synergistic effects of environmental and trail design factors on taxonomic communities. Although state park communities are subject to disturbances from non-consumptive recreation on a daily basis, those communities are also subject to the natural dynamics in the environment and to park management decisions on trail structure. Therefore, I modeled the potential effects of non-consumptive trail use, environmental factors, and trail design on avian, mesocarnivore, understory woody vegetation, and overstory woody vegetation communities for each park.

I considered 15 initial predictor variables from non-consumptive trail use, environmental, and trail design data that were likely to affect state park taxonomic communities (Table 2.4). I first log-transformed all non-normal variables to improve their normality. I then used cluster analyses (PROC VARCLUS; eigenvalue = 0.8) to reduce the number of variables and multicollinearity within each taxonomic community at each park. I chose variables having the lowest $1 - R^2$ value within each cluster to represent the other variables in that respective cluster. This procedure resulted in reducing the initial 15 variables to 4 – 6 variables per park which captured between 76.4 – 91.5% of the variability in the data (Table 2.5).

I used a stepwise approach with Akaike Information Criteria adjusted for small sample sizes (AIC_c) and regression analyses to determine the effects of the non-consumptive trail use, environmental factors, and trail design on the community metrics of each taxonomic group in the parks. I created 3 candidate model sets (e.g., richness, evenness, and diversity) for each of the 4 taxonomic communities in each park resulting in 12 model sets per park (Tables 2.6 – 2.17). Each model set included both single variable models and multivariate models. I began developing each model set with the

global model (i.e., all variables from the cluster analysis), a null model (i.e., intercept-only), and single-variable models. Single variable models that had an AIC_c less than the null model were kept to create multivariate models, with the single variable model having the lowest AIC_c value used as a starting point for creating 2-variable models. This process was repeated to include additional variables until AIC_c had been minimized (Burnham and Anderson 2004). I then considered only models $\leq 2 \Delta AIC_c$ values from the most parsimonious model and with AIC_c values less than the null model as supported (Burnham and Anderson 2004). For model sets that had competing models, I calculated a composite model with standardized parameters (β') and Akaike relative weights (ω) for each variable in the composite model.

RESULTS

Variable Summary Results

Taxa community metrics.— Please refer to Chapter I for a summary of community metrics for each trail and state park.

Non-consumptive trail user rates.— I spent approximately 469 hours observing trail use over the course of study. Forty-two percent (195 hours) of that time was from structured trail user counts where each trail in each park received equal amounts of observation time (approximately 49 hours per park). The remaining 58% (274 hours) of observation time was from the opportunistic trail use observations and included 73 hours at Petit Jean, 69 hours at Mount Magazine, 67 hours at Pinnacle Mountain, and 65 hours at Mount Nebo.

The mean rate of trail use was different among parks ($F_{3,22} = 4.22$, $P = 0.017$; Table 2.1). Mount Magazine (0.23 ± 0.20 ; mean ± 1 SD throughout) had a lower trail use

rate than Pinnacle Mountain (0.97 ± 0.81) and Petit Jean (0.88 ± 0.79) which had high rates of use; Mount Nebo (0.32 ± 0.15) had a moderate trail use rate. Trail use varied between trails at Petit Jean ($F_{5,12} = 12.0$, $P = 0.000$) and Pinnacle Mountain ($F_{7,16} = 18.5$, $P \leq 0.001$; Table 2.1) but not at Mount Magazine ($F_{5,12} = 1.73$, $P = 0.202$) or Mount Nebo ($F_{5,12} = 0.35$, $P = 0.871$). Within Petit Jean, the Cedar Falls trail had the greatest amount of trail use compared to all other trails within the park with no differences among the other trails. At Pinnacle Mountain, the West Summit trail had the highest rate of trail use and trail use rates overlapped among the other trails.

Environmental data.— Mean minimum temperatures, mean maximum temperatures, and mean precipitation amounts did not differ among the parks ($F_{3,8} = 1.10 - 2.31$, $P = 0.153 - 0.404$; Table 2.2). Canopy cover also did not differ among the parks ($F_{3,22} = 0.90$, $P = 0.459$; Table 2.2). Pinnacle Mountain had steeper slopes compared to Petit Jean and Mountain Magazine ($\chi^2_3 = 12.9$, $P = 0.005$; Table 2.2); slopes at Mount Nebo were similar to all of the parks.

Differences in cover and slope were also found between the trails within the parks (Table 2.3). Canopy cover did not differ among trails at Pinnacle Mountain ($F_{7,44} = 1.09$, $P = 0.388$) or Petit Jean ($\chi^2_5 = 8.94$, $P = 0.112$) but differed between trails in Mount Magazine ($\chi^2_5 = 14.5$, $P = 0.013$) and Mount Nebo ($\chi^2_5 = 24.1$, $P = 0.000$; Table 2.3). At Mount Magazine, the Greenfield trail had the densest canopy cover except compared to the Mossback Ridge trail; all other trails in the park had similar canopy cover densities. At Mount Nebo, the Bench Road B trail had the densest canopy cover of all trails. Slope differed among trails at Mount Magazine ($F_{5,54} = 3.71$, $P = 0.006$), Petit Jean ($F_{5,53} = 4.52$, $P = 0.002$), and Pinnacle Mountain ($F_{5,44} = 3.40$, $P = 0.005$), but did not differ

within Mount Nebo ($F_{5,50} = 0.18$, $P = 0.970$; Table 2.3). At Mount Magazine, the Signal Hill trail had the steepest slope compared to the Benefield, Mossback Ridge, and Greenfield trails, which all had similarly low slopes. The Rim and Will Apple's trails had moderate slopes that did not differ compared to the other trails. At Petit Jean, the CCC Hike and Bike trail had the lowest slope compared to the Cedar Falls, Cedar Creek, and Seven Hollows A trails. The Canyon and Seven Hollows B trails had moderately low slopes that did not differ from the other trails. The Kingfisher trail had the least slope compared to the East and West Summit trails at Pinnacle Mountain. Additionally, the Base, Rocky Valley, Ouachita, and East Quarry trails at Pinnacle Mountain all had similarly low planes of slope which did not differ compared to the slope of the other trails.

Trail design data.— Mean trail width ($F_{3,22} = 46.6$, $P \leq 0.001$) and mean trail incision depth ($F_{3,22} = 3.22$, $P = 0.042$) were different among the parks (Table 2.2). Mount Nebo had the widest trails and Mount Magazine had the narrowest trails. Petit Jean and Pinnacle Mountain had moderate trail widths that were wider than trails at Mount Magazine but narrower than trails at Mount Nebo. Mount Nebo also had the deepest trails compared to Petit Jean and Pinnacle Mountain; trail depths within Mount Magazine were not different from the other parks.

Trail differences in most parks were confined to a specific trail (Table 2.3). At Mount Magazine, the Rim trail had the narrowest width compared to all other trails within the park ($F_{5,54} = 9.98$, $P \leq 0.001$). The Bench Road trails had the widest trail widths compared to all other trails at Mount Nebo ($F_{5,50} = 29.5$, $P \leq 0.001$). At Petit Jean, the CCC Hike and Bike trail was the widest trail ($\chi^2_5 = 22.5$, $P = 0.000$). At Pinnacle

Mountain, the Base trail was narrower than the East Summit trail; all other trails had similar widths ($F_{5,44} = 3.23$, $P = 0.008$).

Trail incision depths also differed among trails in all of the parks (Table 2.3). At Mount Magazine, the Will Apple's and Mossback Ridge trails were the deepest trails ($\chi^2_5 = 45.2$, $P \leq 0.001$). At Mount Nebo, the Summit Park trail had the deepest trail depth and the North Rim trail had the shallowest trail depth. Further, the Bench Road, Nebo Steps, and Varnall Springs trails all had similar trail depths that were shallower than Summit Park trail but deeper than the North Rim trail ($\chi^2_5 = 25.6$, $P = 0.000$). At Petit Jean, the Cedar Creek trail had the deepest incision depth within the park ($\chi^2_5 = 36.7$, $P \leq 0.001$). The Base trail had the deepest trail depth of any trail in Pinnacle Mountain ($\chi^2_7 = 45.7$, $P \leq 0.001$), with all other trails having very shallow trail depths.

Effects of Anthropogenic, Environmental, and Trail Design Factors on Taxonomic Community Metrics

Avian community metrics.— For avian community richness (Table 2.6), all parks had only 1 parsimonious model each that included 71 – 85% of the Akaike model weights. Trails with greater richness in the surrounding overstory vegetation had the highest avian richness at Mount Magazine; avian richness was also negatively affected by higher temperatures. At Mount Nebo, avian richness was highest along trails with wider paths and lower along trails that had higher overstory vegetation evenness. The global model was the most parsimonious for the Petit Jean and Pinnacle Mountain model sets indicating that all the observed variables had some effect on avian richness at these parks. At Petit Jean, avian richness was highest in trails with higher understory vegetation richness and evenness, trails with higher diversity in overstory vegetation, and during

greater amounts of rainfall. Avian richness was also negatively affected by higher temperatures and by higher rates of trail use. At Pinnacle Mountain, avian richness was highest when there were lower amounts of rainfall, lower evenness in understory vegetation, and along trails that had a lower rate of trail use. Additionally, avian richness increased with understory vegetation diversity and along trails with greater incision depths.

For avian community evenness (Table 2.7), 3 competing models at Mount Magazine were identified to include 70% of the Akaike model weights; 2 competing models at Mount Nebo were identified to include 81% of the model weights; and 1 parsimonious model was identified at both Petit Jean and Pinnacle Mountain that included 49% and 75% of the model weights, respectively. Both the global and null models were included in the competing model set for Mount Magazine, however, the global model had a lower ΔAIC_c value than the null model, indicating weak support that all the observed variables affected avian evenness within the park. Evidence suggested that avian evenness was greater along trails that had a greater diversity in overstory vegetation (composite $\beta' = 0.77$; relative Akaike weight $\omega = 0.55$); along wider trails ($\beta' = 0.74$; $\omega = 0.33$) with more horizontal slopes ($\beta' = -0.33$; $\omega = 0.33$); and during periods of warmer temperatures ($\beta' = 0.32$; $\omega = 0.33$) and less rainfall ($\beta' = -0.33$; $\omega = 0.33$). Conversely, avian evenness was lower along trails with greater overstory vegetation richness ($\beta' = -0.42$; $\omega = 0.33$). At Mount Nebo, higher values of overstory vegetation evenness ($\beta' = 0.69$; $\omega = 0.81$) had a strong positive effect on avian evenness whereas wider trails had a moderate negative effect ($\beta' = -0.31$; $\omega = 0.49$). Understory vegetation evenness and total precipitation both negatively affected avian evenness at Petit Jean.

Given that the global model had the lowest ΔAIC_c value in the model set for Pinnacle Mountain, all the variables influenced avian evenness within the park. Avian evenness at Pinnacle Mountain was higher on trails with higher understory vegetation evenness and lower understory vegetation diversity. Avian evenness was also higher along shallower trails that received more rainfall and had higher trail use rates.

For avian community diversity (Table 2.8), 1 model was identified to contain 84% of the model weights for Mount Magazine and 3 competing models were identified for both Mount Nebo and Pinnacle Mountain containing 83% and 85% of the model weights, respectively (Table 2.9). Two competing models were identified at Petit Jean to contain 84% of the model weights. The global model was the most parsimonious at Mount Magazine: avian diversity was highest on trails with greater diversity and richness in overstory vegetation and during lower amounts of rainfall and lower temperatures. Avian diversity was also greater along wider trails with flatter slopes. At Mount Nebo, overstory vegetation evenness had a strong negative effect ($\beta' = -0.51$; $\omega = 0.69$) on avian diversity. Avian diversity was also higher along wider trails ($\beta' = 0.38$; $\omega = 0.46$). Trail use, maximum temperature, understory vegetation evenness, and overstory vegetation diversity all had strong support for influencing avian diversity in Petit Jean ($\omega = 0.84$ for all variables). Avian diversity was highest along trails with greater evenness in understory vegetation ($\beta' = 0.52$), but was lowest along trails that experienced warmer temperatures ($\beta' = -0.48$), higher diversity in overstory vegetation ($\beta' = -0.47$), and higher rates of daily trail use ($\beta' = -0.46$). Additionally, avian diversity was higher along trails with greater richness in understory vegetation ($\beta' = 0.20$), but support for this variable was lower than the other variables ($\omega = 0.27$). At Pinnacle Mountain, more rainfall led to

lower levels of avian diversity ($\beta' = -0.53$; $\omega = 0.85$). There was also strong evidence for lower levels of avian diversity along trails with greater rates of use ($\beta' = -0.37$; $\omega = 0.70$) and shallower incision depths ($\beta' = 0.31$ $\omega = 0.56$).

Mesocarnivore community metrics.— For mesocarnivore community richness (Table 2.9), 2 – 5 competing models were identified for each state park containing 65 – 91% of the model weights. At Mount Magazine, trails that were more narrow ($\beta' = -0.51$; $\omega = 0.80$), received less rainfall ($\beta' = -0.46$; $\omega = 0.80$), and had lower overstory vegetation richness ($\beta' = -0.30$; $\omega = 0.40$) had higher mesocarnivore richness. There was weak evidence suggesting that mesocarnivore richness was highest on trails with lower evenness in understory vegetation ($\beta' = -0.43$; $\omega = 0.42$) at Petit Jean. The null model had the lowest ΔAIC_c value in the Mount Nebo and Pinnacle Mountain model sets indicating very little evidence that any included variable affected mesocarnivore richness at these parks.

I identified 2 – 5 competing models that contained 65 – 93% of the model weights for mesocarnivore community evenness (Table 2.10). Results were similar to that of mesocarnivore richness in that the null model was included in the model set for each park and there was poor support for any given variable affecting mesocarnivore evenness. At Mount Magazine, the only variable to provide some evidence that it affected mesocarnivore evenness more than the null model was total rainfall ($\beta' = -0.37$; $\omega = 0.27$), which had a negative effect on the community metric. There was also slight evidence that lower values of understory evenness may positively affect mesocarnivore evenness at Petit Jean State Park ($\beta' = -0.43$; $\omega = 0.42$). The null model had the lowest ΔAIC_c value for the Mount Nebo and Pinnacle Mountain model sets.

Results for mesocarnivore community diversity (Table 2.1) were also similar to the other mesocarnivore metrics. I again identified 2 – 5 competing models containing 65 – 91% of the model weights. At Mount Magazine, trail width had a strong positive effect on mesocarnivore diversity ($\beta' = 0.57$; $\omega = 0.87$) and mesocarnivore diversity was also higher during greater rainfall totals ($\beta' = 0.37$; $\omega = 0.57$). Similar to mesocarnivore richness, there was very weak evidence that understory vegetation evenness had a positive effect ($\beta' = 0.43$; $\omega = 0.42$) on mesocarnivore diversity at Petit Jean State Park and the null model had the lowest ΔAIC_c value in the Mount Nebo and Pinnacle Mountain model sets.

Understory vegetation community metrics.— Each state park had 1 model for understory vegetation community richness that contained 71 – 99% of the model weights (Table 2.12). Overstory vegetation richness had a strong positive effect on understory vegetation richness at Mount Magazine and at Mount Nebo. Canopy cover also had a strong positive effect on understory vegetation richness at Mount Nebo. At Petit Jean, the global model had the lowest ΔAIC_c value: understory vegetation richness was highest along trails with lower diversity in overstory vegetation and along trails with wider paths. Additionally, trails that received greater rainfall, lower temperatures, and lower rates of trail use had higher richness in understory vegetation. At Pinnacle Mountain, understory vegetation richness was highest along trails with steeper slopes and denser canopy cover.

For understory vegetation evenness (Table 2.13), 3 competing models were identified at Mount Magazine to contain 72% of the model weights and 2 competing models were identified at Petit Jean to contain 99% of the model weights. Both Mount Nebo and Pinnacle Mountain had only 1 top model that contained 74% and 93% of the

model weights, respectively. The model set for Mount Magazine included the null intercept, but there was weak evidence that understory vegetation evenness was higher on trails with greater evenness in overstory vegetation ($\beta' = 0.53$; $\omega = 0.45$) and on slopes with lower inclines ($\beta' = -0.62$; $\omega = 0.32$). At Mount Nebo, understory vegetation evenness was highest on trails where there was lower richness in overstory vegetation and that had steeper slopes. There was strong evidence that understory vegetation evenness was higher along wider trails ($\beta' = 0.67$; $\omega = 0.99$) and less support that this metric was higher along trails with greater diversity in overstory vegetation ($\beta' = 0.18$; $\omega = 0.28$) at Petit Jean. Canopy cover had a strong negative effect on understory vegetation evenness at Pinnacle Mountain.

For understory vegetation diversity (Table 2.14), 3 competing models were identified at Mount Magazine to contain 87% of the model weights. Mount Nebo, Petit Jean, and Pinnacle Mountain all only had 1 top model that contained 90 – 99% of the model weights. At Mount Magazine, a decrease in slope ($\beta' = -0.44$; $\omega = 0.64$) and higher levels of overstory vegetation richness ($\beta' = 0.44$; $\omega = 0.64$) on the trail increased understory vegetation diversity. Conversely, an increase in slope increased understory vegetation diversity at Mount Nebo and at Pinnacle Mountain. Understory vegetation diversity was higher on trails that had greater amounts canopy cover at Mount Nebo but lower at Pinnacle Mountain. At Petit Jean, understory vegetation diversity was highest on trails with wider paths.

Overstory vegetation community metrics.— One model for overstory vegetation community richness was identified for each park which contained 80 – 99% of the model weights (Table 2.15). Overstory vegetation richness was highest on trails that had a

greater richness in understory vegetation at Mount Magazine, Mount Nebo, and Petit Jean. Overstory vegetation richness was also highest on trails with greater diversity in understory vegetation at Petit Jean. At Pinnacle Mountain, the global model was the most parsimonious model: overstory vegetation richness was highest on trails with lower evenness and higher diversity in understory vegetation. Further, overstory vegetation richness was lower on trails that had more trail use, a shallower incision depth, and that received higher amounts of precipitation.

For overstory vegetation evenness (Table 2.16), 1 model was identified at Mount Magazine, Mount Nebo, and Petit Jean containing 87 – 99% of the model weights. Two competing models were identified at Pinnacle Mountain which contained 91% of the model weights. At Mount Magazine, overstory vegetation evenness was highest on trails that had steeper slopes, narrower paths, and low levels of richness in the surrounding understory vegetation. At Mount Nebo, the global model was the top parsimonious model: overstory vegetation evenness was highest on trails with lower richness and higher diversity in understory vegetation; trails with steeper slopes; lesser amounts of trail use; and during lower amounts of rainfall. Understory vegetation richness had a strong negative effect on overstory vegetation evenness at Petit Jean. At Pinnacle Mountain, overstory vegetation evenness was highest on trails that had greater diversity ($\beta' = 0.57$; $\omega = 0.91$) and evenness ($\beta' = 0.33$; $\omega = 0.55$) in understory vegetation.

For overstory vegetation diversity (Table 2.17), I identified 2 competing models for Mount Magazine that contain 84% of the model weights. Mount Nebo, Petit Jean, and Pinnacle Mountain all had only 1 top model that contained 85 – 87% of the model weights. At Mount Magazine, overstory vegetation diversity was higher on trails that had

narrower paths ($\beta' = -0.53$; $\omega = 0.84$) and steeper slopes ($\beta' = 0.35$; $\omega = 0.47$). Overstory vegetation diversity was higher on trails with greater understory vegetation diversity at Mount Nebo and Pinnacle Mountain. Understory vegetation richness also had a positive effect on overstory vegetation diversity at Mount Nebo but a negative effect at Petit Jean.

DISCUSSION

State parks serve an important dual role in conservation by balancing wildlife management with the provision of recreation activities to park visitors. Factors such as the natural dynamics of the environment, vegetative attributes of the surrounding habitat, and trail design within the parks may have additive effects on wildlife communities, though research in recreation ecology on the collective impacts from these factors has been sparse. My results suggested that non-consumptive trail use, environmental factors, and trail design may have had synergistic influences on avian, mesocarnivore, understory woody vegetation, and overstory woody vegetation communities in Arkansas state parks; however, non-consumptive trail use was not as strong of an influence on biotic communities as expected. Prior studies that have associated trail use to negative influences on biotic communities have measured use as a rate of annual area visitation (3.5×10^6 visitors/year; Miller et al. 1998) rather than a rate of daily use and compared biotic communities on trails to areas of non-use parallel to the trails (Riffell et al. 1996, Reed and Merenlender 2008). Thus, the lower intensity of trail use and lack of a reference point in my study may explain why trail use did not have a stronger effect on biotic communities. The surrounding vegetation and trail design had stronger effects on biotic communities, likely by influencing the availability of resources. These results

indicate trail design and environmental factors may play a larger role in shaping communities than non-consumptive use when trail use is regulated to low intensities.

Avian Community Metrics

Effects of non-consumptive trail use.— Non-consumptive trail use negatively affected avian richness and diversity but positively influenced avian evenness. Influences from trail use were only observed in Petit Jean and Pinnacle Mountain, both of which had higher rates of trail use compared to the other 2 parks. High rates of trail use likely affected avian communities primarily through altering trailside vegetation abundance and structure through the compaction of surface soil, direct removal of trailside vegetation, and damaging exposed tree roots (Dale and Weaver 1974, Frissell 1978, Leung and Marion 1996, Torn et al. 2009). Avian communities are positively related to denser and taller vegetation along park trails (Cueto and Casenave 1999) and as such, may have experienced corresponding declines in richness and diversity from the effects of trail use via loss of habitat and visual buffers (Cole 1993, Leung and Marion 2000, Gill et al. 2001). For example, the Cedar Falls trail in Petit Jean and West Summit Trail in Pinnacle Mountain had the highest rates of trail use within the respective parks. These trails also led to major land features and were designed to facilitate multiple trail use activities (Leung and Marion 2000, Tomczyk 2011). Consequently, the high rates of trail use induced by the trail attractions and alterations to trail structure may have resulted in the removal of trailside vegetation which led to corresponding low values of avian community richness and diversity on those trails (Chapter I).

Conversely, high rates of trail use were associated with high levels of avian community evenness at Pinnacle Mountain. Evenness in both avian and understory

vegetation communities reflect species' tolerance to anthropogenic and environmental disturbances, with disturbance-tolerant species increasing in abundance while disturbance-intolerant species decline (Hillebrand et al. 2008). Thus, species that are more tolerant to disturbance gain dominance over low-tolerant species along high use trails, resulting in an uneven distribution of vegetation and avian communities. The high levels of avian evenness in response to high rates of trail use in Pinnacle Mountain may indicate that the avian community was still transitioning between disturbance-intolerant and tolerant species, or that only disturbance-tolerant species were present along park trails. Although Pinnacle Mountain had the highest rate of trail use among the parks, it was the only park that did not permit camping and had a nightly curfew on park activities. Removing the pressure of 24-hour influence from human disturbance may have acted as a buffer that has prolonged the transition of dominance in tolerant vegetation and avian species.

Recreational trail use may also directly act on avian communities through initiating avoidance behaviors in state park avifauna (Knight and Gutzwiller 1995, Marion and Leung 1999, Reed and Merenlender 2008, Deluca and King 2014). Petit Jean and Pinnacle Mountain were observed to have the highest rates of trail use among the study parks. Trail use is positively related to the number and interconnectedness of trails that a park contains (Miller et al. 1998). High diversity in trail activities and high rates of trail use facilitated by interconnected trails may translate into negative effects on a variety of bird foraging and nesting strategies (e.g., ground nesters compared to canopy nesters). Further, high rates of trail use along interconnected trails may force birds into

unfamiliar territories deeper into the forest interior, resulting in an overall decline in avian communities (Campbell 2011, Deluca and King 2014).

Additionally, trails have the potential to increase the amount of induced edge within a park (Yahner 1988) as a result of trails bisecting forested habitat. Greater abundance in edge habitat throughout protected areas has led increased risks of nest parasitism from edge associated species such as blue jays (*Cyanocitta cristata*) and brown-headed cowbirds (*Molothrus ater*; Miller et al. 1998). Although nest parasitism is another factor that could have influenced avian communities (Paton 1994, Miller et al. 1998), it was not observed within my study.

Effects of environmental factors.— Richness of understory and overstory vegetation communities along park trails was a strong predictor of avian communities, which is unsurprising given that avian communities respond positively to increased abundance and height in vegetation adjacent to trails (MacArthur and MacArthur 1961, Franci and Schnell 2000, Pino et al. 2000, Galitsky and Lawler 2015). Avian communities and distributions also typically respond positively to high habitat heterogeneity within local environments (Wiens 1974, Böhning-Gaese 1997). As such, greater richness and diversity within trailside overstory vegetation may have enhanced the availability of nesting sites to canopy nesters, which translated into high avian richness and diversity observed within Mount Magazine and Petit Jean trails. Similarly, higher richness, evenness, and diversity in understory vegetation may have resulted in greater availability of nesting material and high abundances of invertebrates (Yahner 1988) which may have promoted high avian metrics within Mount Nebo, Petit Jean, and Pinnacle Mountain.

Conversely, high values of avian evenness and diversity were observed on Mount Magazine and Mount Nebo trails that had low vegetation evenness and diversity (Chapter I). As aforementioned, unevenness in vegetation communities may result from differences in vegetation tolerance levels to human disturbance. Unevenness in trailside vegetation may then have increased heterogeneity within park habitat and provided a variety of available resources and nesting conditions, thus, supplying habitat to a broader spectrum of avian species and resulting in high avian evenness and diversity (Gill et al. 2001, Hillebrand et al. 2008).

My results indicated moderate to high support that avian communities were also influenced by the natural dynamics of the environment, such as warmer temperatures and total rainfall over the weekly observation period. Mean rainfall and temperature can influence community richness and composition by affecting energy partitioning among avian species (Böhning-Gaese 1997, Cueto and Casenave 1999). For example, prolonged warmer temperatures and high rainfall may have decreased avian detectability through negative influences on behavior, foraging effort, and metabolism (Ralph et al. 1995), in turn, leading to low species detections and low avian richness estimates. The seasonality of bird migrations may have also influenced species detections within the parks given that warmer temperatures and changes in rainfall were correlated in the cluster analyses with the timing of each park visit. Avian detectability may have decreased in response to the timing of park visits as spring migrants left the parks and avian community composition changed. Conversely, high avian evenness was related to warmer temperatures and high rainfall in Mount Magazine and Pinnacle Mountain. For these parks, the weather may have increased invertebrate abundance and greater vegetation

growth, both of which could promote high levels of avian richness and evenness as a result of the increased availability of resources (Galitsky and Lawler 2015).

Effects of trail design.— Trail width and incision depth are both important aspects of trail design that determine the sustainability of a trail towards park flora and fauna (Leung and Marion 2001, Torn et al. 2009) and can be used to mitigate the negative effects of trail use and soil erosion caused by steeper slopes and high rainfall. This may explain why wider and deeper trails were generally related to high levels of avian richness and diversity in all the parks. For example, Dale and Weaver (1974) suggested that widening a trail can provide a greater lateral extent to the area of usable trail. This widening can then dilute the impact of large user groups via spreading out clusters of people (Torn et al. 2009) which may explain the high avian richness and diversity values observed along wide trails in Mount Magazine and Mount Nebo such as the Bench Road trails (Chapter 1). Additionally, deeper trails can reduce the effects of trail use by fencing in trail users along high-use trails and preventing off-trail wandering behaviors (Mason et al. 2007). This may explain the moderate to high levels of avian richness and diversity observed on deeper trails in Pinnacle Mountain, such as the Base trail (Chapter I), despite high rates of trail use.

Conversely, wider and deeper trails resulting from unsustainable trail use can lower avian communities. If trails are shallow or edges are not well defined, trail users may wander off trail or create informal trails, which can result in the removal of vegetation adjacent to the trail (Marion et al. 2011). Further, more frequented trails that lack a resilient trail substrate such as rock or gravel may experience damages to exposed roots and high soil erosion on the trail's surface due to increased foot traffic. Therefore,

wider and deeper trails resulting from the combination of wandering behaviors and high soil erosion may have led to alterations in trailside vegetation and thus declines in avian evenness at Mount Nebo and Pinnacle Mountain.

Mesocarnivore Community Metrics

My models of the mesocarnivore communities indicated minimal influence from the variables because the null model commonly occurred within $\leq 2\Delta AICc$ for all community metrics. Abundant trailside vegetation can provide visual buffers for mesocarnivores to use while foraging and to avoid trail users (Gill et al. 2011), however other abiotic and biotic factors such as the co-occurrence of other mesocarnivores, the availability of prey items or human refuse, and the timing and type of human activities may have been stronger determinants of mesocarnivore community richness and distribution (Coleman et al. 2013, Kowalski et al. 2015, Lesmeister et al. 2015, Fortin et al. 2016). Non-consumptive trail use was not as strong of an influence on mesocarnivore communities compared to the influence of habitat on individual behavior and species interactions in my models. Incorporating a larger, more diverse set of variables into future modelling of mesocarnivore communities may provide a better understanding on the collective influences acting on park mesocarnivore communities.

Effects of non-consumptive trail use.— Several studies have noted avoidance behaviors and low richness in mesocarnivore communities around areas of high trail use and human activity (George and Crooks 2006, Roemer et al. 2009, Coleman et al. 2013). However, these studies have also shown that mesocarnivores will spatially and temporally adjust behaviors in response to human trail use. Fortin et al. (2016), for example, found that spatial and temporal displacement was the most commonly observed

human influence on bear (*Ursus* spp.) behavior. In the same study, bear displacement was reduced when human influences were temporally or spatially predictable. George and Crooks (2006) found a similar response to the predictability of human activity on the presence and behavior of bobcats. Therefore, despite varying rates of trail use, mesocarnivores within the parks may have been habituated to the predictability daily use patterns in the parks, resulting in a lack of observed variable influences on mesocarnivore communities.

Effect of environmental factors.— The availability and quality of habitat also influences mesocarnivore communities in protected areas (Gill et al. 2001, Fischer et al. 2012). For example, denser trailside vegetation and structure may provide visual buffers to mesocarnivores to avoid detection by trail users or other predators and promote high mesocarnivore abundance (Knight and Temple 1995, Gill et al. 2001, Kowaliski et al. 2015, Lesmeister et al. 2015). However, high mesocarnivore richness and evenness values were observed along trails with low evenness in understory vegetation at Petit Jean (Chapter 1). Lower vegetation evenness may have provided a greater heterogeneity of habitat types, which could have translated into a greater diversity and abundance of prey species (Williams et al. 2002). Mesocarnivores, such as red foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*), primarily capture small mammals such as rabbits (*Sylvilagus* spp.), rats (*Rattus* spp.), and squirrels (*Sciurus* spp.; Thompson and Gese 2007). Further, heterogeneity in vegetation structure promotes local scale species richness in small mammals by increasing habitat capacity via influencing species movement and the spatial variability in vegetation structure (Southwood 1996). Therefore, the heterogeneity in trailside vegetation may have provided foraging and denning sites that supported high

abundances of prey species, thus promoting a greater number of mesocarnivore species. Further, with the possible high abundance of prey species made available from uneven vegetation, mesocarnivores may have been able to spatially and temporally partition individual foraging strategies to prevent intra-guild predation and thus lead to high community evenness.

Similar to avian communities, high totals of rainfall were a moderate predictor of mesocarnivore communities within the parks and resulted in low mesocarnivore richness and evenness in Mount Magazine. Poor weather conditions, such as high precipitation and warmer temperatures could have resulted in greater energy expenses in foraging behaviors for park mesocarnivores (Fortin et al. 2016), leading to low species detectability. For example, Lesmeister et al. (2015) found that high rainfall and warmer temperatures led to low detections of striped skunks (*Memphitis memphitis*), bobcats (*Lynx rufus*), and potentially coyotes. As such, influences from climatic conditions on park mesocarnivore foraging behaviors may have resulted in the low community metrics observed in Mount Magazine.

While high rainfall and understory vegetation evenness led to low levels of mesocarnivore richness and evenness, these environmental factors also resulted in high levels of mesocarnivore diversity. These conflicting results may be attributed to how Simpson's diversity is calculated. Simpson's diversity was designed to incorporate richness and evenness independently; however, Wilsey et al. (2005) found that while richness and evenness were negatively correlated, Simpson's diversity was positively correlated to both richness and evenness. Further, I calculated Simpson's diversity as $1 - D$ to create interpretive values of diversity for community comparisons (Magurran 2004).

Therefore, while richness, evenness, and diversity could have been positively correlated, calculating Simpson's diversity as $1 - D$ may have resulted in a negative correlation between diversity and measures of richness and evenness.

Effects of trail design.— Trail design may enhance the predictability of trail user rates and activities to mesocarnivores and thus lead into high levels of mesocarnivore communities (Fortin et al. 2016). For example, high mesocarnivore richness was observed on narrower trails within Mount Magazine. Narrower trail designs increase the predictability of trail user behavior by forcing trail users to walk single file along a trail and prevent off-trail wandering (Marion et al. 2011). Therefore, the predictability elicited by narrow trails may have allowed for mesocarnivores to adjust to varying rates of trail use and temporally or spatially avoid human activities. These changes in timing and location of foraging behaviors to cope with high rates of trail use then could have resulted in higher mesocarnivore community richness (George and Crooks 2006, Fortin et al. 2016). Although narrow trails increased mesocarnivore richness, this trail design had a negative influence on mesocarnivore diversity. Further, considering the relationship between measures of richness and evenness to diversity, mesocarnivore evenness likely also declined to some degree. Predictability of human trail use may have only benefitted certain mesocarnivore species depending on differences in foraging strategies and human tolerance. For example, canids, such as coyotes and foxes, prefer open habitats for prey acquisition and may associate with human-derived resources of food, thereby benefitting from the high predictability of trail use; however, cryptic species such as bobcats and mountain lions, are ambush predators and thus may be less tolerant to human intrusion (Lesmeister et al. 2015). Therefore, these differences in foraging strategies may have

promoted species tolerant to human intrusion over more cryptic mesocarnivore species, thus resulting in low levels of mesocarnivore diversity on the narrower trails.

Alternatively, these results may also be reflective of how I calculated Simpson's D, as aforementioned.

Understory Woody Vegetation Community Metrics

Effects of non-consumptive trail use.— Non-consumptive use only occurred within $\leq 2 \Delta AICc$ in the global model for understory richness in Petit Jean, and was not included in the model sets for the remaining parks or metrics. Unlike my results, much of the prior literature has detailed the negative effects of recreational trail use on understory vegetation (Dale and Weaver 1974, Cole 1993, Leung and Marion 1996, Leung and Marion 2000, Torn et al. 2009). High rates of trail use can lead to greater rates of soil erosion on and adjacent to trails from foot traffic, trampling damage to exposed roots, and widening of trails from vegetation loss and soil exposure (Dale and Weaver 1974, Leung and Marion 2000, Leung and Marion 2001, Hammitt et al. 2015). The effects of trail use on understory vegetation are primarily restricted to vegetation located on or adjacent to trails, with understory vegetation more than 2-m away typically left unaffected (Dale and Weaver 1974, Weaver and Dale 1978). This restriction of trail use effects to adjacent vegetation may explain why trail use led to declines in Petit Jean understory vegetation richness. A majority of Petit Jean trails began in or were adjacent to camp grounds, increasing the likelihood of use and removal of understory vegetation by park visitors. Further, I conducted my vegetation sampling on modified sampling points that created a 5-m buffer away from edge of each trail, which likely masked any observable effects of trail use on trailside vegetation.

Effect of environmental factors.— Environmental variables are well known to alter the composition and structure of vegetation communities (Brosfoske et al. 2001, Leung and Marion 2000, Harrison et al. 2006, Tomczyk 2011), and have been suggested to be stronger determinants of understory vegetation communities in protected areas compared to visitor trail use (Leung and Marion 1996, Leung and Marion 2000). My models indicated strong support that high levels of overstory vegetation community richness and evenness were generally related to high richness and evenness in understory vegetation communities. These results may be attributed to overstory and understory vegetation responding to historic climatic conditions and land uses across the parks that promoted disturbance-tolerant vegetation species (Hillebrand et al. 2008). Disturbance-tolerant overstory species were likely to be more evenly distributed across the landscape due to clearings provided from the loss of disturbance-intolerant species and to their resiliency to human activity. Thus, disturbance-tolerant overstory species were more likely to successfully disperse seeds, leading to similarly high richness and evenness values in the resulting understory growth.

Conversely, high overstory diversity resulted in low understory richness in Petit Jean. Although high overstory richness and evenness may have led to corresponding high levels of understory richness and evenness through seed dispersal, high overstory diversity may have altered the canopy and forest structure in a way that lowered understory vegetation productivity. Certain overstory species that were dominant in the forest may have changed the structure of the canopy, possibly restricting the amount of sunlight and moisture available to understory vegetation. Restrictions from overstory diversity on understory resource acquisition could have also resulted in a low number of

understory species able to cope with the lack of available resources, leaving only the most resilient understory vegetation species and lowering overall understory richness (Cole and Landres 1995, Naumburg and DeWald 1999).

Influences from canopy cover and slope were also strong predictors of understory vegetation communities within my model sets. Denser canopy covers can reduce the availability of soil moisture and solar radiation available to understory vegetation communities (Brosfoske et al. 2001) which are important factors for understory community structure (Naumburg and DeWald 1999). Similarly, trails in Pinnacle Mountain that had denser canopy covers were observed to have low values of understory evenness and diversity. For example, the Arkansas trail had a moderately dense canopy cover and comparatively low levels of evenness and diversity in understory vegetation communities (Chapter 1). The denser canopy cover may have outcompeted understory vegetation communities for available sunlight and moisture compared to trails that had an open canopy, potentially leading to low understory evenness and diversity (Anderson et al. 1969).

Conversely, trails with denser canopy covers in Mount Nebo resulted in high understory community richness and diversity. Denser canopy covers can provide a greater abundance of organic material to the forest floor and promote moist conditions required for faster litter decomposition (Sheils et al. 2015). This may explain why understory richness was high on the Bench Road B trail compared to other Mount Nebo trails (Chapter 1), in that the trail also had the densest canopy cover in the park. The denser canopy along the Bench Road B trail could have improved soil conditions for

understory vegetation growth, thus resulting in higher understory richness values compared to trails with more open canopies such as the North Rim trail (Chapter I).

Slope can also influence the amount of solar radiation and moisture received by understory vegetation communities and the level of soil erosion on trail surfaces (Chen et al. 1999, Brosfoske et al. 2001). For example, steeper slopes are subject to greater amounts of soil erosion from increased water runoff during rain (Torn et al. 2009) and from trail users trying to maintain their footing (Marion et al. 2011). At Mount Magazine, the Signal Hill trail had the steepest slopes in the park while also having some of the lowest understory evenness and diversity values compared to more horizontal trails such as the Mossback Ridge trail (Chapter I). The steeper inclination of the Signal Hill trail may have increased soil erosion, leading to the observed low values of evenness and diversity. Conversely, steeper trails in Mount Nebo and Pinnacle Mountain were associated with high understory community metric values along trails. This may reflect park management decisions on trail structure to mitigate the effects of slope on soil erosion. One technique that park managers can use to mitigate past unsustainable trail designs is to construct rocky, stair-step trail paths on steeper trails (Leung and Marion 1996, Marion et al. 2011, Tomczyk 2011). For example, both the Nebo Steps trail in Mount Nebo and the West Summit trail in Pinnacle Mountain had rocky, stair-step structures and were some of the steepest trails in the respective parks. This stair-step design could have helped minimize the impact of water runoff on soil erosion (Torn et al. 2009), thus resulting in the high understory evenness and diversity observed along the 2 trails (Chapter I).

Effects of trail design.— Wider trails were a moderate predictor of high understory richness, evenness, and diversity in Petit Jean State Park. Trail width serves as an important determinant in the type of activity and level of use that a trail receives (Weaver and Dale 1978) as well as the sustainability of a trail towards soil erosion and trampling damage (Marion and Leung 2001, Torn et al. 2009). Park managers may widen trails to alleviate some of the direct trampling effects of trail use on understory vegetation (Torn et al. 2009) by allowing trail users to walk abreast on the trail opposed to single file (Weaver and Dale 1978). Allowing users to walk alongside each other can also dilute the repetitive impact of foot traffic on soil and understory vegetation observed on narrower trails. Further, wider trails lessen off-trail wandering in trail users and prevent informal trails by providing ample traveling and footing space (Weaver and Dale 1978, Mason et al. 2007). These combined trail design characteristics may explain why the CCC Hike and Bike trail, the widest trail in Petit Jean (Chapter I) had some of the highest levels of understory evenness and diversity in the park (Chapter I). Additionally, greater growth of trailside vegetation from the lack of trampling could have fenced in trail users and may have further prevented wandering behaviors in users on vegetation further away from the trail (Mason et al. 2007).

Overstory Woody Vegetation Community Metrics

Effects of non-consumptive trail use.— Similar to understory vegetation communities, models for overstory communities did not indicate a strong influence from non-consumptive trail use. Effects of non-consumptive trail use on overstory communities are similar to those described for understory vegetation communities and often result from unsustainable overuse of trails (Cole 1993, Leung and Marion 1996).

However, high rates of trail use may also act directly on overstory vegetation communities and occur both on and off trail paths (Frissell 1978). Overstory trees on or adjacent to trails are often thinned to facilitate visitor trail use (Dale and Weaver 1974), which results in direct declines in overstory richness and evenness. Trail users may also directly remove overstory vegetation adjacent to trails for firewood, camping spots, and tent poles (Cole 1993, Cole and Landres 1995, Leung and Marion 1996). These direct impacts on trailside overstory vegetation may explain why high rates of trail use led to low overstory evenness in Mount Nebo trails. For Example, the North Rim trail, which passed through several areas of human development (e.g., playgrounds, cabins, houses), had some of the lowest overstory evenness and diversity values among Mount Nebo trails (Chapter I). Overstory vegetation along the trail may have been removed to facilitate high rates of trail use and to clear areas for manmade structures. Further, trail users and campers along the trail may have lowered overstory evenness by removing woody vegetation for firewood. Similar reasoning could also explain why high rates of trail use led to low overstory richness in Pinnacle Mountain trails.

Effects of environmental factors.— My models for overstory communities indicated strong support for a relationship between understory vegetation communities and overstory vegetation communities. Prior research has generally found strong negative associations between these 2 communities (Riegel et al. 1992, Powers et al. 1997, Saunders and Puettmann 1999, Hart and Chen 2008). My results generally contrasted previous research, with high values of understory community metrics resulting in high values in overstory community metrics. These results may reflect the influences that understory woody vegetation communities can have on understory herbaceous plants.

High abundances of herbaceous plants on the forest floor can prevent the germination and establishment of overstory woody vegetation seedlings (Knoop and Walker 1985) and enhance competition for below ground resources. However, greater abundances of understory woody vegetation can lower herbaceous plant productivity by shading out or outcompeting understory herbaceous species (Anderson et al. 1969, Knoop and Walker 1985). Therefore, depending on how park forests were managed, understory communities could have been abundant enough to reduce root competition from weedy, herbaceous plants on the availability of below ground resources for overstory woody vegetation (North et al. 2005) and resulted in high richness, evenness, and diversity in overstory communities.

Conversely, high understory richness led to low overstory evenness in Mount Nebo and Petit Jean. This difference in overstory response to understory metrics compared to my other findings may suggest a threshold of understory density beneficial to overstory communities. High understory vegetation richness may have increased competition on below ground resources not only on understory herbaceous plants, but also on overstory roots, thus reducing overstory evenness in areas of dense understory vegetation (Riegel et al. 1992).

Steeper slopes were observed to have high overstory vegetation evenness and diversity in Mount Magazine and Mount Nebo. As aforementioned, steeper slopes typically result in low vegetation community metric values due to increased soil erosion from water runoff and trail use (Weaver and Dale 1978, Franklin et al. 1993, Marion et al. 2011). Increased erosion on trails usually translates into trampling damage on exposed overstory roots, which leads to declines in richness and evenness in adjacent overstory

vegetation. Conversely, steeper slopes were observed to have high levels of overstory evenness and diversity in Mount Magazine and Mount Nebo trails. These results may indicate another park management strategy used to mitigate the effects of steep, highly frequented trails. Trail designs that are less resilient to soil erosion, such as trails that ascend mountain slopes, are commonly attributed to past management decisions which were not restricted to the guidelines that trail design presently must follow (Frissell 1978, Paige 1985, Marion et al. 2011). To mitigate the effects of historic trail design, park managers in Mount Magazine and Mount Nebo may have worked to increase the evenness and diversity of overstory vegetation adjacent to park trails to stabilize the surrounding soil and prevent surface soil erosion. This strategy would then lead to direct increases in overstory evenness and diversity while producing favorable conditions for continued overstory growth along those trails.

Effects of trail design.— While wider trails were positively related to understory communities, wider trails resulted in low overstory evenness and diversity in Mount Magazine. Although trails that are designed to be wider can be beneficial to surrounding vegetation communities, wider trails caused by wandering behaviors and unsustainable trail use may lower overstory vegetation richness and diversity as a result from trampling and compaction of soil (Leung and Marion 1996, Leung and Marion 1999, Leung and Marion 2000). Marion et al. (2011) found that visitor impacts on poorly designed trails primarily resulted in trail widening and the creation of casual trails off main trail paths and Weaver and Dale (1978) showed that wider trails facilitated high rates of trail use. Thus, wider trails created by trampling and soil erosion may have encouraged high trail use rates which then reduced overstory evenness and diversity through the direct removal

of trees and damages in trail surfaces caused by wandering trail use. The inverse then is true for narrower, rockier trails which typically reduce rates of trail use and the subsequent effects of use on surrounding overstory vegetation (Torn et al. 2009, Marion et al. 2011). For example, the Rim trail in Mount Magazine had the highest overstory vegetation diversity of all Mount Magazine trails (Chapter I) despite it having moderate rates of trail use. The Rim trail was the narrowest trail in the park, had a rockier substrate, and circumvented the north slope of the mountain. Therefore, the combined narrow design and more resilient trail substrate may have restricted user movement and reduced soil erosion, thus translating into greater diversity in overstory vegetation (Abbe and Manning 2007).

Trail depth is suggested to be a function of soil compaction and therefore depends on changes in surface substrate, user activity, and vegetation type (Weaver and Dale 1978). For example, grassier, less rocky surface substrates produce deeper trails as a result of increased soil erosion from trail use and water runoff. Rockier or paved trail substrates then are more resilient to high rates of trail use and typically facilitate multiple use activities to encourage trail users to stay on the trail (Mason et al. 2007, Torn et al. 2009). The combination of trail depth and soil substrate may explain why high overstory richness was observed on deeper trails in Pinnacle Mountain. Deeper trails, such as the Base trail, had a mixed soil/rocky substrate and occurred along steeper slopes around the mountain base. The deeper trail depth could have prevented users from wandering off trail while the more resilient substrate prevented soil erosion from high rates of trail use, both promoting in high overstory richness along the trail.

Management Recommendations

For managers of protected areas such as state parks, understanding the collective influences acting on biotic communities is important to formulate the best strategies for conservation. Confinement strategies such as limitations on trail use, buffer zones, and prohibition of certain trail activities may act to mitigate the direct effects of trail use on communities. However, taxonomic communities in protected areas are also subject to an array of biotic and abiotic influences outside of trail use, which can synergistically affect communities. Based on my results, employing management decision frameworks that consider the collective effects from anthropogenic and environmental variables will be required to effectively ensure the coexistence of wildlife with human recreation. Park managers are advised to continue utilizing confinement strategies to regulate trail use, while also managing for trailside vegetation through educating trail users on their potential impacts to vegetation and restricting mowing and vegetation clearing along trails. Further, improving on past trail designs to strengthen trail resiliency to trampling and soil erosion via constructing wider and deeper trails that have rockier substrates may additionally be required to conserve biotic communities while still promoting human recreation.

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Table 2.1. Mean daily rate of trail use per 30min per trail calculated from bootstraps of structured and opportunistic trail counts at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks or trails within parks ($P < 0.05$).

Park trails	Rate of use per visit			Mean (± 1 SD) full season trail use
	1	2	3	
<i>Mount Magazine^a</i>				
Benefield	0.00	0.00	0.60	0.20 ± 0.35 ^a
Greenfield	0.00	0.49	0.00	0.16 ± 0.28 ^a
Mossback Ridge	0.00	0.01	0.00	0.00 ± 0.01 ^a
Rim	0.25	0.46	0.25	0.32 ± 0.12 ^a
Signal Hill	0.48	2.13	0.25	0.95 ± 1.02 ^a
Will Apple’s Road	0.00	0.38	0.34	0.24 ± 0.21 ^a
<i>Mount Nebo^{ab}</i>				
North Rim	0.35	0.07	0.81	0.41 ± 0.37 ^a

Bench Road A	0.07	0.03	0.52	0.21 ± 0.27^a
Bench Road B	0.29	0.14	0.49	0.30 ± 0.18^a
Summit Park	0.01	1.34	0.27	0.54 ± 0.70^a
Nebo Steps	1.05	0.00	0.01	0.35 ± 0.60^a
Varnall Springs	0.00	0.00	0.35	0.12 ± 0.20^a
<i>Petit Jean</i> ^b				
Canyon	0.71	1.68	0.00	0.80 ± 0.84^b
CCC Hike and Bike	0.20	0.42	0.41	0.34 ± 0.12^b
Cedar Creek	5.09	2.18	0.48	2.58 ± 2.33^b
Cedar Falls	12.5	9.79	7.61	9.97 ± 2.46^a
Seven Hollows A	0.83	0.63	0.51	0.66 ± 0.16^b
Seven Hollows B	1.12	0.71	0.06	0.63 ± 0.53^b
<i>Pinnacle Mountain</i> ^b				
Arkansas	0.84	0.55	0.13	0.50 ± 0.36^c
Kingfisher	2.63	3.94	0.86	2.48 ± 1.54^{bc}

Ouachita	0.22	0.42	0.29	0.31 ± 0.10^c
Base	0.51	2.76	1.67	1.65 ± 1.13^{bc}
East Quarry	0.00	0.77	0.42	0.39 ± 0.38^c
Rocky Valley	0.77	0.90	0.84	0.84 ± 0.07^{bc}
East Summit	2.96	4.14	2.31	3.14 ± 0.93^b
West Summit	15.5	20.2	8.09	14.6 ± 6.09^a

Table 2.2. Average environmental variables of minimum temperature (°C), maximum temperature (°C), precipitation totals (mm), canopy cover (%), slope (%), mean trail depth (mm), mean trail width (m; mean \pm 1 SD for all environmental data) from daily recordings of climatic data and trail sampling point recordings for Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks for each variable ($P < 0.05$).

Park	Min. temp	Max. temp	Precip.	Cover	Slope	Trail depth	Trail width
Mount Magazine	18.3 \pm 5.80 ^a	27.7 \pm 5.80 ^a	7.27 \pm 6.54 ^a	69.9 \pm 6.94 ^a	0.16 \pm 0.40 ^b	179 \pm 280 ^{ab}	0.32 \pm 0.30 ^c
Mount Nebo	21.4 \pm 2.62 ^a	32.1 \pm 3.23 ^a	8.33 \pm 5.08 ^a	75.6 \pm 12.7 ^a	0.69 \pm 0.24 ^{ab}	268 \pm 204 ^a	2.04 \pm 0.51 ^a
Petit Jean	20.7 \pm 2.16 ^a	32.1 \pm 3.50 ^a	1.87 \pm 3.06 ^a	75.7 \pm 5.17 ^a	0.01 \pm 0.86 ^b	96.1 \pm 201 ^b	0.96 \pm 0.23 ^b
Pinnacle Mountain	23.2 \pm 0.60 ^a	34.7 \pm 2.42 ^a	0.49 \pm 0.84 ^a	77.7 \pm 9.56 ^a	1.29 \pm 0.89 ^a	87.3 \pm 207 ^b	0.70 \pm 0.20 ^b

Table 2.3. Average vegetative attributes and trail design data of cover (%), slope (%), trail incision depth (mm), and trail width (m; mean \pm 1 SD for all data) from data recorded at sampling points for Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Different letters indicate differences between parks trails for each variable ($P < 0.05$).

Park and trails	Cover	Slope	Trail width	Trail depth
<i>Mount Magazine</i>				
Benefield	68.5 \pm 11.1 ^{bc}	3.50 \pm 2.86 ^b	1.70 \pm 1.01 ^a	0.00 \pm 0.00 ^b
Greenfield	79.5 \pm 6.03 ^a	2.25 \pm 0.94 ^b	1.44 \pm 0.51 ^a	0.02 \pm 0.04 ^b
Mossback Ridge	76.7 \pm 5.72 ^{ab}	3.46 \pm 2.22 ^b	1.71 \pm 0.41 ^a	0.33 \pm 0.26 ^a
Rim	72.3 \pm 9.47 ^b	5.31 \pm 3.67 ^{ab}	0.85 \pm 0.40 ^b	0.04 \pm 0.06 ^b
Signal Hill	61.1 \pm 10.5 ^{bc}	10.4 \pm 6.00 ^a	1.40 \pm 0.41 ^a	0.00 \pm 0.00 ^b
Will Apple's Road	65.3 \pm 14.3 ^{bc}	3.86 \pm 1.03 ^{ab}	1.94 \pm 0.35 ^a	0.69 \pm 0.24 ^a
<i>Mount Nebo</i>				
North Rim	57.1 \pm 31.6 ^{bc}	8.11 \pm 5.05 ^a	3.73 \pm 0.90 ^b	0.02 \pm 0.05 ^c
Bench Road A	82.8 \pm 5.87 ^b	8.96 \pm 4.78 ^a	3.29 \pm 0.56 ^a	0.27 \pm 0.34 ^b

Bench Road B	92.0 ± 6.25^a	7.23 ± 11.1^a	1.61 ± 0.55^a	0.20 ± 0.22^b
Summit Park	82.3 ± 5.85^b	9.11 ± 7.04^a	1.40 ± 0.19^b	0.64 ± 0.28^a
Nebo Steps	73.6 ± 13.6^{bc}	10.8 ± 2.02^a	1.39 ± 0.53^b	0.27 ± 0.33^b
Varnall Springs	66.0 ± 20.2^{bc}	8.75 ± 5.30^a	1.16 ± 0.15^b	0.22 ± 0.02^b

Petit Jean

Canyon	81.9 ± 4.88^a	4.36 ± 2.64^{ab}	1.23 ± 0.60^b	0.01 ± 0.02^b
CCC Hike and Bike	71.8 ± 24.6^a	1.65 ± 1.36^b	3.09 ± 0.10^a	0.00 ± 0.00^b
Cedar Creek	76.9 ± 3.90^a	5.38 ± 2.42^a	1.59 ± 0.83^b	0.51 ± 0.19^a
Cedar Falls	80.5 ± 5.63^a	8.00 ± 4.80^a	1.75 ± 0.69^b	0.03 ± 0.07^b
Seven Hollows A	68.3 ± 19.2^a	6.62 ± 10.3^a	1.52 ± 0.87^b	0.02 ± 0.04^b
Seven Hollows B	74.9 ± 17.7^a	4.07 ± 2.59^{ab}	1.41 ± 0.87^b	0.01 ± 0.03^b

Pinnacle Mountain

Arkansas	85.7 ± 1.95^a	2.25 ± 2.06^{bc}	2.58 ± 0.06^{ab}	0.00 ± 0.00^b
Kingfisher	78.7 ± 4.65^a	0.50 ± 0.50^c	1.95 ± 0.09^{ab}	0.00 ± 0.00^b
Ouachita	83.9 ± 3.40^a	4.25 ± 3.07^{abc}	1.93 ± 0.57^{ab}	0.00 ± 0.00^b

Base	73.8 ± 24.3^a	5.47 ± 2.55^{abc}	1.63 ± 0.75^a	0.59 ± 0.22^a
East Quarry	56.8 ± 48.6^a	3.83 ± 3.25^{abc}	1.90 ± 0.52^{ab}	0.00 ± 0.00^b
Rocky Valley	82.9 ± 3.38^a	5.21 ± 1.73^{abc}	1.79 ± 0.75^{ab}	0.11 ± 0.11^b
East Summit	75.1 ± 5.68^a	6.79 ± 3.30^{ab}	4.81 ± 3.89^b	0.00 ± 0.00^b
West Summit	85.0 ± 4.16^a	8.33 ± 1.03^a	2.96 ± 0.53^{ab}	0.00 ± 0.00^b

Table 2.4. Description and abbreviations of variables used included in models to determine the effects of non-consumptive trail use, environmental factors, and trail design on taxonomic community metrics in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Variable	Abbrev.	Description
<i>Non-consumptive trail use</i>		
Mean daily rate of trail use per visit	Use	Continuous variable
Observation time	Visit	Weekly visit (1 – 3)
<i>Environmental</i>		
Understory woody vegetation richness	UVS	Continuous variable
Understory woody vegetation evenness	UVE	Continuous variable (0 – 1)
Understory woody vegetation diversity	UVD	Continuous variable (0 – 1)
Overstory wood vegetation richness	OVS	Continuous variable
Overstory woody vegetation evenness	OVE	Continuous variable (0 – 1)
Overstory woody vegetation diversity	OVD	Continuous variable (0 – 1)

Canopy cover at sampling point	Cover	Continuous variable (%)
Slope at sampling point	Slope	Continuous variable (%)
Average precipitation per visit	Rain	Continuous variable (mm)
Minimum temperature per visit	MinT	Continuous variable (C°)
Maximum temperature per visit	MaxT	Continuous variable (C°)

Trail design

Trail width	Twidth	Continuous variable (m)
Trail depth	Tdepth	Continuous variable (mm)

Table 2.5. Selected variables from cluster analyses for stepwise regression models to examine effects of non-consumptive trail use, environmental factors, and trail design on taxonomic communities in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Descriptions and abbreviations of variables are found in Table 2.2.

Taxon and park	Representative variable per cluster						Total explained variability
	1	2	3	4	5	6	
<i>Avian</i>							
Mount Magazine	OVD	MaxT	UVE	OVS	Slope	Rain	87.3%
Mount Nebo	UVD	MinT	OVE	Slope	TUse	TWidth	91.5%
Petit Jean	UVS	UVE	MaxT	Rain	OVD	TUse	85.8%
Pinnacle Mountain	UVE	Rain	UVD	TDepth	TUse		81.8%
<i>Mesocarnivore</i>							
Mount Magazine	OVD	MaxT	UVE	OVS	Slope	Rain	87.3%
Mount Nebo	UVD	MinT	OVE	Slope	TUse	TWidth	91.5%

Petit Jean	UVS	UVE	MaxT	Rain	OVD	TUse	85.8%
Pinnacle Mountain	UVE	Rain	UVD	TDepth	TUse		81.8%
<i>Understory vegetation</i>							
Mount Magazine	OVE	MinT	Slope	OVS			78.1%
Mount Nebo	Rain	Cover	OVS	TUse	Slope		89.3%
Petit Jean	TWidth	OVD	MaxT	Rain	Tuse		81.7%
Pinnacle Mountain	Rain	Slope	TDepth	Cover	TUse		80.8%
<i>Overstory vegetation</i>							
Mount Magazine	Slope	MinT	TWidth	UVS			76.4%
Mount Nebo	UVD	Rain	UVS	Slope	TUse		90.3%
Petit Jean	UVD	UVS	MaxT	Rain	TUse		85.6%
Pinnacle Mountain	UVE	Rain	UVD	TUse	TDepth		85.6%

Table 2.6. Most parsimonious models for estimating avian community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Table includes standardized parameter estimates, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.63(OVS) - 0.38(MaxT)	3	46.98	0.00	0.71
<i>Mount Nebo</i>				
Intercept - 0.69(OVE) + 0.42(TWidth)	3	35.87	0.00	0.84
<i>Petit Jean</i>				
Intercept + 0.61(UVS) + 0.29(UVE) - 0.35(MaxT) + 0.31(Rain) + 0.07(OVD) - 0.40(TUse)	7	51.43	0.00	0.85
<i>Pinnacle Mountain</i>				
Intercept - 0.50(UVE) - 0.43(Rain) + 0.29(UVD) + 0.46(TDepth) - 0.42(TUse)	6	68.11	0.00	0.85

Table 2.7. Competing models for estimating avian community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 1.01(OVD) + 0.32(MaxT) + 0.74(TWidth) - 0.42(OVS) - 0.33(Slope) - 0.33(Rain)	7	-77.65	0.00	0.33
Intercept + 0.41(OVD)	2	-76.78	0.86	0.22
Intercept	1	-76.04	1.61	0.15
<i>Mount Nebo</i>				
Intercept + 0.64(OVE) - 0.31(TWidth)	3	-82.92	0.00	0.49
Intercept + 0.76(OVE)	2	-82.06	0.86	0.32
<i>Petit Jean</i>				
Intercept - 0.45(UVE) - 0.45(Rain)	3	-86.83	0.00	0.49
<i>Pinnacle Mountain</i>				
Intercept + 0.64(UVE) + 0.17(Rain) - 0.41(UVD) - 0.52(TDepth) + 0.36(TUse)	6	-126.96	0.00	0.75

Table 2.8. Competing models for estimating avian community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.59(OVD) - 0.15(MaxT) + 0.28(Twidth) + 0.57(OVS) - 0.23(Slope) - 0.46(Rain)	7	-147.29	0.00	0.84
<i>Mount Nebo</i>				
Intercept - 0.57(OVE)	2	-142.31	0.00	0.37
Intercept - 0.46(OVE) + 0.33(TWidth)	3	-142.02	0.29	0.32
Intercept + 0.50(TWidth)	2	-140.40	1.95	0.14
<i>Petit Jean</i>				
Intercept - 0.48(TUse) - 0.49(MaxT) + 0.52(UVE) - 0.50(OVD)	5	-163.55	0.00	0.57
Intercept - 0.42(TUse) - 0.47(MaxT) + 0.52(UVE) - 0.40(OVD) + 0.20(UVS)	6	-162.07	1.48	0.27
<i>Pinnacle Mountain</i>				
Intercept - 0.53(Rain) + 0.30(TDepth) - 0.36(TUse)	4	-206.73	0.00	0.41
Intercept - 0.54(Rain) - 0.39(TUse)	3	-205.99	0.75	0.29

Intercept - 0.48(Rain) + 0.34(TDepth)	3	-204.72	2.00	0.15
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Table 2.9. Competing models for estimating mesocarnivore community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept - 0.54(TWidth) - 0.46(Rain)	3	-33.64	0.00	0.40
Intercept - 0.47(TWidth) - 0.46(Rain) - 0.30(OVS)	4	-33.63	0.01	0.40
<i>Mount Nebo</i>				
Intercept	1	-29.35	0.00	0.26
Intercept - 0.33(UVD)	2	-28.90	0.45	0.21
Intercept - 0.32(OVE)	2	-28.78	0.57	0.19
Intercept + 0.18(TUse)	2	-27.42	1.93	0.10
<i>Petit Jean</i>				
Intercept - 0.43(UVE)	2	-30.52	0.00	0.42
Intercept	1	-29.35	1.18	0.23
<i>Pinnacle Mountain</i>				
Intercept	1	-50.93	0.00	0.31
Intercept - 0.24(TUse)	2	-49.95	0.98	0.19
Intercept - 0.21(UVE)	2	-49.59	1.34	0.16

Intercept - 0.17(UVD)	2	-49.25	1.68	0.13
Intercept + 0.14(TDepth)	2	-49.01	1.92	0.12

Table 2.10. Competing models for estimating mesocarnivore community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept - 0.37(Rain)	2	-29.50	0.00	0.27
Intercept	1	-29.35	0.16	0.25
Intercept + 0.32(OVD)	2	-28.72	0.78	0.18
Intercept - 0.26(OVS)	2	-28.04	1.46	0.13
Intercept + 0.20(Slope)	2	-27.56	1.94	0.10
<i>Mount Nebo</i>				
Intercept	1	-29.35	0.00	0.26
Intercept - 0.33(UVD)	2	-28.90	0.45	0.21
Intercept - 0.32(OVE)	2	-28.78	0.57	0.19
Intercept + 0.18(TUse)	2	-27.42	1.93	0.10
<i>Petit Jean</i>				
Intercept - 0.43(UVE)	2	-30.52	0.00	0.42
Intercept	1	-29.35	1.18	0.23

Pinnacle Mountain

Intercept	1	-50.93	0.00	0.31
Intercept - 0.24(TUse)	2	-49.95	0.98	0.19
Intercept - 0.21(UVE)	2	-49.59	1.34	0.16
Intercept - 0.17(UVD)	2	-49.25	1.68	0.13
Intercept + 0.14(TDepth)	2	-49.01	1.92	0.12

Table 2.11. Competing models for estimating mesocarnivore community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.57(TWidth) + 0.37(Rain)	3	-35.22	0.00	0.57
Intercept + 0.57(TWidth)	2	-33.94	1.27	0.30
<i>Mount Nebo</i>				
Intercept	1	-29.35	0.00	0.26
Intercept + 0.33(UVD)	2	-28.90	0.45	0.21
Intercept + 0.32(OVE)	2	-28.78	0.57	0.19
Intercept - 0.18(TUse)	2	-27.42	1.93	0.10
<i>Petit Jean</i>				
Intercept + 0.43(UVE)	2	-30.52	0.00	0.42
Intercept	1	-29.35	1.18	0.23
<i>Pinnacle Mountain</i>				
Intercept	1	-50.93	0.00	0.31
Intercept + 0.24(TUse)	2	-49.95	0.98	0.19

Intercept + 0.21(UVE)	2	-49.59	1.34	0.16
Intercept + 0.17(UVD)	2	-49.25	1.68	0.13
Intercept - 0.14(TDepth)	2	-49.01	1.92	0.12

Table 2.12. Competing models for estimating understory vegetation community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.96(OVS)	2	10.76	0.00	0.71
<i>Mount Nebo</i>				
Intercept + 0.70(OVS) + 0.46(Cover)	3	38.02	0.00	0.99
<i>Petit Jean</i>				
Intercept + 0.72(TWidth) - 0.93(OVD) - 0.02(MaxT) + 0.01(Rain) - 0.09(TUse)	6	29.99	0.00	0.93
<i>Pinnacle Mountain</i>				
Intercept + 0.54(Slope) + 0.53(Cover)	3	66.12	0.00	0.96

Table 2.13. Competing models for estimating understory vegetation community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.65(OVE) - 0.62(Slope)	3	-120.46	0.00	0.32
Intercept	1	-120.15	0.31	0.27
Intercept + 0.24(OVE)	2	-118.69	1.77	0.13
<i>Mount Nebo</i>				
Intercept - 0.55(OVS) + 0.42(Slope)	3	-92.31	0.00	0.74
<i>Petit Jean</i>				
Intercept + 0.65(TWidth)	2	-92.50	0.00	0.71
Intercept + 0.73(TWidth) + 0.18(OVD)	3	-90.61	1.89	0.28
<i>Pinnacle Mountain</i>				
Intercept - 0.93(Cover)	2	-142.23	0.00	0.93

Table 2.14. Competing models for estimating understory vegetation community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept - 0.41(Slope) + 0.40(OVS)	3	-70.25	0.00	0.41
Intercept - 0.51(Slope)	2	-69.86	1.19	0.23
Intercept + 0.51(OVS)	2	-68.98	1.27	0.23
<i>Mount Nebo</i>				
Intercept + 0.91(Cover) + 0.45(Slope)	3	-151.52	0.00	0.99
<i>Petit Jean</i>				
Intercept + 0.72(TWidth)	2	-102.62	0.00	0.98
<i>Pinnacle Mountain</i>				
Intercept + 0.76(Slope) - 0.57(Cover)	3	-179.84	0.00	0.90

Table 2.15. Competing models for estimating overstory vegetation community richness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.96(UVS)	2	22.08	0.00	0.86
<i>Mount Nebo</i>				
Intercept + 0.81(UVS)	2	49.97	0.00	0.96
<i>Petit Jean</i>				
Intercept + 0.72(UVS) + 0.52(UVD)	3	-6.85	0.00	0.80
<i>Pinnacle Mountain</i>				
Intercept - 1.11(UVE) - 0.06(Rain) + 0.45(UVD) - 0.37(TUse) + 0.16(TDepth)	6	40.61	0.00	0.99

Table 2.16. Competing models for estimating overstory vegetation community evenness in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept + 0.48(Slope) - 0.48(TWidth) - 0.38(UVS)	4	-98.56	0.00	0.87
<i>Mount Nebo</i>				
Intercept + 0.63(UVD) - 0.01(Rain) - 0.93(UVS) + 0.60(Slope) - 0.10(TUse)	6	-88.40	0.00	0.97
<i>Petit Jean</i>				
Intercept - 0.81(UVS)	2	-88.34	0.00	0.99
<i>Pinnacle Mountain</i>				
Intercept + 0.49(UVD) + 0.33(UVE)	3	-106.90	0.00	0.55
Intercept + 0.69(UVD)	2	-106.08	0.83	0.36

Table 2.17. Competing models for estimating overstory vegetation community diversity in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015. Table includes standardized estimates and standard error for parameters, number of parameters (K), Akaike Information Criterion values adjusted for small sample sizes (AIC_C), distance from the lowest AIC_C values (ΔAIC_C), and Akaike model weights (ω). Descriptions and abbreviations of variables are found in Table 2.2.

Models	K	AIC_C	ΔAIC_C	ω
<i>Mount Magazine</i>				
Intercept - 0.48(TWidth) + 0.35(Slope)	3	-121.34	0.00	0.47
Intercept - 0.59(TWidth)	2	-120.87	0.48	0.37
<i>Mount Nebo</i>				
Intercept + 0.95(UVD) + 0.10(UVS)	3	-206.04	0.00	0.85
<i>Petit Jean</i>				
Intercept - 0.60(UVS)	2	-98.30	0.00	0.86
<i>Pinnacle Mountain</i>				
Intercept + 0.59(UVD)	2	-133.29	0.00	0.87

CHAPTER III:

MAPPING DETECTION PROBABILITIES OF STATE PARK AVIFAUNA TO ENCOURAGE VISITOR CONSERVATION ATTITUDES

Protected areas, such as national parks and wildlife reserves, serve as important tools in conserving biodiversity by providing wildlife habitat (Chape et al. 2005), serving as core areas for species recovery (Coleman et al. 2013), and as study sites for conservation research (Sinclair and Byrom 2006). Many protected areas also serve a dual function as an important source of outdoor human recreation, maintaining a series of trails and campgrounds that facilitate activities such as hiking, camping, hunting, and fishing (Leung and Marion 2000, Kays et al. 2016). As such, managers face the challenge of balancing the protection of biotic populations while also providing opportunities for recreation to the visiting public (Kowalski et al. 2015, Thompson 2015).

Granting recreational users access to protected areas is an important issue for wildlife managers to consider in conservation planning and management (Sinclair and Byrom 2006, Reed and Merenlender 2008). Human recreation, such as trail use and camping, is a major source of temporary and long-term disturbance to biotic communities in protected areas (Knight and Temple 1995, Kangas et al. 2010, Rodriguez-Prieto et al. 2014, Hammitt et al. 2015). For example, repeated human use of recreational trails and facilities can alter surrounding vegetation structure in the park, which in turn can have cascading effects on the reproductive and foraging behaviors of multiple taxa (Weaver and Dale 1978, Cole 1993, Knight and Temple 1995, Leung and Marion 2000, Steven et al. 2011, Thompson 2015). These alterations in behavior may then translate into negative effects on population dynamics, survival, and physiological health of taxonomic

communities (Cole 1993, Miller et al. 1998, Miller and Hobbs 2000, Reed and Merenlender 2008, Steven et al. 2011) via the abandonment of familiar habitats, lowering reproductive success, and greater vulnerability to predation and invasive species (Safina and Burger 1983, Gutzwiller et al. 1994, Riffell et al. 1996, Miller et al. 1998, Sekercioglu 2002, Knight and Swaddle 2007).

Amid the negative effects of human use of protected areas, human recreation serves an important role in biological conservation (Frumkin 2001, Reed and Merelender 2008, Outdoor Federation 2016). Providing opportunities for the public to view and experience natural resources helps to maintain public support for protected areas, both financially and intrinsically (Campbell 2011, Rodriguez-Prieto et al. 2014, Hammitt et al. 2015, Thompson 2015, Kays et al. 2016). Revenue generated from visits to protected areas is the third largest contributor to the U.S. economy (Cordell et al. 2008), stemming from funds acquired from area access and use, hunting and fishing equipment, and tools used in wildlife observation (e.g., binoculars, photography equipment) (Kays et al. 2016, Outdoor Foundation 2016). Further, protected areas may act as the primary source of access of natural resources to the public, especially to those residing in metropolitan and urban areas (Reed and Merenlender 2008). Beyond the financial benefits to conservation, access to nature can provide multiple health benefits to the visiting public (Frumkin 2001, Monz et al. 2009) and positively influence attitudes towards sustainable use of natural resources (Brewer 2002, Halpenny 2010). Therefore, it is important to develop holistic management strategies that continue to promote recreation in protected areas, while also finding ways to simultaneously manage the possible negative effects of recreation on biotic populations (Casey et al. 2005).

Current methods to mitigate the effects of human recreation in protected areas primarily consist of confinement strategies; techniques in which wildlife managers restrict access to portions of protected area from public use (Knight and Temple 1995, Anderson et al. 2014). These techniques include temporal and spatial restrictions that place curfews on recreational trail use based on time and season (Knight and Gutzwiller 1995), prohibit certain trail activities from specific trails (Tomczyk 2011), or designate barriers and buffer zones in heavily used habitats (Fernandez-Juricic et al. 2005). Buffer zones divert human recreational use away from habitat based on the flushing responses and flight initiation distances of disturbance-intolerant species (Taylor and Knight 2003, Fernandez-Juricic et al. 2005). Although these methods have assisted in lowering the amount of recreationist-caused disturbance in protected areas for a variety of taxa (Anderson et al. 2014), they force potentially negative behavioral changes on recreationists. For example, the creation of buffer zones or alterations to trail structure may prohibit access to popular park attractions. This forced change risks lowering the quality of experience to the recreationist which may consequently have a negative influence on visitor attitudes towards natural resource conservation (Lynn and Brown 2003, Monz et al. 2009, Dorwart 2010, Halpenny 2010).

Pro-environmental behaviors generally develop based on prior experiences and are often the product of an individual's attitude, level of environmental awareness, and strength of personal attachment to a protected area (Mesch and Manor 1998). Halpenny (2010) found that place attachment, or the cognitive bond between a visitor and an area, strongly predicted an individual's attitudes towards conservation. As such, when positively reinforced, this place attachment may influence an individual's interest in

environmental sustainability, conservation, and scientific inquiry (Trumbull et al. 2000). Therefore, by incorporating non-restrictive management techniques that improve an individual's place attachment, such as park educational programs and informational trail signage, park managers may potentially improve the willingness of visitors to help conserve wildlife without negatively affecting their park experience (Trumbull et al. 2000, Brewer 2002, Vaske and Kobrin 2010).

One possible technique that could enhance environmental education while targeting personal attitudes on wildlife conservation could be the creation of species detection maps. Influencing the attitudes and motivations of recreationists for wildlife conservation often begins with visually showing visitors the distributions of species populations within a protected area (Miller et al. 1998, Taylor and Knight 2003, Coleman et al. 2013). This visual relates a species to an individual's activity and level of use, thus promoting a personal connection, or place attachment, to the conservation of that species (Halpenny 2010). Additionally, focusing detection maps on flagship species may enhance the effectiveness of maps in influencing personal attitudes. Flagship species are those that are charismatic and popular to visitors and thus can serve as rallying points for stimulating positive attitudes towards conservation (Caro and O'Dehrty 1999, Clucas et al. 2008, Home et al. 2009). Flagship species are commonly restricted to megafauna such as giant pandas (*Ailuropoda melanoleuca*; Clucas et al. 2008) or tigers (*Panthera tigris* spp.; Williams et al. 2000). However, restricting flagship species to megafauna limits the application of the flagship species concept in areas that lack such species, such as in most protected areas in North America (Verissimo et al. 2014). Songbirds have been suggested as an alternative to the megafauna approach (Verissimo et al. 2009) due to their

popularity among a large subset of wildlife enthusiasts (Koskimies 1989, Sekercioglu 2002), their visual and auditory appeal, and to their sensitivity to factors acting on a variety of habitats and scales (Noss 1990, Riffell et al. 1996). Thus, creating detection maps of charismatic songbird species within protected areas may aid in improving public attitudes on conservation by appealing to the public with species of visual and conservational interests while also relating the detectability of those species to visitor activities.

State parks represent a subset of protected areas that provide habitat for a diversity of residential and migratory species from a diversity of taxa while also experiencing a high rate and variety of recreational activities (Knight and Gutzwiller 1995, Miller and Hobbs 2000, Hammitt et al. 2015). Of those taxonomic groups that benefit from state parks, avian populations are of upmost interest to both park managers and visitors (Sekercioglu 1989). State parks provide stopover habitats for migratory bird species, which then encourages birdwatchers and wildlife enthusiasts to visit the park. Birdwatchers form the largest group of recreationists that visit protected areas (Koskimies 1989) and have the potential to benefit state parks through investments of time and money. Further, bird watching appeals to a wide range of amateur and professional wildlife enthusiasts, raising the potential to influence motivations of a wider audience of diverse backgrounds on the importance of wildlife conservation and the future use of state parks (Cordell et al. 2008). Therefore, focusing detection maps on avifauna within state parks may act as a non-restrictive method of visitor outreach by providing recreationists information on where to view birds, what species are present, and how varying rates of park use influence those species.

Understanding the location and detectability of park avian populations is imperative to enhancing visitor knowledge on how human activities influence park avifauna without negatively affecting visitor experience. Visually demonstrating the relationship between recreationist park use and the distributions and detectability of flagship avifauna may strengthen place attachment in park visitors, further promoting wildlife conservation without the restriction of visitor activities. Therefore, my overall objective was to create detection maps of 5 flagship avian species along park trails in 4 Arkansas state parks to facilitate sustainable trail use. Visually relating the detection of flagship avifauna to varying rates of human trail use may encourage sustainable use behaviors in park visitors without restricting use by educating visitors on the potential impacts of their activities on the species distributions.

METHODS

Study Area

Please see the study area description in Chapter I.

Avian Data Collection

Please see the taxa data collection methods in Chapter I.

Visitor Use of Trails

Please see the non-consumptive trail use rates methods in Chapter II.

Occupancy Models

Prior approaches to mapping the occurrence and detectability of avian populations across a landscape focus on quantifying the abundance of individuals through the use of counts or indices (Ralph et al. 1995, Martin et al. 1997). While these methods can provide useful estimates for management practices, some species may go undetected even

when present within an area due to influences of observation timing, species avoidance behaviors, and species adaptations to the environment (Fiske and Chandler 2011). This imperfect detection may complicate estimations of community distributions. Further, traditional methods can lack the intricacy to include covariates such as observation time and environmental conditions as a result of their simplicity (Mackenzie and Royle 2005). Thus, a sophisticated sampling method, such as occupancy modeling that can account for imperfect detection while also considering influences from observer and site covariates must be used to appropriately analyze and display the detectability of species across a landscape (MacKenzie and Royle 2005, Olson et al. 2005, Fiske and Chandler 2011, Welsh et al. 2013, Shannon et al. 2014).

Occupancy modeling provides a framework to enumerate species occupancy and detectability, defined as the proportion of sampling sites in which a target species is present and the likelihood of counting a species during a site visit, respectively (MacKenzie et al. 2002, MacKenzie and Royle 2005, MacKenzie et al. 2006). This approach acknowledges that a species may occur in an area even if the detection probability of any specific survey is <1 (MacKenzie et al. 2002, Shannon et al. 2014). Species presence is recorded as a series of detections (1) and non-detections (0) during repeated visits to sampling sites that occur either temporally or spatially. These detections are organized into encounter histories which are used in calculating species occupancy, detectability, and to produce distribution maps of current and future species locations (Mackenzie and Royle 2005). Further, occupancy models allow for the inclusion of observer and site-level covariates to help identify variables that may influence the probability of occupancy and detection of a species at specific sites (Fiske and Chandler

2011). Incorporating occupancy models with a dynamic mapping program such as ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA) has the potential to create maps of species detection probabilities to visually educate recreationists on how the detectability of park avifauna may change in response to the rate of park trail use.

I chose 5 forest bird species for the focus of the detection maps based on life history factors that influence avifauna sensitivity to human disturbance and on species potential to serve as flagships to influence visitor behavior. High sensitivity of avian species to recreational trail use has been shown to be dependent on species conspicuousness to trail users (Gutzwiller et al. 1998), larger body sizes (Fernandez-Juricic et al. 2002, Campbell 2011), height of nest placement (Holmes et al. 1993), and location of foraging behaviors. Thompson (2015) found that bird species that nested or foraged on the ground had the greatest sensitivity to human trail use compared to canopy nesters as a result of more frequent and direct interactions with walking or running disturbances. Further, Campbell (2011) found that avian body size was also related to lower tolerance to disturbance due to species' conspicuousness and difficulty of flight initiation.

Additionally, I considered avifauna that had characteristics which paralleled requirements of flagship species to elicit a stronger place attachment in visitors and thus influence visitor behavior and attitude. Flagship species must be charismatic or visually appealing, be detectable by visitors within a study area, and offer some focus of conservation concern (Caro and O'Dehrty 1999, Home et al. 2009). Considering these criteria, I chose ovenbirds (*Seiurus aurocapilla*; Rodriguez-Prieto et al. 2014), northern cardinals (*Cardinals cardinalis*; Smith-Castro and Rodewald 2010, Campbell 2011),

Carolina wrens (*Thryothorus ludovicianus*; Franci and Schnell 2002), blue-gray gnatcatchers (*Polopptila caerulea*; Blair 1996, Franci and Schnell 2002), and scarlet tanagers (*Piranga olivacea*; Friesen et al. 1995, Chace and Walsh 2004) as the focal species for my detection maps. These 5 species all have characteristics similar to those described for predicting high sensitivity to recreational trail use and have prior research observing their sensitivity to human activities (Gutzwiller et al. 1998, Franci and Schnell 2002, Chace and Walsh 2008). These species are also somewhat familiar to wildlife enthusiasts and are detectable on multiple trails within the study parks, which make them ideal to demonstrate how the rate of visitor trail use can influence avifauna detectability.

I used a single season, single species occupancy model to calculate the occupancy of each species separately within each park and to estimate species-specific detectability along trails within each park. To meet the assumptions of the single season model, I assumed that populations were closed during the field season; detection histories for each sampling point, trail, and repeated park visit were independent; and that species were correctly identified when present (Ball et al. 2005, Anderson et al. 2014). I accounted for the latter 2 assumptions in my sampling design with an avian point count regime that included 3 independent visits to each of the 4 parks over the field season, with each sampling point per trail receiving 3 visits/park visit, once by each observer (Chapter I). This methodology resulted in 9 independent visits which composed the encounter history for each species at each sampling point. Further, all observers were experienced in visual and auditory identification of common Arkansas avifauna.

Although there was a potential for the first assumption to be violated as a result of breeding season productivity of the species and the extension of point counts into July

and August (Ralph et al. 1995), MacKenzie and Royle (2005) noted that this assumption can be relaxed by incorporating site-level covariates into the occupancy model. Site-level covariates are those that vary depending on the site but are held constant through the sampling regime, such as specific sample location. My objective was to calculate detection probabilities for each species on each trail, as such, I considered the specific trails within each park as site-level covariates in my model. Further, while detectability can vary with respect to time of visit, the repeated park and observer visits were incorporated into the encounter history for each sampling point. Although this removes observation date and specific observer variables from my model, it increases the number of repeated detections per sampling point from 3 to 9, which aided in producing more reliable detection probabilities (Welsh et al. 2013).

I used the unMarked package in Program R (Fisk and Chandler 2011, R Core Team 2016) to construct a single a priori model for each species in each park. Choosing species' detections/non-detections and the exact trails within each park to serve as my model covariates reflected the possible influence of trail use on species detectability. Further, these covariates allowed me to maximize the likelihood of species-specific occupancy within each park while also examining variations in detectability of species along park trails (Holbrook et al. 2015). Package unMarked organizes encounter histories and site-level covariates into a $M \times T$ matrix of values called an "unmarkedOccuFrame", which displays encounter histories and site covariates as n sites by n visits (Fisk and Chandler 2011). After creating the unmarkedOccuFrame, I used the "occu" function to construct the occupancy model for each of the parks as "species specific detection/non-detections = Occupancy(1) + probability of detection (trail)". Occupancy was held

constant in the model (~ 1) and was a function of overall occupancy of a species within each separate park (Fiske and Chandler 2011). Probability of detection was modeled as a function of each specific trail within each park. Additionally, package `unMarked` calculates logit occupancy and detectability as direct linear values and as such may be hard for park visitors to interpret. I used the “`plogis`” function in `unMarked` to back transform occupancy and detection probabilities for each species in each park. This function bounds occupancy and detectability between 0 – 1 which may be better interpreted by park visitors (Fiske and Chandler 2011).

Detection Maps

I used ArcMap to create 1 map for each species at each park (Figs. 3.1 – 3.20). I used a polygon shapefile for each state park (<https://gis.arkansas.gov/>) overlaid onto a high resolution Digital Ortho Quarter Quad (DOQQ; <ftp://gis.arkansas.gov>) image to serve as the base layer for each map. I then overlaid line shapefiles for each trail using georeferenced data points of each sampling point collected in the field with a handheld GPS. I populated each trail’s attribute table with the mean rate of trail use/30min and detection probabilities of each species.

Considering that the typical park visitor spends an average of 5 seconds looking at trail signage (Ross and Gillespie 2008), differences in the amount of trail use needed to be easily distinguishable among trails. Thus, for each park I classified trail shapefiles based on the rate of trail use attribute with a graduated color symbology between yellow to red representing increasing rates of trail use. To better relate the possible influence of trail use rates on species specific detectabilities, I also included a table within each map that displayed trails in each park in ascending rate of trail use alongside the

corresponding detectabilities of each species for each trail. Maps also included a statement to instruct visitors on the purpose of the maps and how species detectabilities were to be interpreted.

RESULTS

Avian Data Collection

In total, I conducted 2,043 repeated visits to 227 sampling points located on trails across 4 Arkansas state parks to calculate occupancy and detection probabilities for 5 avian species found within the parks. Survey effort was highest at Mount Magazine (540 visits), followed by Petit Jean (531), Mount Nebo (504 visits), and Pinnacle Mountain (468 visits).

Visitor Use of Trails

Please refer to Chapter II Results for a summary of rates of visitor use for each trail and state park.

Species Occupancy and Detectability Models

Mount Magazine.— Mount Magazine had the greatest variation in occupancy probabilities across the 5 focal species (0.71 ± 0.81 ; mean \pm 1SE for all values), with Carolina wrens, blue-gray gnatcatchers, and scarlet tanagers having lower occupancy probabilities compared to the other 3 parks (Table 3.1). Detection probabilities were lower than occupancy probabilities in all 5 species except for blue-gray gnatcatchers (Table 3.2), indicating external influences on the detection of all species (Welsh et al. 2013, Holbrook et al. 2015). Ovenbirds had moderate levels of detectability (0.53 ± 0.59) and appeared to respond to rates of trail use. The greatest probability of detection for ovenbirds occurred on moderate to low use trails such as the Benefield or Mossback

Ridge trails and lower detection probabilities were observed on higher use trails such as the Rim trail (Figure 3.1). Carolina wrens had relatively low detectabilities (0.23 ± 0.75) compared to the other species within the park and had the lowest detectability on the Signal Hill trail, which had the highest rate of use of all trails in the park (Figure 3.2). However, Carolina wren detections varied in response to the different rates of trail use and also had lower detectabilities on low use trails such as the Greenfield and Benefield trails (Figure 3.2), indicating that factors other than rate of trail use may have had a stronger influence on Carolina wren detection. Northern cardinals (0.37 ± 0.81 ; Figure 3.3) and blue-gray gnatcatchers (0.50 ± 1.00 ; Figure 3.4) also had low detection probabilities on the highly frequented Signal Hill trail, with species detections on the other trails varying in response to rates of trail use. Blue-gray gnatcatcher detection probabilities had the greatest variability of the 5 species, and were either recorded as a definite detection (0.99) or as a definite non-detection (0.00 – 0.01) among Mount Magazine trails, with detection probabilities following no clear trend in response to rates of trail use. Scarlet tanagers (0.23 ± 0.66) had moderate to low detection probabilities along all trails within the park, with the lowest detection probability observed at the Greenfield trail, the second lowest used trail (Figure 3.5). Additionally, scarlet tanagers, like the other focal species, generally did not follow a direct response to rates of trail use and had low detection probabilities observed across a spectrum of trail use rates.

Mount Nebo.— Compared to Mount Magazine, Mount Nebo had higher occupancy probabilities (0.93 ± 0.85) in all species except for northern cardinals (Table 3.1). Occupancy probabilities were high for ovenbirds, blue-gray gnatcatchers, and scarlet tanagers, with occupancy of Carolina wrens and northern cardinals only being

slightly less. Ovenbird detection probabilities (0.40 ± 1.00 ; Table 3.3) varied in response to different rates of trail use, and were highest on moderate to high use trails (e.g., North Rim Trail) as well as on less frequented trails (e.g., Varnall Springs; Figure 3.6).

Comparatively, ovenbirds had low detection probabilities on the Bench Road trails, which had relatively low rates of trail use, and on the Summit Park trail, which had the highest rate of trail use. Some of the lowest detection probabilities for Carolina wrens (0.36 ± 0.61 ; Figure 3.7), northern cardinals (0.39 ± 0.62 ; Figure 3.8), blue-gray gnatcatchers (0.28 ± 0.63 ; Figure 3.9), and scarlet tanagers (0.35 ± 0.69 ; Figure 3.10) also occurred on the highly frequented Summit Park trail. However, the lowest detection probabilities for each of the 4 species varied along a spectrum of low to moderate use trails, with no discernable relationship to trail use rates. Additionally, detection probabilities for all the focal species were collectively low along the Bench Road A trail, despite it having a low rate of trail use.

Petit Jean.— Occupancy probabilities were consistently high for all 5 species in Petit Jean (0.98 ± 0.93 ; Table 3.1). Detection probabilities for the focal species showed similar variations across a spectrum of trail use rates as observed in Mount Magazine and Mount Nebo (Table 3.4). Northern cardinal detections were an exception to this similarity in that there was weak evidence supporting lower detection with high rates of trail use. Ovenbirds (0.36 ± 1.00) had low detection probabilities on the 2 highest used trails in the park, the Cedar Falls and Cedar Creek trails (Figure 3.11). Conversely, ovenbirds also had low detection probabilities within low use trails, such as the Seven Hollows trails. Carolina wrens (0.55 ± 0.59), northern cardinals (0.57 ± 0.63), and blue-gray gnatcatchers (0.42 ± 0.64) all had the lowest detection probabilities within the Canyon

trail, which had moderate rates of trail use (Figures 3.12 – 3.14). Northern cardinals (Figure 3.13) had low detection probabilities on high use trails like the Cedar Creek and Cedar Falls trails. Detection probabilities for Carolina wrens (Figure 3.12) and blue-gray gnatcatchers (Figure 3.14) varied among different rates of trail use, with high detection probabilities in both species observed on low use trails (e.g., CCC Hike and Bike trail) and high use trails (e.g., Cedar Falls trail). Scarlet tanagers (0.21 ± 0.73) were the only species to have a non-detection within Petit Jean trails, which occurred at the second most frequented trail in the park, the Cedar Creek trail (Figure 3.15). However, like the other focal species, scarlet tanager detections varied across trail use rates, with the highest probability of detection on the Cedar Falls trail, the most frequented trail in the park.

Pinnacle Mountain.— Occupancy probabilities were also consistently high for species in Pinnacle Mountain (0.91 ± 0.88 ; Table 3.1), with blue-gray gnatcatchers again having the lowest occupancy probability of the 5 species. Similar to Mount Nebo and Petit Jean, ovenbirds and scarlet tanagers again were the only species with non-detections (Table 3.5). Ovenbirds (0.44 ± 0.93 ; Figure 3.16) had non-detections on trails over a variety of trail use rates including the low use Ouachita and East Quarry trails and the high use Kingfisher and West Summit trails. The highest detection probabilities for ovenbirds occurred on the Rocky Valley trail, a moderate use trail. Detection probabilities for Carolina wrens (0.59 ± 0.68), northern cardinals (0.57 ± 0.67), and blue-gray gnatcatchers (0.56 ± 0.73) were generally higher at Pinnacle Mountain compared to the other 3 parks, but showed similar variations in response to trail use rates. Detection probabilities for Carolina wrens (Figure 3.17), northern cardinals (Figure 3.18), and blue-

gray gnatcatchers (Figure 3.19) were high within low use trails like the Ouachita and East Quarry trails, but were also high within high use trails such as the Kingfisher and East Summit trails. Detection probabilities for scarlet tanagers (0.63 ± 0.97) varied from 0.00 – 0.99 along Petit Jean trails and also did not correspond with differences in trail use rates (Figure 3.20). Low detection probabilities in scarlet tanagers were generally clustered around low to moderate use trails such as the Arkansas and Rocky Valley trails. Additionally, detection probabilities were generally low for all species along the Arkansas trail, despite it having a low rate of use.

DISCUSSION

Park managers must balance conservation of wildlife and promote recreational trail use within protected areas. Understanding the distribution of park avifauna with respect to various rates of trail use may provide the necessary data required to balance the dual role fulfilled by state parks. I calculated detection probabilities for 5 focal avian species across 4 parks to determine how detectability varied among trails with respect to rates of trail use. I modeled high probabilities of occupancy for all focal species across the parks except for in Mount Magazine, which had comparatively low levels of occupancy for Carolina wrens, blue-gray gnatcatchers, and scarlet tanagers. Further, detection probabilities for all species were consistently lower than park occupancy probabilities, indicating that species detections were influenced by external factors that varied among the trails. There was weak evidence that ovenbirds in Mount Magazine and northern cardinals in Petit Jean responded negatively to high rates of trail use. However, detection of the 5 focal species generally did not respond to high rates of trail use within

the parks and I observed low detection probabilities in all species over a spectrum of trail use rates.

Although high rates of trail use have been shown to reduce detections in protected area avifauna (Cole 1993, Steven et al. 2011, Thompson 2015), trail use did not have a strong relationship with species detectability in my study. Prior study designs used to evaluate rates of trail use measured use as the number of users on an annual basis (Miller et al. 1998) or have simulated trail use as a controlled number of trail passes (Riffell et al. 1996). As such, avian communities in these studies were subject to a greater intensity of trail use compared to the rates measured in my study which may have resulted in the lack of association between high trail use and species detectability. Research also suggests that the effects from the physical placement of trails may influence avian detectability rather than the corresponding effects of human use on trails (Miller et al. 1998, Thompson 2015). The lack of a relationship between low detection probabilities and high rates of trail use in my study may suggest that environmental and trail structure factors were stronger determinants of species detection compared to the possible influences of trail use (Francl and Schnell 2000, Rodriguez-Prieto et al. 2014, Thompson 2015).

Additionally, I calculated large standard error values in focal species detection along several trails, which was likely due to the low number of detections for several species, a common issue observed in occupancy modeling (Welsh et al. 2013). Thus, low detection probabilities for the focal species may have also been influenced by my sampling methodology, indicating >9 repeated visits per sampling point may be required to improve the accuracy of species detection probabilities (Smith et al. 2006). As such, these results are a step forward in creating dynamic models and GIS maps to facilitate

sustainable trail use through visualization of species detectability with respect to rate of trail use, but may require improvements in sampling design for future surveys.

Species-Specific Occupancy Models

Ovenbirds.— There was weak evidence suggesting a relationship between lower detection probabilities of ovenbirds with greater rates of trail use in Mount Magazine trails. However, responses in ovenbird detection to different rates of trail use were inconsistent among the other 3 parks, with low detection probabilities also occurring on less frequented trails. Prior research has demonstrated a positive relationship between vegetative characteristics (e.g., density, height, patchiness) and habitat availability to high avian community richness and diversity (Mills et al. 1989, Franci and Schnell 2002, Gill et al. 2001, Chace and Walsh 2004). Additionally, ovenbirds are ground nesters and foragers and will respond negatively to the removal of ground cover and trailside vegetation (Cornell Lab of Ornithology 2015). Therefore, ovenbirds may have been influenced by alterations in trailside vegetation caused by either high rates of trail use or trail design.

A primary consequence of high rates of trail use is a corresponding decline in trailside vegetation from trampling, soil erosion, and direct removal for firewood and tent poles (Dale and Weaver 1974, Cole 1993, Leung and Marion 2000). As ground nesters, ovenbirds depend on dense trailside vegetation for nesting material and to act as visual buffers between their nests and trail users (Gill et al. 2001). Thus, the removal of trailside vegetation and cover from high rates of trail use could have resulted in the lower ovenbird detection probabilities observed along high use trails in Mount Magazine by removing visual buffers. For example, the Will Apple's and Signal Hill trails which had

low detections of ovenbirds had some of the highest rates of use in Mount Magazine (Chapter II) as well as some of the lowest values in overstory vegetation richness and diversity (Chapter I). The high rates of use on these trails could have damaged trailside overstory vegetation, resulting in a decline in overstory richness and diversity.

Petit Jean and Pinnacle Mountain had higher rates of trail use compared to Mount Magazine (Chapter II) but were not observed to elicit the same relationship between ovenbird detectability and trail use rates. This may be explained by the effects of trail design on adjacent vegetation that act independently of recreational trail use. For example, ovenbirds have been shown to be sensitive to forest fragmentation and patchiness, which can be caused by the removal of adjacent vegetation to trails and having softer trail substrates that lead to high soil erosion (Hillebrand et al. 2008, Torn et al. 2009). This could explain why ovenbird detection was low on the Arkansas trail in Petit Jean, which had some of the lowest rates of trail use in the park (Chapter II). Park managers will widen trails to help dilute the effects of trail use and to facilitate a greater variety of trail user activities (Marion et al. 2011). However, the construction of wider trails can also lead to initial declines and removal of trailside vegetation. The Arkansas trail had a moderately wider path compared to other Petit Jean trails (Chapter II), and thus could have resulted in low detection probabilities of ovenbirds despite the low rate of trail use due to the removal of trailside vegetation from trail design.

Conversely, trail design can also influence the availability of edge habitat and determine the type of user activity on a trail. The interconnectedness of trails introduces edge habitat within parks (Dale and Weaver 1974, Yahner 1988, Kangas et al. 2010) which may benefit ovenbirds by promoting understory vegetation growth for visual

buffers and nesting material as well as increasing invertebrate abundance (Yahner 1988). Variations in trail user behavior facilitated by trail design may further influence ovenbird detection. For example, Smith-Castro (2010) demonstrated that birds were more likely to abandon nests along trails when trail users directly approached birds as opposed to indirect trail passes. The combination of greater edge habitat and type of user activity may explain why ovenbird detection probabilities varied with respect to rates of trail use, in that ovenbirds either utilized trailside vegetation made available by edge conditions or tolerated indirect pass-byes from trail users through trail designs providing buffers for off-trail nest placement. This may explain why ovenbird detection probabilities were high along trails of moderate use, such as the Benefield trail in Mount Magazine. Wider and shallower trail designs, such as the Benefield trail (Chapter II), promote edge conditions in vegetation and habitat adjacent to park trails and dilute trail users along the trail to prevent direct approach behaviors (Yahner 1988, Leung and Marion 1999). Thus, the design of the Benefield trail may have prevented damage to trailside vegetation important for ovenbird nesting and foraging (Gill et al. 2001), leading to moderate probabilities of detection.

Carolina wrens.— Carolina wrens are a residential bird species in Arkansas which tend to have a higher level of tolerance to human recreation due to prolonged exposure to human disturbance compared to migratory forest birds such as the ovenbird or scarlet tanager (Smith-Castro and Rodewald 2010). Further, Carolina wrens are more versatile nesters compared to the other species in this study and tend to place their nests in tree cavities 1 – 2m off the ground or in anthropogenic locations (e.g., flowerpots, mailboxes; Cornell Lab of Ornithology 2015). The combination of high, more versatile nest

placement and tolerance to human activities may explain the varied responses in Carolina wren detection to different rates of trail use. Placing nests higher off the ground may mitigate the direct effects of trampling and trail user approach on Carolina wren nests while also lengthening the distance at which Carolina wrens perceive trail users, thus reducing avoidance behaviors. For example, despite the high rate of trail use, the Rim trail in Mount Magazine had the greatest overstory diversity compared to the other park trails (Chapter I). This diversity in trailside vegetation may have provided sufficient cavities for nesting, which could have mitigated the effects of high rates of trail use on Carolina wren detection.

In contrast, the high use North Rim trail in Mount Nebo had the lowest overstory vegetation diversity of park trails (Chapter I), but passed through a greater variety of human structures (e.g., mailboxes, cabins, porches). Despite the high rate of trail use and low diversity in trailside vegetation, the North Rim trail had one of the highest detection probabilities for Carolina wrens in the park. As a result of their tolerance to human disturbance and versatility in nest placement, the abundance of anthropogenic structures along the trail may have translated into high detection probabilities in Carolina wrens regardless to the rate of use. Similar reasoning could explain the high detection probabilities observed on the Cedar Falls trail in Petit Jean and West Summit trail in Pinnacle Mountain. Both trails had the highest rates of trail use in the respective parks and were bordered by picnic areas or had popular recreation attractions. These recreational areas adjacent to the trails consequently included a diversity of anthropogenic sources for nesting locations which could have led to high Carolina wren detectability despite the high rates of trail use.

Despite their tolerance to human recreation, previous studies have demonstrated some evidence for low detection probabilities of Carolina wrens in response to high rates of trail use (Francel and Schnell 2002). This relationship was reflected in the most frequently used trails in Mount Magazine and Mount Nebo where Carolina wren detection was low. Compared to the detection probabilities observed at the other parks, these results may indicate a threshold rate of trail use that Carolina wrens were tolerant of before the initiation of avoidance behaviors (Kangas et al. 2010).

Northern cardinals.— Northern cardinals share similar life history characteristics in nesting and foraging behaviors to ovenbirds and Carolina wrens and I expected them to have parallel variations in detection probabilities. Northern cardinals prefer open woodland and shrub areas like Carolina wrens, but tend to place nests in denser vegetation at lower heights 0 – 5m above the ground like ovenbirds (Cornell Lab of Ornithology 2015). Kangas et al. (2010) noted that 3 main factors influence ground or low nesting avifauna: direct disturbance from visitors, indirect effects caused by trail users, and physical alterations to vegetation. Northern cardinal detections may have been higher on trails with lower rates of use in Petit Jean as a result of a greater abundances in adjacent vegetation structure responding to the corresponding low rates of use. Trail use rates can be influenced by park management decisions on trail structure, such as trail width and depth (Weaver and Dale 1978, Leung and Marion 2000, Torn et al. 2009). For example, the CCC Hike and Bike trail in Petit Jean had the lowest rate of trail use while also having the widest trail path and one of the shallowest depths of Petit Jean trails (Chapter II). This trail structure may have been implemented by park managers to dilute the effects of foot traffic and to encourage trail users to not wander off trail (Weaver and

Dale 1978, Torn et al. 2009). Community diversity and richness in trailside vegetation may have then positively responded to the reduced trail use which could have translated into high northern cardinal detections.

Prior research has shown that greater rates of trail use may lead to declines in northern cardinal abundance and detectability (Franci and Schell 2000, Smith-Castro and Rodewald 2010); however, this pattern was not observed in my detection maps for Mount Magazine, Mount Nebo, and Pinnacle Mountain. Similar to Carolina wrens, northern cardinals are permanent residents in Arkansas and may tolerate human disturbance more than other focal species (Burhans and Thompson 2006, Leston and Rodewald 2006). This may explain why northern cardinal detection probabilities generally did not decline with greater rates of trail use and were high along several moderate use trails such as the Will Apple's trail in Mount Magazine and the North Rim trail in Mount Nebo. Additionally, northern cardinals may be more conspicuous and sought out by trail users compared to the other species included in this study (Sekercioglu 2002). Conspicuousness in a species may encourage direct human interactions, which result in either greater avoidance behaviors or habituation to repeated human exposure (Gutzwiller et al. 1998, Smith-Castro and Rodewald 2006). Therefore, high detection probabilities in northern cardinals along trails with high rates of use such as the North Rim trail in Mount Nebo may be the result of northern cardinal habituation to direct user interactions caused by ease of visual detection (Sekercioglu 2002).

Blue-gray gnatcatchers.— Detection probabilities of blue-gray gnatcatchers in Mount Nebo and Petit Jean showed a weak negative response to high rates of trail use; however, low detection probabilities occurred across different rates of trail use within all

the parks, with no generally pattern observed. Lower detection probabilities of blue-gray gnatcatchers in Mount Nebo and Petit Jean may be in response to damage of trailside vegetation from high rates of trail use (Chace and Walsh 2004) or from the fragmentation of forest habitat by park trail design and location (Leung and Marion 2000, Cornell Lab of Ornithology 2015). Blue-gray gnatcatchers nest in forested habitat with denser canopies compared to nesting behaviors of Carolina wrens and northern cardinals (Cornell Lab of Ornithology 2015). Additionally, blue-gray gnatcatchers place their nests higher up on tree limbs compared to the other focal species and forage in dense outer tree foliage (Cornell Lab of Ornithology 2015). While high rates of trail use may have influenced Mount Nebo and Petit Jean blue-gray gnatcatcher detectabilities, the removal of the vegetation due for trails may have had a stronger influence on species detections in the other parks regardless of rates of trail use (Blair 1996, Chace and Walsh 2004).

Vegetation adjacent to trails is often modified to facilitate visitor use of trails (Torn et al. 2009) and can result in declines of vegetation community evenness and richness depending on the function and design of the trail (Weaver and Dale 1978, Marion et al. 2011). For example, the Signal Hill trail in Mount Magazine led to a major park attraction and had a wider, steeper path compared to other park trails (Chapter II). Wider trails can encourage high use and off-trail wandering if trailside vegetation is not tall enough to keep users on the trail (Dale and Weaver 1974). Further, steep slopes can lead to soil erosion from water runoff and the creation of treads by trail users maintaining their footing (Marion et al. 2011). The combination of a wider and steeper trail design may have led to low trailside understory and overstory woody vegetation richness (Chapter I) and consequently low detection probabilities of blue-gray gnatcatchers from

habitat removal. Trails in other parks that had wider and steeper trail designs also resulted in similar low detection probabilities of blue-gray gnatcatchers, regardless of the rate of trail use (e.g., Bench Road A trail in Mount Nebo, CCC Hike and Bike trail in Petit Jean, and the Base trail in Pinnacle Mountain). Low detection probabilities regardless of the rate of trail use suggests then that the detection probabilities of blue-gray gnatcatchers were more related to the effects of trail design on the surrounding vegetation than to trail use.

Species' nesting behavior may be an additional factor that influenced blue-gray gnatcatcher detectability instead of trail use. For example, the Summit Park trail in Mount Nebo and the Cedar Falls trail in Petit Jean had the highest rates of use within the 2 parks and witnessed moderate levels of detection in blue-gray gnatcatchers. The high detection probabilities with high rates of trail use may be related to the relationship between species' nest height and ability to perceive trail user presence (Kangas et al. 2010). Despite the high rates of trail use, both trails had moderate levels of surrounding overstory vegetation richness and diversity (Chapter I), likely the result of both trails having narrower and rockier paths within the respective parks (Chapter II). The rockier substrate may have been more resilient to the high rates of foot traffic and the narrower trails may have fenced in trail users, preventing disturbance to adjacent vegetation (Torn et al. 2009). These conditions likely provided the nesting conditions preferred by blue-gray gnatcatchers despite the high rates of use, which consequently allowed the birds to perceive trail users at a further distance to promote temporary avoidance and habituation, thus leading to high detection probabilities (Smith-Castro and Rodewald 2010).

Scarlet tanagers.— Detections of scarlet tanagers were lower compared to the other 4 species which was likely the result of their high nest placement. Detection probabilities of scarlet tanagers were expected to be akin to blue-gray gnatcatchers due to similarities in nesting behavior, however the detection probabilities for scarlet tanagers varied in response to rates of trail use and were highest at both ends of the trail-use spectrum across the parks. This species has higher nest placement and are more visually conspicuous compared to the other focal species, but are rarely visually detected due to their preference to high tree canopies (Cornell Lab of Ornithology 2015).

Scarlet tanagers are also a forest interior species and depend on larger, continuous tracts of forest (Cornell Lab of Ornithology 2015). As such, forest fragmentation from park trail systems may have affected this species more than the other focal species (Friesen et al. 1995, Chace and Walsh 2004). Scarlet tanagers are intolerant to disturbance resulting from forest fragmentation (Chace and Walsh 2004) which can change with historic regional processes or local park management decisions (Chapter I). The lack of a clear relationship between scarlet tanager detection and rates of trail use may suggest that detection probabilities for this species were better explained by larger scale influences such as area geology, topography, and historic land uses (Harrison and Cornell 2008). While the high nest placement of scarlet tanagers may have reduced the direct influences from recreation by enhancing the species' perceptibility of trail users (Smith-Castro and Rodewald 2010), alterations in park structure and historic management decisions may have had detrimental effects on scarlet tanager high nesting behaviors from the removal of overstory vegetation. For example, the highest detection probability for scarlet tanagers in Petit Jean was on the most frequented trail, the Cedar

Falls trail. The Cedar Falls trail also had moderate levels of understory and overstory woody vegetation community richness and diversity (Chapter I). Further, the Cedar Falls trail was more offset from the main area of the park compared to other park trails, which may have resulted in less removal of overstory vegetation. As such, scarlet tanager detection may have been high regardless of the rate of trail use on the Cedar Falls trail due to sufficient vegetation conditions that mitigated the ground level effects on scarlet tanager nesting behavior.

The timing of repeated visits may have also resulted in the low detection probabilities recorded for scarlet tanagers, despite high occupancy probabilities observed across the parks and the >9 repeated visits in my sampling design (MacKenzie and Royle 2005, Welsh et al. 2013). MacKenzie and Royle (2005) recommend sampling a greater number of points less intensively for cryptic species, with a minimum of 3 repeated visits per sampling point sufficient when detection and occupancy probabilities are high. Due to the matrix framework used in program unMarked, a low number of detections of scarlet tanagers could have reduced the accuracy of model predictions for occupancy and detectability, leading to the high standard error values and inconsistencies in the expected responses of detection probabilities to high rates of trail use (Fiske and Chandler 2011, Welsh et al. 2013). Further, these results may indicate the need for a greater number of repeated visits per sampling point or for different methodologies to collect the data required to accurately assess scarlet tanager detectability (MacKenzie and Royle 2005). Thus, reducing the number of repeated visits to just once per park visit and including a greater number of sampling points may have improved the accuracy of the scarlet tanager detection models.

Scarlet tanager detections generally declined with high rates of trail use in Mount Nebo compared to detection patterns in the other 3 parks. Although high rates of trail use have been shown to negatively affect scarlet tanager populations (Francel and Schnell 2002), it is unlikely that the response of scarlet tanagers to high rates of trail use would not have been observed in the other high use parks like Petit Jean and Pinnacle Mountain (Chapter II). Therefore, lower scarlet tanager detections in Mount Nebo could also be explained by the effects of trail design on forest composition and structure. For example, scarlet tanager detections were lowest on the Summit Park trail, which had the highest rates of use but also one of the lowest densities of canopy cover among Mount Nebo trails (Chapter II). The Summit Park trail also descends the mountain and begins in a group of cabins. To facilitate cabin locations and trail use for park visitors, surrounding overstory vegetation may have been actively removed by park management, thus altering nesting habitat which led to the absence of scarlet tanagers in that area. As such, detections of scarlet tanagers along the Summit Park trail were low likely due to poor habitat conditions for scarlet tanager nesting behavior. Comparatively, the Bench Road B trail, which had lower rates of trail use but denser canopy cover (Chapter II), had higher detection probabilities of scarlet tanagers, further supporting the possible importance of habitat structure and landscape planning on scarlet tanager detection compared to rates of trail use.

Management Recommendations

Protected areas serve under a dual role to protect biotic communities while promoting recreation opportunities to park visitors; however, recreation can negatively affect park biotic communities (Chapter II) and may not be compatible with this

management goal. Park managers can reduce the effects of trail use through establishing buffer zones, trail curfews, and trail barriers, but may restrict park visitor experiences in the process. These restrictions on trail use can the result in negative attitudes towards conservation and sustainable resource use in park visitors. Considering the importance of recreation as a source of funding and conservation education, interventions by park managers are suggested to address the negative effects of high trail use while minimizing restriction on park visitors. Creating detection maps of park wildlife communities may help mitigate the effects of trail use without restricting visitor experience through visually relating visitor activities to park wildlife through a passive learning process.

My maps provide visualization of the effects of trail use on several flagship bird species, but have not yet been tested in their efficacy to educate park visitors. Further, detection probabilities for most species varied over a spectrum of trail use rates, suggesting that detection may be attributed to factors other than trail use, such as alterations in trailside vegetation and sampling methodologies. Incorporating a wider variety of biotic and abiotic covariates in future occupancy models may better explain and visualize the collective influences acting on park avifauna. Additionally, extending educational opportunities to visitors on the importance of trailside vegetation and proper trail etiquette may help to mitigate the influences acting on park avifauna beyond those of trail use.

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Table 3.1. Occupancy probabilities (\pm 1SE) for ovenbirds (*Seiurus aurocapilla*), Carolina wrens (*Thryothorus ludovicianus*), blue-gray gnatcatchers (*Polopptila caerulea*), northern cardinals (*Cardinals cardnalis*), and scarlet tanagers (*Piranga olivacea*) in Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas, 2015.

Park	Ovenbird	Carolina wren	Northern cardinal	Blue-gray gnatcatcher	Scarlet tanager
Mount Magazine	0.99 ± 1.00	0.66 ± 0.63	0.99 ± 1.00	0.27 ± 0.79	0.66 ± 0.63
Mount Nebo	0.99 ± 1.00	0.86 ± 0.62	0.84 ± 0.61	0.99 ± 1.00	0.99 ± 1.00
Petit Jean	0.99 ± 1.00	0.99 ± 1.00	0.92 ± 0.66	0.99 ± 1.00	0.99 ± 1.00
Pinnacle Mountain	0.99 ± 1.00	0.99 ± 1.00	0.97 ± 0.82	0.60 ± 0.59	0.99 ± 1.00

Table 3.2. Detection probabilities ($\pm 1\text{SE}$) for ovenbirds (*Seiurus aurocapilla*), Carolina wrens (*Thryothorus ludovicianus*), blue-gray gnatcatchers (*Polopptila caerulea*), northern cardinals (*Cardinals cardinalis*), and scarlet tanagers (*Piranga olivacea*) at Mount Magazine State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.

Species	Mossback	Greenfield	Benefield	Will Apple's	Rim	Signal hill
Ovenbird	0.66 ± 0.59	0.54 ± 0.60	0.73 ± 0.57	0.43 ± 0.59	0.33 ± 0.58	0.48 ± 0.60
Carolina wren	0.20 ± 0.66	0.00 ± 1.00	0.18 ± 0.59	0.44 ± 0.64	0.54 ± 0.63	0.00 ± 1.00
Northern cardinal	0.35 ± 0.81	0.54 ± 0.81	0.02 ± 0.73	0.72 ± 0.76	0.57 ± 0.76	0.00 ± 1.00
Blue-gray gnatcatcher	0.99 ± 1.00	0.99 ± 1.00	0.00 ± 1.00	0.00 ± 1.00	0.99 ± 1.00	0.01 ± 1.00
Scarlet tanager	0.41 ± 0.64	0.08 ± 0.76	0.26 ± 0.60	0.12 ± 0.68	0.14 ± 0.66	0.36 ± 0.64

Table 3.3. Detection probabilities ($\pm 1\text{SE}$) for ovenbirds (*Seiurus aurocapilla*), Carolina wrens (*Thryothorus ludovicianus*), blue-gray gnatcatchers (*Polopptila caerulea*), northern cardinals (*Cardinals cardinalis*), and scarlet tanagers (*Piranga olivacea*) at Mount Nebo State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.

Species	Varnall Springs	Bench Road A	Bench Road B	Nebo Steps	North Rim	Summit Park
Ovenbird	0.99 ± 1.00	0.00 ± 1.00	0.00 ± 1.00	0.42 ± 1.00	0.99 ± 1.00	0.01 ± 1.00
Carolina wren	0.18 ± 0.69	0.36 ± 0.56	0.44 ± 0.58	0.54 ± 0.62	0.38 ± 0.58	0.24 ± 0.61
Northern cardinal	0.44 ± 0.66	0.33 ± 0.60	0.34 ± 0.61	0.37 ± 0.64	0.53 ± 0.60	0.34 ± 0.62
Blue-gray gnatcatcher	0.56 ± 0.65	0.19 ± 0.56	0.36 ± 0.60	0.11 ± 0.74	0.21 ± 0.60	0.22 ± 0.63
Scarlet tanager	0.55 ± 0.70	0.09 ± 0.58	0.46 ± 0.62	0.66 ± 0.63	0.31 ± 0.62	0.00 ± 1.00

Table 3.4. Detection probabilities ($\pm 1\text{SE}$) for ovenbirds (*Seiurus aurocapilla*), Carolina wrens (*Thryothorus ludovicianus*), blue-gray gnatcatchers (*Polopptila caerulea*), northern cardinals (*Cardinals cardinalis*), and scarlet tanagers (*Piranga olivacea*) at Petit Jean State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.

Species	CCC Hike and Bike	Seven Hollows A	Seven Hollows B	Canyon	Cedar Creek	Cedar Falls
Ovenbird	0.99 ± 1.00	0.03 ± 1.00	0.03 ± 1.00	0.99 ± 1.00	0.04 ± 1.00	0.05 ± 1.00
Carolina wren	0.70 ± 0.59	0.52 ± 0.59	0.49 ± 0.59	0.22 ± 0.58	0.65 ± 0.60	0.72 ± 0.60
Northern cardinal	0.80 ± 0.62	0.79 ± 0.62	0.79 ± 0.62	0.12 ± 0.61	0.65 ± 0.63	0.28 ± 0.68
Blue-gray gnatcatcher	0.36 ± 0.64	0.59 ± 0.62	0.66 ± 0.61	0.11 ± 0.60	0.26 ± 0.67	0.54 ± 0.63
Scarlet tanager	0.12 ± 0.75	0.34 ± 0.66	0.32 ± 0.66	0.08 ± 0.61	0.00 ± 1.00	0.37 ± 0.68

Table 3.5. Detection probabilities (± 1 SE) for ovenbirds (*Seiurus aurocapilla*), Carolina wrens (*Thryothorus ludovicianus*), blue-gray gnatcatchers (*Polopptila caerulea*), northern cardinals (*Cardinals cardinalis*), and scarlet tanagers (*Piranga olivacea*) at Pinnacle Mountain State Park, Arkansas, 2015. Trails are organized in ascending rate of trail use from left to right.

Species	Ouachita	East Quarry	Arkansas	Rocky Valley	Base	Kingfisher	East Summit	West Summit
Ovenbird	0.00 \pm 1.00	0.00 \pm 1.00	0.03 \pm 0.73	0.70 \pm 0.76	0.19 \pm 0.81	0.00 \pm 1.00	0.36 \pm 0.81	0.00 \pm 1.00
Carolina wren	0.41 \pm 0.61	0.56 \pm 0.63	0.39 \pm 0.58	0.42 \pm 0.61	0.37 \pm 0.60	0.66 \pm 0.63	0.25 \pm 0.62	0.46 \pm 0.63
Northern cardinal	0.49 \pm 0.61	0.62 \pm 0.63	0.33 \pm 0.59	0.42 \pm 0.62	0.33 \pm 0.59	0.50 \pm 0.63	0.12 \pm 0.65	0.36 \pm 0.64
Blue-gray gnatcatcher	0.63 \pm 0.63	0.84 \pm 0.69	0.20 \pm 0.60	0.62 \pm 0.69	0.39 \pm 0.64	0.20 \pm 0.77	0.55 \pm 0.65	0.41 \pm 0.75
Scarlet tanager	0.99 \pm 1.00	0.00 \pm 1.00	0.00 \pm 1.00	0.00 \pm 1.00	0.99 \pm 1.00	0.00 \pm 1.00	0.99 \pm 1.00	0.99 \pm 1.00

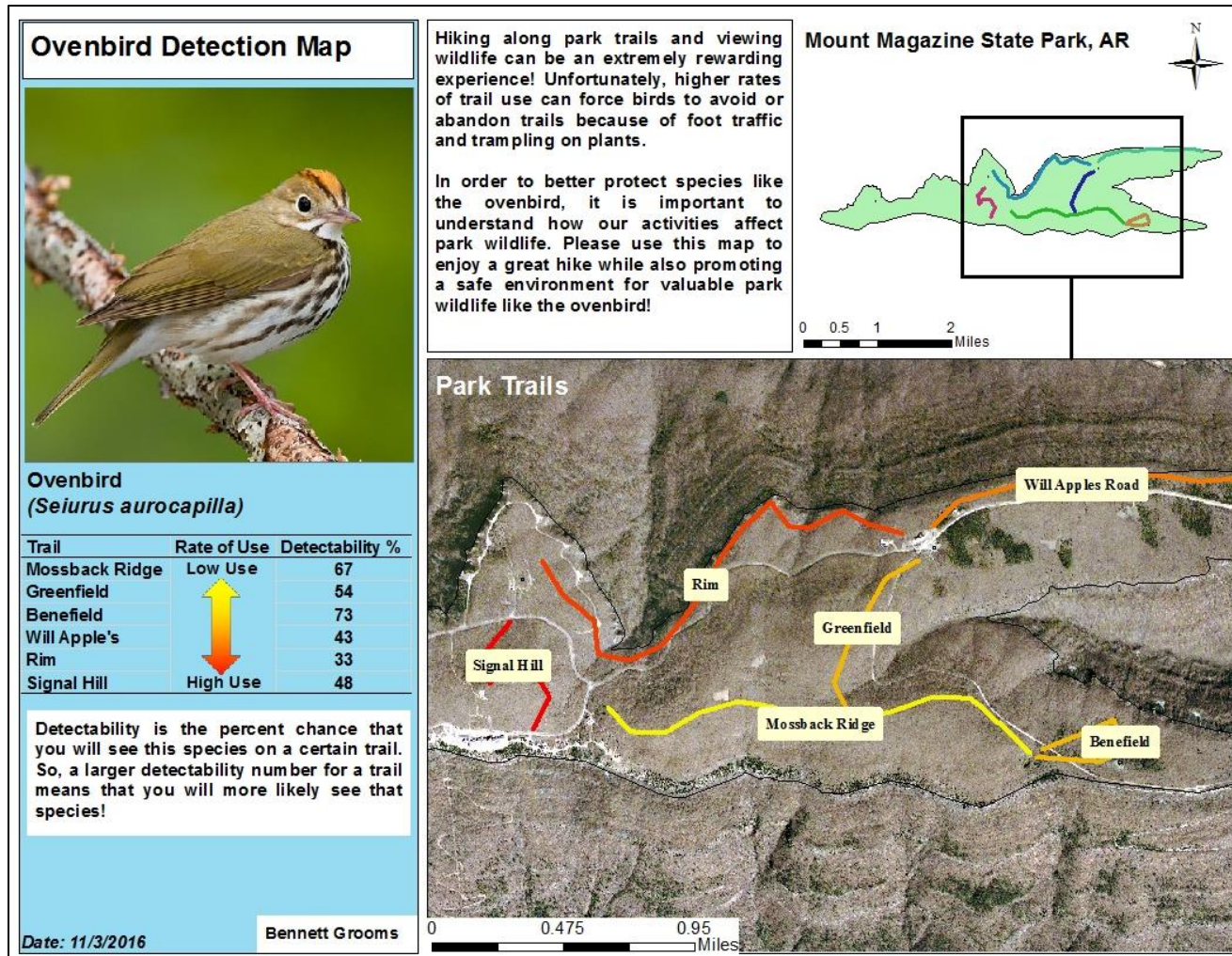


Figure 3.1. Detectability of ovenbirds (*Seiurus aurocapilla*) in relation to rate of trail use at Mount Magazine State Park, Arkansas, 2015.

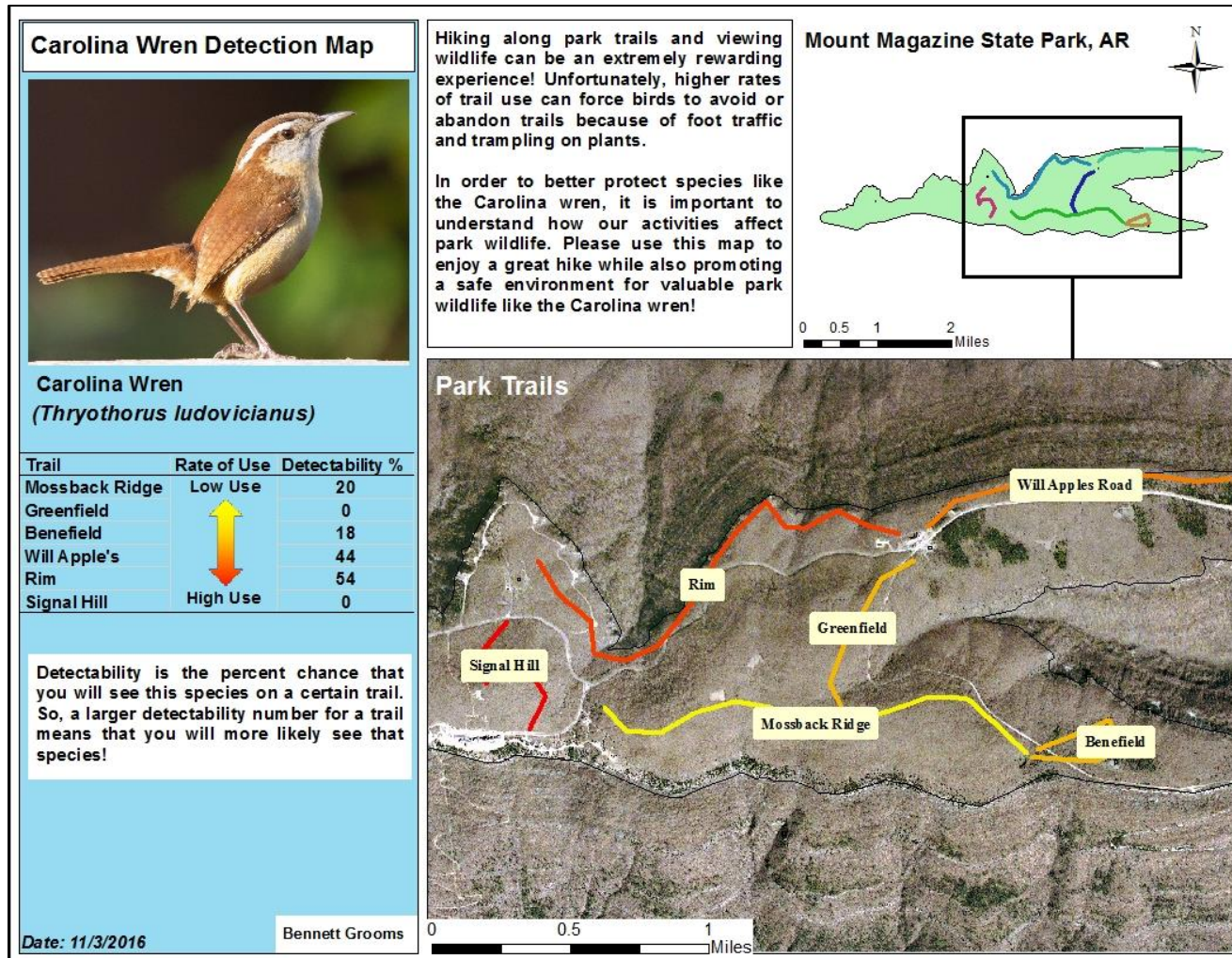


Figure 3.2. Detectability of Carolina wrens (*Thryothorus ludovivianus*) in relation to rate of trail use at Mount Magazine State Park, Arkansas, 2015.

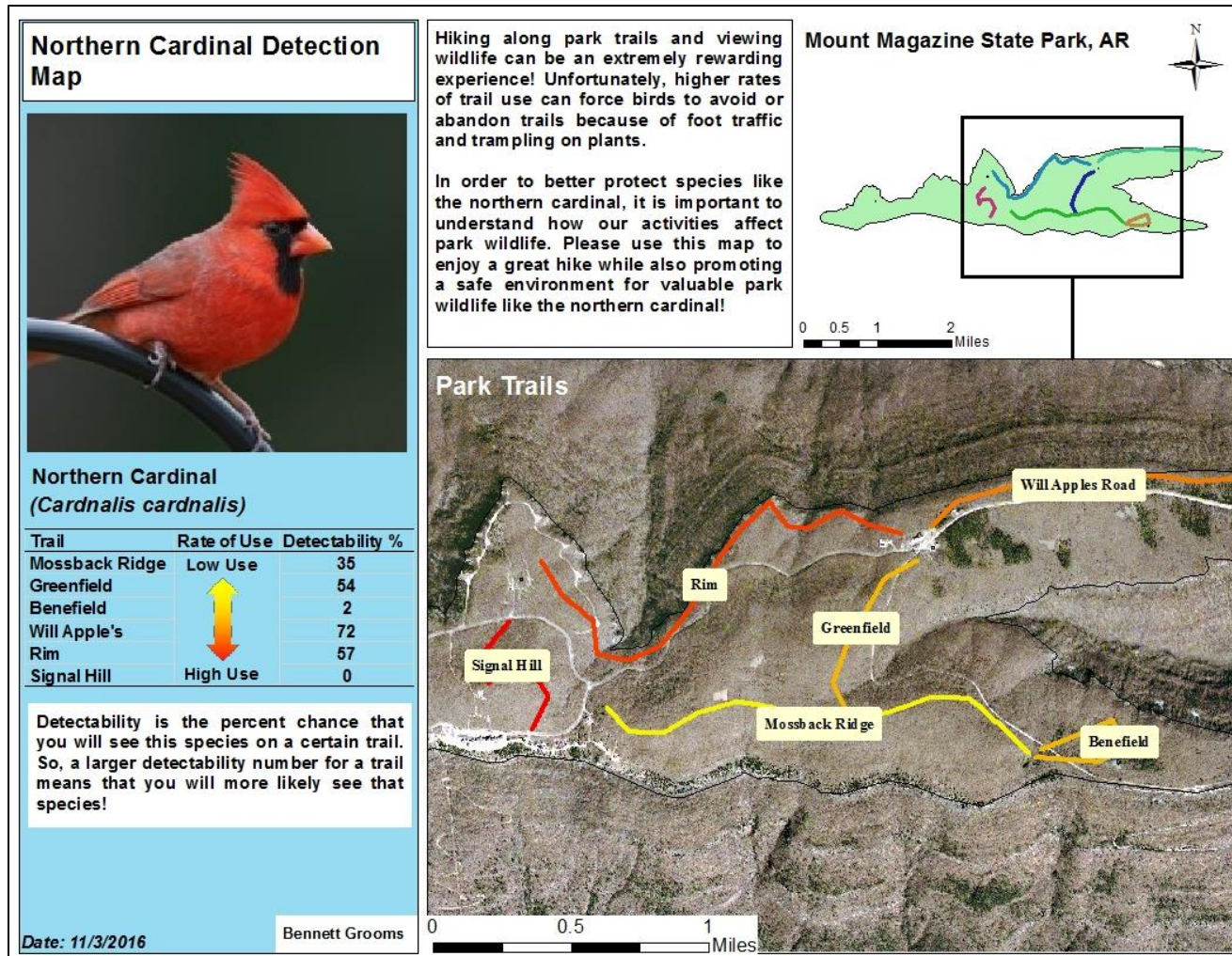


Figure 3.3. Detectability of northern cardinals (*Cardinals cardinalis*) in relation to rate of trail use at Mount Magazine State Park, Arkansas, 2015.

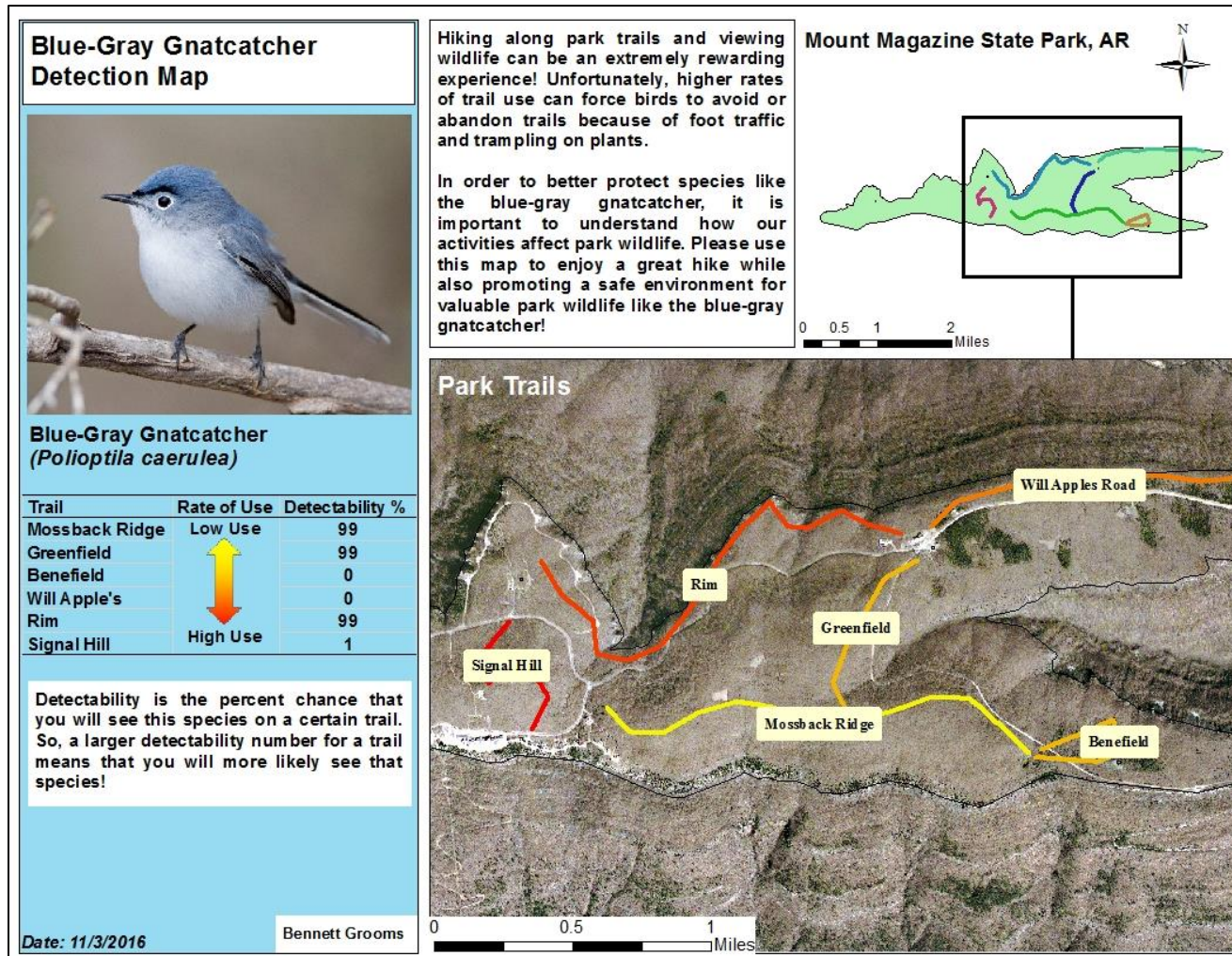


Figure 3.4. Detectability of blue-gray gnatcatchers (*Polopptila caerulea*) in relation to rate of trail use at Mount Magazine State Park, Arkansas, 2015.

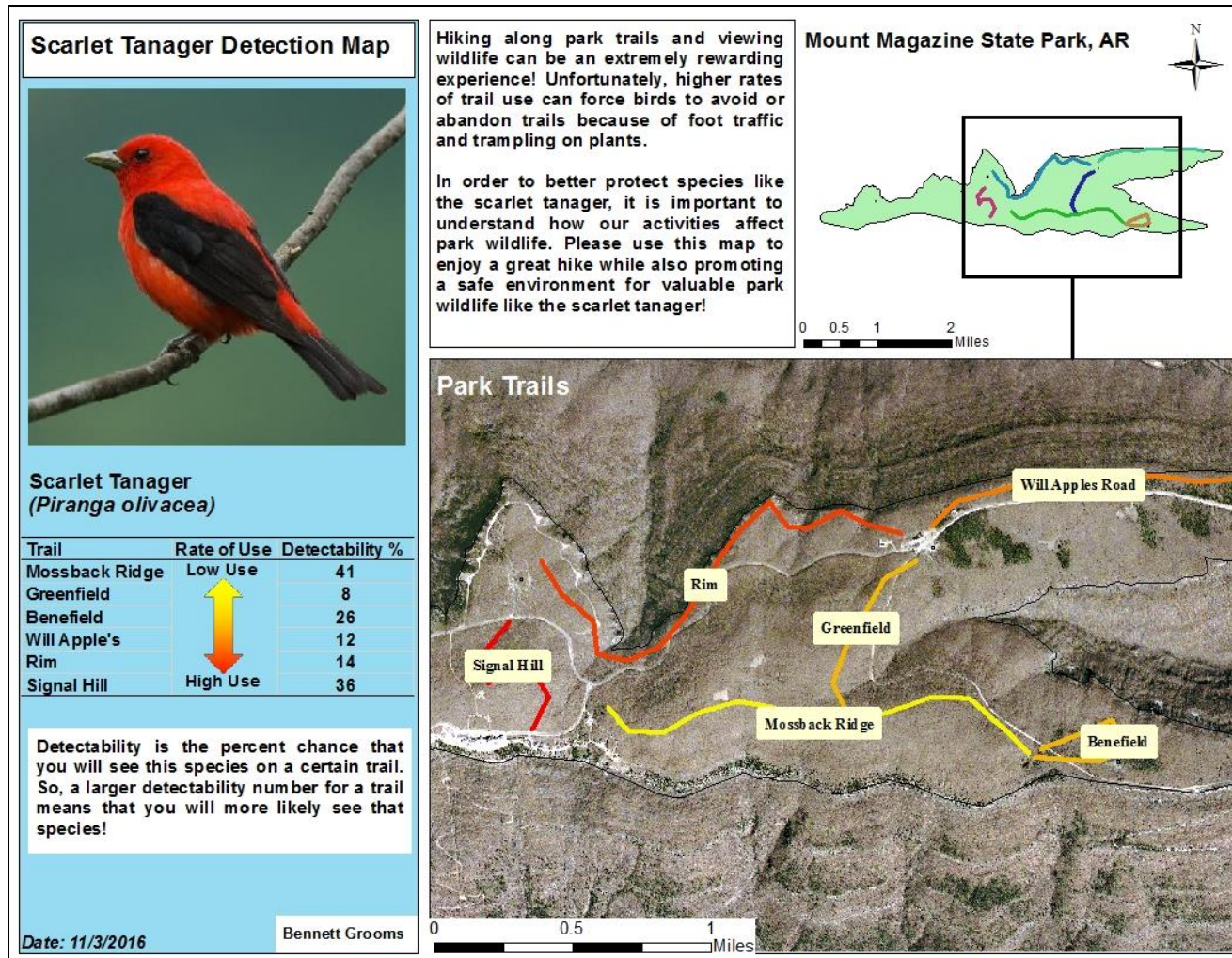


Figure 3.5. Detectability of scarlet tanagers (*Piranga olivacea*) in relation to rate of trail use at Mount Magazine State Park, Arkansas, 2015.

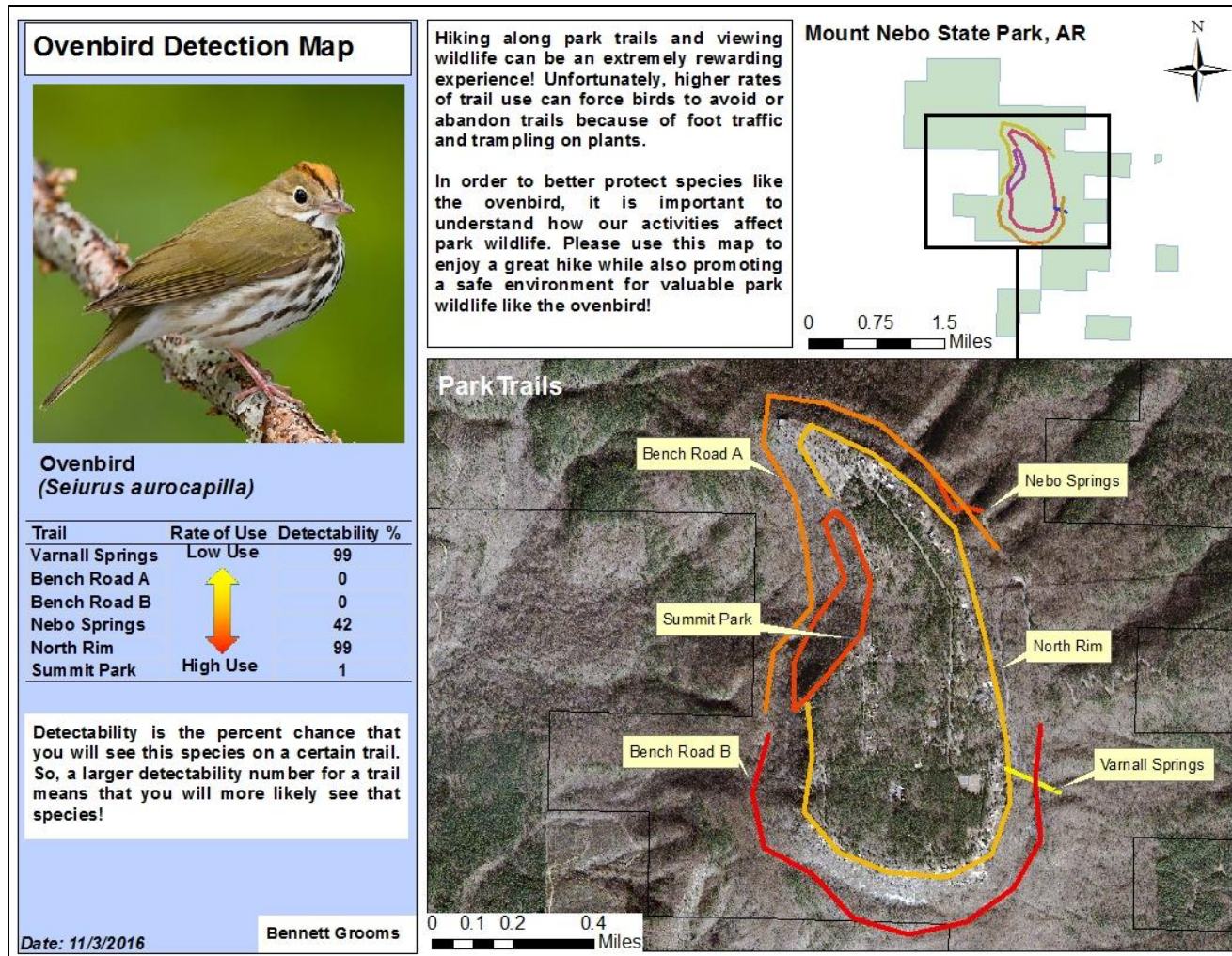


Figure 3.6. Detectability of ovenbirds (*Seiurus aurocapilla*) in relation to rate of trail use at Mount Nebo State Park, Arkansas, 2015.

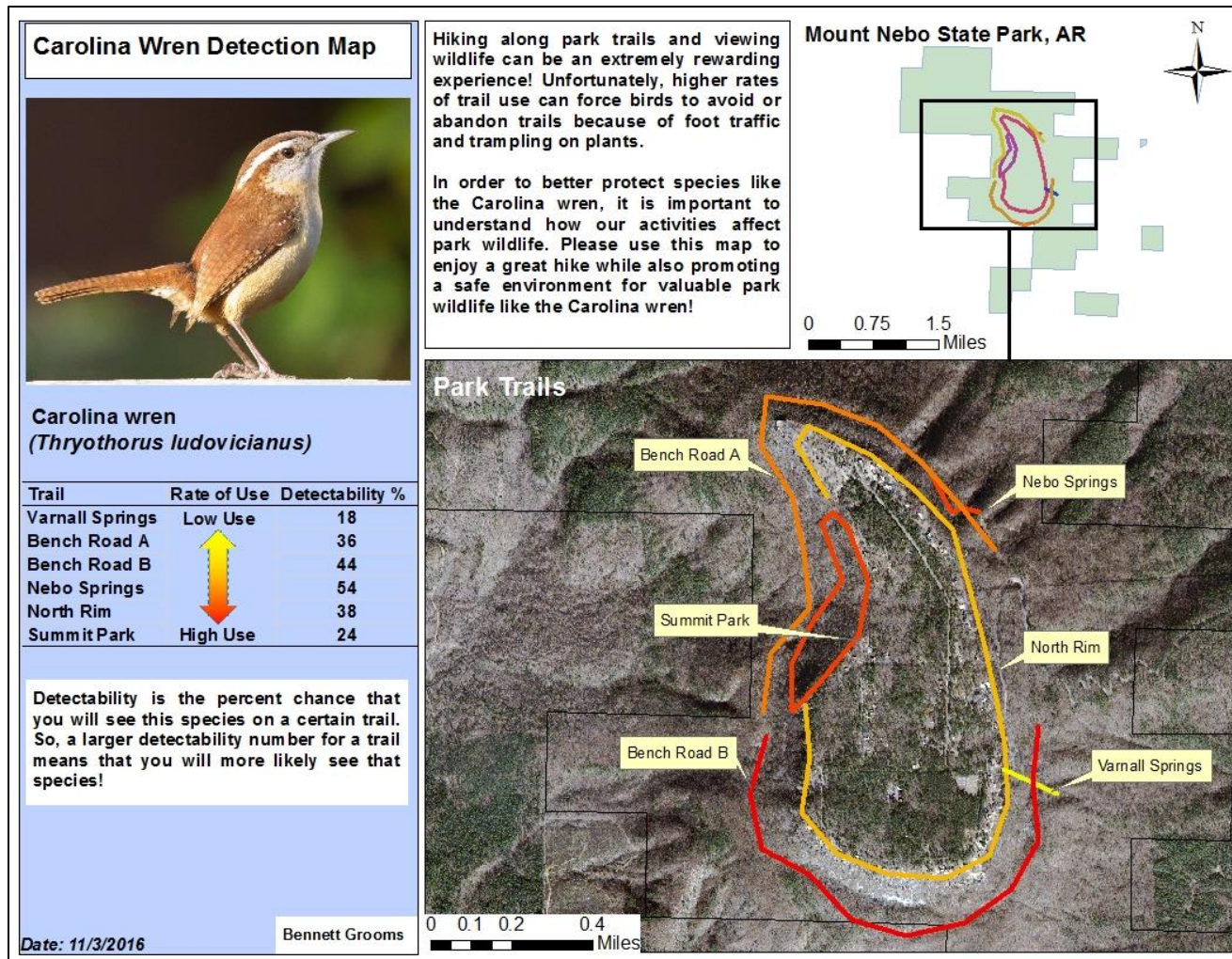


Figure 3.7. Detectability of Carolina wrens (*Thryothorus ludovivianus*) in relation to rate of trail use at Mount Nebo State Park, Arkansas, 2015.

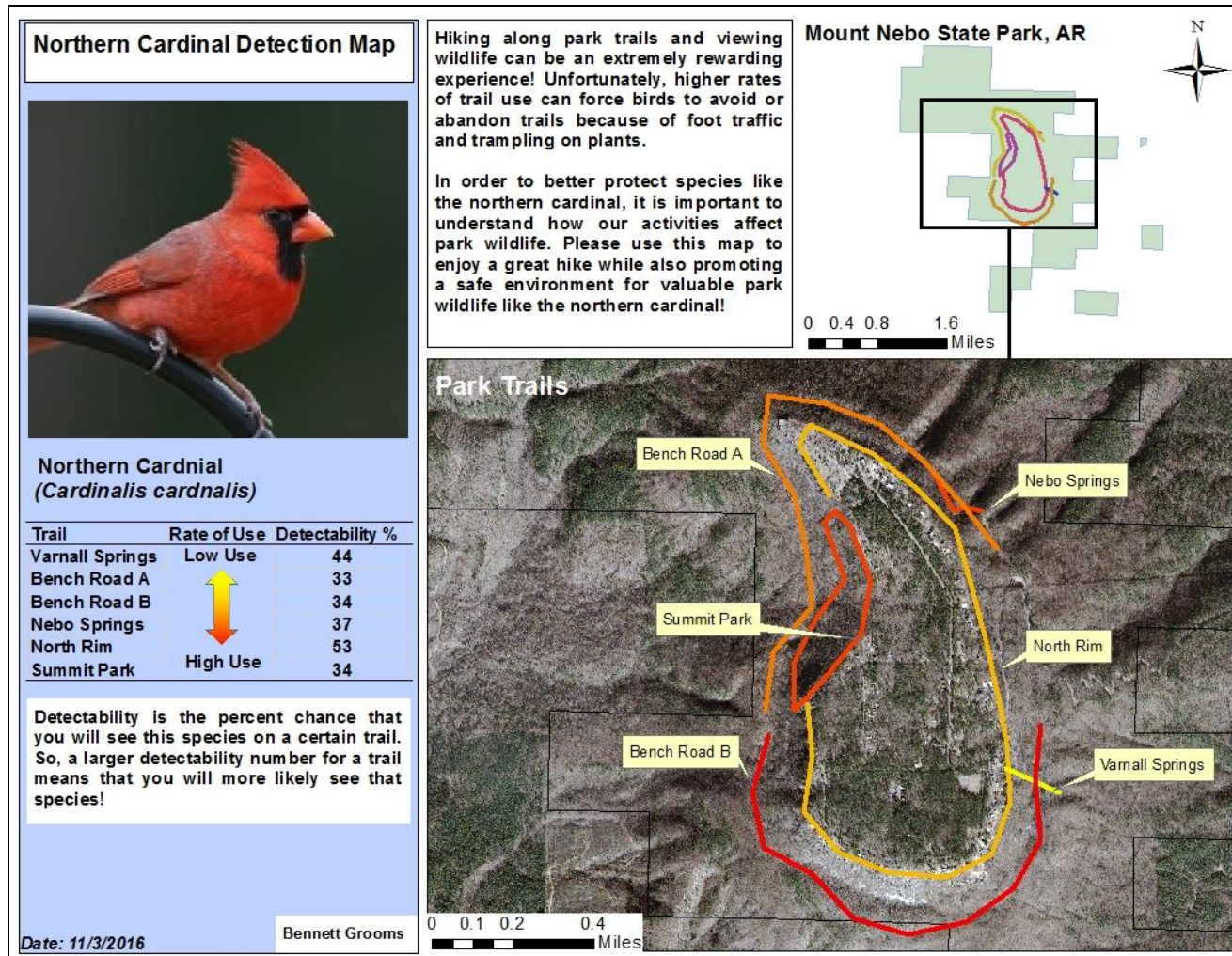


Figure 3.8. Detectability of northern cardinals (*Cardinals cardinalis*) in relation to rate of trail use at Mount Nebo State Park, Arkansas, 2015.

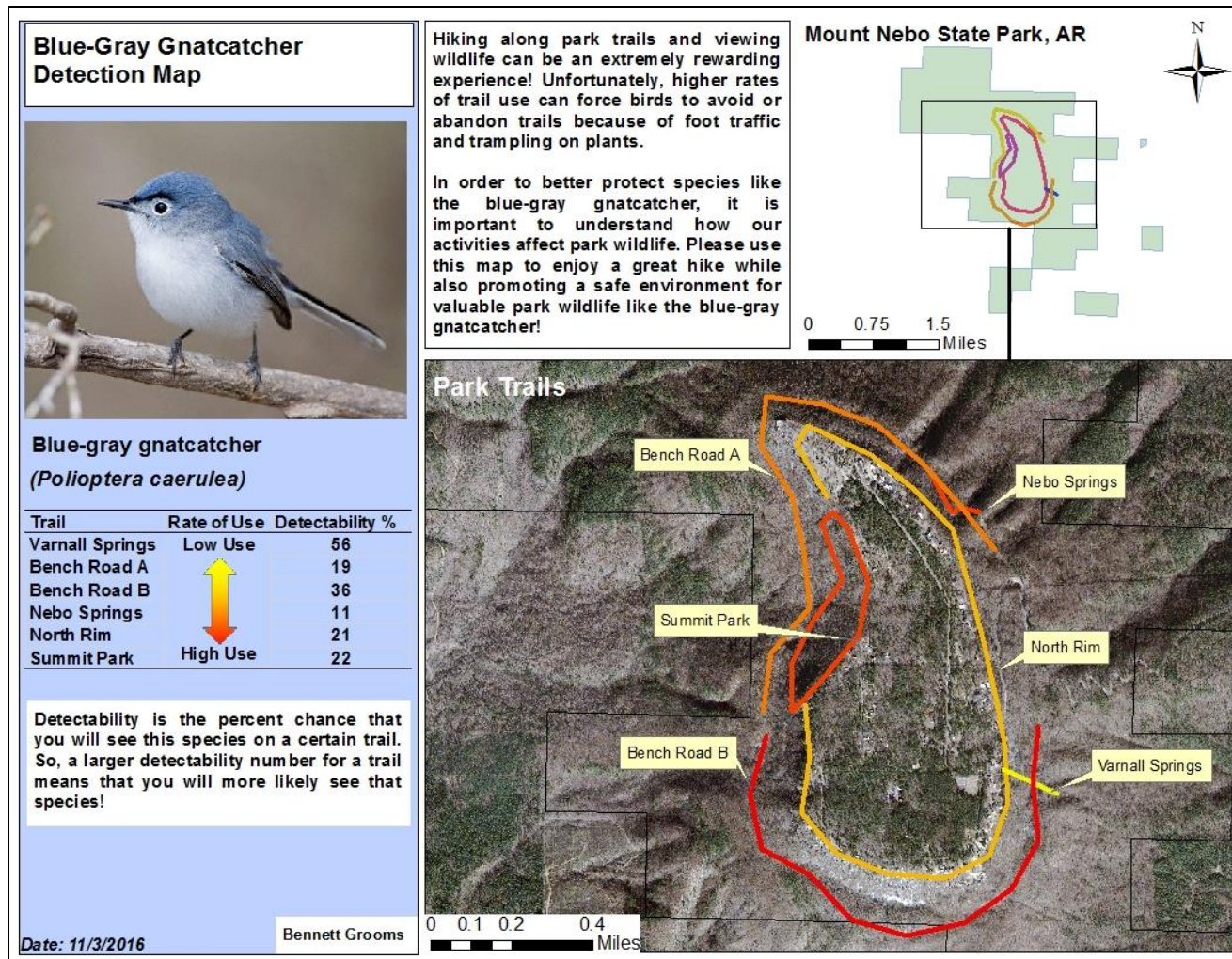


Figure 3.9. Detectability of blue-gray gnatcatchers (*Polopptila caerulea*) in relation to rate of trail use at Mount Nebo State Park, Arkansas, 2015.

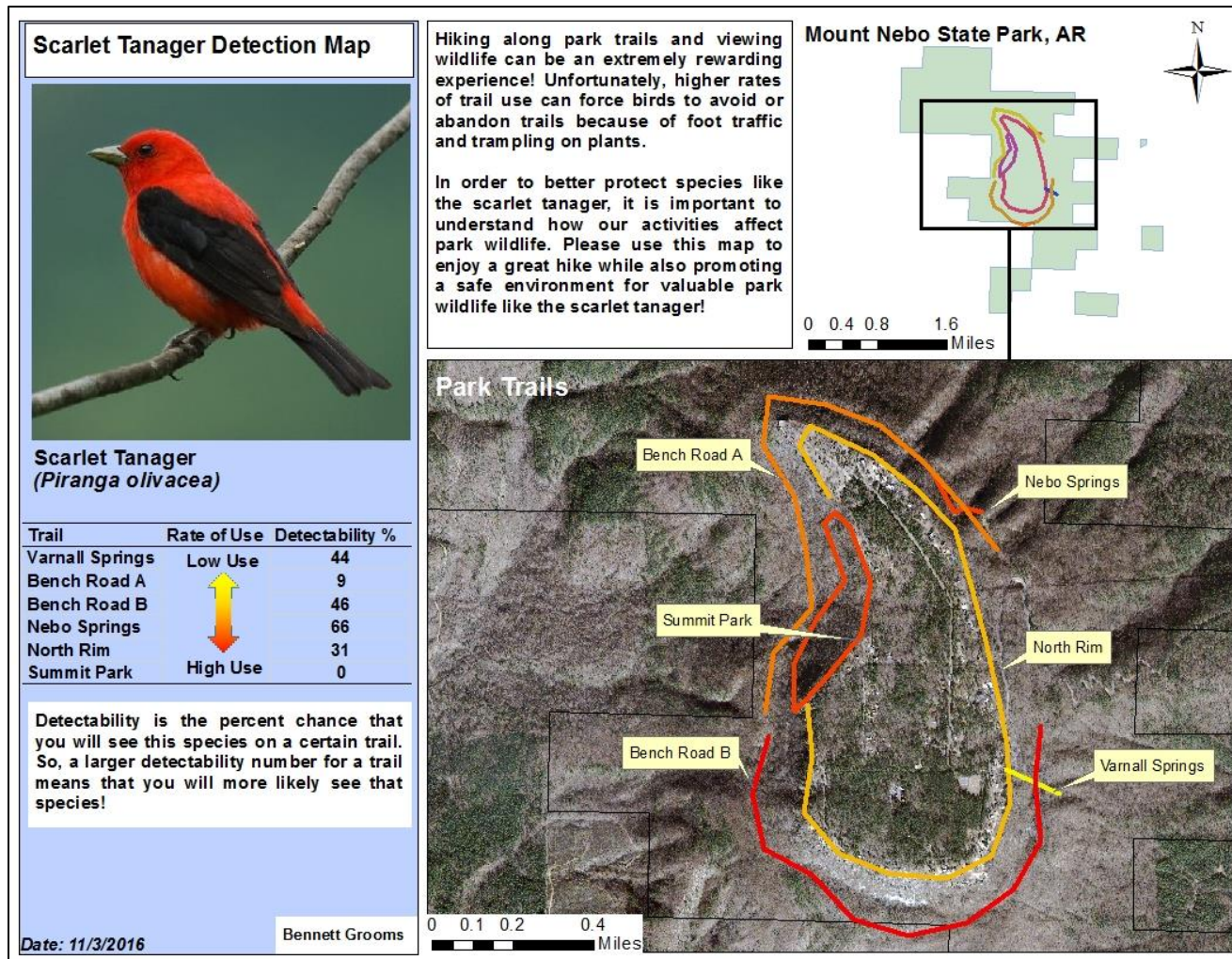


Figure 3.10. Detectability of scarlet tanagers (*Piranga olivacea*) in relation to rate of trail use at Mount Nebo State Park, Arkansas, 2015.

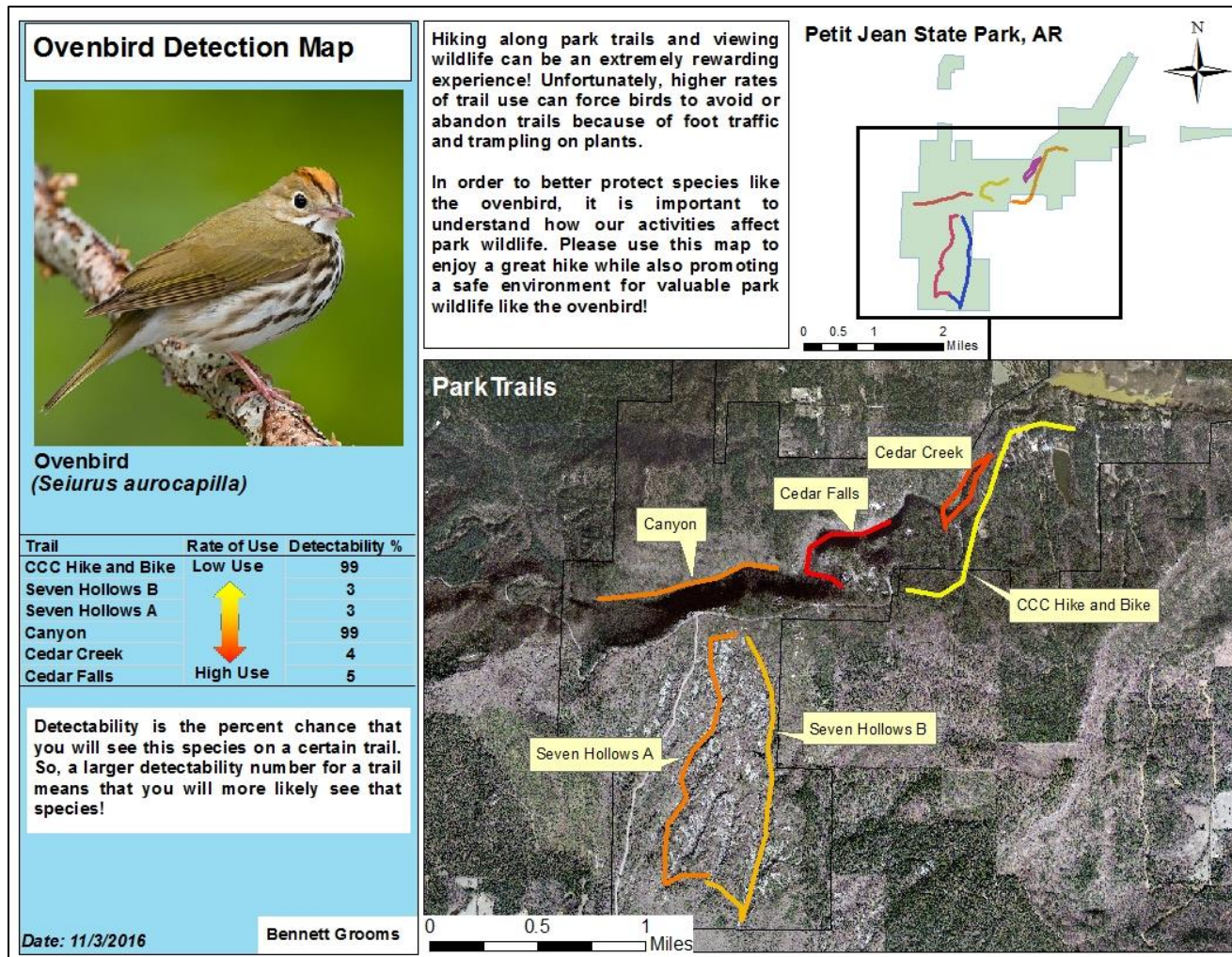


Figure 3.11. Detectability of ovenbirds (*Seiurus aurocapilla*) in relation to rate of trail use at Petit Jean State Park, Arkansas, 2015.

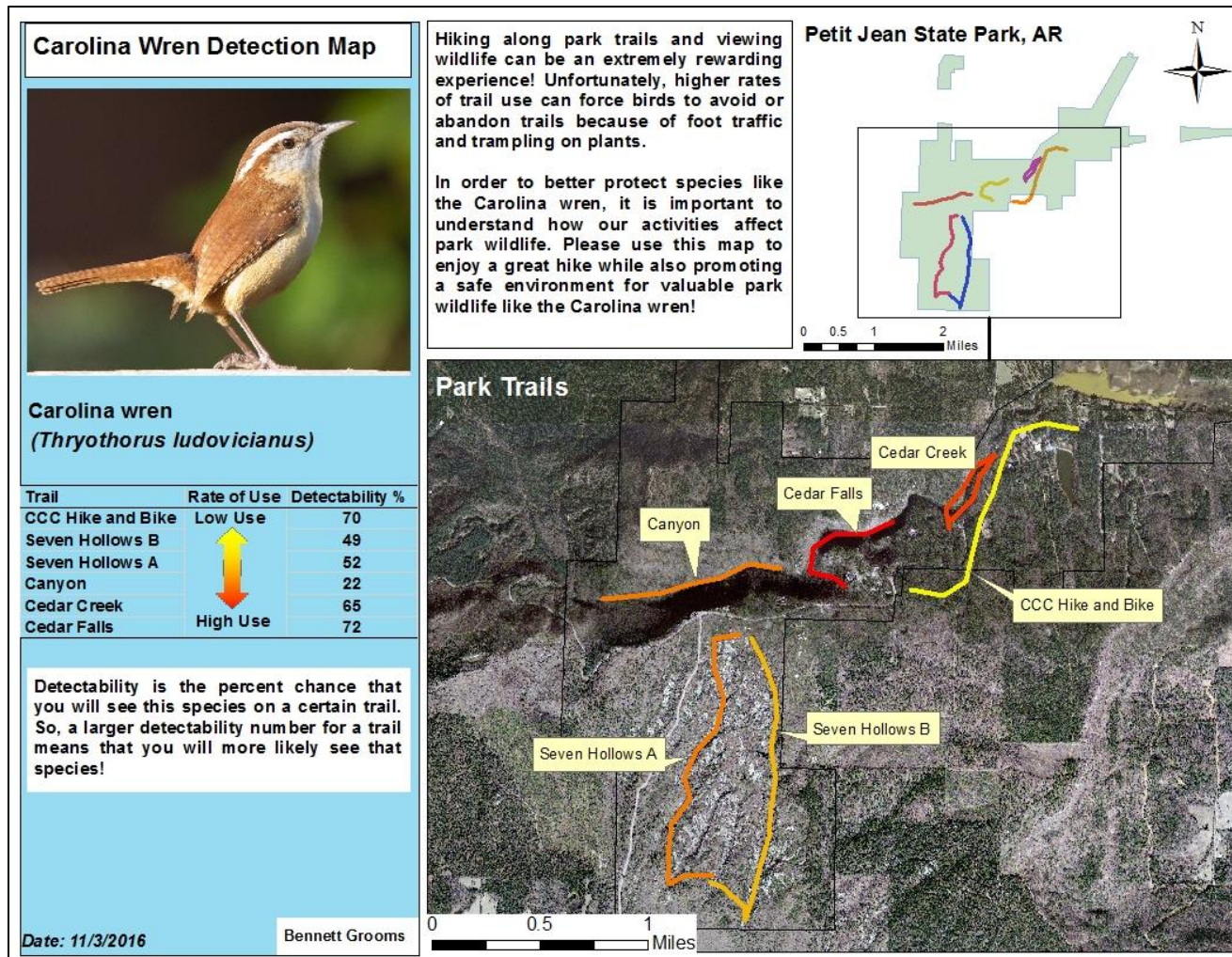


Figure 3.12. Detectability of Carolina wrens (*Thryothorus ludovicianus*) in relation to rate of trail use at Petit Jean State Park, Arkansas, 2015.

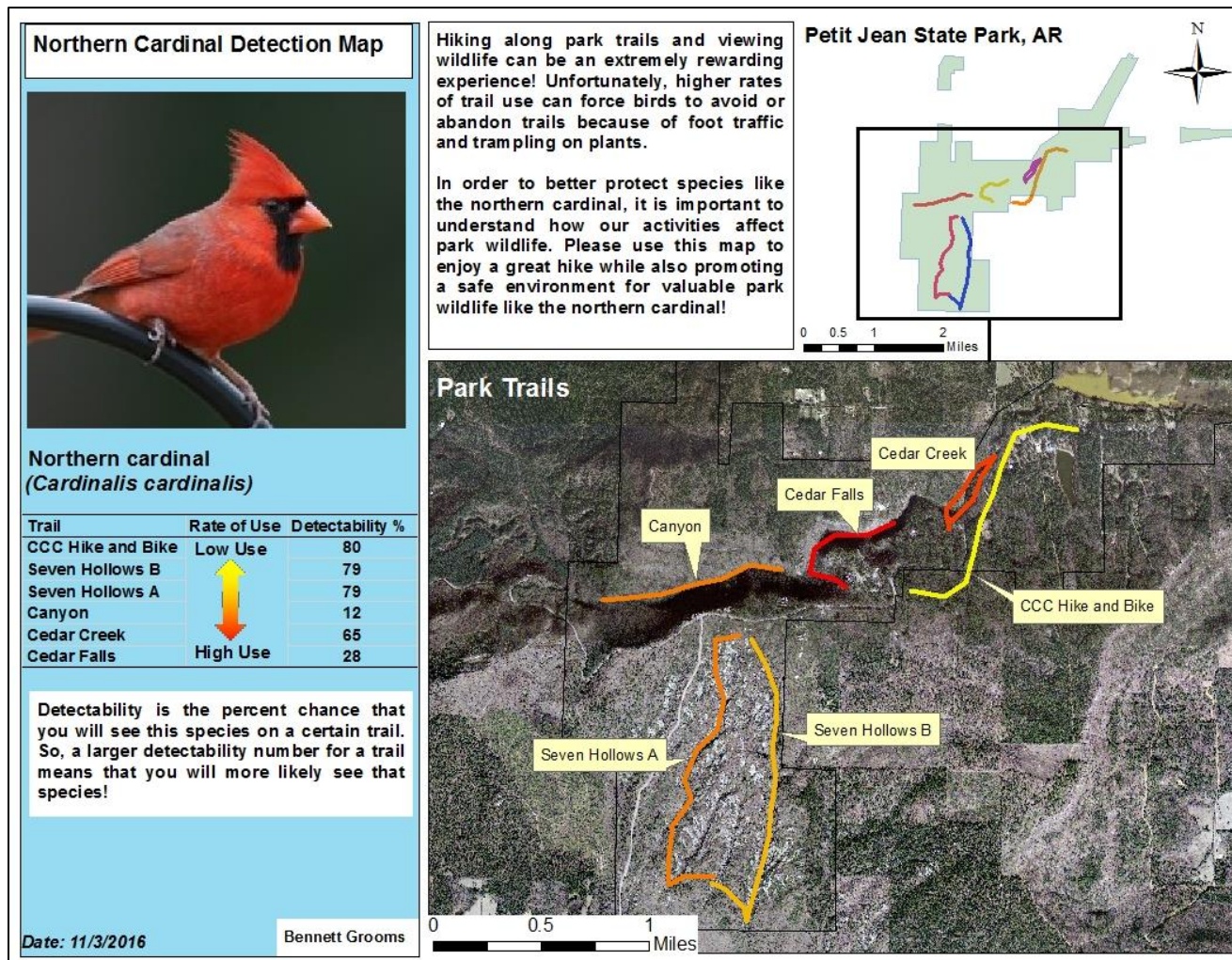


Figure 3.13. Detectability of northern cardinals (*Cardinals cardnalis*) in relation to rate of trail use at Petit Jean State Park, Arkansas, 2015.

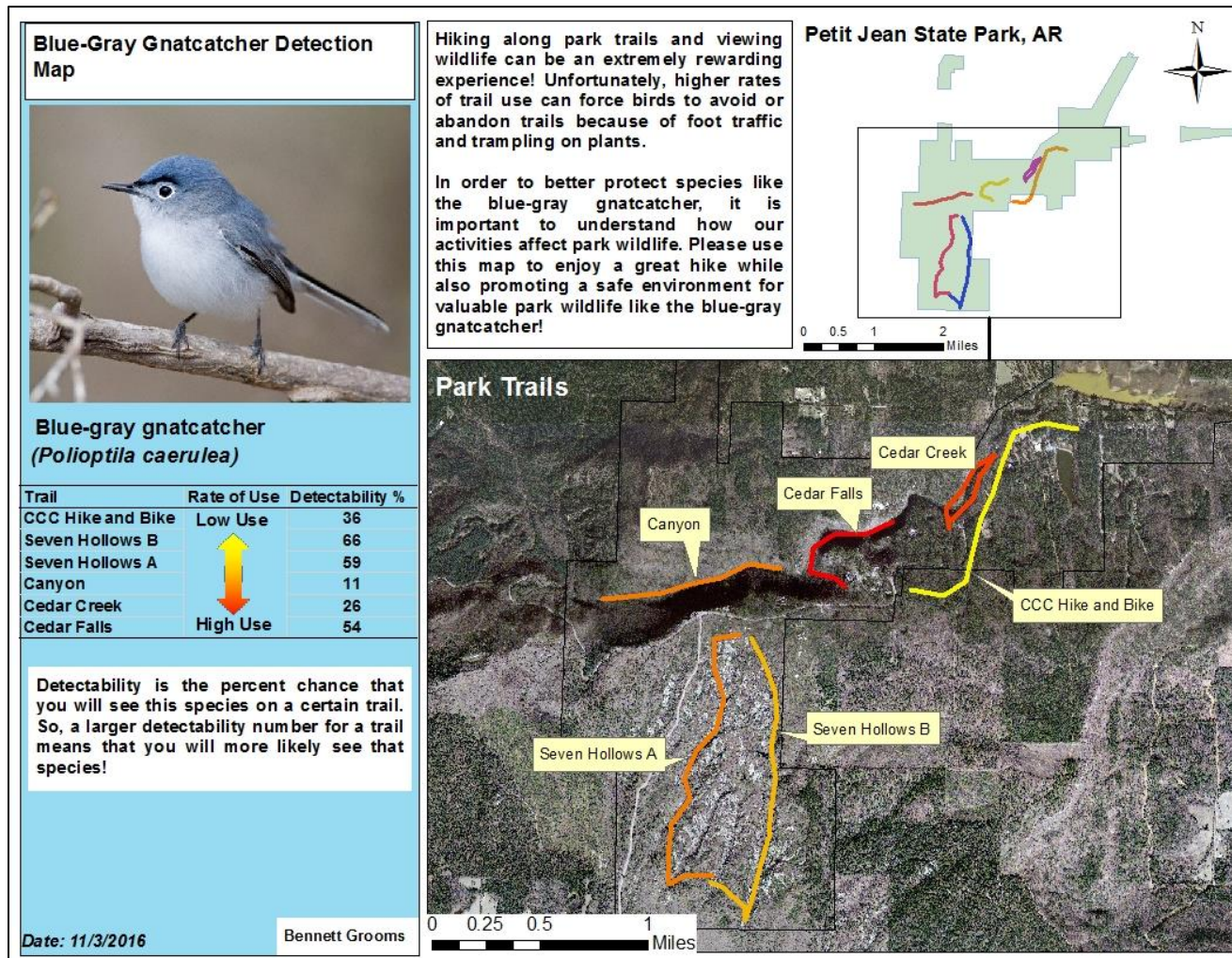


Figure 3.14. Detectability of blue-gray gnatcatchers (*Polioptila caerulea*) in relation to rate of trail use at Petit Jean State Park, Arkansas, 2015.

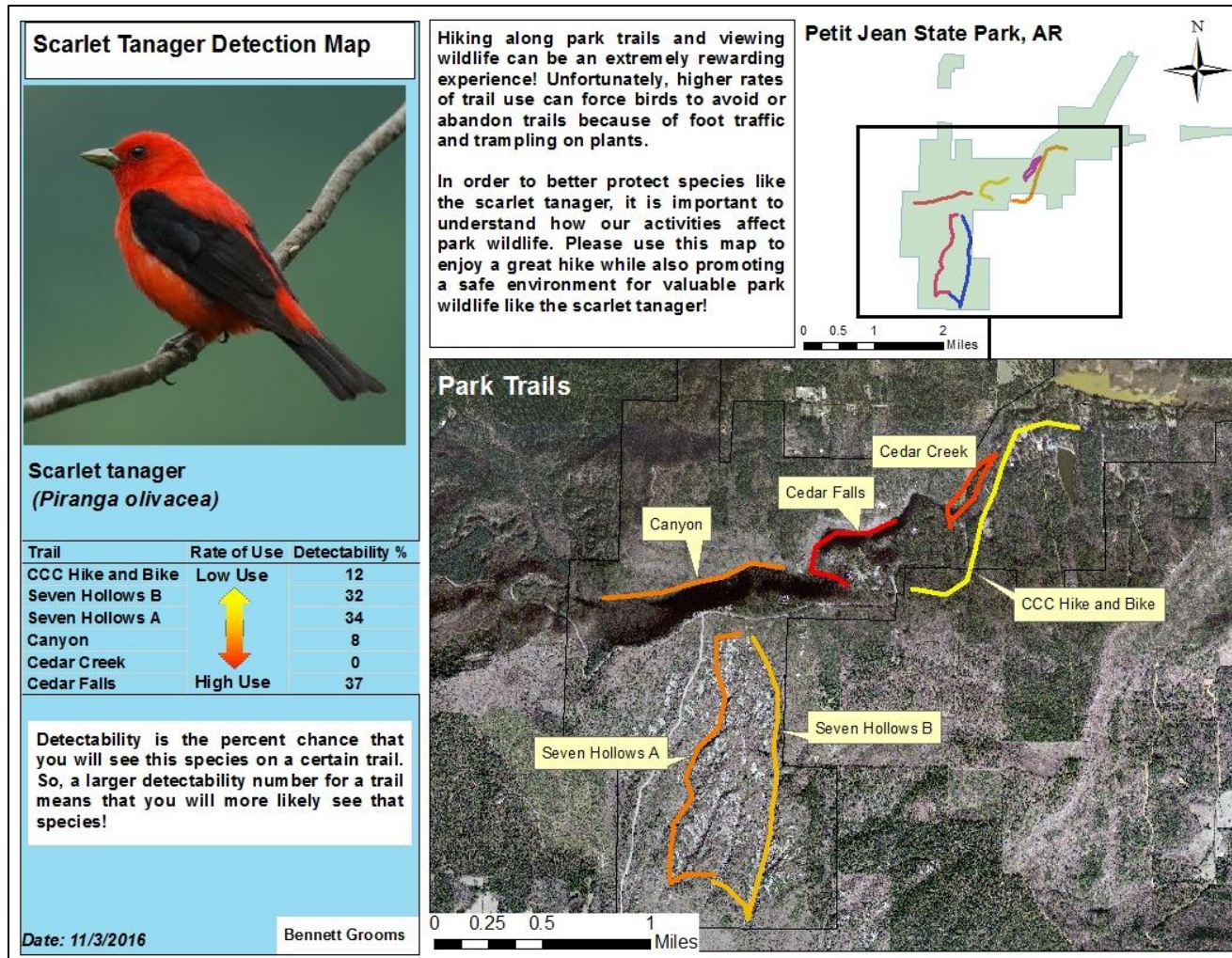


Figure 3.15. Detectability of scarlet tanagers (*Piranga olivacea*) in relation to rate of trail use at Petit Jean State Park, Arkansas, 2015.

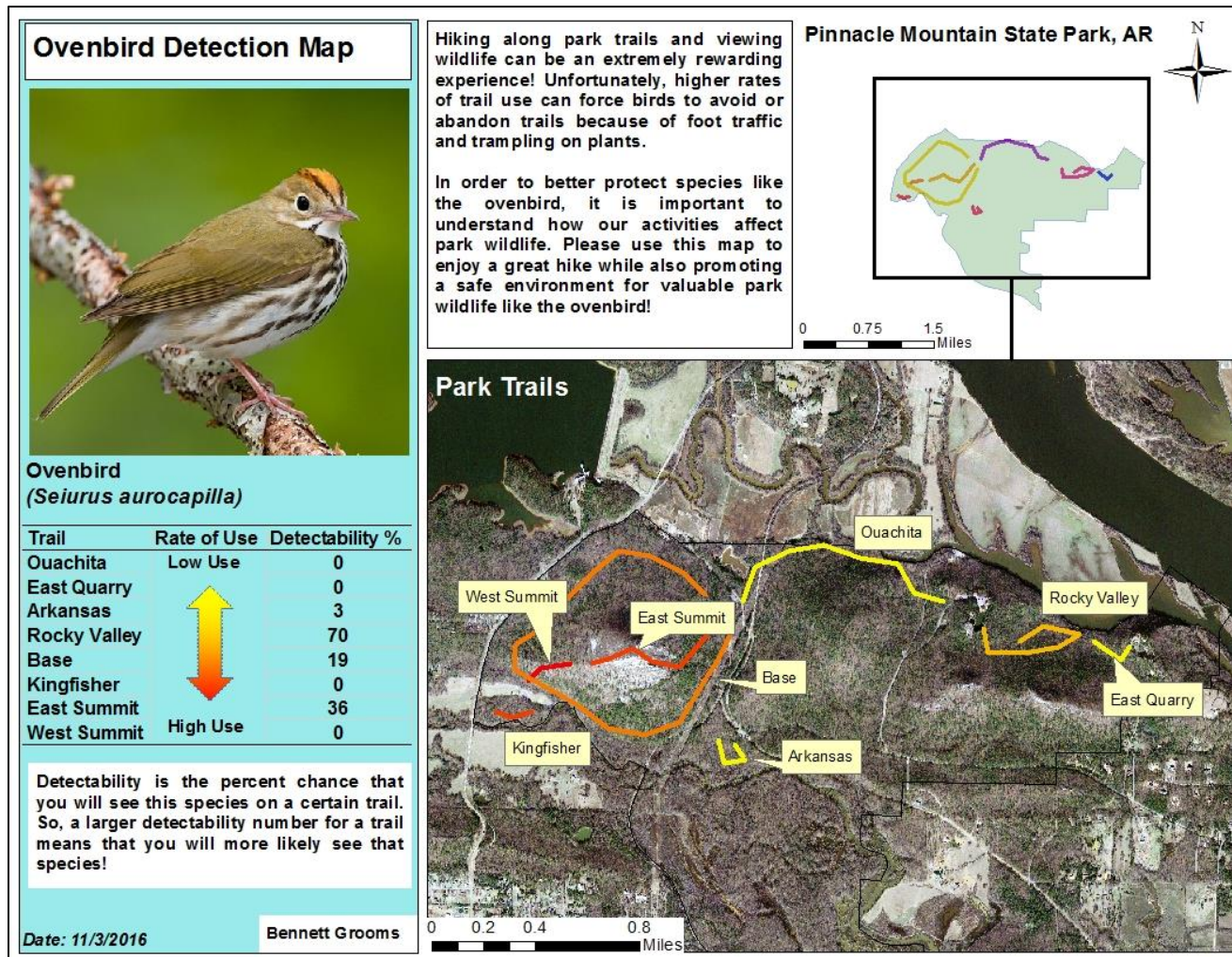


Figure 3.16. Detectability of ovenbirds (*Seiurus aurocapilla*) in relation to rate of trail use at Pinnacle Mountain State Park, Arkansas, 2015.

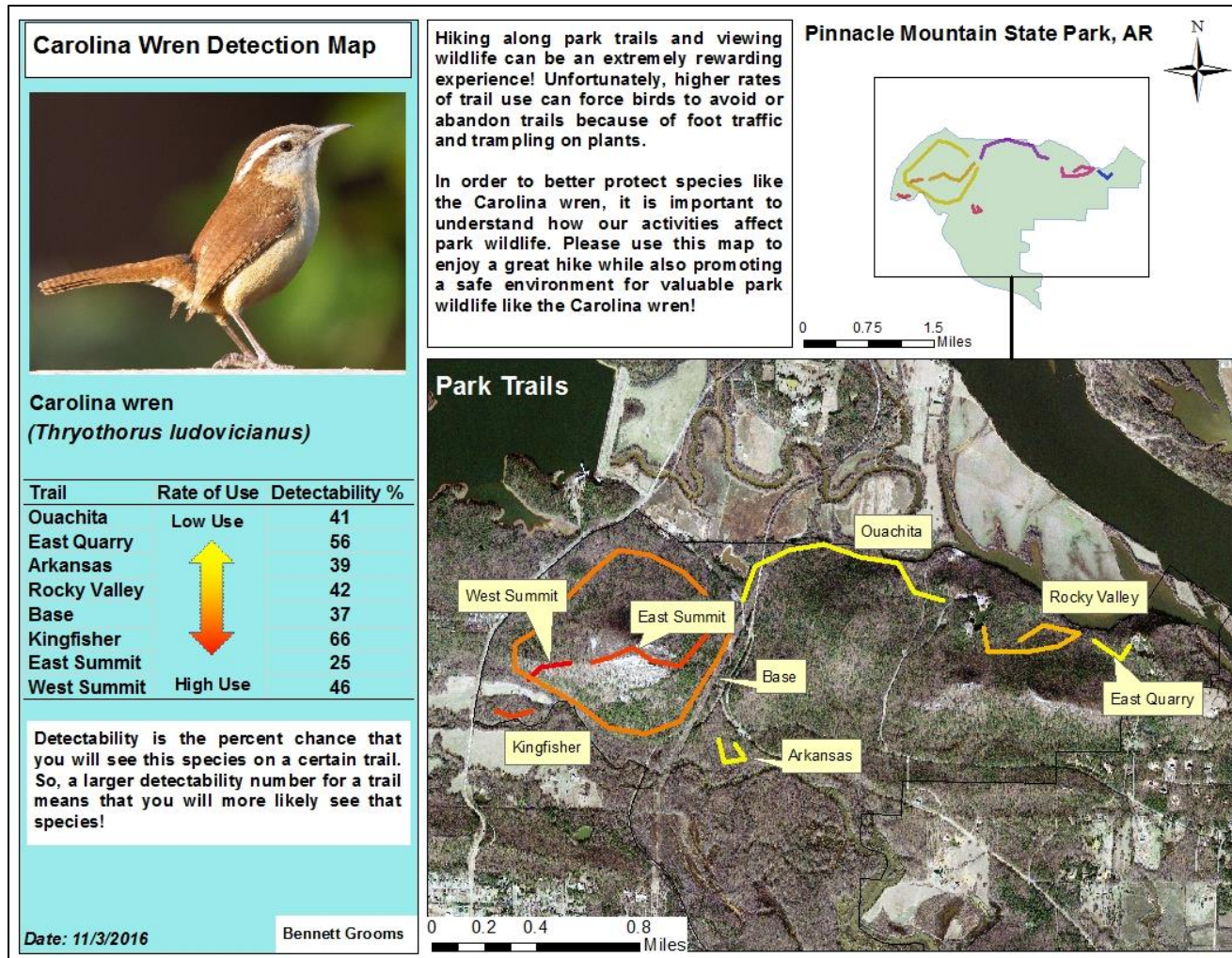


Figure 3.17. Detectability of Carolina wrens (*Thryothorus ludovicianus*) in relation to rate of trail use at Pinnacle Mountain State Park, Arkansas, 2015.

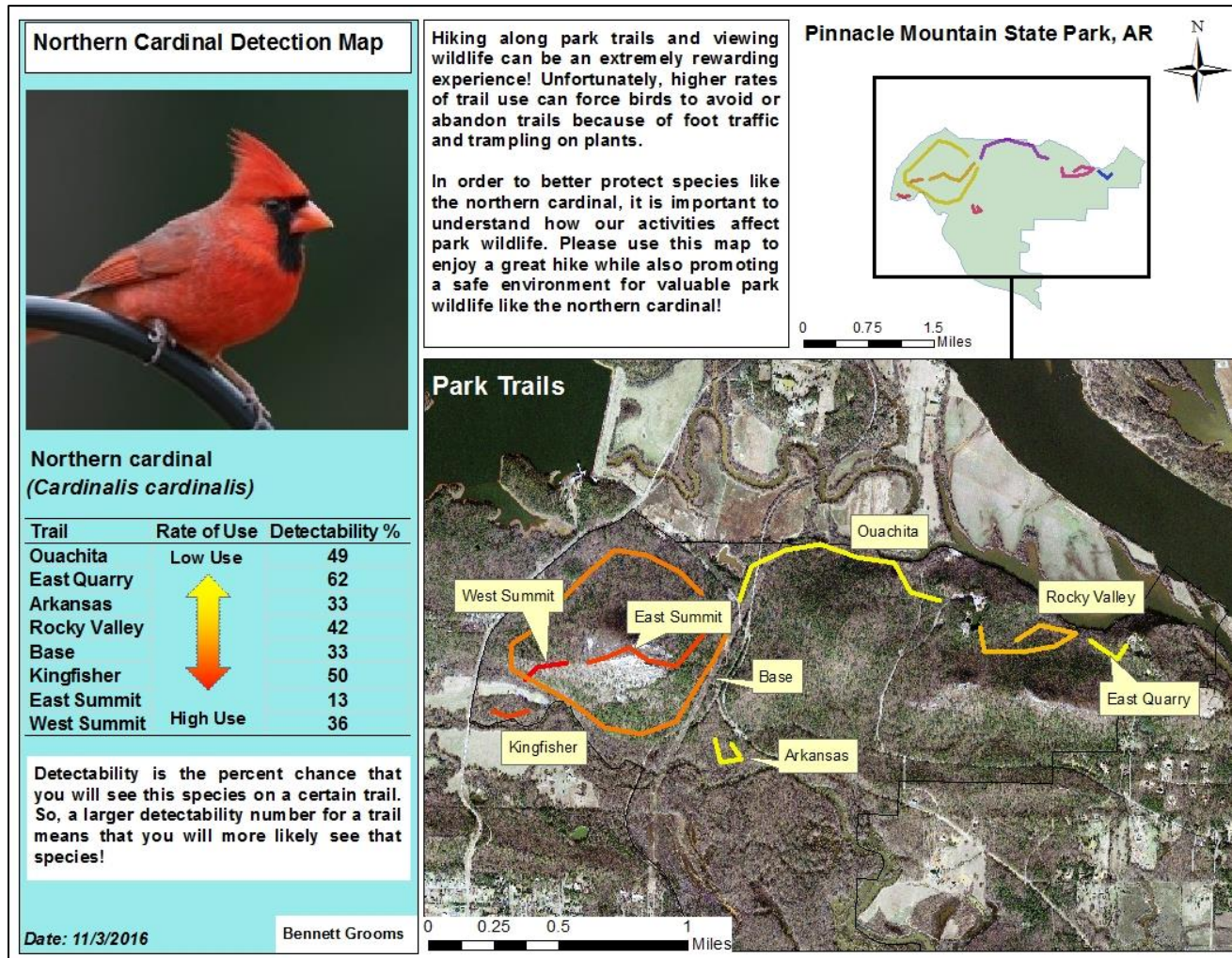


Figure 3.18. Detectability of northern cardinals (*Cardinals cardnalis*) in relation to rate of trail use at Pinnacle Mountain State Park, Arkansas, 2015.

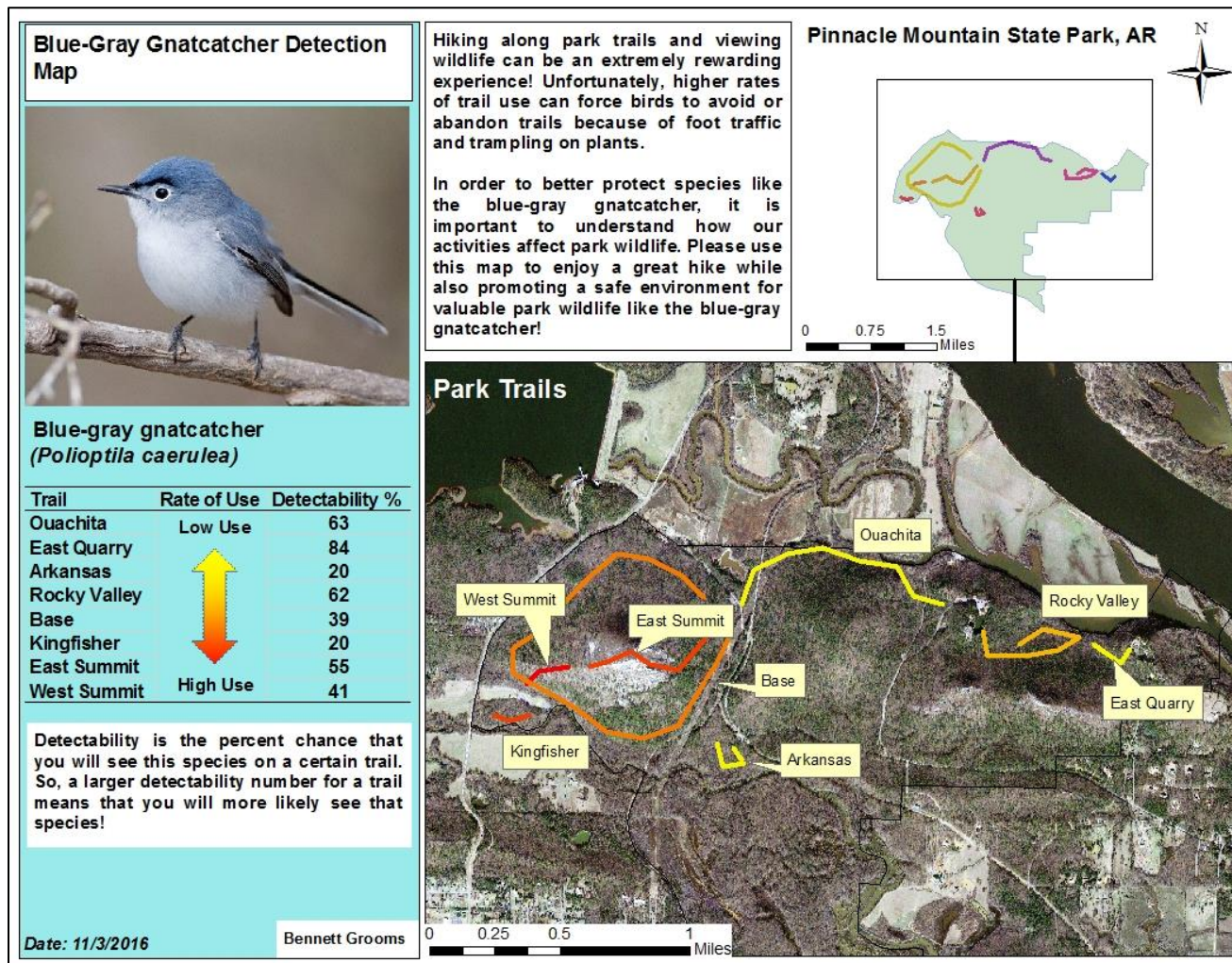


Figure 3.19. Detectability of blue-gray gnatcatchers (*Polopptila caerulea*) in relation to rate of trail use at Pinnacle Mountain State Park, Arkansas, 2015.

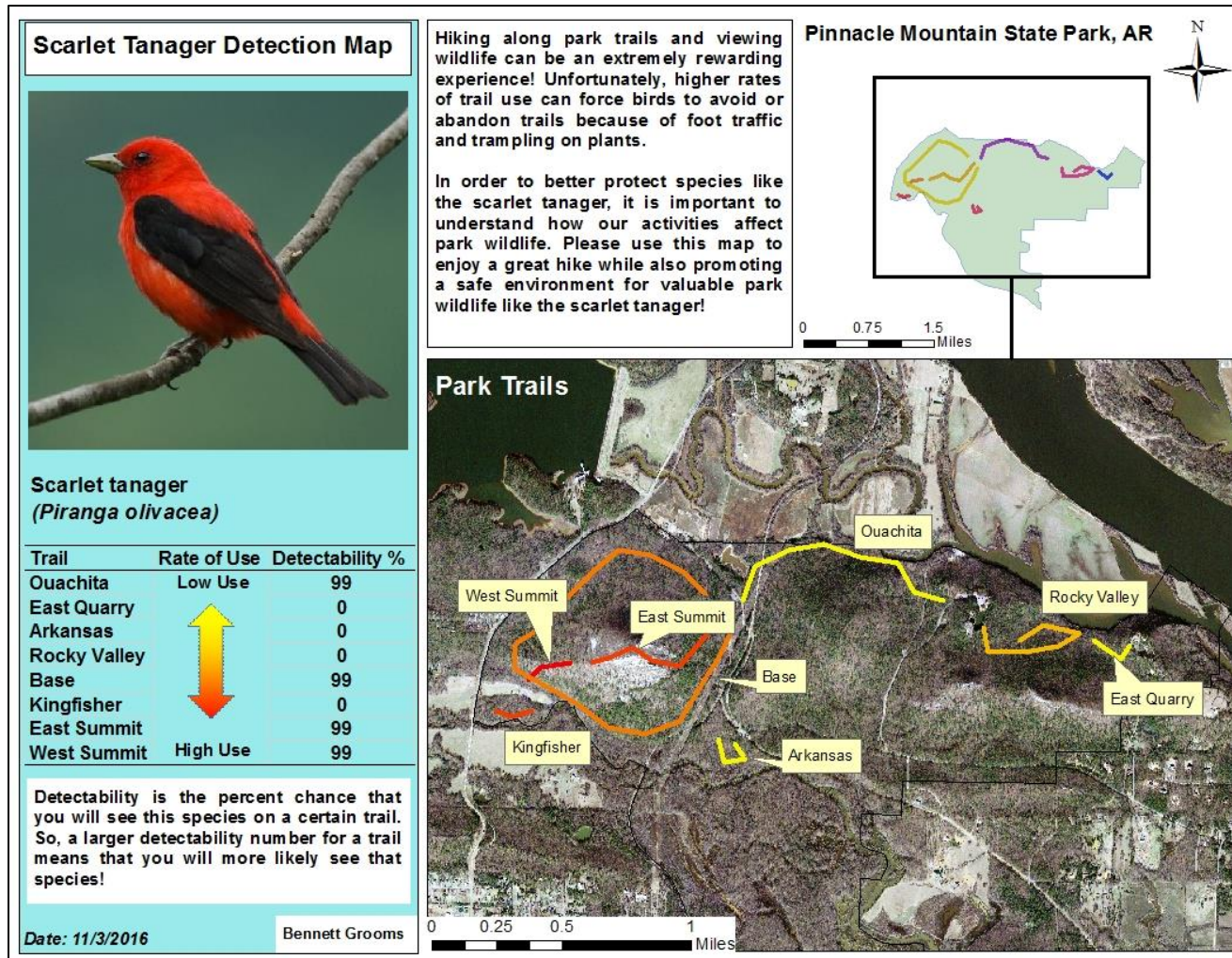


Figure 3.20. Detectability of scarlet tanagers (*Piranga olivacea*) in relation to rate of trail use at Pinnacle Mountain State Park, Arkansas, 2015.

CHAPTER IV:
EFFICACY OF A PILOT CITIZEN SCIENCE PROGRAM FOR ARKANSAS
STATE PARKS

Citizen science is the holistic combination of ecological research with environmental education and participation (Trumbull et al. 2000, Galloway et al. 2006, Dickinson et al. 2012). It uses citizens to collect, input, and organize field data for scientific research in a mutually beneficial process to scientists and volunteers (Lepczyk 2005, Bonney et al. 2009, Silvertown 2009, Crall et al. 2011, Kremen et al. 2011, Gardiner et al. 2012, Silvertown et al. 2013). Incorporating citizen science into ecological studies is a useful method of collecting large amounts of data while simultaneously involving non-professionals in wildlife research (Bonney et al. 2009, Crall et al. 2010, Dickinson et al. 2012). Citizen science programs thus have the potential to bridge the gap between traditional field sampling methods and volunteer data collection in a non-exclusive process that allows collaboration from many individuals, regardless of age, education, and experience (Trumbull et al. 2000, Bonney et al. 2009, Silvertown 2009, Dickinson et al. 2012, Gardiner et al. 2012).

One of the major strengths of citizen science lies in its ability to monitor and record large varieties and quantities of taxa which would typically require extensive amounts of observations over an array of habitats and time (Bonney et al. 2009, Kremen et al. 2011, Gardiner et al. 2012). Data collected by volunteers in citizen science projects typically consists of surveys that monitor the location, behavior, and presence/absence count of ≥ 1 species (Brandon 2003, Galloway et al. 2006, Lotz and Allen 2007, Delaney et al. 2008, Kremen et al. 2011, Gardiner et al. 2012). This model of research has been

beneficial in studying insects (Oberhausen and Prysby 2008, Gardiner et al. 2012), micro-invertebrates (Boudreau and Yan 2004, Delaney et al. 2008, Crall et al. 2011), woody vegetation (Brandon 2003), mammals (Newman et al. 2002, Toms and Newson 2006, Weckel et al. 2010), amphibians (Genet and Sargent 2003, Lotz and Allen 2007), and avian communities (Trumbull et al. 2000, Altizer et al. 2004, Cohn 2008, Crall et al. 2010, Farmer et al. 2012). Notable citizen science projects such as the Christmas Bird Count and the Breeding Bird Survey from the Cornell Lab of Ornithology (Trumbull et al. 2000, Silvertown 2009) and the Monarch Larva Monitoring Project (Kremen et al. 2011) have created large databases of species' demographic, behavioral, and spatial data which are publicly available and have yielded sufficient data for population conservation and management (Trumbull et al. 2000, Cohn 2008, Kremen et al. 2011, Dickinson et al. 2012).

Three recurring benefits have been observed with the implementation of citizen science in ecological research: 1) reduced costs in research, tools, and sampling methods; 2) increased spatial and temporal sampling of species; and 3) more opportunities for public outreach and scientific education. Citizen science relies on individuals that show an interest in scientific learning and empowerment, often attracting volunteers already heavily interested in the focal taxa. Volunteers usually cover the costs of participation, travel, and field equipment (e.g., field guides and test kits; Ericsson and Wallin 1999, Trumbull et al. 2000, Leslie et al. 2004, Crall et al. 2011), thus, circumventing the costs of traditional field research. Employing citizen science also facilitates larger scale research designs, which can aid in collecting enough data for inferences on patterns and trends of populations across varying spatial scales (Delaney et al. 2008, Bonney et al.

2009, Silvertown 2009, Crall et al. 2010, Kremen et al. 2011). Furthermore, citizen science provides scientific outreach and wildlife education opportunities to the public (Galloway et al. 2006, Lotz and Allen 2007, Delaney et al. 2008, Kremen et al. 2011). Evaluations of volunteers before and after participating in citizen science has indicated positive impacts on their understanding of the scientific process (Trumbull et al. 2000) as well as encouraged personal interests in wildlife viewing and sustainable wildlife recreation (Lotz and Allen 2007, Dickinson et al. 2012).

The principle hesitations among the scientific community with citizen science are the validity of the data collected by volunteers (Penrose and Call 1995, Brandon 2003, Delaney et al. 2008, Crall et al. 2010) including possible inaccuracies and biases resulting from variations in participant experience, background knowledge, and demographics (Lotz and Allen 2007, Delaney et al. 2008, Dickinson et al. 2010, Farmer et al. 2012). Researchers in many large-scale monitoring projects have been unable to validate volunteer data, leading to possible errors in data pools used for subsequent research (Firehock and West 1995, Genet and Sargent 2003, Delaney et al. 2008). Observer-level errors typically consist of the misidentification of species (Engle and Voshell 2002, Galloway et al. 2006), over-reporting rare species (Harnick and Ross 2003, Galloway et al. 2006, Gardiner et al. 2012), and bias in under-recording common species (Gardiner et al. 2012). Additionally, variations in the human dimensions of citizen science participants can affect the accuracy of data (Delaney et al. 2008, Farmer et al. 2012). Participant demographics such as education level, age, income level, species identification experience, and scientific knowledge can all affect participant accuracy in recording field data (Trumbull et al. 2000, Leslie et al. 2004, Crall et al. 2011), although few projects

have heavily analyzed these relationships (Delaney et al. 2008, Crall et al. 2011, Gardiner et al. 2012).

State park systems offer an ideal setting for the implementation and validation of citizen science studies in ecological research. State parks serve under a dual role to conserve the flora and fauna within the parks while also providing outdoor recreation and education to park visitors (Leung and Marion 2000, Reed and Merenlender 2008, Larson 2015, Kays et al. 2016), following similar goals to that of citizen science. These goals are accomplished through data collection gained from park managers encouraging floral and faunal observation by park visitors via facility use and guided programs (Brownson et al. 2000, Cohn 2008, Black 2009). Data collection techniques typically consists of a presence/absence methodology, combining opportunistic observations from park officials supplemented by wildlife sightings relayed from park visitors (Marsh and Trenham 2008, Mattsson and Marshall 2009, Shannon et al. 2014). While these data have been used to assess how visitors utilize park facilities and how park activities influence wildlife populations (Cole 1993, Kight and Swaddle 2007, Marsh and Trenham 2008), they often lack sufficient data to observe long-term community trends. Considering the importance of conserving biotic communities while also promoting outdoor recreation opportunities to park visitors, increased efforts in monitoring taxonomic communities could provide state parks the ability to assess their current management regimes (Noon et al. 2012) and to observe associations between human park use and wildlife communities (Boyle and Samson 1985, Cole 1993, Marion and Leung 2001, Jones 2011, Van Strien et al. 2013).

The Arkansas Division of State Parks (ADSP) serves as a primary example of the state park system's potential ability to incorporate citizen participation in wildlife and

park use studies. State parks in Arkansas include 6 natural ecoregions that each sustain an abundance of common, migratory, and rare species spanning across multiple taxa (USEPA 2016). The current ADSP wildlife monitoring program, established in 2013, is composed of presence/absence wildlife sightings recorded by park staff into an online Natural Resource Inventory Database (NRID). Data in the NRID includes the scientific and common name of the species sighted, its location in the park, and the time and date of the sighting. These data then can be compiled into species checklists for each taxon and each park; used in park-to-park comparisons of species composition; and to observe community dynamics and distributions of wildlife populations in the parks. While this approach has provided useful data on the common and migratory species that reside in Arkansas state parks, only a select few park officials regularly contribute to the NRID, with those observations typically restricted to species of personal interests. As such, incorporating citizen participation in the NRID could greatly add to the understanding of park communities by increasing the frequency, diversity, and total number of species recorded.

In 2014, the ADSP developed an experimental citizen science survey instrument with the goal of incorporating presence/absence data gathered by visitors on species within Arkansas state parks into the NRID system. In 2015, the survey tool was made available at 4 Arkansas state parks and provided park visitors the opportunity to record species observed during their visit. Survey dispersal and collection followed a passive approach, with participants responsible for collecting and returning surveys. To my knowledge, no prior citizen science projects have followed this passive approach, rather they have enlisted volunteers or led guided data collection regimes (Galloway et al. 2006,

Lotz and Allen 2007, Delaney et al. 2008, Kremen et al. 2011, Gardiner et al. 2012). My objectives were to validate the quality of avian, mesocarnivore, and woody vegetation community metric data collected by participants in the new ADSP citizen science project to assess the accuracy and precision of visitor taxa reports and to observe for any visitor observation biases. It is also imperative to understand whom is participating in citizen science and what their motivations are in order to provide recommendations for future outreach and to address the possible inaccuracies that stem from variations in participant experience and demographics (Delaney et al. 2008, Raddick et al. 2010, Crall et al. 2011). Therefore, I used a human dimensions survey to investigate participant demographics, scientific background, and motivations which was made available with the ADSP citizen science survey. Placing greater emphasis on data validation techniques and sampling designs focused on recording participant demographics could address the potential observer errors encountered in previous citizen science research and provide useful information for the future implementation of citizen science in Arkansas state parks.

METHODS

Study Area

Please see the study area description in Chapter I.

Standard Taxa Data Collection

Please see the taxa data collection methods in Chapter I.

Citizen Science Taxa Data Collection

The ADSP citizen science survey (Appendix A) was made available at display posters in the visitor centers of the 4 state parks from May 2015 – May 2016. Display

posters included the survey, information explaining the details of the ADSP citizen science project, and the importance of wildlife monitoring in state parks (Appendix B). Surveys were comprised of a threefold taxa input sheet where participants recorded information on species name, the date of their sighting, location of the sighting (specific park and position in the park), the number of each species seen, and any notes taken for the sighting. Prior to deployment, I calculated that I would need approximately 1,000 surveys to conduct accuracy and precision analyses between the standard taxa data and citizen science taxa data (population size $\approx 25,000$, $\alpha = 0.05$, $\pm 3\%$ sampling error). In response, ADSP printed 8,000 surveys, with each of the 4 parks receiving an initial pack of 500 surveys for the display. Efforts were made by some park staff to advertise and encourage visitors to take part in the survey, but survey administration was primarily a passive process, with the collection and return of the surveys left to the responsibility of the participant.

Citizen Science Human Dimensions Survey

Variations in participant demographics (e.g., age, ethnicity, gender), level of education, personal motivations, and scientific background can all affect the accuracy and level of participation in citizen science projects (Galloway et al. 2006, Crall et al. 2010). I constructed a supplemental human dimension survey to examine these factors in NRID survey participants (Appendix C). My survey was compiled of 12 questions designed to collect information on participant demographics (e.g., age, gender, education, ethnicity, and occupation), knowledge and motivations for participating in the citizen science project, and information on visitor park use. These questions were presented as a combination of categorical multiple choice and Likert scale question formats (Mauer and

Pierce 1998, Crall et al. 2011). The human dimensions survey was in-folded into the ADSP citizen science survey and located on the same display in the 4 state parks; collection and return of this survey were also the responsibility of the participant. To assess if a possible non-response bias was present within the participant population, I opportunistically surveyed park visitors during standard taxa data collection (Chapter I) on their participation in the ADSP citizen science survey. If park visitors had not participated in the NRID survey, I provided them a copy of the human dimensions survey to complete, noting on the survey that the participant did not participate in the citizen science project.

Data Analyses

Taxonomic data.— I ran a series of validation comparisons between the citizen science taxa data (hereafter, participant data) and the data I collected (Chapter I) to examine participant accuracy, precision, and possible observation bias. I calculated species richness, evenness, diversity, and composition community metrics from participant data for avian, mesocarnivore, understory woody vegetation, and overstory woody vegetation communities via the same processes used for the standard taxa data collection (please see Chapter I Data Analyses). Participant data were calculated to the species level when possible, but also to the genus level based on the assumption that participants were not likely to record mesocarnivore and woody vegetation to the species level (George and Crooks 2006, Toms and Newson 2006). Further, I only calculated community metrics based on participant data to the park level for each taxonomic community, assuming that participant observations did not occur at established sampling points or would provide sufficient location data for comparisons between trails.

For validation comparisons, I defined accuracy as how close the participant data values were to the standard data set (Hellman and Fowler 1999). I used Mann-Whitney U tests (PROC NPAR1WAY, “WILCOXON” in the PROC statement, $\alpha = 0.05$; SAS Institute, Cary, North Carolina) to compare the participant and standard data sets for each taxonomic community because participant responses were highly variable in recorded species and thus were not normally distributed (Galloway et al. 2006, Thelen and Thiet 2008). Sampling point data were used as replicates for the standard data and participant surveys served as replicates for participant data in these analyses. Additionally, I compared the actual species recorded by participants to the standard data. I designated true positives (TP) as species detected by both the participant and standard data, false positives (FP) as species recorded by participants but not by the standard data, and false negatives (FN) as species recorded in the standard data but not recorded by participants (Jordan et al. 2012). I then used these summed observations to calculate an accuracy score for species richness with the following equation: $100 \times TP / (TP + FP + FN)$ (Jordan et al. 2012).

I assessed bias in the participant data as systematic overestimates (positive bias) or underestimates (negative bias; Farmer et al. 2012) of participant species/family detections with the Bray Curtis similarity index (Plotkin and Muller-Landau 2002, Kremen et al. 2011), which calculates differences in species abundance between 2 sets of data based on species counts per set. I categorized biases as either negative or positive depending on the direction of participant estimates compared to the standard data. I also calculated the precision of species richness, evenness, and diversity of all taxonomic

groups calculated from participant data with the coefficient of variation of total recordings for each data set (Hellman and Fowler 1999).

Citizen scientist human dimensions data.— I summarized data from the human dimensions survey by demographics, scientific understanding, knowledge of citizen science, and state park use to characterize participants for each state park and the entire participant population. For responses to non-Likert scale questions, I summed the total survey responses to each question and calculated percentages for each answer from the total responses for each park. For Likert scale items, I summarized participant responses as ordinal data and used modal values to provide a central response to characterize participant attitudes. I used the same methods as used in the participant surveys to summarize data collected from human dimension surveys of non-respondents. I then used chi-square analyses (PROC FREQ) with Fisher's exact test (EXACT statement) to detect any non-response bias in survey participation (Edwards and Anderson 1987, Whitehead et al. 1993, Crall et al. 2010).

I also used chi-square analyses with Fisher's exact test to observe for potential sampling biases (Whitehead et al. 1993). Response categories for demographic questions in my survey were different from categories used in the state census survey, thus I pooled my survey response categories together to facilitate the sampling bias comparisons. I compared all the survey participant demographics from the 4 parks to the statewide Arkansas 2015 census and the survey demographics from each park separately to its nearest major city (defined as cities with populations $\geq 5,000$ citizens; UNCB 2015). Russellville, Arkansas was used for bias comparisons for Mount Magazine and Mount

Nebo; Little Rock, Arkansas was used for Pinnacle Mountain; and Morrilton, Arkansas was used for Petit Jean.

Next, I used chi-square analyses with Fisher's exact test to examine for differences in the proportion of responses to survey questions regarding demographics, park use preferences, and citizen science experiences for the overall survey participant population. Lastly, to gain a better understanding on how the specific management goals and available recreational opportunities offered by each park possibly influenced survey participant demographics and park use preferences, I compared participant responses to survey questions between the 4 parks.

RESULTS

Of the 2,000 NRID and human dimension surveys that were distributed to visitors among the 4 state parks, I collected a total of 5 NRID citizen science surveys and 38 human dimensions surveys. Unfortunately, park officials who collected both surveys did not follow my collection instructions. At Mount Nebo, park officials had separated the NRID surveys ($n = 5$) and human dimensions surveys ($n = 10$) and all of the human dimension surveys collected by staff at Pinnacle Mountain ($n = 14$), Mount Magazine ($n = 12$), and Petit Jean ($n = 2$) were unaccompanied by any NRID surveys. None of the human dimensions surveys collected at any park indicated that the visitors did not participate in the NRID survey. This mistake by the park staff resulted in my inability to determine which human dimensions surveys may have been collected with the 5 NRID surveys at Mount Nebo. Additionally, the park staff were unable to tell me whether the visitors who submitted the human dimensions surveys tried to collect NRID data, but did not observe any species, or if they chose not to participate in the NRID survey at all.

Further complicating the results, no visitors complied to the requests made by my technicians and me to answer the human dimensions survey intended to assess non-response bias.

Citizen Science Taxa Data

Nineteen species representing 5 taxonomic groups were recorded from the citizen science surveys collected from Mount Nebo. Birds (31.6%) and mammals (31.6%) comprised the majority of species reported by participants, followed by invertebrates (21.1%); reptiles and amphibians (10.5%); and woody vegetation (5.26%). Of the 19 recorded species, 5 (26.3%) observations were too vague to determine a species-level classification (e.g., “blue bird with white back”). The other 14 observations were recorded to the species level or described in enough detail to facilitate an accurate estimation of the species observed [e.g., “deer” representing a white-tailed deer (*Odocoileus virginianus*)]. In comparison, 161 total species were recorded in the standard taxa data representing 3 major taxonomic groups: woody vegetation (52.8%), birds (43.5%), and mesocarnivores (3.73%). Given the low response in participant NRID survey data, comparisons of accuracy, precision, and bias for taxa communities between the participant and standard data sets could not be calculated.

Citizen Science Human Dimensions Survey

Non-response bias.— Due to the collection problems of the human dimensions survey by park officials and the lack of cooperation of visitors when I opportunistically approached them during the standard taxa data collection, I could not assess any potential non-response bias. Further, since it was unclear whether visitors who submitted the human dimensions survey participated in the NRID survey, the following results can only

be read in terms of park visitors who chose to respond to the human dimensions survey (hereafter survey participants), regardless of their participation in the NRID citizen science project.

Sampling bias.— Among the entire survey participant population, I found no sampling bias in participant gender ($\chi^2_1 = 0.74$ $P = 0.421$), ethnicity ($\chi^2_5 = 10.5$ $P = 0.062$), or age ($\chi^2_1 = 0.19$ $P = 0.804$). However, survey participants held a higher level of education compared to the general Arkansas population ($\chi^2_1 = 92.4$ $P < 0.001$). Comparisons between Mount Magazine, Mount Nebo, and Pinnacle Mountain and their respective closest cities also did not yield a sampling bias for gender ($\chi^2_1 = 0.81 - 1.78$ $P = 0.217 - 0.431$). Petit Jean was not included in the individual park analyses due to only receiving 2 surveys. Pinnacle Mountain survey participants were older ($\chi^2_1 = 11.0$ $P = 0.005$), held a higher level of education ($\chi^2_1 = 18.1$ $P \leq 0.001$), and were primarily Caucasian ($\chi^2_4 = 13.8$ $P = 0.017$) compared to Little Rock citizens. Mount Magazine and Mount Nebo responses did not yield a sampling bias for participants in age ($\chi^2_1 = 2.75 - 4.82$ $P = 0.086 - 0.267$) or in ethnicity ($\chi^2_4 = 1.18 - 10.3$ $P = 0.119 - 0.783$). Mount Magazine survey participants had a higher level of education than the general Russellville population ($\chi^2_1 = 39.4$ $P \leq 0.001$) but no sampling bias existed between Mount Nebo participants and Russellville citizens ($\chi^2_1 = 0.06$ $P = 1.00$).

Survey participant demographics.— Participant demographics from the pooled data had an equal sex ratio of women and men (22:16; $\chi^2_1 = 0.95$ $P = 0.418$), were predominantly Caucasian ($\chi^2_1 = 59.1$ $P < 0.001$) and showed no bias in age, with participants ranging in age from 18 – 74 ($\chi^2_1 = 5.58$ $P = 0.369$). A majority of participants held at least a bachelor's degree or higher level of education (47%; $\chi^2_1 = 38.3$ $P < 0.001$)

and described their occupation as some form of teacher or educator (26%; $\chi^2_1 = 15.1$ $P = 0.037$). In general, responses to demographic questions did not differ between the 3 parks for age ($\chi^2_{10} = 14.3$ $P = 0.154$), gender ($\chi^2_2 = 3.68$ $P = 0.199$), educational level ($\chi^2_{12} = 14.7$ $P = 0.242$), or race ($\chi^2_4 = 3.62$ $P = 0.856$). However, a greater number of Mount Magazine participants were identified as educators or as an unlisted occupation (17%; 14%, respectively) compared to Mount Nebo (3%; 6%, respectively) or Pinnacle Mountain (8%; 3%, respectively) participants ($\chi^2_{14} = 23.6$ $P = 0.027$).

Survey participants were asked to rank their top 3 purposes for visiting the parks on the day they participated in the survey. Overall, hiking and/or walking was noted as the first and second primary purposes for park visitation, with personal relaxation as the third primary purpose for park visitation (Figure 4.1). The primary purpose for park visitation of survey participants differed between the parks ($\chi^2_{16} = 16.3$ $P = 0.037$). Participants primarily visited Mount Magazine for educational events; Mount Nebo for hiking or walking; and Pinnacle Mountain for some form of wildlife viewing. Participants at all of the parks generally ranked hiking or wildlife viewing as their second purpose for visitation ($\chi^2_{16} = 15.8$ $P = 0.288$). The third ranked purpose of park visitation also differed between the parks ($\chi^2_{16} = 29.2$ $P = 0.008$). Participants visited Mount Magazine for hiking; Mount Nebo for relaxation; and Pinnacle Mountain for wildlife observation. Correspondingly, state park hiking and walking trails were the primary location of participant wildlife viewing experiences when visiting the parks (Figure 4.2) and there were no differences between the parks in this response ($\chi^2_8 = 9.84$ $P = 0.219$).

When asked to rank the importance of the role of science and wildlife conservation in their personal lives, participants rated viewing wildlife; understanding

science; being sustainable; incorporating science in problem solving; and having wildlife education in state parks as all being very important (modal value 5 for all statements) and participation in scientific research as being important (4). No differences were found among survey participants in previous knowledge or participation in citizen science overall ($\chi^2_1 = 1.68 - 2.63$ $P = 0.143 - 0.256$) or between the parks ($\chi^2_2 = 2.76 - 3.74$ $P = 0.134 - 0.254$).

Personal interests in wildlife viewing and outside influences from park officials were the primary motivators for survey participation overall ($\chi^2_6 = 26.1$ $P \leq 0.001$; Figure 4.3), though no differences in participant motivation were evident within each park ($\chi^2_{12} = 13.2$ $P = 0.345$). However, this question was directed towards participation in the NRID survey and not the human dimensions survey. Participant motivations then must either relate to the NRID survey, meaning that participants did not return the NRID portion, or that participants were mistaken and referred to their participation in the human dimensions survey.

Lastly, when asked on their confidence in identifying 3 major taxonomic communities in parks (birds, mammals, and woody vegetation), the overall survey population responded with a modal value of 4 (range of 1 – 5) for all taxa, indicating that they were confident in their ability to identify biotic communities. Participant confidence levels in identifying each taxon group were similarly confident among the 3 parks ($\chi^2_{6-8} = 2.38 - 7.25$ $P = 0.557 - 0.922$). Survey participants in Mount Magazine, Mount Nebo, and Pinnacle Mountain responded as generally confident in their identification birds and trees (modal values 3 – 5). However, survey participants in Mount Magazine were

generally unconfident in their ability to identify mammals (modal value 2) compared to survey participants in Mount Nebo and Pinnacle Mountain (modal value 4 – 5).

DISCUSSION

The inclusion of citizen science in ecological studies provides educational and logistical benefits to both participants and researchers but is still subject to errors in participant data quality. My research objectives were to validate the quality of avian, mesocarnivore, and woody vegetation taxa data collected by participants in the ADSP NRID survey to assess the accuracy, precision, and possible bias of visitor taxa surveys. I additionally investigated participant demographics, scientific background, and motivations to characterize participants and assess possible non-response and sampling biases. Response rates (2%) for both the NRID and human dimension surveys were extremely low, indicating that the passive collection and dispersal method for NRID surveys was ineffective. The passive dispersal technique lacked the interpersonal connection accomplished by the active advertisement, recruitment, and training methodologies used by other citizen science projects which resulted in a lack of participant motivation and low return rates. Additionally, about a quarter of the citizen science species observations were inconsistent or too vague to facilitate comparisons to the standard data. Although some information was gained regarding biases in visitor demographics, scientific knowledge, and motivations for participating in citizen science projects, the data provided minimal insight into park visitor characteristics when considering the number of annual visitors to these parks. Meager results as they may be, they are the first step in creating a more effective citizen science project that can be

passively administered while still involving and educating the general public and accumulating reliable data on state park biotic communities.

Citizen Science Taxa Data

The standard data set included a lower variety of taxonomic groups compared to participant data, which was the direct result of the methodologies employed by my study. Collectors for the standard data set were trained and experienced in the focal taxonomic groups and followed procedures established by prior studies (James and Shugart 1970, Ralph et al. 1995, Gompper et al. 2006, Martin et al. 1997) which occurred at specified sampling points within each park. Comparatively, while participant data included a greater variety of taxonomic groups recorded (i.e., herpetofauna and arthropods), data collection had no restrictions on location, time, or procedure as a result of the passive administration process. This may be a benefit of the passive technique compared to traditionally structured validation studies (Galloway et al. 2006, Crall et al. 2011, Kremen et al. 2011, Gardiner et al. 2012) in that the lack of restrictions on data collection allowed for participants to collect a greater diversity of recordings that encompassed a larger area of the parks (Trumbull et al. 2000). However, this lack of restriction may also have led to the unidentifiable species due to vaguely described participant observations and untrained participants in identifying specific species.

Previous research in validating the accuracy of species data collected by citizen scientist have followed a directed and active approach in recruiting project volunteers (Delaney et al. 2008, Bonney et al. 2009, Crall et al. 2010, Dickinson et al. 2012). This tactic includes actively targeting participants based on personal interests or background experience (Leslie et al. 2004, Delaney et al. 2008, Thelen and Thiet 2008), providing

participants practice material to study (Lotz and Allen 2007, Kremen et al. 2011), and training participants prior to data collection (Galloway et al. 2006). Providing participants some form of training prior to data collection has led to higher levels of accuracy in data collected as a result of improving participant accountability (Brandon 2003, Bonney et al. 2009). For example, Kremen et al. (2011) enlisted citizen scientists to identify the abundance of pollinators, during which a specific group of participants was chosen, trained during a 2-day period, and received 1-on-1 field experience with professionals prior to data collection. Further, study sites were fixed and participants sampled them on a scheduled basis which all resulted in participant data that was similar in accuracy to professional data. Thus, incorporating participant training, specifying sampling points, or the dissemination of educational material to park visitors may be methods that could improve the accuracy and participation rate in the NRID survey.

Issues in the reliability of participant observations may also be contributed to biases present in a participant's ability to identify common and uncommon species (Fore et al. 2001, Dickenson et al. 2012). Participants in other validation studies have exhibited high levels of accuracy when identifying common or "easy" species compared to identifying uncommon species or those that look similar to one another. When asked to identify woody vegetation, Brandon (2003) found that citizen science participants had difficulty distinguishing between certain species of oaks (*Quercus spp.*) and elms (*Ulmus spp.*), but had high levels of accuracy in most maple species (*Acer spp.*). Certain elm species such as slippery elm (*Ulmus rubra*) and American elm (*Ulmus americana*) are very similar in appearance, which may make identification difficult to participants that do not have experience in identifying trees. Further, their unfamiliarity in elms or other

species may influence participants to not record an observation due to a lack of confidence (Trumbull et al. 2000). Conversely, birds and mammals were the 2 most common taxonomic groups recorded by NRID participants and are the 2 most common groups that data is collected for in citizen science projects (Larson 2015) due to their familiarity and charisma to the general public (Thelen and Thiet 2008). Species familiarity and charisma may explain why the majority of NRID participant observations were focused on bird and mammal species and observations in other taxonomic groups such as insects or trees were vague and less common.

Among errors in accuracy and bias attributed to participant background and experience, perceived observer confidence can also serve as an important source of error in species observations (Farmer et al. 2012). For example, overconfident participants may overestimate their abilities in general data collection compared to less confident participants, and thus can be prone to observational errors. When asked to rank their confidence levels in identifying bird, mammal, and tree species within the parks, survey participants responded as being highly confident in their abilities to identify species across the 3 taxon groups. However, approximately 25% of the species recorded from the few returned NRID surveys were not identified to the species level (e.g., blue bird with a white back, grasshopper). With survey participants ranking their wildlife identification skills as highly confident, it would be expected that all species records would be properly identified. The vagueness present in some taxon observations may be attributed to survey participants overestimating their confidence in identifying park wildlife (Miller et al. 2011, Farmer et al. 2012).

Citizen Science Human Dimensions

Research into the demographics of citizen science participants is scarce in that most studies do not passively administer surveys and know prior to data collection the demographics of recruited participants (Crall et al. 2006). Participants in the NRID survey were primarily Caucasian, higher-educated individuals that worked in education and had some level of personal interest in wildlife viewing and data collection. While these conclusions are tentative due to an inadequate sample size, these demographics are similar to participant groups in other citizen science projects (Trumbull et al. 2000, Crall et al. 2011). Unlike the NRID survey, most citizen science projects recruit volunteers either through advertisement and screening processes (Leslie et al. 2004, Lotz and Allen 2007, Delaney et al. 2008) or through outreach to special interest groups (Cohn 2008). These recruitment methods tend to be bias towards participants who either have a prior interest in the focal species or who are members of taxon-specific organizations. For example, volunteers for Frogwatch USA (Association of Zoos and Aquaria) must be a member of a Frogwatch chapter to participate. Volunteer recruitment then is highly restricted, with advertisements only reaching members or citizens who have had exposure to the project by visiting a zoo. In a similar way, this may explain why influences from park officials and personal interests in wildlife observation were the primary motivators for overall survey participation. Although the surveys were passively administered, park staff were encouraged to advertise the survey during park tours, which are typically attended by special interest groups and those who have a personal interest in wildlife viewing.

A majority of the overall survey participants and participants within each respective park held a bachelor's degree or higher level of education, whereas the majority of Arkansans had lower levels of education (USCB 2015). People interested in citizen science typically have preexisting knowledge and interests towards a project's focal taxon and thus tend to be better educated and more aware of the importance of wildlife research in conservation compared to the general population (Trumbull et al. 2000, Evans et al. 2005).

Previous studies examining the demographics of citizen scientists found that participants tended to be older, of an equal sex ratio, and reported a general interest in science (Trumbull et al. 2000, Crall et al. 2011). Gender ratios and personal interests in science in my survey were similar to participants in previous citizen science projects. However, my human dimension survey did not exhibit an overall age bias except at Pinnacle Mountain where survey participants tended to be older. An age bias may not have been observed in Mount Magazine and Mount Nebo due to the passive dispersal of the survey combined with the variety of people that visit state parks. State parks encourage participation in conservation across a spectrum of visitor age groups and backgrounds. Thus, having the survey available to all state park visitors compared to other citizen science projects that restrict participation to special interest groups may have resulted in a greater inclusion of participant age levels. Alternatively, the lack of sampling bias found in participant age groups across the parks may be attributed to differences in census data categories compared to my survey. Census Bureau data were only available for citizens <18 and >65 years of age, whereas most my survey participants were between 18 – 74 years of age. Therefore, a sampling bias may have

been present, but went undetected due to the lack of smaller age classes in Census Bureau data.

There were no differences observed in the number of park visitors that completed the human dimensions survey that were either familiar with citizen science or had prior experience in citizen science. This is uncommon in most citizen science projects, in that participants typically have prior experience with citizen science or are familiar with the concept (Leslie et al. 2004, Thelen and Thiet 2008, Crall et al. 2010). This may be the result of other projects recruiting from special interest groups, in which participants are familiar in conservation sciences and consequently familiar with citizen science.

Implementing the passive survey administration may have aided the human dimensions survey in reaching a more diverse audience by not being restricted to only wildlife enthusiasts or special interest groups.

The lack of different citizen science backgrounds in human dimension survey participants may also have been attributed to a lack of motivation to participate. Although the passive approach may have helped diversify participant backgrounds, it struggled to elicit a personal motivation in visitors to participate in data collection seen in more structured citizen science studies (Genet and Sargent 2003, Leslie et al. 2004, Galloway et al. 2006). Prior studies have benefitted from recruiting participants already interested in the focal taxon via participants covering their own travel and supplies. For example, Leslie et al. (2004) found that participants with personal interests in volunteering only required either personalized communication or the provision of food as motivators to participate compared to a monetary motivator. Potential participants in the human dimensions survey and the NRID survey may not have seen the intrinsic value of

participation that participants in other projects have due to lack of personal interests in conservation and lack of interpersonal interaction with my survey team, which could have led to the low survey response.

Management Recommendations

The ADSP NRID survey was ineffective at incorporating park visitors in taxa data collection due to a lack of park staff collaboration, participant motivation, and survey advertisement. Although the passive dispersal method has the potential to involve a greater diversity of participants, the lack of communication from park staff and disconnect to park visitors failed to achieve the level of personal involvement seen in citizen science projects that actively recruit participants. State parks may improve participation by advertising to special interest groups (Trumbull et al. 2000, Leslie et al. 2004), training individuals prior to data collection (Delaney et al. 2008, Kremen et al. 2011), and offering intrinsic or monetary compensation to participants (Leslie et al. 2004). Collecting participant data through online databases or personal interactions with participants (Delaney et al. 2008, Thelen and Thiet 2008, Gardiner et al. 2012) may also increase survey return rates in future efforts by improving participant motivation and avoiding confusion from park staff on the logistics of survey collection.

The low level of participation recorded in my study may also reflect the restriction of survey advertisement to the visitor centers in each park. Park visitors indicated trail use and hiking as their top purposes for visiting state parks, which may have resulted in park visitors bypassing the visitor center. Advertising the NRID survey at the trailheads of hiking trails may increase recruitment by promoting the survey within the primary areas of park use. Further, targeting survey advertisements to specific

participant groups and park visit preferences could also improve participation. For example, advertising during educational talks may improve survey participation in Mount Magazine while relating the benefits of the survey to wildlife observers may improve participation at Pinnacle Mountain. Additionally, considering the importance of science and wildlife education to survey participants, refocusing the message of the NRID survey to target these values may encourage personal motivation to promote future involvement.

Methodologies for participant data collection must also be easily understood to accommodate the wide variety of educational and experience backgrounds in survey participants. The “fill-in” format of the NRID survey may have discouraged participation by intimidating participants that were less familiar identifying species. Redesigning the NRID survey as a checklist format instead of a fill-in format may ease survey effort and improve participant confidence and accuracy which could encourage participation from a wider variety of demographic groups. Lastly, creating a form of accountability towards participants, either through compensation (e.g., food, souvenirs) or follow-up from park staff that are well informed on the surveys will likely also improve participation and return rates of the surveys.

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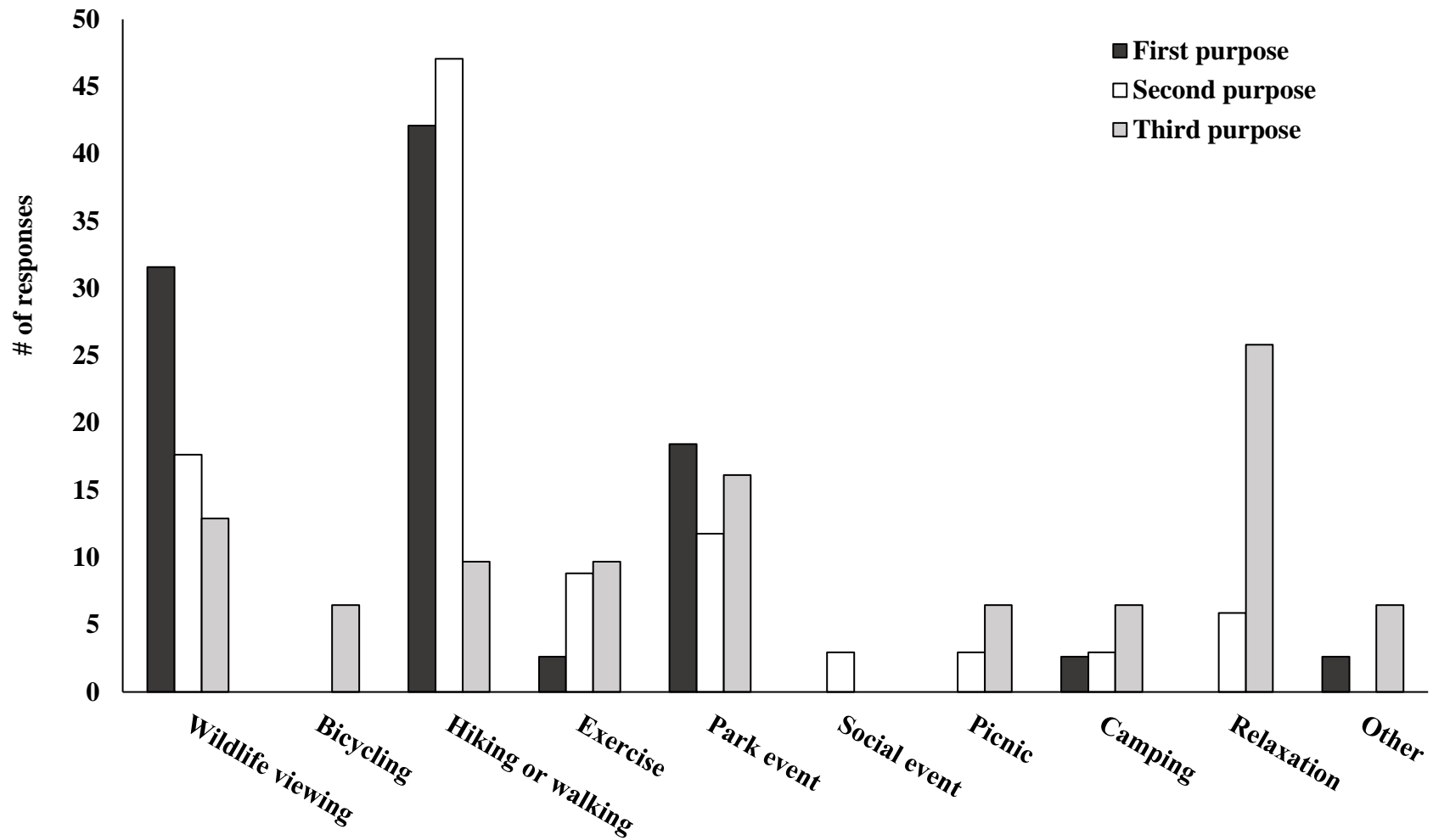


Figure 4.1. Top 3 ranked purposes for park visit of survey participants at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016.

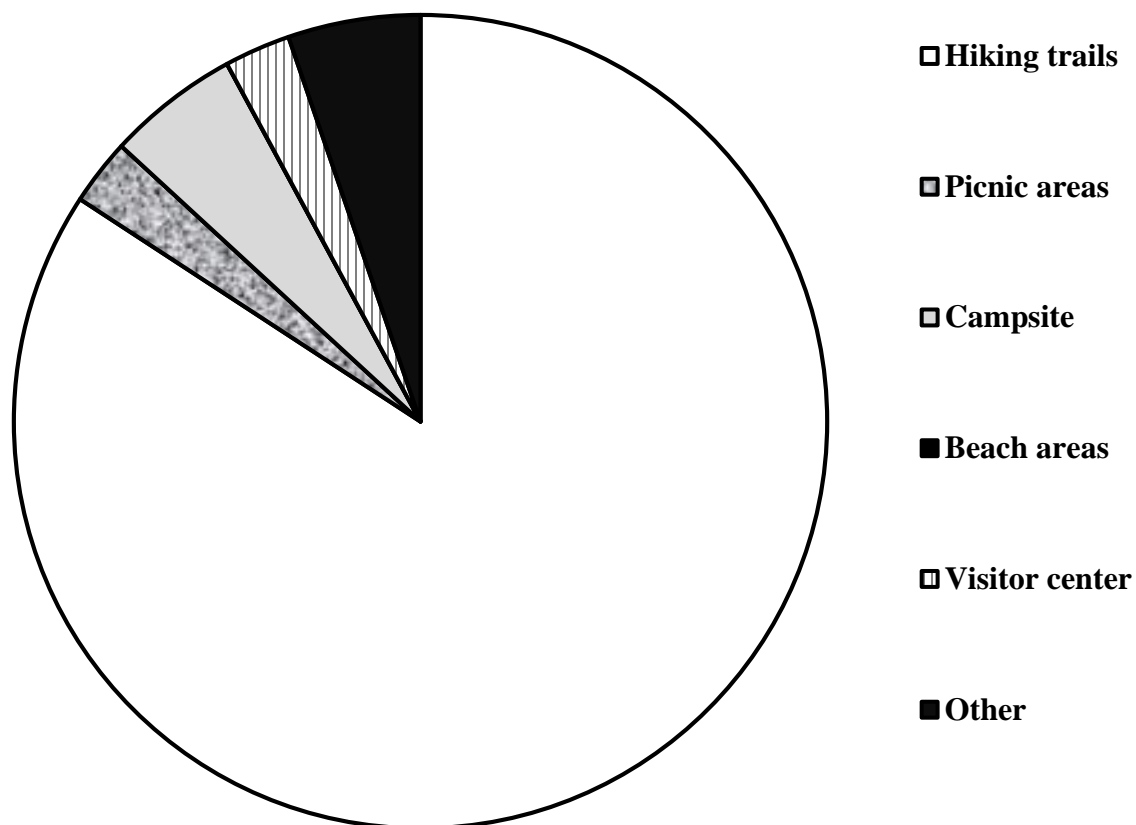


Figure 4.2. Percent of responses designating the primary location of survey participant wildlife viewing experiences per park visit at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016.

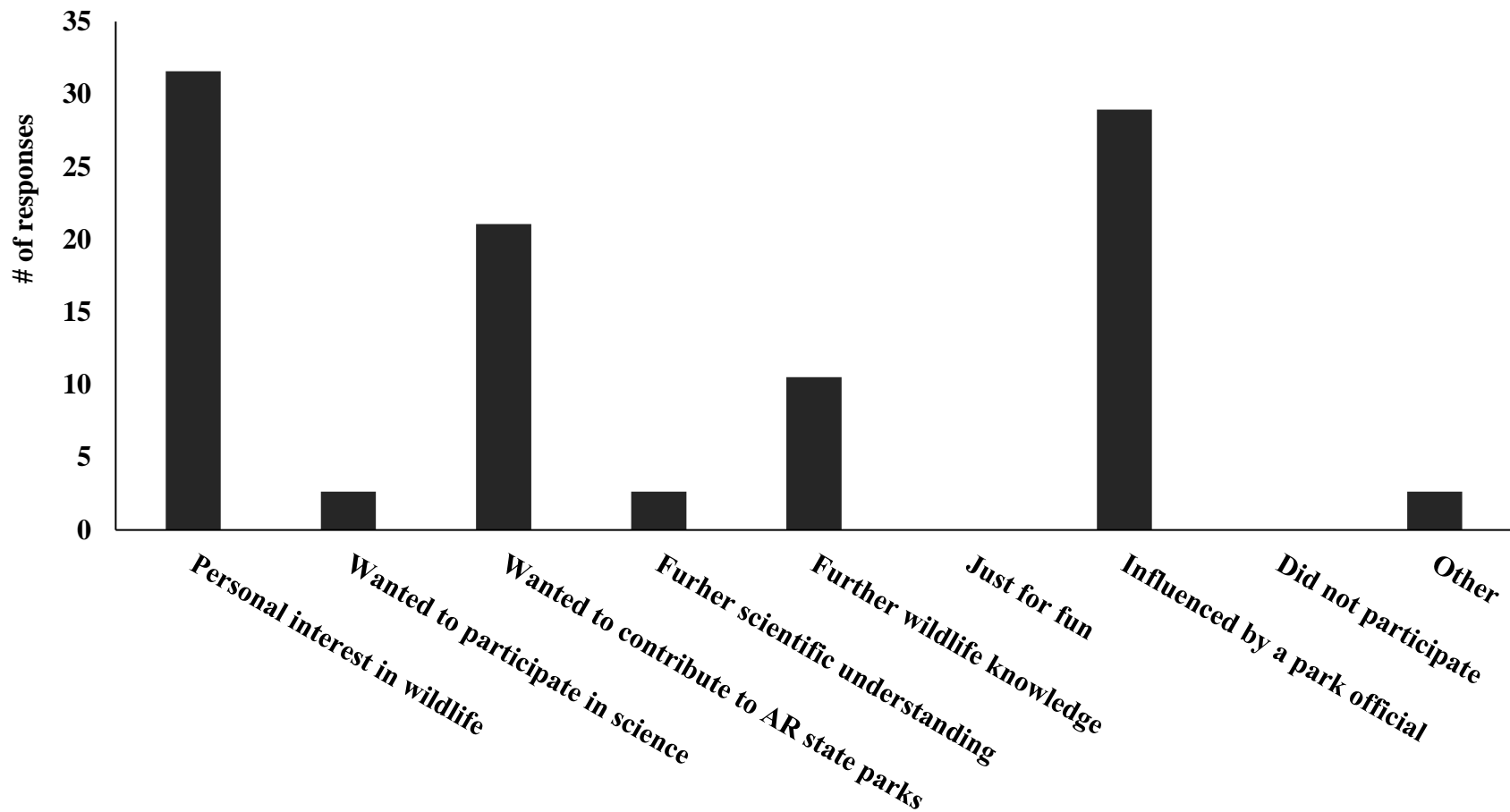
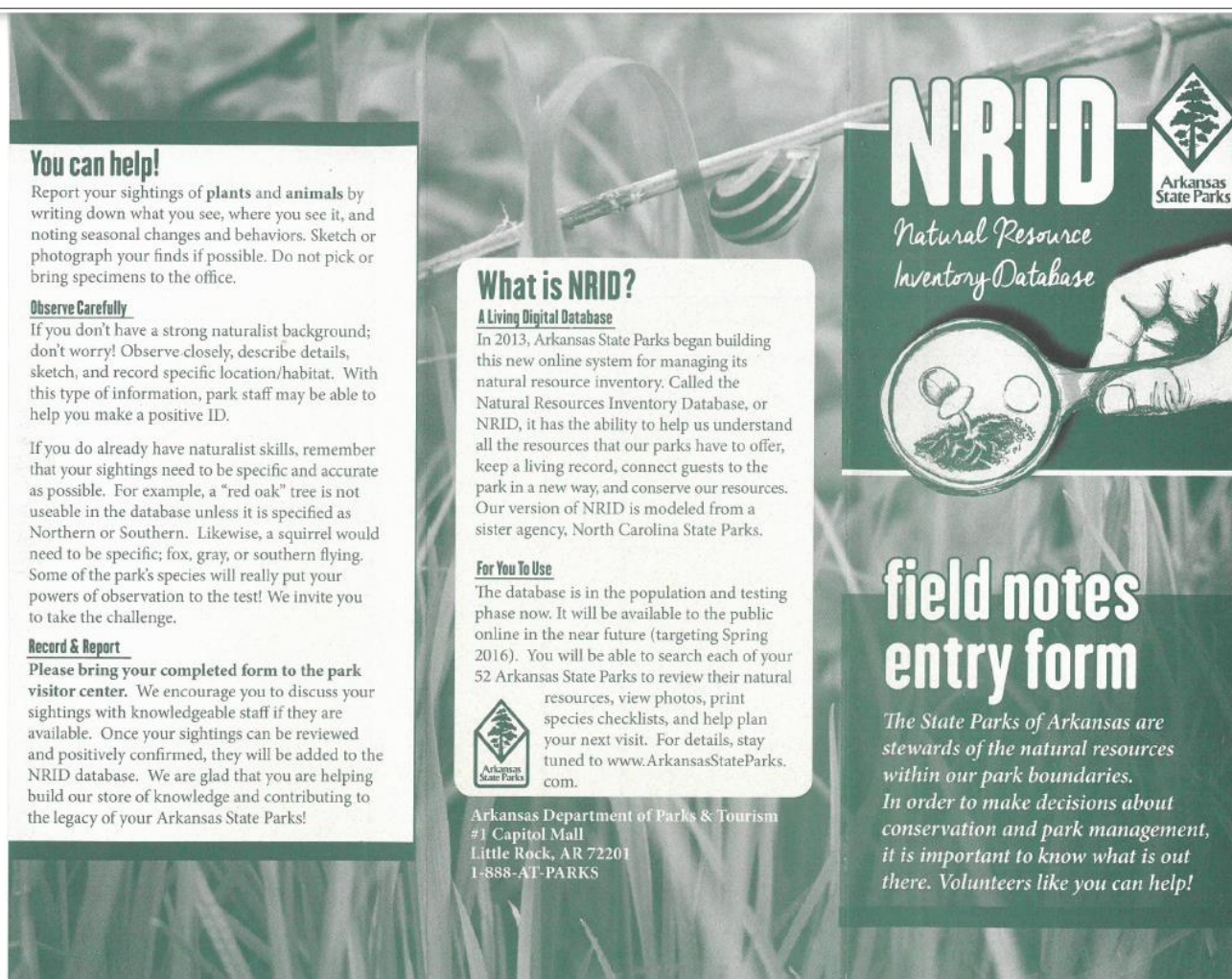


Figure 4.3. Primary motivations of survey participants for participating in the Arkansas Division of State Parks Natural Resource Inventory Database survey at Mount Magazine, Mount Nebo, Petit Jean, and Pinnacle Mountain State Parks, Arkansas 2015 – 2016.

APPENDIX A. ARKANSAS DIVISION OF STATE PARKS (ADSP) NATURAL RESOURCE INVENTORY DATABASE (NRID) CITIZEN SCIENCE SURVEY



You can help!

Report your sightings of **plants** and **animals** by writing down what you see, where you see it, and noting seasonal changes and behaviors. Sketch or photograph your finds if possible. Do not pick or bring specimens to the office.

Observe Carefully

If you don't have a strong naturalist background; don't worry! Observe closely, describe details, sketch, and record specific location/habitat. With this type of information, park staff may be able to help you make a positive ID.

If you do already have naturalist skills, remember that your sightings need to be specific and accurate as possible. For example, a "red oak" tree is not useable in the database unless it is specified as Northern or Southern. Likewise, a squirrel would need to be specific; fox, gray, or southern flying. Some of the park's species will really put your powers of observation to the test! We invite you to take the challenge.

Record & Report

Please bring your completed form to the park visitor center. We encourage you to discuss your sightings with knowledgeable staff if they are available. Once your sightings can be reviewed and positively confirmed, they will be added to the NRID database. We are glad that you are helping build our store of knowledge and contributing to the legacy of your Arkansas State Parks!


What is NRID?


A Living Digital Database

In 2013, Arkansas State Parks began building this new online system for managing its natural resource inventory. Called the Natural Resources Inventory Database, or NRID, it has the ability to help us understand all the resources that our parks have to offer, keep a living record, connect guests to the park in a new way, and conserve our resources. Our version of NRID is modeled from a sister agency, North Carolina State Parks.

For You To Use

The database is in the population and testing phase now. It will be available to the public online in the near future (targeting Spring 2016). You will be able to search each of your 52 Arkansas State Parks to review their natural resources, view photos, print species checklists, and help plan your next visit. For details, stay tuned to www.ArkansasStateParks.com.

 Arkansas Department of Parks & Tourism
#1 Capitol Mall
Little Rock, AR 72201
1-888-AT-PARKS

NRID 
*Natural Resource
Inventory Database*

**field notes
entry form**

The State Parks of Arkansas are stewards of the natural resources within our park boundaries. In order to make decisions about conservation and park management, it is important to know what is out there. Volunteers like you can help!

Park Name

species common name	date	location seen in park <small>(provide lat./long. coordinates if possible) (give county if necessary)</small>	# seen	observer name	notes: <small>(suggestions: color, size, time of day, distinctive field marks, behavior, # of petals, etc.)</small>
Cardinal	10/10/15	camp area A, site #37	2	Jay Miller	bright and reddish-brown, 1 male, 1 female perching in tree

**APPENDIX B. ARKANSAS DIVISION OF STATE PARKS (ADSP) NATURAL RESOURCE INVENTORY DATABASE
(NRID) CITIZEN SCIENCE SURVEY DISPLAY POSTER**

Citizen Science

You can help State Parks bridge the gap between formal science and recreational enjoyment of nature.

What is NRID?

ARKANSAS STATE PARKS is building the new online system for managing its natural resource inventory, called the Natural Resource Inventory Database, or NRID. It has the ability to help us understand all the resources in our parks, including plants, animals, and geological resources. We need your help to make it better. In a few years, we will have a better understanding of our parks and the resources they contain. The database is in the population and breeding phase now. It will be available to the public online in the near future (spring 2010). We will be able to search for all of your 50 Arkansas State Parks to answer their natural resource, very important questions, and help park staff make decisions about the future of our parks. We need your help to make it better. Please take a form from the "State Parks of Arkansas" brochure rack.

Be a Citizen Scientist...

Please take a Field Notes Entry Form from the outdoor air rack.

Use this brochure to record and report your sightings of plants and animals by writing down what you see, when you see it, and noting unusual characteristics. Please identify or photograph your finds if possible. Use red ink or bring specimens to the office.

A participant survey is also included in the brochure for a citizen science study being conducted by students at Arkansas Tech University. Your completion of the survey is voluntary and appreciated.

If you don't have a strong naturalist background, don't worry! Observing, describing, and recording what you see is a fun and easy way to help you make a positive impact.

If you do already have naturalist skills, remember that your sightings need to be specific and accurate. For example, a "bird call" note is not useful in the database unless it is specific to a location or location. Likewise, a sighting would need to be specific (e.g., bird, or Southern Bluebird). Address to be as specific as possible. Some of the park's species will really put your powers of observation to the test. We hope you'll have fun with it.

Please take your completed Field Notes Entry Form - along with your observations - to the office to be entered into the database.

Once your entry has been entered and accepted, it will be added to the NRID database. We are glad that you are helping build our store of knowledge and contributing to the legacy of your Arkansas State Parks!

You can help!

Arkansas State Parks
TECH

APPENDIX B. HUMAN DIMENSIONS PARTICIPANT SURVEY

Citizen Science Participation

9. Have you heard the term citizen science before participating in this survey?
☐ Yes ☐ No

10. Have you ever participated in a citizen science research project before (e.g., collected field data for an organization or research)?
☐ Yes ☐ No

11. What is your primary motivation for participating in the Citizen Science NRID Survey? (Please choose one)

- ☐ Already maintain a personal interest in wildlife
- ☐ Wanted to participate in scientific research
- ☐ Wanted to contribute to AR state parks
- ☐ Interested in furthering personal scientific understanding
- ☐ Interested in furthering personal wildlife knowledge
- ☐ Thought it would be fun
- ☐ Was influenced by a park representative
- ☐ Did not participate
- ☐ List other: _____

12. Please rate your confidence level for identifying species in to each animal group.

	Very unconfident		Neutral		Very confident
Birds	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mammals	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Trees	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Any questions regarding your rights as a participant in this survey may be addressed at:
http://www.atu.edu/research/human_subjects.php

Your Voluntary Participation

Your participation in this survey is greatly appreciated and completely voluntary. There is no obligation to complete part or any of the survey and no known risks associated with the research. All individuals who participate and information collected will remain anonymous. All data collected will only be used by Arkansas State Parks and Arkansas Tech University to help improve the citizen science survey and observe who is participating—Thanks!


About our Project

I am a graduate student working with Arkansas Tech University and Arkansas Division of State Parks to assist in the new citizen science survey. The information that you provide from this survey and the NRID will help in:

- Characterizing park visitors and citizen science participants
- Gathering data on what wildlife and plants visitors are seeing in state parks
- Gathering information on how people use and enjoy state parks
- Creating maps of wildlife locations along park trails to increase wildlife viewing opportunities.


If you have any questions or concerns regarding this study and the data collected please contact:
 Bennett Grooms, Arkansas Tech University graduate student. E-mail: bgrooms@atu.edu

This project has been reviewed and approved by the Arkansas Tech University Internal Review Boards for work with human subjects (#Urbanek_04032015)



ARKANSAS TECH UNIVERSITY

NRID Participant Survey



Using your input to conserve wildlife, improve our state parks, and to provide you a better, more wonderful outdoor experience.

Park: _____

Date: _____

How You Can Help!

When you complete this survey, please turn it in to the visitor center along with your NRID entry form. By filling this information out, you are allowing us to see who is participating in the citizen science project and what people are doing at state parks. This information will allow us to help you by:

- Improving outreach programs for park visitors
- Improving wildlife viewing opportunities
- Creating an overall more enjoyable experience for you in Arkansas State Parks

Please also fill out the NRID entry form to help us better:

- Understand wildlife in Arkansas State Parks
- Make decisions on conservation and park management
- Understand how we can provide greater wildlife experiences for you



Tell us a little about yourself

1. What is your gender?
☐ Male ☐ Female

2. What is the highest level of education you have completed?

- ☐ Less than a high school degree
- ☐ High school degree or equivalent
- ☐ Some college with no degree
- ☐ Associate Degree
- ☐ Bachelor Degree
- ☐ Graduate Degree
- ☐ Doctorate Degree
- ☐ Professional Degree

3. What is your current occupation?

- ☐ Student
- ☐ Teacher/educator
- ☐ Scientist
- ☐ Healthcare
- ☐ Retired
- ☐ Military
- ☐ Professional/technical
- ☐ Volunteer/nonprofit worker
- ☐ Self-employed
- ☐ List other: _____

4. What is your age?

- ☐ Under 18 ☐ 45-54
- ☐ 18-24 ☐ 55-64
- ☐ 25-34 ☐ 65-74
- ☐ 35-44 ☐ 75-older

5. Which best describes your ethnicity or cultural background?

- ☐ American Indian or Alaskan Native
- ☐ Asian
- ☐ Pacific Islander
- ☐ Hispanic or Latino
- ☐ White/Caucasian
- ☐ Black or African American
- ☐ List other: _____

Your Park Visit

6. What are the primary activities you took part in while you visited the park? (Rank up to 3, with 1 being your primary activity)

- ☐ Plant/wildlife viewing
- ☐ Social event
- ☐ Bicycling
- ☐ Picnicking
- ☐ Hiking/walking
- ☐ Camping
- ☐ Exercise/fitness
- ☐ Relaxing
- ☐ Education/Park Event
- ☐ Other: _____

7. Choose the primary location in the state park where a majority of your wildlife viewing experience occurred.

- ☐ Hiking/walking trails
- ☐ Picnic areas
- ☐ Camp sites
- ☐ Swimming/fishing/beach areas
- ☐ Visitor center
- ☐ List other: _____

8. Please rate the following statements on how important each one is to you in everyday life.

	Very unimportant		Neutral		Very important
Viewing wildlife in your personal time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Participating in scientific research and data collection	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Understanding science	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using science to solve problems	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Being sustainable/helping wildlife conservation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wildlife education in state parks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

