Biodiversity Journal, 2016, 7 (1): 25–32

Patterns of Butterfly distribution in Alabama, USA (Lepidoptera)

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ABSTRACT Butterflies (Lepidoptera) are an iconic group of insects and are emphasized in ecological research and biodiversity conservation due to the role in ecological processes. Alabama (USA) has 139 species of butterflies in 6 families based on the previous field surveys. In this study the information from the previous field survey was analyzed with environmental information for the general patterns across 67 counties of Alabama. The results indicate that the counties with the higher butterfly species are mainly within the metropolitan areas; power-law relationship exists between average species number and occupied county number; there is higher number of butterfly species at counties with either the highest or the lowest forest coverage; there is positive correlation between latitude and butterfly species density; counties with the lowest or the highest species number usually have higher standard deviations in annual air temperature or precipitation; butterflies with a big distribution area do not have significantly bigger wing size in comparison to ones with a small distribution area; and with the increase of latitude, the average wing size of butterflies increases. The results provide new understanding for the butterfly distribution at a regional level.

KEY WORDS Alabama; butterflies; climate; latitude; species number; wing size.

Received 02.02.2015; accepted 21.03.2016; printed 30.03.2016

INTRODUCTION

The Butterflies (Lepidoptera) play an important role in ecosystems and conduct ecological services (Tiple et al., 2006), such as pollination and herbivores. Butterflies are considered as good ecological indicators of the health of some terrestrial ecosystems (New, 1991; Thomas, 2005; Bonebrake et al., 2010). The beautiful color of butterflies and unique features also provide recreation resource to human society. Butterflies are greater sensitive than other taxonomic groups to reflect human disturbance (Thomas, 2005). Monitoring butterfly species at an area can indicate human mismanagement and pollution (Wilson, 1997). Due to climate change, altered land use (e.g., habitat loss), and pollutants (e.g., pesticides and herbicides), the butterflies are in declining, such as in Europe (van Swaay et al., 2006). The loss of native plants, which are food for leaf-eating caterpillars and nectar sipping adult butterflies, by the replacement of exotic invasive species has devastated butterflies. Butterflies are an iconic group of insects and are emphasized in ecology and biodiversity conservation.

The state of Alabama (USA) has 139 species of butterflies in six families (Hesperiidae, Papilionidae, Pieridae, Lycaenidae, Riodinidae, and Nymphalidae). The information of distribution, habitat, food, life history and wingspan for all 139 species is listed in the book "Butterflies of Alabama" based on the field records (Howell & Charny, 2010). This information provides an opportunity for integrated study, such as analyzing patterns of butterfly distribution and uncovering the related factors.

One of the important features of butterflies is their wingspan or body size. Body size is a key trait related to the life history of individuals, the wing size (a proxy for body size) of butterflies significantly decreased in response to warmer summers in high arctic area (Bowden et al., 2015). Based on the Bergmann's rule, larger individuals occur at higher latitudes and in colder environments (Sand et al., 1995). Similarly, smaller adult size should be in higher temperatures or southern area. Although both Bergmann's rule and the temperature–size rule predict larger individuals in colder environments, however, the opposite pattern also reported (Blanckenhorn & Demont, 2004; Angilletta, 2009). Several ways were proposed that temperature may affect body size.

Two mechanisms related to external temperatures may impact body size in different directions.

First, the metabolic rates increase with warmer temperatures, organisms become smaller if they cannot offset energy losses under high metabolic costs.

Second, rising temperatures in seasonal environment make longer growing seasons, which may let organisms grow larger.

The extended seasons could also low plant-food quality during late season (Awmack & Leather, 2002). Baguette & Stevens (2013) suggested that wingsize of butterflies is positively related to minimum area requirements. Butterflies with big wing size should have a big distribution area. Host-range relationship may be primarily determined by ecological and population-genetic factors (Barrett & Heil, 2012). For example, generalists should be promoted by volatile host communities, while specialists should be favored in places where host communities are stable (Jaenike, 1990). This means that harsh and volatile climate in a temperate region could have more generalists and favorable and static climate have more specialists. For the distribution area, plants are food and habitats to butterflies, forests harbor between 50% and 90% of Earth's terrestrial species including diverse of plant species (World Resources Institute et al., 1992), there should have more butterfly species in forest areas than at less or none forest areas.

It is also known that butterflies are sensitive to habitat fragmentation (Öckinger et al., 2010), so with the increased landscape fragmentation in one region, such as in a metropolitan area, butterfly species number may decrease. Therefore, the goal of this study is to use the collected butterfly information from Howell & Charny (2010) combined with climate and environmental information to indicate the general patterns of butterfly distribution in the state of Alabama and test the above hypotheses. The specific objectives include (i) distribution pattern of butterfly species along latitude; (ii) relationship between wing size of butterflies and latitude; (iii) relationship between butterfly species number and plant species number and forest cover at county level; and (iv) relationship between butterfly species number and urbanization at the county level. This study will provide understanding of the patterns of butterfly distribution in Alabama.

MATERIAL AND METHODS

Study area

Alabama is located in the southern region of USA. and between the southern foothills of the Appalachian Mountain Range and the Gulf of Mexico. There are total 67 counties in Alabama (Fig. 1). Since the State of Alabama runs roughly from 31° to 35°N, the climate in the southern part is warmer than the northern part. Northern Alabama has a warm, humid, temperate climate, and the south has a subtropical climate. Summers are hot and humid with an average high temperature around 33°C; winters are typified by a series of cold fronts. The annual precipitation varies from 150 cm to 162 cm in the northern part and 180 cm to 195 cm in the southern part (Carter & Carter, 1984). Based the inventory data from Alabama Forestry Commission (www.forestry.state.al.us), 70% of the state is covered by forests. Due to mild climate and heterogeneous landscape, Alabama has great species diversity. The county level is selected in this study because most data are only available at this level.

Data

Butterflies: the butterfly information is from the book of Howell & Charny (2010), which was based on the year-round field observations from 2001 to 2009 by the authors, their students and colleagues. Photographic survey which is broadly applied for biodiversity research (e.g, McGrath, 2015) was conducted at each county. The spatial resolution of butterfly distribution is at county level, which means the distribution covers the entire county as long as this butterfly species is found at one location. More information can be found in Howell & Charny (2010). In this study, the information of distribution and the average wing size is used.

Climate: the climate information is from local weather stations in each county from 2001 to 2009.

Plants and forest: the information of plant species diversity in each county of Alabama is from http://www.alabamaplants.com. The forest coverage (%) in each county at that time is from Chen (2009).

Human population: the human population at each county during the corresponding time period is obtained from Alabama Quick Facts at the USCensus Bureau (http://quickfacts.cencus.gov/qfd/index).

Statistical method

Standard deviation was used to characterize the fluctuation in air temperature and precipitation in each county. The commonly used least squares technique was used in correlation analysis and T-test of SAS (SAS Institute Inc., NC, USA.).The statistical test was considered significant at $p<0.05$. Data aggregation was applied when the statistical test on individual county data was not significant, but the trend might exist, such as the bin of [0, 10], [11, 20],… [70, 80] was applied for the rank of butterfly species number while testing power-law between the average species number and appeared county number. The butterfly species density in each county was estimated by the total butterfly species number /county area.

RESULTS

Jefferson County has 79 butterfly species, which is the highest number. The counties with the category of highest butterfly species (50–79) include Madison, Jackson, Tuscaloosa, Jefferson, Ribb, Shelby, and Baldwin (Fig. 1). These counties are mainly within the metropolitan areas of Huntsville, Birmingham, and Mobile cities. There are six counties (Choctaw, Coffee, Crenshaw, Dale, Greene, and Lamar) without any butterflies or with very limited species number. There is a power-law relationship between the average of butterfly species number and appeared county number (Fig. 2).

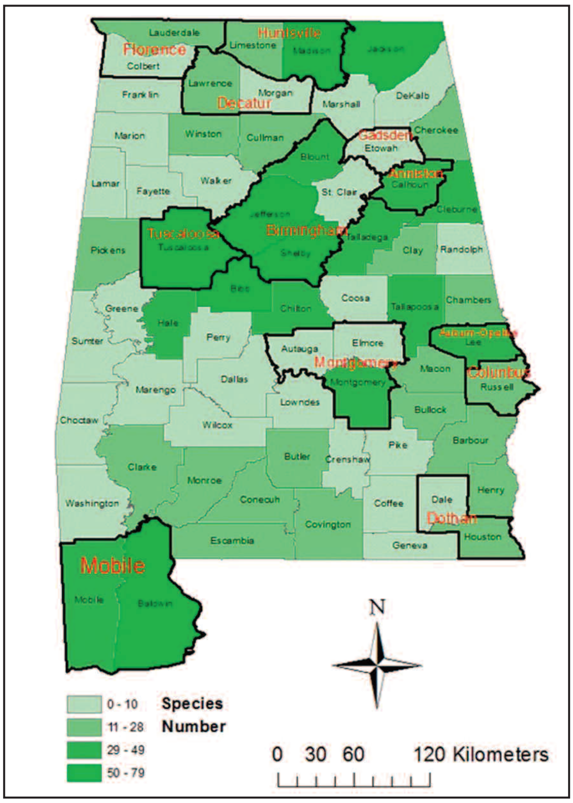

Figure 1. The butterfly distribution across the counties of Alabama (bold lines indicate metropolitan area).

The relationship between county size and butterfly species number is not obvious (Fig. 3). The correlation between human population in each county and butterfly species is not significant ($p> 0.05$) (Fig. 4). The relationship between plant species number and butterfly species number among all the counties is not obvious (Fig. 5). There is higher number of butterfly species at areas with either the highest or the lowest forest coverage (Fig. 6).

There is positive correlation between latitude and butterfly species density (Fig. 7). The correlation between the average annual air temperature or average annual precipitation and species density is not significant ($p>0.05$) (Fig. 8), but there is a general trend of decreased species density with

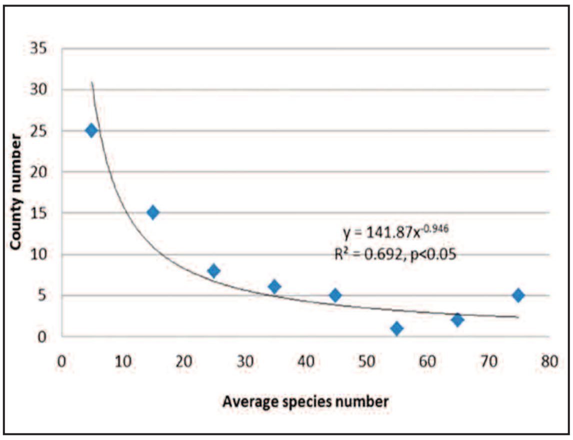

Figure 2. The correlation between average butterfly species number and appeared county number.

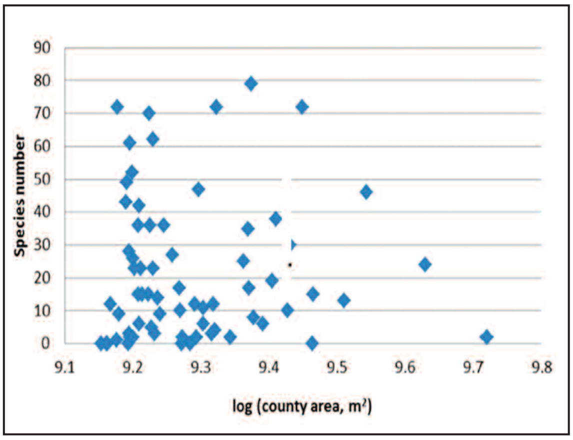

Figure 3. The relationship between county size and butterfly species number.

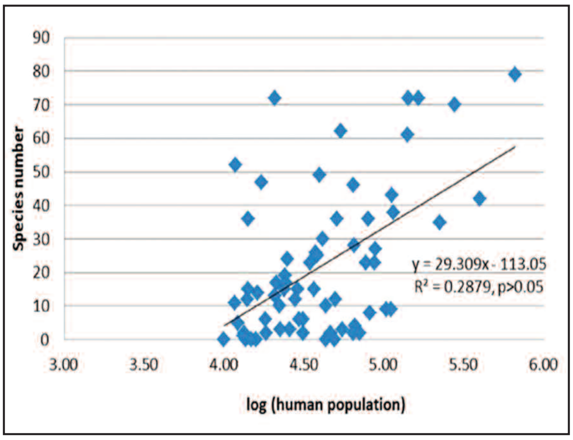

Figure 4. The relationship between human population and butterfly species number among counties.

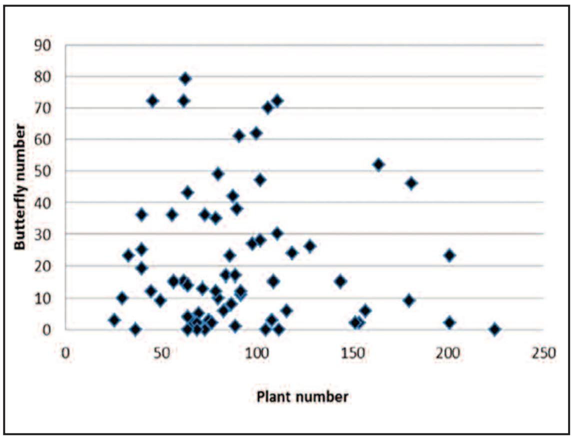

Figure 5. The relationship between plant species number and butterfly species number in counties.

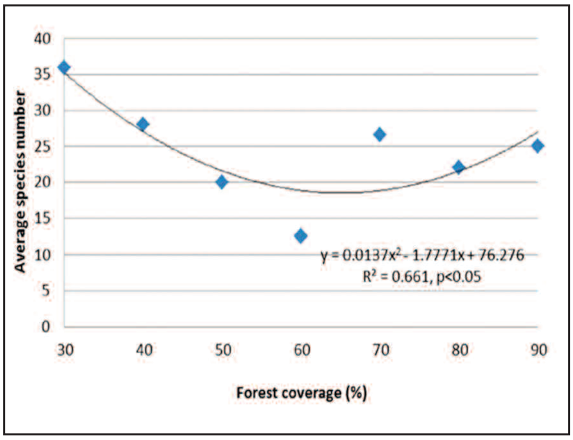

Figure 6. The relationship between forest coverage and butterfly species number in counties.

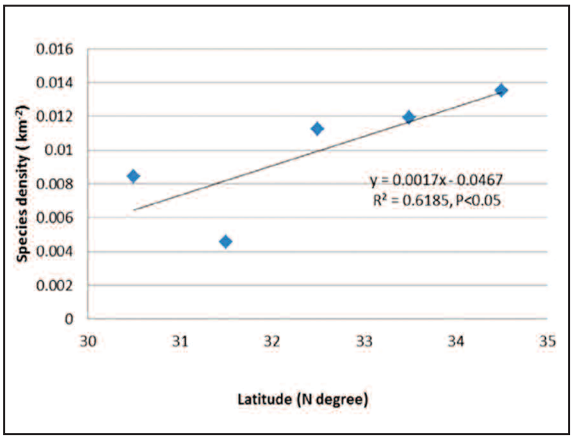

Figure 7. The relationship between latitude and density of butterfly species.

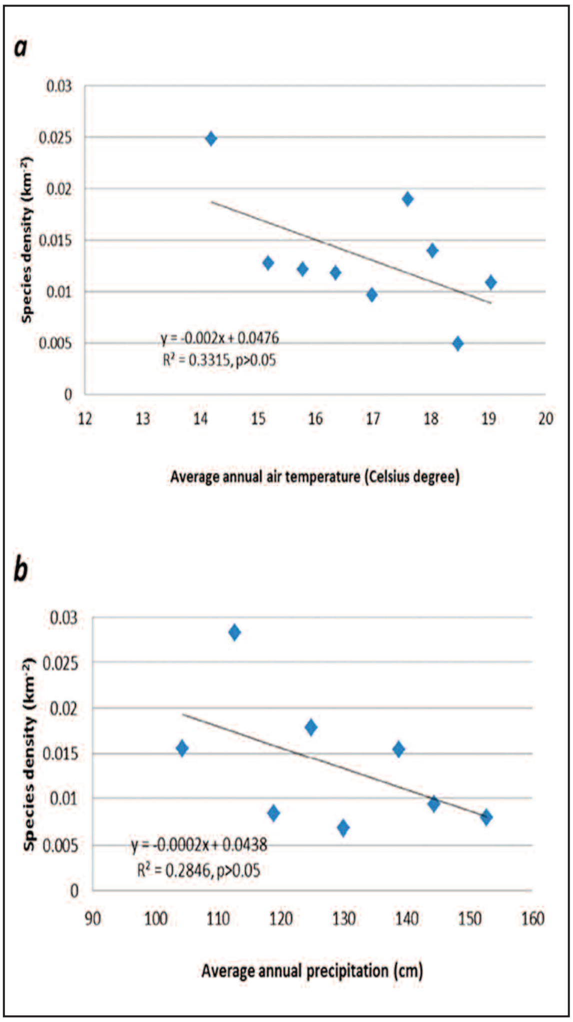

Figure 8. The relationship between butterfly species number and average annual air temperature (a) and average annual precipitation (b).

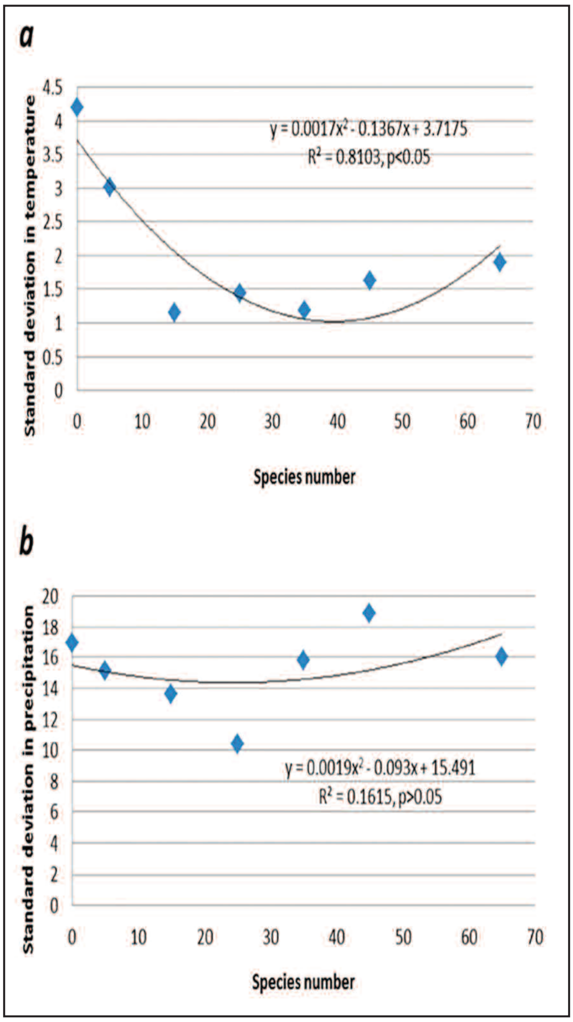

Figure 9. The relationship between butterfly species number and standard deviation of annual air temperature (a) and standard deviation of annual precipitation (b).

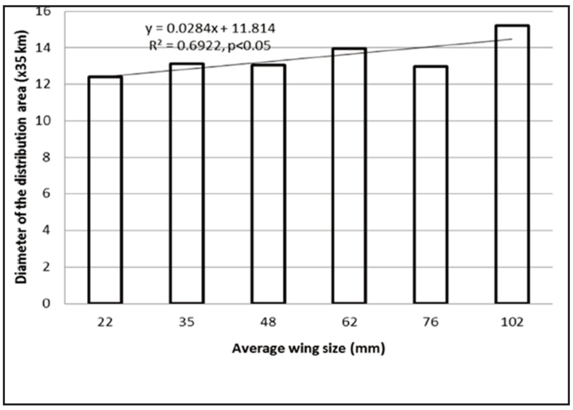

Figure 10. The relationship between average wingsize of butterfly and the diameter of the distribution area.

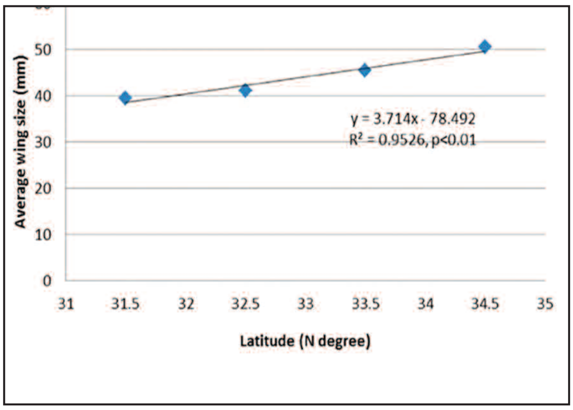

Figure 11. The relationship between latitude and butterfly wingsize.

increased temperature or precipitation. There is a pattern that counties with the lowest or the highest species number have higher standard deviations in annual air temperature or precipitation (Fig. 9).

The correlation between the average wingsize and diameter of distribution area at each county level is not significant ($p>0.05$). However, after the data aggregation in wingsize, there is a general trend between the average wingsize and the diameter of distribution area (Fig. 10). The average wingsize of the broadly distributed species (or generalists) is 53.7 ± 25.7 mm and 51.0 ± 23.7 mm for narrow distributed species (or specialists). The difference in wing size between generalists and specialists is not statistically significant ($p> 0.05$). With the increase of latitude, the average wingsize increases for all species polled over (Fig. 11).

DISCUSSION AND CONCLUSIONS

There are some patterns of butterfly distribution in Alabama after the integrated analysis with other information. Some counties have a high species number, but others have limited species. The power-law relationship between average species number and appeared county number is similar to those with plants and animals in California (Chen et al., 2006). The phenomena may be related to the spatial occupying process and tolerance of habitat for all the species, but the mechanism is not known. With the increase of county size in area, this does not necessary lead to the increase in the number of butterfly species, which means big counties may not have more butterfly species. The island biogeography theory does not apply to butterfly species here. The counties with higher number of butterfly species are mainly within these metropolitan areas (e.g., major cities of Birmingham, Huntsville and Mobile areas). It seems that the higher number of butterfly species is related to human population and land use change, although the correlation between butterfly species number and human population in each county is not significant. This is consistent to that (i) no obvious relationship between butterfly species number and plant species number among all counties; (ii) there is high species number at areas with either the lowest or highest forest coverage. After comparing the butterfly species diversity in urban, suburban and rural areas, Mukherjee et al. (2015) indicated that butterfly species diversity is related to landscape heterogeneity. Usually there is higher landscape heterogeneity at the metropolitan areas due to diverse vegetation pattern under different land uses from land owners, but relatively homogeneity landscape in urban and rural areas. Earlier studies suggested that butterfly diversity is attributed to plant species (Kuussaari et al., 2007). But in this study, there is no obvious correlation between plant species and butterfly species at county level. These butterfly species may only like some specific plants for hosting (Howell & Charny, 2010).

Usually in warmer area, such as tropical areas, there is higher species diversity. However, in this study the relationship between latitude and butterfly species is on the opposite. There is higher density of butterfly species in northern Alabama. This result is also consistent with that there is a general trend of decreased species density with increased temperature. The possible cause may be that the rule at continental (or global) level may not always work at a regional level. Some additional factors may attract to butterfly species diversity at a regional level. Also, in low latitude areas there are high species number as overall, but not necessary for butterfly species.

The results in this study also identify that counties with large fluctuations in annual air temperature and precipitation have either the highest or the lowest species number of butterfly. Under the stable climate condition (e.g., lower standard deviation in annual temperature or precipitation) there is an intermediate high number of butterfly species. The changing climate may provide more niche space for various butterfly species if they can tolerate. The degree to which phenotypic plasticity and adaptation ultimately play a role under this changing climate remains to be further studied (Bowden et al., 2015). Bergmann's rule, describing the relation between latitudinal and body size, is confirmed in this study. Our results indicate that the average wingsize of butterfly increases with the increase of latitude in Alabama.

There are generalists of butterfly with a large distribution area from the south to north and also several specialists with limited distribution in Alabama (such as only one county). But the sizes of their wingspans are not significantly different. This result may indicate that butterfly species with big wingspans may not necessary show greater migration capacity or the specialists may also be distributed broadly if resource is suitable. The size of wingspan may not determine the fate of some specialist of butterflies under changing environment which was considered as venerable (Dapporto & Dennis, 2013).

After analyzing the records of butterfly species and the environmental factors in Alabama, the emergent patterns at a regional level appear for the distribution of butterfly. The uneven distribution of butterfly species may be related to land use and climate fluctuations. The species diversity and body size related with latitude and temperature may provide helpful information for butterfly conservation and mitigation under climate change. This study may provide a background map for study of butterfly distribution under environmental change (McGrath, 2015). Periodically monitoring the body size and distribution of butterfly species and other biodiversity may be necessary for sustainable regional development.

ACKNOWLEDGMENTS

This work was partially supported by the USDA National Institute of Food and Agriculture McIntire Stennis project (1008643).

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