Acta Herpetologica 2(2): 97-115, 2007
ISSN 1827-9643 (online) © 2007 Firenze University Press

Emergent spatial pattern of herpetofauna in Alabama, USA

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Abstract. Analyzing spatial pattern of regional biodiversity and its relationships with environmental factors is important for biodiversity conservation at large scales. The emergent spatial pattern of herpetofauna in Alabama is examined by combining thousands of historical records from 132 species of 24 families and environmental conditions. Our results indicate that species richness of herpetofauna increases with the increase of latitude, while it decreases with the increase of elevation. A negative spatial association exists between amphibians and reptiles on the scale of 10 km^2, but 40% of habitats are still shared by amphibians and reptiles at this scale. The highest species richness of herpetofauna is in the Mobile and Baldwin Counties. Power-law relation exists between the county size and the average species richness. Total stream length, and road density are highly correlated with species richness at the county level. With the increase of annual precipitation, species richness decreases. Species richness is higher in the area with the annual average temperature around 17-18 °C. Herpetofaunal diversity in the Coosa/Tallapoosa River, the Alabama River, and the Tombigbee River basins is relatively higher than in the Perdido River and the Escatawpa River basins. The highest species richness exists at the Gulf Coastal Plain, but its species density is the lowest. The highest species richness of herpetofauna exists in the Longleaf-Slash Pine and Loblolly-Shortleaf Pine forests, while lower in Oak-Hickory forest. The emergent spatial pattern may provide important implications for herpetofauna conservation in the face of global climate change and large-scale habitat destruction. The spatial pattern and the possible underlying ecological processes have to be considered for the large scale land zoning and planning.

Keywords. Alabama, amphibians, reptiles, herpetofauna, spatial pattern.

INTRODUCTION

Herpetofauna plays an important role in both aquatic and terrestrial ecosystems, such as an energetic link in trophics (Pough, 1980; Whiles et al., 2006). Holomuzki et al. (1994) and Wissinger et al. (1999) indicated that amphibians may have large impacts on ecosystem structure because they are keystone species in some habitats. Regester et al. (2006)

reported that salamander communities transfer an average net flux of 350 g yr^{-1} in ash-free dry mass into small forest ponds, which is considered equal to or higher than fish or other macroinvertebrates. However, during the recent decades, a decline status for amphibian and reptile species was reported as a global phenomenon (e.g., Gibbons et al., 2000; Gardner, 2001; Stuart et al., 2004). A number of factors were considered to shed doubt on the responsibility for the world-wide decline of amphibians and reptiles, such as physical habitat modification and habitat loss (Sjogren, 1991; Alford and Richards, 1999; Chen et al., 2006a), ultraviolet radiation (Blaustein et al., 1994; Ovaska et al., 1997; Crump et al., 1999), chemical pollutions (Beebee et al., 1990; Lips, 1998; Carey et al., 2001; Sparling et al., 2001), diseases (Laurance et al., 1996), and climate change (Pounds and Crump, 1994; Pounds, 2001; Chen et al., 2006b). Furthermore, both empirical and theoretical investigations indicated that the extinction of some species will result in the extinction of other species in ecosystems by trophic cascades (Jennings et al., 1992; Lavin, 1999).

Due to the global decline of biodiversity and the possible complexity of underlying mechanisms, the previous reductionist approach, which only focuses on a single (or several) species, may not work well to provide general picture about the entire herpetofauna, their suitable habitats and their regional conservation strategies (Smallwood et al., 1998; Chase et al., 2000; Chen et al., 2005). Just like the accurate description of the behavior of a single air molecule, may not help to understand the atmospheric dynamics. Thus, a top-down approach to evaluate the general regional herpetofauna in their entirety may help us to understand some of their emergent properties. This method may identify the critical resource needs for overall herpetofauna and may lead to infer the important underlying processes for all species (Chen et al., 2005). Despite the fact that different processes may result in same spatial pattern, analysis of spatial pattern of regional herpetofauna can provide information that can not be obtained from a single species (or several species) approach.

The herpetofauna of Alabama have been received more attention for its richness and diversity in the USA. Several factors interrelated to produce this diversity, such as mild and humid climate, remarkable surface drainage and diverse physiographic subdivisions (Mount, 1975). In 1838, Holbrook made the earliest significant contribution to Alabama herpetofauna by the description of *Emys* (*Pseudemys*) *mobilensis* at the Mobile area. Since then numerous investigators contributed significantly about the herpetofaunal species and locality records (e.g. Agassiz, 1857; Cope, 1880; Yarrow, 1882; Baur, 1893; Brimley, 1904; Holt, 1919; Dunn, 1920; Löding, 1922; Blanchard, 1924; Haltom, 1931; Viosca, 1937; Snyder, 1944; Grobman, 1950). In 1960s the most significant herpetological event in Alabama was the discovery and subsequent description of *Phaeognathus hubrichti* (Highton, 1961). In 1970 Mount and Schwaner published the distribution relationships between *Natrix rhombifera* and *N. taxispilota*. New locality data for *Ambystoma texanum* and *Trionyx ferox* were published later (Scott and Johnson, 1972; Scott, 1973). However, there is limited study on the quantitative and synergetic analysis of herpetofauna in this region. The study of the spatial characteristics of herpetofauna in Alabama based on all historical records of locality can provide some emergent properties of herpetofauna in this area, such as habitat, diversity distribution and gradient, as well as its relation with the environmental condition. The more important information about the strategies of regional herpetofauna conservation can also be inferred. The main aims of this study are (i) to investigate of the spatial pattern of herpetofauna in Alabama; (ii) to examine the relationships between spatial distribution of herpetofaunal diversity and environmental conditions; (iii) to compare the spatial characteristics of herpetofauna with some current theories at a large area; and (iv) to provide implications for large scale conservation.

MATERIALS AND METHODS

Study area

The study area covers the state of Alabama of USA, which is located between the southern foothills of the Appalachian Mountain Range and Gulf of Mexico (between 31° and 35°N) and includes 67 counties. Alabama has warm, humid, subtropical climate. Summers are hot and humid with high temperature around 33 °C. In late summer and fall, it is the driest time of the year. Winters are typified by series of cold fronts. Regional rainfall varies from 150 cm to 162 cm in the north part and 180 cm to 195 cm along the coast (Carter and Carter, 1984).

In Alabama, there are five recognized physiographic zones: the Highland Rim, the Cumberland Plateau, the Alabama Valley and Ridge, the Piedmont Upland, and the East Gulf Coastal Plain (Fenneman, 1938). Alabama's forests mainly consist of four types – pine, pine-hardwood mixture, bottomland hardwood and upland hardwood. South Alabama is abundant in pure stands of pine. From South to North, the type changes to mixed pine-hardwood conditions and then to more complex hardwood forests near Tennessee boundary (http://www.forestry.auburn.edu/fpdc/alforest.html, the last visit time is July 31, 2007). In this study, the general forest types in Alabama are the Longleaf-Slash Pine, the Loblolly-Shortleaf Pine, the Oak-Pine, and the Oak-Hickory.

Dataset and GIS layers

The dataset of herpetofauna in Alabama is from the book "The Reptiles and Amphibians of Alabama" (Mount, 1975), which included thousands of locality records of 132 species in 24 families examined by its author and literature. All the records were digitized by ArcGIS 9 (ESRI, 2004). We recognize that this dataset does not represent all species and does not represent the current distribution of species. But it does represent all historical data records in 1970s. This data set represents the time prior to when the most recent major growth in suburban development was initiated, so it can provide a bench marker of spatial pattern of herpetofauna in Alabama.

The GIS data of state boundaries, county boundaries and streams were obtained from Alabama State Water Program (http://www.aces.edu/waterquality, the last visit time is July 31, 2007). The human population data of each county during this study time period (1970s) was from US Census Bureau. Historical roads (including freeway, highway and country way) and other information related with long term average climate condition were from maps provided by the University of Alabama (http://alabamamaps.ua.edu, the last visit time is July 31, 2007).

Spatial association

Spatial association is the extent that different species (or species groups, here amphibians and reptiles) live together. Coomes et al. (1999) suggested the following index to measure spatial association (SI):

$$SI_{ij}(r) = \sum N_{ij}(r) / (\pi r^2 N_i N_j / Q) \quad (1)$$

where N_{ij} is the number of grid of species *j* (e.g. amphibians) within a distance *r* of species group *i* (e.g., reptiles). N_i and N_j are the total numbers of grid covered by species *i* and *j*, respectively. *Q* is the total study area. In this study, *r* is chosen as 10 km. However, with the increase of *r* the spatial association will be increased. When SI > 1, positive association is indicated, whereas SI < 1 indicates negative association.

Spatial overlay ratio

Chen et al. (2005) suggested spatial overlay ratio to measure the percentage of same location occupied by two or more species groups. It can be estimated by the following simple equation:

$$P_{ij} = \frac{AB}{A + B - AB} \quad (2)$$

where P_{ij} is the spatial overlay ratio and ranges from 0 to 1 (or 0-100%). *AB* is the number of the same locations used by species *A* and *B* (here amphibians and reptiles). *A* and *B* are the numbers of grids for species *A* and *B*, respectively. Where P_{ij} is the spatial overlay ratio is also scale dependent. Within the area of 10 km^2 (10×10 km), two locations were considered as spatial overlay.

Measurement of compositional similarity

Similarity is used to estimate the similarity of species composition in two locations. The Jaccard index of similarity was used in this study (Legendre and Legendre, 1998):

$$J = s_{ij} / (s_{ij} + s_i + s_j)$$

where S_{ij} is the number of species common to sampling sites *i* and *j*; S_i is the number of species present on site *i* but absent on site *j*; S_j is the number of species present on site *j* but absent on site *i*. *J* is in the range of 0-1.

Data categorization and statistical method

In this study, the county size, stream length, and road density were categorized. For county size (m^2), they were categorized as 9.1, 9.2…..9.8 with the $\log_{10}$. It is similar for the total stream lengths (m) in all counties, they were classified into 9.8, 9.9….10.4 with its $\log_{10}$. However, the data of road density (km × km^{-2}) in all counties were classified from 2.725 to 3.175 with increment of 0.05. Frequency is calculated by the records in the range divided by the total records. The common used least mean square technique with used in regression analysis for the relationships between species richness and environmental factors.

RESULTS

Pattern along latitude, longitude and elevation

Herpetofaunal and reptile species richness increase with the increase of latitude (UTM) (Fig. 1a). There exist significant relationships for both herpetofauna and reptiles: herpetofaunal species richness = 70.71 × UTM – 162.46 ($R^2 = 0.81$, $P < 0.01$), and reptile species richness = 86.19 × UTM – 258.19 ($R^2 = 0.81$, $P < 0.01$). Species richness pattern along longitude is not significant, but it appears to be a constant of 110. With the increase of elevation, the species richness decreases gradually (Fig. 1b). The relationships between species richness and elevation are significant: herpetofaunal species richness = -0.12 × elevation + 121.74 ($R^2 = 0.89$, $P < 0.01$), reptile species richness = -0.071 × elevation + 73.67

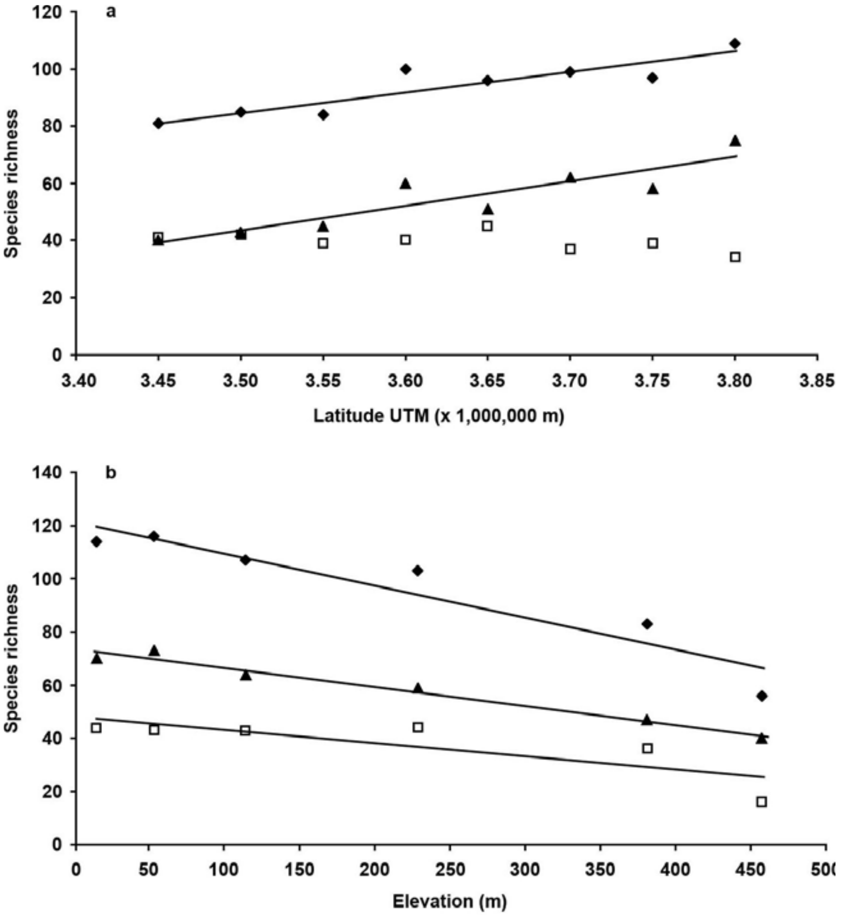

Fig. 1. The different patterns of herpetofaunal species richness in Alabama along latitude (a) and altitude (b). Universal Transverse Mercator (UTM) system was used for latitude and longitude.

($R^2 = 0.97$, $P < 0.01$), and amphibian species richness = -0.050 × elevation + 48.06 ($R^2 = 0.66$, $P < 0.05$). There exists negative spatial association (SI = -0.32) between amphibians and reptiles on the scale of 10 km^2, but the spatial overlay ratio between amphibians and reptiles is about 0.4. This result indicates that although there is a negative spatial association between amphibians and reptiles, there is 40% occasions that they occurred together within the area of 10 km^2.

Species richness at county level

Because different counties have different integrated environmental conditions and land management policies, there exists uneven spatial distribution in herpetofauna in the counties of Alabama (Appendix 1a). The highest species richness of herpetofauna is located in the Mobile and Baldwin Counties. The relationship between county size and

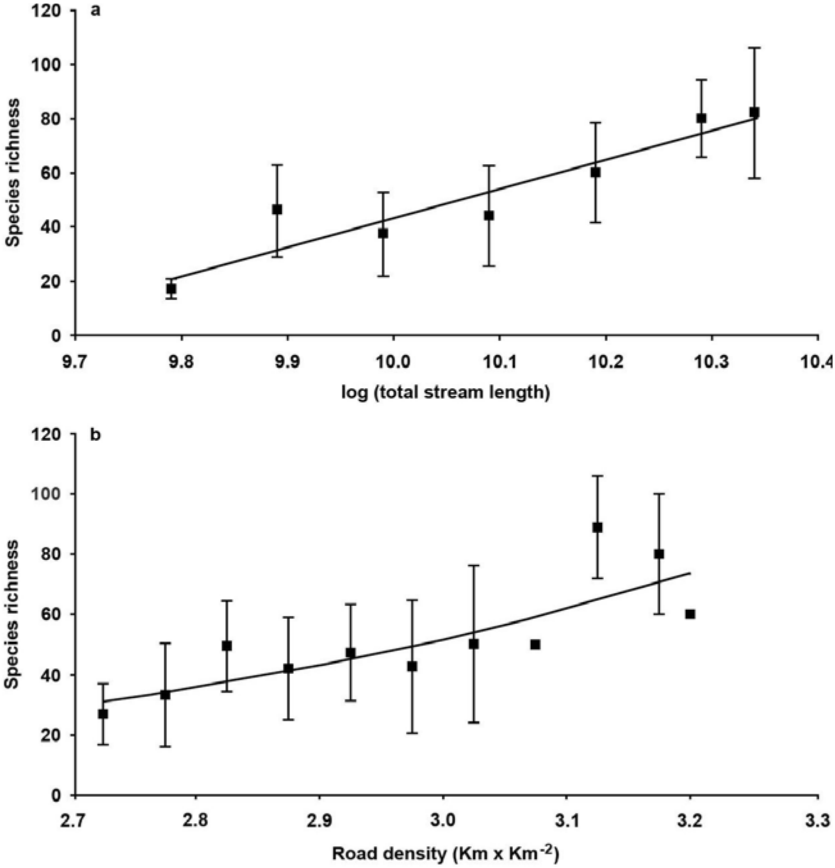

Fig. 2. Herpetofaunal species richness increases with total stream length (a) and road density (b) (error bar stands for standard deviation).

species richness is not straightforward. However, if the county sizes are categorized, there is a significant linear relationship between the log value of county size and the average species richness (Appendix 1b), Average species richness = 123.7 × log(area) - 1111.6 ($R^2 = 0.88$, $P < 0.01$). Average species richness increases with increasing county size. On the county level, there exists nonlinear relationship between species richness and its frequency (Appendix 1c), frequency (%) = -0.0035 × (species richness)^2 + 0.3573 × species richness + 0.6848 ($R^2 = 0.58$, $P < 0.05$).

The relationship between the total human population and species richness is not obvious at county level. After data categorization, there is linear relationship between total stream length (m) and species richness (Fig. 2a, species richness = 107.58 × log(total

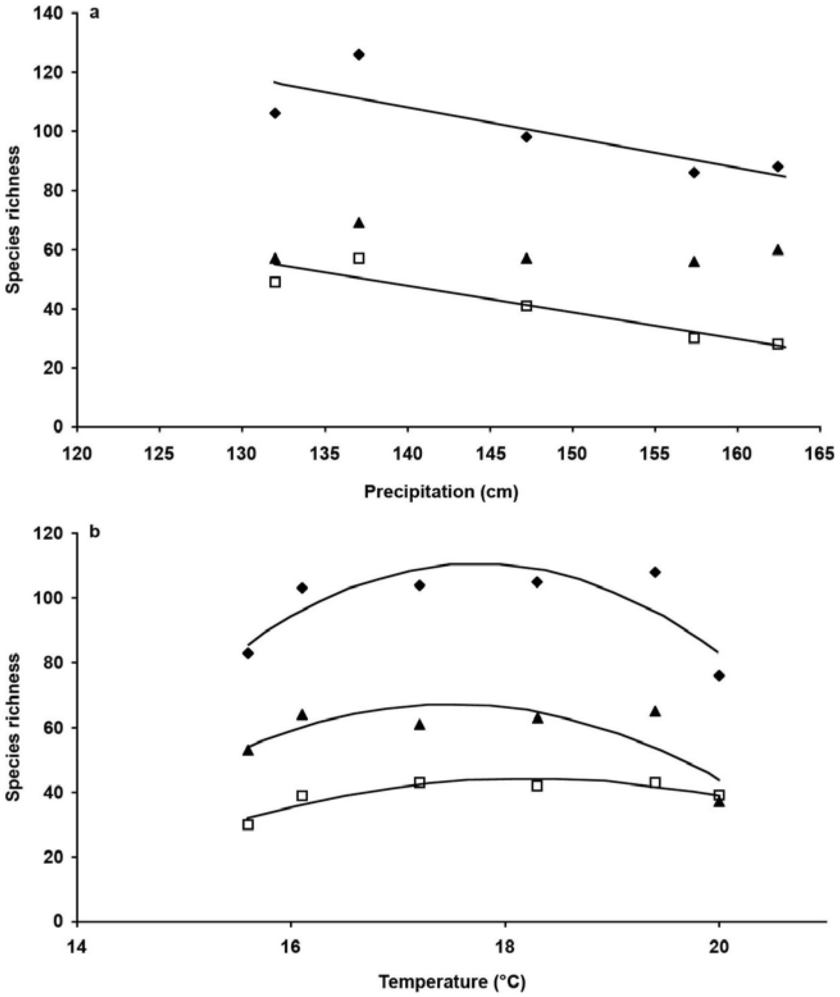

Fig. 3. Varied relationships between herpetofaunal species richness and annual average precipitation (a) and annual average temperature (b).

stream length) – 1032.5, $R^2 = 0.89$, $P < 0.01$); road density is also correlated significantly with species richness (Fig. 2b, species richness = 0.1396 × (road density)$^{5.3898}$, $R^2 = 0.73$, $P < 0.05$).

Climate and herpetofaunal diversity

There exists linear relationship between annual average precipitation and species richness (Fig. 3a), herpetofauna species richness = -1.015 × precipitation + 250.26 ($R^2 = 0.66$, $P < 0.01$) and amphibian species richness = -0.89 × precipitation + 171.50 ($R^2 = 0.86$, $P < 0.01$). With the increase of annual precipitation, total species richness and amphibian richness decreases significantly. The relationship between species richness and annual mean air temperature is significant for amphibians, reptiles and the total (Fig. 3b, herpetofauna species richness = -5.41 × (temperature)^2 + 191.94 × temperature - 1591.8, $R^2 = 0.67$, $P <$

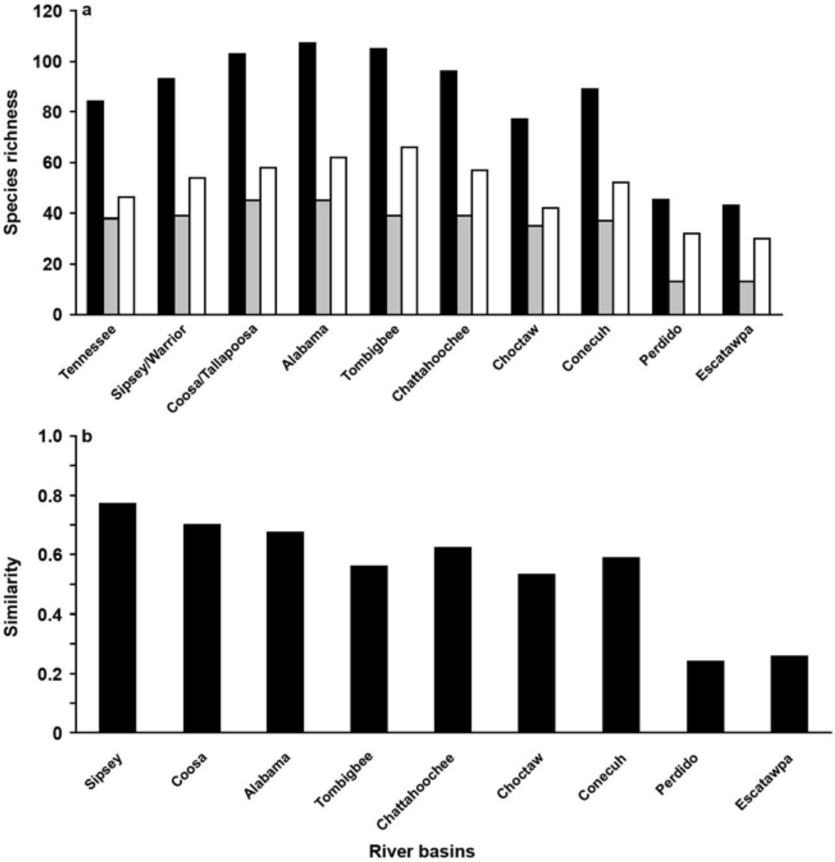

Fig. 4. Pattern of herpetofaunal species richness at different river basins (a) and the composition similarity with those in Tennessee River basin (b).

0.05; reptile species richness = -3.68 × (temperature)^2 + 128.72 × temperature - 1059, $R^2 = 0.60$, $P < 0.05$; amphibian species richness = -1.73 × (temperature)^2 + 63.22 × temperature - 532.72, $R^2 = 0.85$, $P < 0.01$). There are higher species richness in the area with the annual average temperature around 17-18 °C. With the annual average temperature is out this threshold, species richness decreases.

Herpetofaunal diversity in river basins

Species richness in different river basins was studied because of its relationships with stream length and precipitation. In Alabama there are higher herpetofaunal diversity in the Coosa/Tallapoosa River, the Alabama River, and the Tombigbee River basins, and less herpetofaunal diversity in the Perdido River and Escatawpa River basins (Fig. 4a). The Sipsey River basin has the highest similarity of species compared with the Tennessee River basins (Fig. 4b), whereas less similarity in the Perdido River and the Escatawpa River basins.

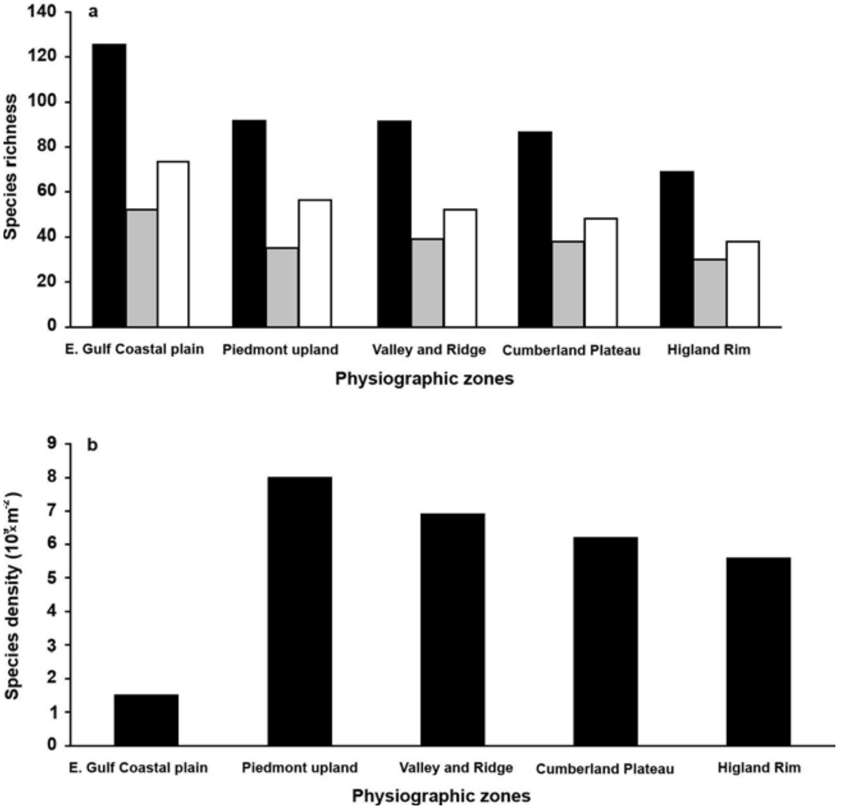

Fig. 5. Pattern of herpetofaunal species richness in physiographic zones (a) and the species density (b).

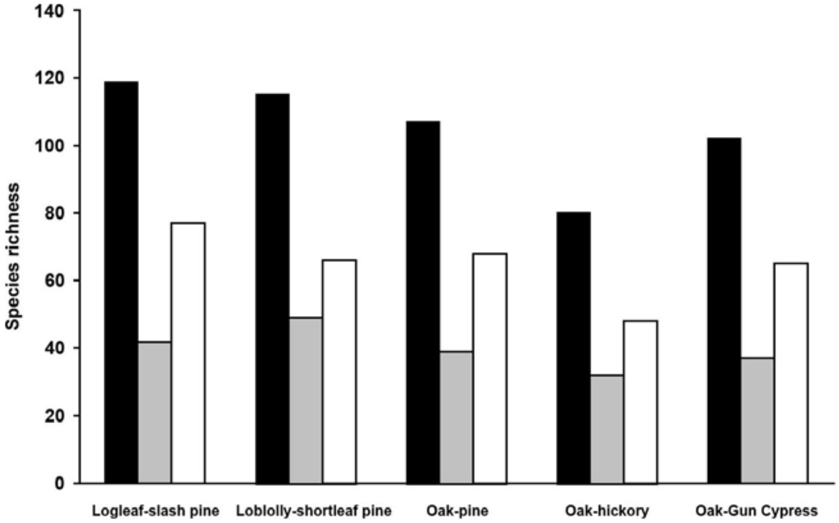

Fig. 6. Pattern of herpetofaunal species richness at different forest types.

Herpetofaunal diversity in physiographic zones

The highest species richness exists at the Gulf Coastal Plain among the five physiographic zones of Alabama (Fig. 5a), while fewest herpetofaunal species exists at the Highland Rim. Species density is the highest at the Piedmount Upland and the lowest at the Gulf Coastal Plain (Fig. 5b). There are relatively higher species richness and species density at the Piedmont Upland, the Valley and Ridge, the Cumberland Plateau and the Highland Rim.

Forest types and herpetofaunal diversity

The highest species richness of herpetofauna exists in the Longleaf-Slash Pine and Loblolly-Shortleaf Pine forests, while lower herpetofaunal diversity in the Oak-Hickory forest (Fig. 6). Similar pattern exists for amphibians and reptiles, respectively. This means that forests (Oak-Hickory and Oak-Pine) in northern Alabama have relatively lower herpetofauna diversity than forests (Longleaf-Slash Pine, Loblolly-Shortleaf Pine and Oak-Gun Cypress) in southern Alabama.

DISCUSSION

The latitude gradient of increasing species richness toward tropical area may be considered as the most fundamental pattern of life on earth (Rosenzweig, 1995; Willig et al., 2003). Willig (2000) suggested that this principle applies to most taxonomic groups in terrestrial, freshwater, and marine environments. However, in this study, species richness of herpetofauna increases with the increase of latitude. This result seems to contrast with the global pattern of biodiversity. Lyons and Willig (1999) suggested that the form of the gradient in biodiversity is likely to be scale dependent. The species richness increases toward equatorial regions if the latitudinal domain is sufficiently extensive (spans more than 15 degrees of latitude) to avoid local variation in geography, climate or edaphic features (Willig et al., 2003). Alabama only runs across about 4° in latitude. Thus, in this study, the latitude pattern of species richness decreases toward equator may be due to local variations, such as geography, habitat, and climate. There is no variation in herpetofaunal diversity along the longitude. The mechanisms may be the same as those for the latitude pattern. Herpetofauna is considered sensitive to environmental temperature and moisture conditions. In this study, our result indicated that with the increase of elevation, the species richness decreases. Other studies suggested that maximum species richness is at intermediate elevation (Li et al., 2003; Sanders et al., 2003; Fischer and Lindenmayer, 2005). The possible reason for maximum species richness at intermediate elevations is that high and low specialists may co-occur in these areas (Fischer and Lindenmayer, 2005). Therefore, the large scale pattern of biodiversity from other research may not apply for the herpetofauna along the latitude and elevation in Alabama.

Species-area relationships (SAR), which follow power-law relation, strongly reflect difference in overall diversity and difference between small and large areas (Lennon et al., 2001). Drakare et al. (2006) conducted a quantitative meta-analysis of 794 SAR from a wide span of organisms, habitats and locations and suggested that the average exponent is 0.24 for independent census. They also suggested that spatial scale measured as grain plays a small role for variation in the exponent, and the differences in SAR between the aquatic and terrestrial realm are minor. In this study, the exponent of SAR is 1.91 (the slope of the fitting line between log (area) and log (species)) which is higher than expected. The possible reason is that the classified data (for area) was used here. The range of the sampled scale can significantly affect the exponent (or slope) of power-law and semi-log SAR (Drakare et al., 2006). The SAR in this study could provide a baseline for the analysis of herpetofaunal diversity in this region or extrapolation of species "carrying capacities". Comparing the variations of SAR exponents or frequency distribution may be useful for the local diversity monitoring. Applying different SAR may improve the management in planning nature reserves and species conservation prioritization (Zurlini et al., 2002).

Human population size is often considered as the driving force for biodiversity loss (e.g. Holdren and Ehrlich, 1974; Thompson and Jones, 1999; Cincotta et al., 2000). However, the direct relationships between human population size and biodiversity are obscure in this study because indirect effects from increasing human population (such as urban development and land use change) also affect biodiversity change. Liu et al. (2003) used the household instead of human population size to study its relationship with biodiversity and indicated that household number and higher per capita resource consumption pose serious challenges to biodiversity conservation. But this information is not available in Alabama. There is a high correction between herpetofaunal species richness and the total stream length or road density if aggregated data is used. This result may indicate that most herpetofauna (possible more than 65%) in this area are water related. Many amphibians have complex life cycles occupying different habitats, usually aquatic and terrestrial.

Inger et al. (1986) and Ranvestel et al. (2004) indicated that some tadpoles are particularly abundant in ponds and streams. Many snake species like to feed on one or more amphibian life stages (Jennings et al., 1992). Stream and river banks provide important habitats for herpetofauna in Alabama. Our results also indicate high positive correlation between herpetofaunal diversity and road density. Herpetofauna usually suffer from existence and construction of roads (e.g. Vos and Chardon, 1998; Forman et al., 2002). The high correction between species richness and road density may have several meanings: (i) Roads might create good habitats for certain herpetofauna before road density reaches certain threshold, such as the threshold of habitat fragmentation; (ii) more observations might occur in the area with roads; and (iii) more roads were constructed in the counties with high species richness. All of them may be possible in this study. Herpetofauna are ectotherms, which mean that their body temperature is regulated by ambient temperature. As such, herpetofaunal species may be attracted to warm surfaces of roads and highways where they can raise their body temperature. Also, many amphibians depend on seasonal pools along roads for reproductive purposes. During storm events, roadside drainage ditches contribute surface flow of waters used for reproduction (Lannoo, 1998; Forman et al., 2002). Although roads may cause habitat fragmentation, Wiegand et al. (2005) studied the effects of habitat loss and fragmentation on population dynamics by computer simulation and indicated that habitat amount accounted for 68% of population variation while fragmentation only accounted for about 13%. They further suggested that study of fragmentation effects requires a good understanding of the biology and habitat use of the species in question. Felix et al. (2004) suggested that intermediate disturbances cause the increase of herpetofaunal species richness and abundance.

By overlaying the maps of herpetofauna distribution to the long term annual average climate, we found that there are higher species richness in the area with the annual average temperature around 17-18 °C. With the increase of annual precipitation, the total species richness and amphibian richness decrease, but it is not significant for reptiles. Both temperature and moisture influence amphibian ecology and physiology because amphibians must maintain moist skin for oxygen and ionic exchange and temperature influences metabolic rates (Pounds et al., 1999; Alexander and Eischeid, 2001). Wilson and McCranie (2004) studied the herpetofaunal diversity of cloud forests and indicated that some species only live under the narrow climate condition. It is unsurprising that the changing climate may change species distribution or result into increasing extinction (e.g. Gardner, 2001).

Different diversities of herpetofauna exist among the five forest types of Alabama. The highest species richness occurred in the Longleaf-Slash Pine and the Loblolly-Shortleaf Pine forests in comparison with the Oak-Hickory forest. This result is consistent with the study of Loehle et al. (2005) that the pine forest was richer in the total herpetofaunal richness than the pine-hardwood type. However, Mitchell et al. (1997) reported that amphibians were more abundant in mature hardwoods than in a white pine plantation. DeGraaf and Rudis (1990) also indicated that northern hardwood and red maple forest supported more species than balsam fir forest. Different herpetofaunal richness in different forest types may also reflect site-specific abiotic factors (Loehle et al., 2005). Lewis et al. (2000) suggested that differences among forest types in herpetofauna in Texas were related to differences in moisture availability. Fleet and Autrey (1999) observed that change in altitude formed a natural moisture gradient across forest types that accounted for the differences in herpetofaunal richness. It is not clear whether forest type itself directly affect herpetofaunal richness. However, arboreal lizards are associated with structurally complex forests and four parameters of a forest stand (canopy coverage, litter depth, woody plant cover, and large woody debris) explained much of the variation in herpetofaunal species by Crosswhite et al. (2004).

Due to all these biotic and abiotic factors, the distribution of herpetofauna is not uniform among the counties, river basins and geophysical regions of Alabama. The Baldwin and Mobile Counties, which only cover about 7% land area of the Alabama, host the highest species of herpetofauna. In the five physiographic zones the Gulf Coastal Plain hosts the highest species richness but least species density. Fewer herpetofaunal species exist at the Piedmont Upland, the Valley and Ridge, the Cumberland Plateau, and the Highland Rim, while there are relative higher species richness and species density in those areas. River basins in the middle and south part of Alabama (the Coosa/Tallapoosa, the Alabama, and the Tombigbee) have higher species richness. Special physiographic feature could be important for herpetofauna due to the impact on main ecological processes (Wilson and McCranie, 2004), such as in this study the drier Cumberland Plateau and the Valley and Ridge physiographic zones occur to the west and a rain shadow exists to the east. Analysis of the herpetofauna of central Texas revealed that the majority of species (77%) of herpetofauna are limited by the Balcones Escarpment (Smith and Buechner, 1947). Loehle et al. (2005) indicated that most intensively managed watersheds had higher species richness in herpetofauna than those less intensively managed. They suggested watershed scale forest management (including plantation management) did not affect and even enhanced habitat diversity for herpetofauna. The uniqueness of species and the landscapes in which they live can provide us a good understanding of spatial pattern of herpetofauna.

Implications for conservation

Our study may provide a baseline for the spatial pattern of herpetofauna in Alabama. The macro pattern identified here may have potential important consequence in the face of global climate change and large-scale habitat destruction. On the large scale, land zoning and planning need to maintain the ecological processes along latitude and elevation which formed the gradient in species richness of herpetofauna. Urban development or human settlement should not affect spatial pattern of biodiversity or their major ecological processes. Large scale habitat loss and fragmentation should be avoided. Current policy regarding land zoning and planning should incorporate large scale (or landscape scale) biodiversity conservation and important threatening processes while understanding of species distribution pattern is a prerequisite (Manning et al., 2004). Also planning under different scales may produce different outcomes. Scheiner and Willig (2005) suggested that any environmental factors that affect the number of individuals in an area will increase richness because of three mechanisms (random placement or passive sampling, local extinction, and speciation). Spatial heterogeneity in landscapes (e.g. topography, vegetation types, and hydrological regimes) can enhance species richness.

The SAR is a strong indicator of the sensitivity to the loss of habitat and climate sensitive space. Maintaining the integrity of stream and river systems can improve habitats within both the channel and adjacent floodplains. In the areas with high road density, intensive safe passages or crossings should be provided for herpetofauna under or over roadways, especially in areas where roads bisect important habitats or corridors (e.g. roads that parallel water bodies). Ecological barriers (such as fences, sheet piles and concrete walls) that run parallel to roads may be constructed to reduce animal mortality and road hazards.

ACKNOWLEDGEMENTS

We thank Dr. Luca Luiselli, Dr. Marco A.L. Zuffi, Dr. Roberto Sacchi and an anonymous referee for suggestions on the earlier version of the manuscript. This research was partially supported by the School of Agricultural and Environmental Sciences of Alabama A & M University, NSF (HRD-0420541) and DE-FC26-06NT43029-005.

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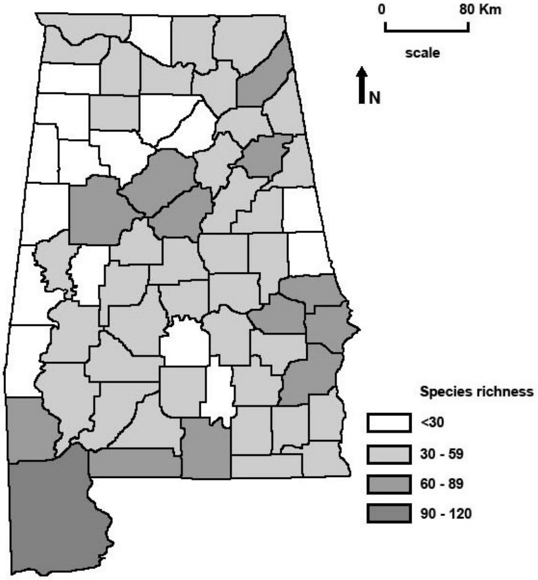
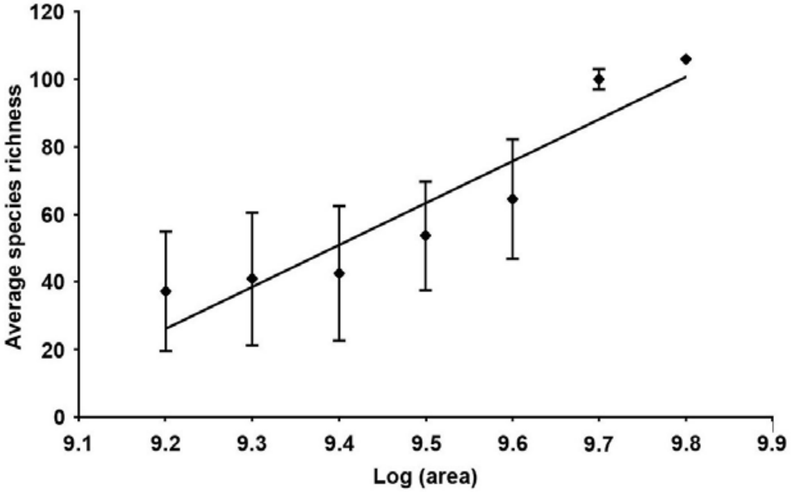
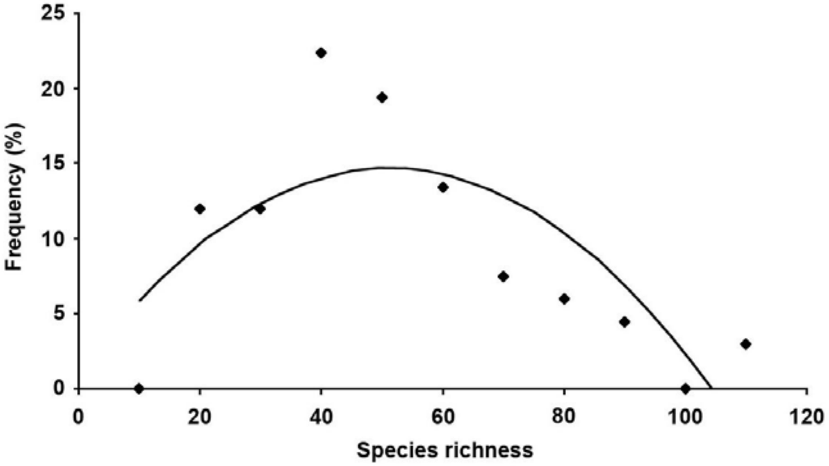
Appendix 1. Herpetofauna species richness in different counties. Counties with different herpetofauna species richness (a), area-species relationship (b), and richness-frequency relationship (c).




Average species richness
0
20
40
60
80
100
120
9.1
9.2
9.3
9.4
9.5
9.6
9.7
9.8
9.9
Log (area)


Frequency (%)
0
5
10
15
20
25
0
20
40
60
80
100
120
Species richness