EXTENT OF ALABAMA'S TERRESTRIAL NATURE RESERVE SYSTEM

IN REPRESENTING ECOSYSTEM DIVERSITY:

A COARSE-FILTER GAP ANALYSIS

by

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ABSTRACT

Numerous studies reveal that existing nature reserves do not effectively represent ecosystem diversity and biodiversity. In this study, Alabama's public and private reserve lands were analyzed to see how representative they were of biodiversity. The spatial distribution and characteristics of Alabama's nature reserves were examined using gap analysis, a technique used to assess the distribution of nature reserves. In Alabama, a gap analysis that includes public (including Department of Defense) and private nature reserves has not been conducted. This analysis had two objectives: 1) to examine the distribution and characteristics of nature reserves across ecoregions; and 2) to analyze where gaps in the Alabama nature reserve system existed and to characterize the drivers of the identified gaps in nature reserve coverage. GIS shapefiles of reserves were collected. A database featuring the total number of reserves, reserve ecoregion, reserve size, owner type (federal, state, local, landtrust), property type (public, private), and connectivity (distance between reserves) was created. Public property was comprised the majority of all nature reserve land area. However, private parcels were the most common land parcels in the four northeasternmost ecoregions (Interior Plateau, Southwestern Appalachians, Ridge and Valley, Piedmont). The two southernmost ecoregions (Southeastern Plains, Southern Coastal Plain) were predominantly comprised of public parcels. The results indicated that reserve lands cover the Southern Coastal Plain most effectively and Southeastern Plains and Interior Plateau the least. I hypothesized that the distribution of nature reserves based on property and owner type was influenced by race, socioeconomic status, and presence

of cities. This study will fill a dearth in research and help researchers, private, state, and federal agencies to make well-informed decisions to set and meet conservation goals and policy.

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1. Introduction

Anthropogenic degradation of the environment has resulted in the global decline of biological diversity (Polasky et al., 2000; Scott et al., 2001; MacDonald, 2003; Wilson et al., 2005; Hunter and Gibbs, 2007; Primack, 2008; Wu et al., 2011; Piekielek and Hansen, 2012). The exponential human population growth that has been occurring throughout the last two centuries has resulted in exploitation of resources, the introduction of alien invasive species, habitat destruction and fragmentation, and the subsequent global endangerment and extinction of many species (Powell et al., 2000; Scott et al., 2001; Primack, 2008; Cantu-Salazar and Gaston, 2010; Piekielek and Hansen, 2012). Currently, anthropogenic destruction of the environment attributes to “[m]ore than 99% of modern species extinctions” (Primack, 2008). In the history of life on earth, there have been five periods of mass extinction (Hunter and Gibbs, 2007; Primack, 2008). Although extinction is a natural process, current rates of species extinctions are 100 to 1000 times greater than past relative constant rates of extinction (Hunter and Gibbs, 2007; Primack, 2008). The appearance of humans in the last 30,000 years has coincided with these relatively rapid species extinctions (MacDonald, 2003), and many biologists have hypothesized these events will lead to our sixth mass extinction (Hunter and Gibbs, 2007; Primack, 2008).

Habitat fragmentation is hypothesized to endanger or cause extinction in many species (MacDonald, 2003; Hunter and Gibbs, 2007; Primack, 2008). Fragmented habitats are small, heterogeneous, isolated patches where several deleterious issues to populations can arise: (1)

decreases in varying species' population and resource base and (2) increases in species' vulnerability of genetic variation loss events, such as genetic bottlenecks, inbreeding depression, and loss of evolutionary flexibility (MacDonald, 2003; Nikolakaki, 2003; Hunter and Gibbs, 2007; Primack, 2008).

Globally, governmental and non-governmental programs use nature reserves (NRs) to combat the decline of biological diversity by protecting habitats and their inhabitants from fragmentation and other negative anthropogenic impacts (Polasky et al., 2000; Salomon et al., 2006; Cantu-Salazar and Gaston, 2010; Piekielek and Hansen, 2012). NRs are used to "ensure the persistence of biodiversity and the ecological processes that maintain it" (Salomon et al., 2006). However, numerous studies conducted at multiple spatial and temporal scales have revealed that existing NRs do not effectively represent biodiversity or are experiencing declines in biodiversity because of anthropogenic encroachment around NRs (Jenkins and Joppa, 2009; Wu et al., 2011; Piekielek and Hansen, 2012).

In this study, I compiled a dataset of private and public NRs in Alabama, USA and analyzed the extent and effectiveness of Alabama's NR system in representing biodiversity. Alabama is ranked 25th in land area among the USA, but it is ranked 4th in biodiversity, after only Hawaii, Florida, and California (Primack, 2008; Union of Concerned Scientists, 2009; Paemelaere and Balmer, 2011). The biodiversity of Alabama is attributed, in part, to physiographic diversity and latitude (ADCNR, 2005). Alabama is ranked second in the country in number of fauna per hectare (Paemelaere and Balmer, 2011). However, Alabama ranks third in the number of "threatened and endangered species" behind Hawaii and California (Paemelaere and Balmer, 2011). According to the US Geological Survey's Protected Area's database,

Alabama has 4% of its public land area permanently protected, which makes it the least publically protected state in the southeastern US (PAD-US, 2007).

This study examines the spatial distribution and characteristics of the NR system in Alabama using coarse-filter gap analysis, a technique used to assess the ecological representation and distribution of regionally representative ecological communities (Dietz and Czech, 2005; Huber et al., 2007; Hunter and Gibbs, 2007; Piekielek and Hansen, 2012). A gap analysis identifies ecological components that are not represented in a nature reserve network. In Alabama, a gap analysis to this extent, which considers public (including Department of Defense lands) and private reserves, has never been conducted. A comprehensive gap analysis is used to target areas where biological elements are unprotected by the nature reserve system and help researchers, private, state, and federal agencies to make well-informed decisions to set and meet conservation goals and policy. This study has three primary objectives:

- (1) Quantify spatial distribution of nature reserves across Alabama ecoregions
- (2) Document characteristics such as area, isolation, ecoregion location, property type, and owner type
- (3) Identify potential factors that influence area, isolation, location, property type, and owner type

2. Study area and methods

2.1. Study area

Alabama is located in the southeastern US and has a land area of 135,775 square kilometers (Fig. 1) (Encyclopedia of Alabama, 2011). Forest cover occupies 67% of Alabama land area (Yarrow and Yarrow, 1999). The state extends north from the State of Tennessee at 35°N to the Gulf of Mexico in the south at 30°N. The climate is classified as humid mesothermal with hot summers and mild winters (Thorntwaite, 1948; ADCNR, 2005). Mean annual rainfall ranges from 114 to 165 cm across the state (ADCNR, 2005).

In this study, I analyzed ecosystem diversity, as opposed to species richness, in each ecoregion. Ecosystem diversity is used to describe diversity of the biophysical environment at the landscape level. It represents the “collective response of all interacting species to different environmental conditions” (Primack, 2008). Although Alabama’s land area is comparatively moderate among other US states, Alabama is ecologically and physiographically diverse. Physiographic units are broad-scale regions based on geologic structure, soils, and topography (Fenneman, 1938). A three-tiered classification system, which divides physiographic regions into divisions, provinces, and sections, is used to spatially organize physical features (Fenneman, 1938). The major physiographic provinces of Alabama are the Interior Plateau (or Highland Rim), Southwestern Appalachians (or Cumberland Plateau), Ridge and Valley, Piedmont, and East Gulf Coastal Plain (Fenneman, 1938; ADCNR, 2005). Physiographically unique edaphic and topographic features influence vegetation coverage and the distribution of

Fig. 1 Alabama, shaded in dark gray, in the United States

other biotic organisms (ADCNR, 2005). These areas of relative biotic and abiotic homogeneity are ecoregions. Ecoregions are interpretive subdivisions based on biotic and abiotic patterns such as “geology, topography, vegetation, climate, soils, wildlife, and hydrology” (Omernik, 1987; Yarrow and Yarrow, 1999; ADCNR, 2005; EPA, 2011). In this study, Omernik’s (1987) and the EPA’s (2001) Level III ecoregions served as a surrogate of habitat types across Alabama (Margules and Pressey, 2000). The Level III ecoregions for Alabama are roughly proportional to the major physiographic regions of Alabama. Level III ecoregions are used for coarse-scale conservation planning throughout various state organizations including Alabama’s Nongame Wildlife Conference and the Alabama Gap Analysis Program (ADCNR, 2005). The six ecoregions are the Interior Plateau, Southwestern Appalachians, Ridge and Valley, Piedmont, Southeastern Plains, and Southern Coastal Plain (Table 1, Fig. 2). Biological diversity results from having six different ecoregions in one state, which provides a greater opportunity for protection by NRs (EPA, 2011). These ecoregions serve as a means to compare the spatial distribution and characteristics of nature reserves.

The northernmost ecoregion is the Interior Plateau (IP) (Fig. 2) (EPA, 2001). The topography in the ecoregion varies from hilly to flat near water (Fenneman, 1938; Smalley, 1983; Yarrow and Yarrow, 1999). The geology and soils of the region are relatively diverse. The soils in the IP are generally well-drained with moderate fertility (Smalley, 1983). The rock types in the IP are distinctively different than those in the bordering Southeastern Plains (EPA, 2011). The valley floor is typically limestone, and the ridges are composed of sandstone (ADCNR, 2005). The dominant forest type is oak-hickory, but some pines are present in the IP. Bottomland forests were drastically reduced by dams build by the Tennessee Valley Authority

Table 1 Size (ha) and relative land area of ecoregions in Alabama

Ecoregion	Size (ha)	Land Area (%)
Interior Plateau	863,762	6.4
Southwestern Appalachians	1,957,773	14.6
Ridge and Valley	1,159,539	8.7
Piedmont	1,251,224	9.3
Southeastern Plains	7,975,097	59.5
Southern Coastal Plain	190,882	1.4
Total	13,398,277	100

Fig. 2 EPA's Level III ecoregions in Alabama

and Corp of Engineers (Smalley, 1983). Remaining forest land has been greatly fragmented by logging, grazing, and fire (Smalley, 1983). The IP ecoregion is characterized by a mosaic springs, sinks, and caves, which contribute to the distinguished species in the area (Fenneman, 1938; EPA, 2001; ADCNR, 2005).

The Southwestern Appalachians (SWA) border the IP to the south and east. Low plateaus and valleys are characteristic of this region (Fenneman, 1938; Yarrow and Yarrow, 1999; EPA, 2001; Hart and Clatterbuck, 2011). Alluvial soil around streams, rivers, and lakes is v common in the Tennessee Valley region of the SWA. Wildlife is the most productive in the areas with fertile alluvial soils because of the presence of high quality browse (Yarrow and Yarrow, 1999). Other soils in the region are not as fertile or productive to wildlife because of low to moderate soil depth and the presence of rocky sandstone and shale fragments (Fenneman, 1938; Smalley, 1979; Springer and Elder, 1980; ADCNR, 2005; Hart and Clatterbuck, 2011). Pine-oak forests are dominant in the SWA except in deep ravines or areas of alluvial soil where mixed mesophytic forests are more dominant (Yarrow and Yarrow, 1999).

The Ridge and Valley (RV) borders the SWA to the south and east and stretches from the northeast corner of Alabama to the southwest in the center of the state (Fenneman, 1938; Yarrow and Yarrow, 1999). Although the RV has a series of ridges and valleys, it is a low-lying in comparison to its surroundings (ADCNR, 2005). The ecoregion is bordered by the Appalachian Mountains in the northwest and the Blue Ridge in the southeast (Fenneman, 1938; EPA, 2001). After the Civil War, the timber resources in the RV were exploited (Yarrow and Yarrow, 1999; ADCNR, 2005). As a result, productive soils were washed away. Today, half of the region is covered in vegetation (ADCNR, 2005). The RV remains a poor site for most wildlife due to low

soil fertility and browse (Yarrow and Yarrow, 1999). However, the RV supports a diverse host of aquatic habitats and species (EPA, 2001).

The Piedmont (PD) ecoregion is southeast of the RV. The PD is an area marked by rolling hills that are the boundary between the mountainous areas of Alabama to the northwest and the flat plains in the southeast (Yarrow and Yarrow, 1999; EPA, 2001; ADCNR, 2005; Neilson, 2011). The ecoregion was heavily cultivated in the early 1800s (Yarrow and Yarrow, 1999; ADCNR, 2005). Today, the soils are depleted and have low productivity, and forest communities are mostly loblolly-short-leaf pine (Yarrow and Yarrow, 1999; EPA, 2001; ADCNR, 2005; Neilson, 2005). Like the RV, habitats in the PD are not productive enough for many types of wildlife due to low quality or scarce browse. However, the PD has some bottomland areas that have soil fertile enough to sustain a wildlife population (Yarrow and Yarrow, 1999).

The largest ecoregion in Alabama is the Southeastern Plains (SEP). The SEP covers two-thirds of Alabama. Elevation and relief in the SEP is much lower than the PD (Fenneman, 1938; EPA, 2001). It is located south of the Fall Line, a physiographic marker of the transition between the older, upland geologic formations in northeast Alabama and the more contemporary geologic formations in south Alabama (Yarrow and Yarrow, 1999; ADCNR, 2005). The soils in the SEP are very diverse and range from clay to sand (Yarrow and Yarrow, 1999). The area of the SEP along the Fall Line Hills is one of the most diverse habitat areas in Alabama. Vegetation in the ecoregion is mostly oak-hickory-pine (EPA, 2001). Bobwhite quail, red-cockaded woodpeckers, and a host of herpetofauna are notable in the SEP (Yarrow and Yarrow, 2001).

The southernmost and smallest ecoregion in Alabama is the Southern Coastal Plain (SCP). The SCP is a diverse region along the Gulf coast containing barrier islands, coastal lagoons, marshes, and swampy lowlands (EPA, 2001; ADCNR, 2005). This ecoregion is notably flatter and wetter than the other ecoregions. Pines and some oak-gum-cypress forests in low-lying areas dominate the region (EPA, 2001). The structural complexity of the SCP makes it one of the most diverse ecoregions in Alabama. Hardwood-dominated bottomlands serve as important wildlife habitats, and barrier islands and marshes serve as habitats for migrant bird species (EPA, 2001). Although protection of this area has been increased in recent years, development has heavily degraded beach and dune habitats (ADCNR, 2005).

2.2. Methods

I created a georeferenced database featuring all public (n = 154) and private (n = 206) NR parcels (Fig. 3). All public and private NR parcels and variables of interest were input into the database. I recorded five different variables for each reserve: (1) area (ha), (2) location (ecoregion), (3) property type (public or private), (4) owner type (locally, state, federally, or land trust), (5) distance (km, parcel isolation from nearest NR). No minimum or maximum size or isolation requirements were established. Thus, there was great variation in area and isolation of nature reserves. I included terrestrial NRs used only for passive recreation, which are areas that are used for activities that place minimal stress on a site (EPA, n.d.). I also chose to include Department of Defense (DoD) lands. Many NR related studies do not include these lands, but DoD lands have been found to be ecologically important (Benton et al., 2008; Havlick, 2011). The DoD has managed public lands and natural resources since 1823 and must follow

Fig. 3 Alabama public and private NRs and their distribution across ecoregions

Table 2 Land trusts and their focus ranges included in this study

Landtrust	Range
Alabama Forest Resources Center	Statewide
Alabama Land Trust	Statewide
Atlantic Coast Conservancy	Regional
Freshwater Land Trust	Statewide
Land Trust of North Alabama	Statewide
Southeast Regional Land Conservancy Inc.	Regional
Southeastern Cave Conservancy Inc.	Regional
The Nature Conservancy	National
Weeks Bay Foundation	Statewide

policies on environmental protection and regulation including the National Environmental Policy Act and the Endangered Species Act (Benton et al., 2008; Stein et al., 2008). Public NR data and shapefiles were acquired from the United States Geological Survey (USGS) Protected Areas Database (PAD) (PAD-US, 2007). Private NR data were collected from various land trusts that are accredited by the Land Trust Alliance (LTA). I chose this method of collecting private NR data to standardize my research and to ensure inclusion of only ethically, legally, and technically managed NRs (Land Trust Alliance, 2007). NRs belonging to land trusts accredited by the LTA or that follow the LTA's standards and practices were included in this study (Table 2) (Land Trust Alliance, 2007). Alabama land trust organizations listed by the LTA as accredited by the LTA or as adoptees of the LTA's standards and practices were contacted. These land trusts provided available data on all conservation easements in perpetuity. The private land trusts that were included in this study provided me with parcel names, coordinates or addresses, and size.

In ArcMap v. 10, public and private NRs were overlaid on the EPA's Level III ecoregion shapefile (EPA, 2011). Public NRs were displayed as polygons. Many land trusts provided NR shapefiles in polygon form, but some land trusts requested that specific boundaries or any other identifying characteristics of easement parcels not be displayed (Morris and Rissman, 2009). The most efficient option for this research was to display private NRs as points in ArcMap. All parcel shapefiles in polygon form were converted to points. Overlap of points in ecoregions or modifiable areal unit problems (MAUPS) were accounted for and corrected using the Intersect tool in GIS to analyze parcel-ecoregion overlap and the measuring tool to measure

proximity in cases where MAUPs might be an issue (Jenkins and Joppa, 2009; ESRI, 2011).

Parcels that overlapped ecoregions were

NR characteristics were evaluated using descriptive and inferential statistics in SPSS v.15. Kolmogorov-Smirnov tests were used to test for normality. In cases where data were not normally distributed, I used non-parametric tests. I used Kruskal-Wallis one-way analysis of variance to compare mean area and distance across Alabama ecoregions. I also used Mann-Whitney U as post-hoc tests. Additionally, I calculated relative NR area of each ecoregion (percent of land area in each ecoregion occupied by NRs). In gap analyses, a predefined minimum extent of each ecological component is considered necessary to analyze ecological function and viability (Villard and Jonsson, 2009; Huber et al., 2010). These conservation thresholds assure that no ecological components are excluded from gap analyses (Margules and Pressey, 2000; Villard and Jonsson, 2009; Huber et al., 2010). I set the threshold for my study at 10% minimum extent coverage by NRs in each ecoregion based on previous studies (Soutullo et al., 2008; Jenkins and Joppa, 2009; Huber et al., 2010; Wu et al., 2011).

3. Results

3.1. Statewide NR characteristics

Nature reserves occupied approximately 840,000 ha (6.2%) of land area in Alabama (Table 3). Public NRs covered 6.0% of Alabama land area, and private NRs cover 0.2% of Alabama land area. The public reserves were comprised of local, state, and federal lands. State-owned reserves represent 58% of all public reserves. Federally owned NRs represented 39% of all public reserves, and locally owned NRs represented 3% of public NRs. Privately owned nature reserves were 100% owned by land trusts.

The analysis of statewide results showed that the ratio of relative NR land area in each ecoregion did not coincide with the land area of Alabama ecoregions (Fig. 4). The SEP occupies 60% of Alabama land area, but SEP NRs only accounted for 40% of NR land area in Alabama. In contrast, the PD occupied 9% of Alabama's land area, but PD NRs accounted for 17% of NR land area in Alabama. The SWA, RV, PD, and SCP exceeded the ratio of relative NR land area to relative land area of Alabama occupied by each ecoregion. The IP and SEP fell short of the ratio. Both public and private NRs ranged widely in area. The mean area for public NRs was 4,789 ha $\pm$ 12,742 standard deviation (SD) and 151 ha $\pm$ 267 ha (SD) for private NRs. The minimum NR area was 0.2 ha, and the maximum was 99,579 ha. The mean distance between public NRs was 4.8 km, and the mean distance between private reserves was 4.3 km.

Table 3 Characteristics of Alabama's NR network

Characteristic	Public	Private
Total Area in Reserve Status (%)	6.0	0.2
Mean (ha)	4,789	151
Minimum (ha)	0.4	0.2
Maximum (ha)	99,579	1,863
Range (ha)	99,579	1,863
Standard Deviation (ha)	12,742	267
Mean Distance Between Reserves (km)	4.8	4.3
Landtrust Owned (%)	--	100
Local Owned (%)	3	--
State Owned (%)	58	--
Federal Owned (%)	39	--

Figure 4 (A) Relative land area of Alabama represented in each ecoregion and (B) relative land area of the Alabama NR system represented in each ecoregion

3.2. Area and Isolation of NRs by Ecoregions

Of the six ecoregions, four had less than 10% of their area protected by NRs (Table 4). The SCP, with 19.3% coverage, and the PD, with 10.4% coverage, were the only ecoregions with 10% or greater coverage. The mean area and standard deviation between ecoregions varied greatly. The IP had a mean area of 833 ha $\pm$ 2,472 (SD). The SWA had a mean area of 2,152 ha $\pm$ 9,059 (SD). The RV has a mean average of 1,274 ha $\pm$ 5,777 (SD). The Piedmont had a mean average of 5,225 ha $\pm$ 19,926 (SD). These averages and standard deviations differ greatly because land parcels are often opportunistically purchased. Thus, there was a large range in NR sizes. The Kruskal-Wallis analysis showed a statistically significant relationship between ecoregion and area ($P < 0.001$). Mann-Whitney U tests between ecoregions showed statistically significant relationships in area between the IP and PD, ($P = 0.002$), the IP and SEP ($P < 0.001$), the IP and SCP ($P = 0.012$), the SWA and RV ($P = 0.012$), the SWA and PD ($p = 0.013$), the SWA and SEP ($P < 0.001$), the SWA and SCP ($P = 0.025$), the RV and PD ($P < 0.001$), the RV and SEP ($P < 0.001$), and the RV and the SCP ($P = 0.004$). This means average size of NRs vary between ecoregions.

Mean distance also varied between ecoregions. In the IP, SWA, and RV, the mean distance between NRs was, respectively, 2.7 km, 2.6 km, and 2.6 km. The SCP had a mean distance of 4.0 km between NRs. The Piedmont had 5.1 km mean distance between NRs. The greatest mean distance between NRs was found in the SEP. The SEP had a mean distance of 7.7 km between reserves. The large distance between reserves may be attributed to the large area of the SEP. The Kruskal-Wallis analysis revealed statistically significant relationships between ecoregions and distance ($P < 0.001$). Mann-Whitney U tests between ecoregions showed

Table 4 Characteristics of NRs by ecoregion

Characteristic	Interior Plateau	Southwestern Appalachians	Ridge and Valley	Piedmont	Southeastern Plains	Southern Coastal Plain
Land Area in Reserve Coverage (ha)	38,302	152,826	107,105	130,636	312,482	36,755
Relative Ecoregion Land Area in Reserve Coverage (%)	4.4	7.8	9.2	10.4	3.9	19.3
Mean Area (ha)	833	2,152	1,274	5,225	2,604	2,450
Minimum Area (ha)	1	3	0.2	16	0.4	0.4
Maximum Area (ha)	14,869	73,049	49,465	99,579	63,533	25,494
Range of Area (ha)	14,868	73,047	49,465	99,563	63,532	25,494
Standard Deviation (ha)	2,472	9,059	5,777	19,926	8,087	6,420
Mean Distance Between Reserves (km)	2.7	2.6	2.6	5.1	7.7	3.9
Public Land Area (%)	96.7	96.5	95.2	97.9	94.5	99.8
Private Land Area (%)	3.3	3.5	4.8	2.1	5.5	0.2
Public Parcels (%)	39	35	21	48	58	72
Private Parcels (%)	61	65	79	52	43	28
Landtrust-Owned Parcels (%)	61	65	79	48	42	28
Locally-Owned Parcels (%)	4	1	1	--	1	--
State-Owned Parcels (%)	11	23	12	36	34	55
Federally-Owned Parcels (%)	24	11	8	16	23	17

statistically significant relationships between some ecoregions and distance. The ecoregions that showed significant differences in distance between NRs were the IP and SEP ($P<0.001$), the IP and SCP ($P=0.012$), the SWA and RV ($P=0.012$), the SWA and PD ($P=0.013$), the SWA and the SEP ($P<0.001$), the SWA and SCP ($P=0.006$), the RV and SEP ($P<0.001$), and the RV and SCP ($P=0.036$). This means mean distance varies between NRs varies between ecoregions.

3.3. NR Property Type by Ecoregion

Public land area accounted for the majority of NR land area in all ecoregions. The SEP had the smallest amount of publicly owned NR land area (94.5%) and the largest amount of privately owned land (5.5%). The SCP had the highest amount of publicly owned NR land (99.8%) and the smallest amount of privately owned NR land (0.2%). However, public and private NR parcels were unevenly distributed throughout ecoregions (Fig. 5). Private NR parcels accounted for the majority of NR parcels in the IP (61%), SWA (65%), RV (79%), and the Piedmont (52%) by a small margin. Public NR parcels accounted for the majority of NR parcels in the SEP (58%) and SCP (72%). The Kruskal-Wallis analysis showed a statistically significant difference between property type and ecoregion ($P<0.001$). Property type was different between ecoregions. Post-hoc testing revealed significant differences and positively correlated differences in property type in the IP and RV ($P=0.032$), the IP and SEP ($P=0.034$), the IP and SCP ($P=0.002$), the SWA and SEP ($P=0.003$), the SWA and SCP ($P<0.001$), the RV and the PD ($P=0.003$), the RV and the SEP ($P<0.001$), the RV and SCP ($P<0.001$), the PD and the SCP ($P=0.028$), and the SEP and the SCP ($P=0.30$).

Fig. 5 Relative NR parcels owned by public or private NRs (percent of NR parcels that are public or private) by ecoregion

Fig. 6 Relative NR parcels comprised of local, state, federal, or land trust owned NRs (percent of NR parcels that are local, state, federal, or land trust) by ecoregion

3.4. NR Owner Type by Ecoregion

Beyond public and private property types, NR parcels varied by owner type (local, state, federal, or land trust) (Fig. 6). Land trusts own over 60% of NR parcels in the IP (61%), SWA (65%), RV (79%), and PD (52%). In contrast, local, state, and federal entities comprise the majority of NR parcels in the SEP and represent 58% of NR ownership. The SCP exhibited a departure in owner type compared to the other ecoregions. In the SCP, 55% of NRs are state-owned. I found statistical significance between ecoregion and owner type ($P < 0.001$). Owner type changed throughout ecoregions. Post-hoc testing revealed significant positive differences in owner types between the IP and RV ($P = 0.022$), the IP and SCP ($P = 0.019$), the SWA and SEP ($P = 0.002$), the SWA and SCP ($P = 0.001$), the RV and PD ($P = 0.004$), the RV and SEP ($P < 0.001$), and the RV and SCP ($P < 0.001$).

4. Discussion

4.1. Statewide NR characteristics

Of all Alabama land area, 6.2% was in NR status. This percentage was lower than the 10% policy-based conservation threshold established by the Convention on Biological Diversity (CBD) that was used to evaluate extent of NR coverage in many studies (Soutullo et al., 2008; Jenkins and Joppa, 2009; Huber et al., 2010; Wu et al., 2011). The 10% conservation threshold is somewhat arbitrary and does not necessarily indicate that ecological diversity of an ecoregion is represented in NR systems. However, a conservation target is better than no target (Margules and Pressey, 2007). The relative coverage number documented was higher than the number of lands reported by PAD-US (2007). However, unlike the PAD-US study, this project included Department of Defense (DoD) lands and private lands. Although this study was more inclusive than the PAD-US study, the conservative 10% threshold was still unmet at the state level.

Public NRs in Alabama were generally much larger than private NRs. Public NRs comprised almost all of Alabama NR land. Of all Alabama land area, 6.0% out of the 6.2% was occupied by NRs was public NR land. The remaining 0.2% was comprised of private NR land. The public NR land was comprised primarily of state and federal land. State-owned NRs accounted for 58% of public NRs and 39% of NRs are owned by federal entities. The high percentage and large mean area of public NRs in Alabama demonstrates the importance of public NRs in conservation. Specifically, I noted that DoD lands represented 11.3% of all Alabama NR land area. The DoD has managed public lands and natural resources since 1823

and must follow policies on environmental protection and regulation including the National Environmental Policy Act and the Endangered Species Act (Benton et al., 2008; Stein et al., 2008). In 1994, the DoD's "Implementation of Ecosystem Management in the DoD" policy emerged (Benton et al., 2008). The goal of this policy was to maintain and improve the sustainability and native biological diversity of terrestrial, aquatic, and marine ecosystems (Benton et al., 2008). As a result of the DoD lands have the highest percentage and densities of federally listed endangered and imperiled species per 1000 km² compared to land managed by the Bureau of Land Management, Forest Service, Fish and Wildlife Service, and National Park Service (Benton et al., 2008; Stein et al., 2008). Despite DoD lands being managed for conservation and restoration of resources, many studies that have evaluated the effectiveness of a nature reserve system have not include DoD lands (Ripley and Leslie, 1997; Bhuta et al., 2011). However, these lands may be vulnerable (to what) because they are subjected to many shifts such in changing political agendas and public expectations as well as some unique processes such as munitions testing and associated fires (Signell and Abrams, 2007; Benton et al., 2008; Havlick, 2011). DoD lands are a major contributor to public lands managed for conservation, future conservation policy, and research including gap analyses. Future research should include DoD lands to obtain comprehensive results of conservation needs.

Ideally, the ratio of NR land area to ecoregion land area would be a 1:1 ratio to ensure NR land is distributed evenly among various ecoregions and their ecological components. The results showed that all Alabama ecoregions either exceed or fall under the ratio. The ratio of NR land area to ecoregion land area can be used to evaluate where conservation land is most needed and best placed. The PD represents 17.0% of the Alabama's NR land area, but it

represented only 9.3% of statewide land. Conservation agencies should consider acquiring land in ecoregions that fall below the ratio to ensure even distribution of NRs and ecoregionally equal protection of ecological elements. NR presence in the IP and SEP should be increased to a representative amount of land area. In the IP and SEP, 6.4% and 59.5%, respectively, of land area should be in NR status.

4.2. Area and Isolation of NRs by Ecoregion

In this study, only two of six ecoregions had 10% or more of land area protected by NRs. Of all SCP and PD land area, 19.3% and 10.4% was NR land, respectively. The RV almost met the threshold with 9.2% of its land area in NR status. The IP, the SWA, and the SEP did not meet the threshold. The PD and RV have endured intensive agricultural and timber practices for more than a century, which has resulted in poor soils and vegetation (Yarrow and Yarrow, 1999; ADCNR, 2005). These ecoregions have lower quality soil and vegetation fertility than other Alabama ecoregions (Yarrow and Yarrow, 1999; ADCNR, 2005). However, these ecoregions had the second and third most NRs, respectively. Lower monetary land values in the PD and RV might make it easier for land trusts to acquire properties in these ecoregions. Regardless of land quality, all ecoregions should have 10% of their typical ecological characteristics are in NRs based on the conservative parameters of this study.

NRs comprised 19% of land area in the SCP. This makes the SCP the most protected ecoregion in Alabama. The tourist industry formed around the ecological richness of the SCP provides many jobs and produces \$2 billion in revenue annually (Douglass, 2012). Although human presence has been productive for the economy, the SCP suffers from beach erosion due

to human-made waterways. This combination of factors makes the SCP an ecoregion particularly targeted for conservation efforts. The focus and methods of protection on the SCP could be replicated for other ecoregions.

Isolation also differed between ecoregions. My study revealed that mean distance between NRs in the SEP was 7.74 km. This means species must travel an average of 7.74 km to reach another NR. For small ground traveling animals or migratory animals, these distance barriers can be challenging and life-threatening. I speculate the 7.7 km mean distance between NRs is because of the large area of the SEP. The mean distance is indicative of a need for greater connectivity between NRs in the SEP. Based on MacArthur and Wilson's (1967) theory of island biogeography, small, isolated islands experience the lowest rates of biodiversity. Diamond (1975) suggested the theory of island biogeography provides a general model for assessing the ability of conservation areas to preserve biodiversity (Diamond, 1975; Margules and Pressey, 2000; MacDonald, 2003). Although Diamond's theory created controversy about nature reserve design, the hypothesis that fragmentation creates a reduction in biodiversity is widely accepted by biologists (MacDonald, 2003).

Connectivity between NRs is important for increased species immigration and the resulting genetic diversity (MacArthur and Wilson, 1967; MacDonald, 2003). Corridors, geographic features that promote dispersal and colonization, link isolated protected areas and create a nature reserve system (MacDonald, 2003; Primack, 2008). Ecological corridors are especially important for animals with small, sexually mature populations and species that must migrate seasonally for food and water (Hunter and Gibbs, 2007; Primack, 2008). However,

corridors are difficult to purchase, and there is still a dearth of research in the effectiveness of corridors (Hunter and Gibbs, 2007).

While the 10% coarse-filter conservation threshold is useful, many other thresholds have been recommended. Various science-based thresholds recommend 30–50% NR coverage of ecoregions (Villard and Jonsson, 2009; Huber et al. 2010). Other authors argue that not one threshold should be applied to every ecoregion because thresholds vary between land types and species (Villard and Jonsson, 2009). In this study, the CBD's very conservative threshold of 10% was used. This threshold does not necessarily ensure protection of ecological diversity in ecoregions. Some reserve lands included in this study may be very similar and representative elements of an ecoregion may be underrepresented. Four out of six Alabama ecoregions did not meet this 10% threshold. This threshold is meant to ensure. No ecoregions in the state meet the science-based conservation threshold.

4.3. Property Type by Ecoregion

NR ownership type for parcels shifted from private NR presence in northeast Alabama to southwest Alabama. The IP, SWA, RV, and PD are the northeastern most ecoregions, and they were also comprised of the highest relative amount of private NR parcels. Over 60% of NR parcels in the IP (61%), SWA (65%), and RV (79%) were privately owned by land trusts, and half of PD NR parcels (52%) were privately owned by land trusts. NRs in the two southernmost ecoregions were comprised of mainly public parcels. NRs in the SEP (58% of NR parcels are public) and the SCP (72% of NR parcels are public) were composed mainly of public NR parcels. The majority of SCP parcels were publicly-owned. As with high relative amount of NR coverage

in the SCP, the high economic and ecological value of the coastal Alabama may be a reason for increased NR coverage. However, the SEP ecoregion did not have the same economic or ecological value placed on the SCP.

I noted a latitudinally shifting distribution of parcel property types throughout Alabama. NR parcels in north and central Alabama were predominately privately owned while NR parcels in south Alabama are predominantly publicly owned. I hypothesize the distribution of parcel property types throughout Alabama is related to a combination of the distribution of socioeconomic status, race, and cities throughout the state. In Alabama, socioeconomic status is higher in north and central Alabama than south Alabama (US Census Bureau, 2012). All regional or local land trusts in this study, except the Weeks Bay Foundation, are headquartered in north or central Alabama or Atlanta, Georgia. In the IP, SWA, and RV, the overwhelming majority of NR parcels were owned by land trusts, which need donors to help land trust continuation. Estabrooks et al. (2003) and Moore et al. (2008) found individuals with low socioeconomic status were less likely to have access to free-for-use resources and limited accessibility to parks. Moore et al. (2008) also found that areas that were predominantly composed of African and Hispanic Americans had lower accessibility to parks. Dwyer (1994) and Tierney et al. (2001) found that African Americans were significantly less likely than whites to participate in rural and wildland activities such as hiking and tent camping in underdeveloped natural areas. In the SEP, where the majority of the poorest, predominantly African-American Alabama counties are located, most NR parcels are mostly comprised of public lands (US Census Bureau, 2012). Land trust presence in south Alabama is minimal while poor African-American presence is high. Similarly, there are few major cities in the south

Alabama. Montgomery and Mobile are the only major cities, and other areas of south Alabama are predominantly rural. This study found that most land trust headquarters and their land were located near cities where wealthy benefactors are more likely to live.

These results indicate that while public agencies are a huge contributor to conservation throughout the state, land trust presence should be increased in to bolster conservation efforts and NR land area in area that fall below the 10% NR land area threshold such as the SEP, IP, SWA, and RV. The SEP, the least protected ecoregion, is home to the two known sites where the Red Hills Salamander occurs. Although the Federal Endangered Species Act of 1973 considers Red Hills Salamanders Threatened, all Red Hills Salamander habitat sites occur on private land used for timber production (AmphibiaWeb, 2013). Sites and species like these are often caught between business and political interests. In Alabama's conservative political climate, where government land acquisition is often seen as a violation of property rights, land trusts must fill in the voids that public lands can no longer fill.

4.4. Owner Type by Ecoregion

Ownership of properties also displayed a latitudinal pattern where dominant ownership types of parcels changed from north to south Alabama. Private parcel ownership dominated the northeastern section of Alabama south to the Piedmont ecoregion. State and federal lands account for the majority of NR land area in north Alabama, but land trusts own the majority of NR parcels in the IP, SWA, RV, and PD ecoregions. As previously mentioned, the SCP and SEP are predominated by publicly owned parcels. These lands are owned by state, federal, and a

few local entities. However, for all ecoregions, public land area was the major contributor of NR land area.

Similar to my hypothesis about the distribution of NR property type, socioeconomic status, race, and amount of cities appear to play a role in the distribution of NR ownership. In the northeastern ecoregions, land-trust owned NR parcels were the dominant parcel type. In these areas, higher socioeconomic status and a higher probability that people had money and will donate it to land trusts in these areas (US Census Bureau, 2012). In the SEP, where NR land area is lower and socioeconomic status is generally lower, there were fewer land trust owned parcels and more state and federal NRs. Poor, rural African-American presence was also higher in the SEP. These characteristics were indicative of a smaller land trust parcel presence in south Alabama. Increased land trust presence in the SEP, where only 3.9% of land area is in NR coverage, could bolster conservation land area. In Alabama and the US's changing political climate, where many are skeptical of centralized government, acquisition of large, public, conservation parcels may be coming to an end (Norton, 2000).

5. Conclusion

This study demonstrated that NRs and their characteristics were distributed differently throughout Alabama ecoregions. A detailed database with public and private NR data and a gap analysis using public and private NR data has never been completed for the State of Alabama. This research added valuable information about the distribution of NRs and the characteristics of NRs. A database was created and the location, area, isolation, property type, and owner type of 360 NRs were analyzed. Statistically significant relationships were found among all ecoregions and variables. The analysis revealed that all but two ecoregions did not meet the conservation threshold of 10% NR coverage. The CBD's 10% conservation threshold is policy-based but conservative. Efforts should be made to increase NR coverage in the ecoregions that do not meet the 10% threshold (the IP, SWA, RV, and SEP). When ecoregions reach the 10% threshold, public and private organizations that manage NRs should consider goal setting to reach the science-based conservation thresholds (30—50% NR coverage for each ecoregion). In this study, DoD lands, 11% of all Alabama NR land area, were found to be a major contributor to Alabama NR land area. This indicates the importance of including DoD lands in future conservation research and gap analyses. Area and isolation of the Alabama NR system indicated the need for an increase in NR parcel coverage in two of six ecoregions and greater habitat connectivity in the SEP. Using nature reserve design based on the theory of island biogeography, larger NR area and less NR isolation may increase species richness in NRs.

However, acquiring parcels deemed ideal by the theory of island biogeography is often unrealistic.

The analysis of property type revealed that public property land areas dominated conservation land. Support for public NR lands is incredibly important to maintaining and building the NR system in Alabama. The analysis of property type of parcels revealed a pattern of property type of parcels shifting from majority private in north and central Alabama to majority public in the south Alabama. The analysis of ownership type revealed the same pattern of a shift from majority private to public ownership from north to south Alabama. State-owned NRs dominated south Alabama. It is hypothesized that the latitudinal shift in NR property and owner type is related to the distribution of socioeconomic status, race, and cities from north to south Alabama. The ecoregion that was an exception to the socioeconomic, race, and locational hypothesis is the SCP, which is located on the Gulf Coast. The SCP was generally viewed as very economically and intrinsically valuable. The SCP also had the highest relative NR land area. The type of emphasis placed on the SCP is a good model for the distribution in other ecoregions. It is important for public and private entities to account for ecological elements of all ecoregions. Although the SCP is highly protected, ecological elements in many other ecoregions, specifically the SEP and IP, are under-protected. Land trusts should increase presence in under-protected ecoregions. The outcomes of this study are indicative of change in Alabama's conservation future. In conclusion, this study documented the ecological gaps in Alabama's NR system and the distribution and characteristics of NRs.

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