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Analysis of museum records highlights unprotected land snail diversity in Alabama*

Russell L. Minton[1] and Kathryn E. Perez[2]

[1] Department of Biology, University of Louisiana at Monroe, 700 University Avenue, Monroe, Louisiana 71209-0520, U.S.A.

[2] Department of Biology, University of Wisconsin at La Crosse, 1725 State Street, La Crosse, Wisconsin 54601, U.S.A.

Corresponding author: perezke@gmail.com

Abstract: In order to address the conservation status and needs of Alabama's land snail species, we examined their diversity and distribution using 11,816 museum records representing 226 land snail species. The Chao-1 statistic identified seven areas of high species richness. The areas with the highest richness contain an estimated 200 species of land snail. These seven areas are not currently well protected by state or federal lands. While taxonomic misidentification and geo-referencing quality may be inflating our results, we suggest that studies like ours provide valuable baseline diversity estimates and launching points for continued studies.

Key words: biodiversity, Alabama, land snail, conservation

In comparison to their better-studied island relatives (Cowie 2001, Chiba 2003), the conservation status of mainland North American land snails remains relatively unknown. Of the over 2,000 recognized species in North America, 75 are thought to be extinct, and all but seven of these were endemic to Hawai'i (NatureServe 2008). Nine of the 75 snails listed as threatened and endangered by the U.S. Fish and Wildlife Service are terrestrial species in the contiguous 48 states (USFWS 2008). Land snail conservation has recently gained interest as population declines and extirpations continue to be documented (Lydeard *et al*. 2004, Steinitz *et al*. 2005). As with other mollusc groups, anthropogenic effects including habitat modification, urbanization, and land use practices can have strong negative effects on land snails (Graveland *et al.* 1994, Örstan *et al.* 2005, Lange 2006) given their low dispersal abilities and limited species ranges (*e.g*., Burch 1955, Riggle 1976, Hubricht 1985, Hotopp 2002). Land snail conservation is important for many reasons. Terrestrial gastropods (snails and slugs) can serve as critical indicator species for a number of ecosystems (Prezio *et al.* 1999, Ovaska and Sopuck 2005). They may play significant roles in food webs and nutrient cycling through decomposition (Mason 1970, Richter 1979), and some species are known dispersers of plant seeds and fungal spores (Richter 1980, Gervais *et al*. 1998). Finally, they are contributors to the overall biodiversity and health of communities (Richter 1980).

Nearly 200 species of land snails are estimated to occur in Alabama (Shelton 1998), and this fauna has been intensively collected for the better part of a century (Clapp 1920, Archer 1939, Hubricht 1985). The state's land snails were last treated in detail eighty years ago (Walker 1928), and have been overshadowed in recent times by the decline of Alabama's freshwater mollusc species. The most recent study dealing with the state's terrestrial molluscs comprised a survey of the 25,000-acre Sipsey Wilderness Area in north-central Alabama (Waggoner *et al*. 2006). The study yielded 58 species from a small portion of the Bankhead National Forest and increased the known richness of the area four fold. The study also stressed the need for assessment of the conservation status of the state's land snails, given their restriction to specific environments and extensive human activity in those same areas. In order to address the conservation status and needs of Alabama's land snail species, we examined their diversity and distribution using museum records from four institutions. Museum records are useful in determining historic patterns of species composition and can provide baseline data when such information is lacking (Mikkelsen and Bieler 2001, Ponder *et al*. 2001). Using estimated richness values and information on the state's protected areas, we hoped to determine how diverse Alabama's land snails are, if discrete areas of high species richness could be identified, and to what extent federally and state protected lands offered the snails protection.

MATERIALS AND METHODS

Museum records for Alabama land snail species were obtained from the following institutions: Auburn University Museum and Natural History Learning Center, Auburn;

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Delaware Museum of Natural History, Wilmington; Field Museum of Natural History, Chicago; and Florida Museum of Natural History, Gainesville. Individual records possessing detailed collection information were geo-referenced using GeoLocate (Tulane University Museum of Natural History) to generate latitude and longitude coordinates. Localities that could not be determined automatically were identified manually on topographic maps. Taxonomy generally followed Turgeon *et al.* (1998), collapsing subspecies into their parent species. While most North American land snails are diagnosed on the basis of shell characteristics and geographic distribution, and few recent studies have been conducted that attempt to revise species and sub-specific classifications, we opted for a more conservative approach toward recognizing taxa. Potential effects of this decision are treated in the discussion. Amphibious species in the genera *Melampus* Montfort, 1810 and *Pomatiopsis* Tryon, 1862 were excluded from the analysis, while alien and invasive species were included. While most alien land snails species exist only in isolated pockets that do not spread (Dundee 1974), species like *Bradybaena similaris* (Ferrusac, 1821) are widespread throughout the U.S. and have become part of the fauna.

Museum record localities were projected on to a state map of Alabama using DIVA-GIS 5.4 (Hijmans *et al.* 2008). Using the analysis functions in DIVA-GIS, we calculated corrected Chao 1 richness (Chao 1984) estimations (S1) for the entire state with a grid size of 0.2 degrees. The corrected estimator S1 is calculated as $S_{obs} + (F1^2 / 2[F2+1]) - (F1F2/2[F2+1]^2)$, where S_{obs} is the number of species observed in a sample, and Fi is the number of species represented by exactly i individuals (i=1 for the frequency of singletons [F1], i=2 for the frequency of doubletons [F2]). This allowed us to identify areas of high estimated richness with less inherent bias.

To determine if the estimated high richness areas are potentially protected, we overlaid our richness estimates with maps of federally and state protected lands including national parks, national forests, reservoirs, and Alabama state parks. Only sites of 640 acres or more are identified in the federal coverage. We then used the reserve selection function in DIVA-GIS to identify sets of grid cells (theoretical "reserves") that would capture a maximum of species diversity in as few cells as possible. The procedure is based on the algorithm by Rebelo (1994), where the cell with highest diversity is chosen first; for cells with equally high diversity, the starting cell is chosen randomly. Additional nearby cells are then chosen iteratively based on the first cell. The result is that cells with high diversity may not contribute much to the overall protected diversity based on their proximity to the first cell. This is a non-linear optimization problem, and the solution of Rebelo and Sigfried (1992) is utilized in DIVA-GIS. We used a smaller grid size (0.1 degrees) to more closely reflect the minimum size of tracts of federally and state protected land, and compared it to the location of our high richness and protected areas.

RESULTS

A total of 11,816 museum records from the four museums were geo-referenced, representing 226 land snail species. Localities were broadly distributed across the state, with some concentrated collections near major metropolitan areas (Fig. 1). Using corrected Chao 1 values, we identified seven areas where estimated land snail diversity was highest (Fig. 2). Many of these areas were near major metropolitan areas. We then overlaid federally protected lands on the estimated richness with the result that none of our highest estimated richness areas corresponded with protected areas. When Alabama state parks were added, parts of one of the high richness areas would be protected by Monte Sano Park near Huntsville. Other state parks, including Cheaha Mountain in the Talladega National Forest and Blanton Springs, were found in

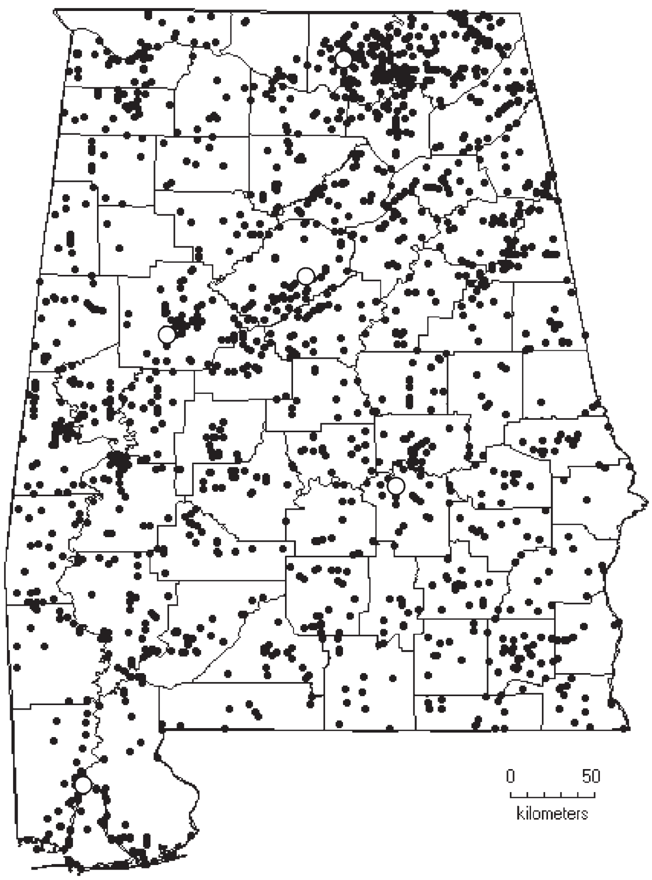

Figure 1. Collection sites based on geo-referenced museum collections. Open circles represent major metropolitan areas (identified in Fig. 2).

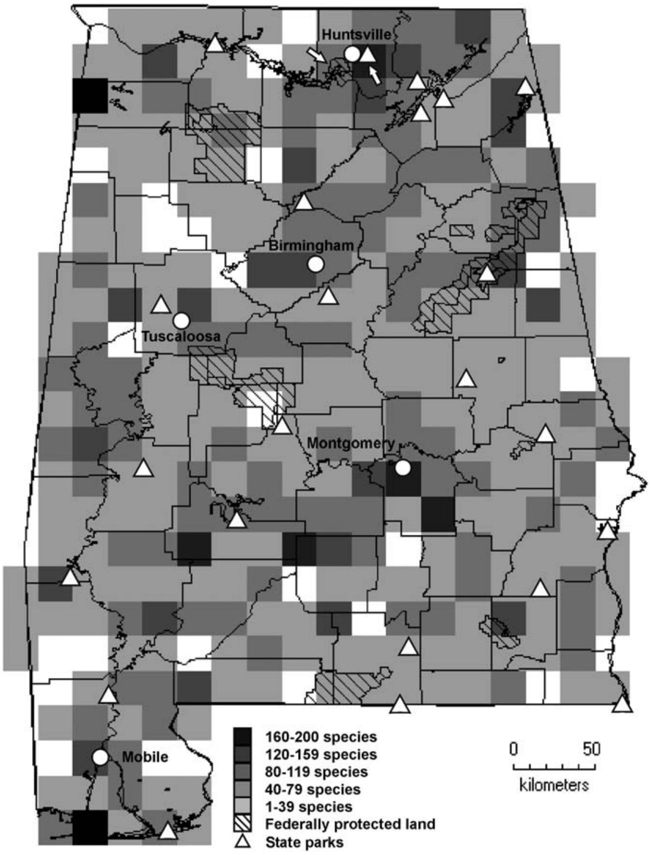

Figure 2. Estimated corrected Chao-1 species richness based on museum records. Hatched areas represent federally protected lands; circles represent major metropolitan areas. Two potentially protected areas of high diversity, Redstone Arsenal and Monte Sano Park, are identified by arrows.

areas of medium estimated richness. The reserve function in DIVA-GIS identified one theoretical reserve in the same high richness area as Monte Sano Park.

DISCUSSION

Our analyses included museum records for 226 species of land snail in Alabama, counting invasive and alien taxa. This value is a bit higher than those generated previously by Hubricht (1985; 145 species) and Shelton (1998; 194 species). We found isolated areas of high land snail diversity throughout Alabama, with few patterns of richness being readily apparent (Table 1). The locations of the highest estimated richness areas show no relationship between the number of collection localities and species diversity. One of the two highest estimated diversity areas is in northwestern Alabama near the Tennessee River, where only a few collections have been made. Repeated sampling of the same species likely explains areas with lower

Table 1. Locations and corrected Chao-1 richness estimations (S1) for the seven most diverse areas predicted by museum records. Ecoregions refer to level III areas designated by the U.S. Environmental Protection Agency.

County	Ecoregion	S1
Colbert/Franklin	Southeastern Plains	200
Mobile	Southern Coastal Plain	163
Madison	Southwestern Appalachians	151
Butler/Wilcox	Southeastern Plains	145
Montgomery 1	Southeastern Plains	140
Montgomery 2	Southeastern Plains	128
Wilcox	Southeastern Plains	128

estimated richness despite more numerous collection sites. Areas around the Tennessee River in the northern part of the state showed high overall diversity compared with other areas. This was expected, as the area around the river tends to be higher altitude with exposed limestone and is more densely wooded than other parts of the state. These high-calcium forested areas have been shown to have high snail diversity (Gärdenfors 1992, Hotopp 2002, Juřičková *et al.* 2008). Only one area of high diversity occurred near either federal or state lands, the region east of Huntsville represented primarily by Monte Sano Park, just outside of the Redstone Arsenal.

The high diversity observed in some of our areas may be a result of including invasive and alien species in our analyses. We feel this is not a serious issue as fewer than ten non-native species occurred together in any one area. Most introduced snails with Alabama records were found in and around Mobile, supporting the notion that invasive and alien species enter through commercial ports and may become established near them (Dundee 1974). A few single widespread records of alien species likely reflect greenhouse species found on imported plant material. While some introduced species have become ubiquitous components of the ecosystem, such as the previously mentioned *Bradybaena*, our inclusion of the occasional non-native should not be interpreted as support for the notion that introduced species are beneficial by increasing species diversity. While invasives may increase diversity on a small temporal and spatial scale, their importance has been well documented in the overall decline of native diversity and overall richness (Davis 2003, Keeley *et al.* 2003).

More likely is that our species diversity and distribution figures in Alabama suffer from two of the limitations identified by Guralnick *et al.* (2007) in using museum specimens. First, taxonomic misidentifications may have inflated our richness estimates. Specimen misidentification rates may be as high as 60% in some groups (Meier and Dikow 2004), producing misleading results. Second, since best practices for geo-referencing are still relatively new (Chapman and Wieczorek 2006), issues of accuracy arise. Although we used GeoLocate as a means for standardization, we did not treat low and high accuracy references differently. Thus, the accuracy of our points varies among data and may further alter our estimates (Guralnick *et al.* 2006). In biodiversity estimates, misidentifications also complicate accurate delineation of areas of endemism and other hotspots (Ng and Tan 2000). Thus, analyses like ours should be seen as starting points for continued studies, and not the final word on richness or distribution.

Using museum records for diversity estimation can be fruitful, but there are also significant biases that may exist in our data. Finding high diversity areas near cities is a common bias encountered when using collection data for richness calculations (Hijmans *et al.* 2000). This potential non-representative sampling bias is the most difficult source of error to correct for in natural history data (Williams *et al.* 2000). Museum data also provide presence-only data and may not reflect the true distribution of a species (Graham *et al.* 2004), either in historical or modern times. The scope of the museum data is over ~150 years of collections, and land use changes have surely affected diversity. In a poorly studied group with morphologically delineated species like land snails, identification errors can skew richness in both directions. Combined with inexactness in collection locality information, misidentifications introduce the most error (Chapman 1999). Even with these potential shortcomings, the increase in availability of museum records has led to a corresponding increase in their incorporation into conservation studies, with positive results (Ponder *et al.* 2001, Hugall *et al.* 2002, Raxworthy *et al.* 2003).

Studies like ours can play an important role in discovering biodiversity hotspots, which are areas with high numbers of endemic species along with specific biotic characteristics (Myers 2003). These hotspots are usually based on floral and vertebrate-oriented estimates, with the assumption that protecting diversity in those two groups will protect a similar number of invertebrates. This is unfortunate, since land snails, as part of the "other 99%" of global diversity (Ponder and Lunney 1999), have been shown to predict vertebrate conservation priorities but not *vice versa* (Moritz *et al.* 2001). By combining museum data with thorough surveying and detailed molecular and morphological taxonomy and systematics, hotspots can be identified and managed appropriately, using methods we described previously for freshwater molluscs (Perez and Minton 2008).

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