Predicting Foraging Habitat of Gray Myotis in Georgia

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Abstract: In the southeastern United States, ongoing urbanization and associated environmental perturbations, such as water quality degradation, potentially affect foraging habitat of the federally endangered gray myotis (*Myotis grisescens*). Conserving foraging areas of gray myotis is critical to this species' recovery, especially as white nose syndrome (*Geomyces destructans*) recently has been documented in this species. From 2000 to 2001, we used acoustic monitoring and spatial models to determine foraging areas of gray myotis near four bachelor/maternity colonies in northwestern Georgia. We detected gray myotis at 34 of 213 sites over 5,100 km^2 surveyed. Gray myotis foraged along major riparian corridors near their roost caves, and our landscape model included these streams and nearby tributaries up to a minimum third-order stream. The landscape model contained 82% of sites where gray myotis were detected and only 14% (1,235 km) of waterways in northwestern Georgia. We recorded gray myotis at 87 of 114 sites predicted by our micro-habitat model, which indicated that gray myotis foraged over structurally uncluttered streams with forested banks that were adjacent to pastures. Our findings suggest that the continued recovery and protection of gray myotis populations depends on conservation of major streams and rivers near roost-caves.

Key words: Anabat, geographic information systems, Georgia, gray myotis, *Myotis grisescens*

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Urbanization and environmental alteration, including forest fragmentation and water pollution, and their impacts on biodiversity increasingly have become a focus of wildlife research (Ghert and Chelsvig 2003). Although some bat species roost in anthropogenic structures and forage in remnant forest patches adjacent to urban areas (Everette et al. 2001, Johnson et al. 2008), many bat species are sensitive to land use changes associated with urbanization (Clergeau et al. 2001, Ghert and Chelsvig 2003). Additionally, degradation of water quality from urbanization, (e.g., sewage effluent and deforestation of riparian zones), may impact aquatic macroinvertebrate communities, potentially affecting arthropod prey base negatively for bats (Kalcounis-Rüeppell et al. 2007). Indeed, conservation of riparian corridors and water quality has received priority in recovery efforts of threatened and endangered bat species (Brady et al. 1982). However, potential effects of urbanization on bat populations through habitat alterations have received less attention, particularly as it pertains to endangered species conservation.

In the Southeast and lower Midwest, the endangered gray myotis (*Myotis grisescens*) is a year-round cave-obligate species that forages almost exclusively over large rivers and reservoirs during summer, making it susceptible to water quality degradation (LaVal et al. 1977, Decher and Choate 1995). Alteration of forested riparian corridors and reduced water quality along large systems such as the Tennessee River and its major tributaries may affect gray myotis negatively (Brady et al. 1982). However, most efforts to recover gray myotis populations have focused on protection of large maternity caves and winter hibernacula (Brady et al. 1982). Although cave protection has resulted in marked increases in numbers of gray myotis over the past two decades (Harvey 1994, Martin et al. 2003), recovery also requires that management actions identify and prevent adverse modifications to water quality and forest cover in foraging areas and travel corridors (Brady et al. 1982). However, few studies of gray myotis have examined habitat components necessary for foraging, particularly those affected by urbanization and land use change. Although it is well established that gray myotis forage over open waterways such as rivers and reservoirs located within 4 km of roost caves (Tuttle 1976, LaVal et al. 1977, Best and Hudson 1996, Brack and LaVal 2006, Yates and Muzika 2006), effects of waterway characteristics such as forest buffers and human development of surrounding lands on ecology of gray myotis has not been determined. Due to their foraging habitat specificity, colonial roosting behavior, and consequently, potential intra-specific competition, gray myotis may forage >30 km from their roost caves, suggesting that large areas may be necessary for conservation (Tuttle 1976, LaVal et al. 1977, Rueter et al. 1992, Best and Hudson 1996, Choate and Decher 1996). Conservation of foraging areas is imperative given the recent documentation of white-nose syndrome (*Geomyces destructans*) in gray myotis (M. Bayless, personal communication, Bat Conservation International).

In northwestern Georgia, four caves are used by gray myotis as bachelor and maternity colonies during summer, but spatial extent of foraging areas of these colonies is unknown (Martin and Sneed 1990). Because these caves are located >11 km from major waterways such as the Tennessee and Coosa rivers, these colonies may travel farther to forage over larger waterways than other populations in the Southeast (Tuttle 1976, Martin and Sneed 1990). Conversely, small streams in proximity to these roost caves could be used as foraging areas and travel corridors and may be locally important habitat components (Brady et al. 1982, Choate and Decher 1996). Rapid expansion of the Chattanooga, Tennessee, and Atlanta, Georgia, metropolitan areas immediately to the north and southeast, respectively, make delineation and protection of specific commuting and foraging areas imperative for gray myotis conservation in northwestern Georgia (Wear and Bolstad 1998). Consequently, our objectives were to determine spatial extent of gray myotis foraging areas in northwestern Georgia and to develop within a geographic information system (GIS), landscape- and micro-habitat-scale models of gray myotis foraging habitat in northwestern Georgia. Because gray myotis roost caves in northwestern Georgia were located >11 km from the Tennessee and Coosa rivers, we hypothesized that spatial extent of gray myotis foraging areas would include large waterways, such as the Oostanaula River and Chickmauga Creek, located in bottomlands near their roost caves. We also predicted gray myotis would use smaller riparian corridors immediately surrounding their roost caves for commuting to primary foraging areas. Lastly, we predicted gray myotis would be present at larger waterways regardless of micro-habitat riparian condition.

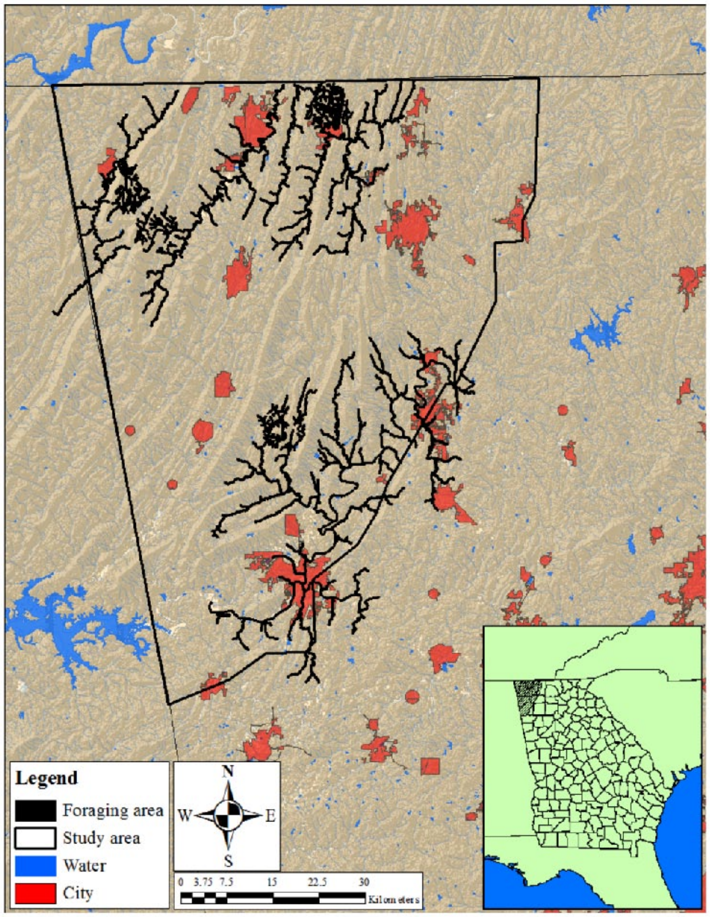

Figure 1. Predicted gray myotis foraging areas in northwestern Georgia, 2000.

Methods

We conducted our study from 2000 to 2001 in the Cumberland Plateau and Ridge and Valley physiographic provinces of northwestern Georgia (Figure 1). Our study area encompassed approximately 8,820 km of streams and rivers. Although the area is largely rural or consisting of small towns and cities (population < 60,000), rapid urbanization is occurring nearby to the north and southeast (Wear and Bolstad 1998). Limestone geology occurs throughout the area and is unique among Georgia's physiographic provinces for its abundance of caves.

To determine spatial extent of gray myotis foraging areas at the landscape (i.e., study area) scale, we sampled 213 sites during summer 2000 (June–August) at waterways by actively recording echolocation passes with an Anabat II (Titley Electronics, Ballina, Australia) bat detector linked to a laptop computer via an Anabat V Zero-Crossing Analysis Interface Module (ZCAIM). We established an 8.3 x 94-km sampling grid over a 5,100-km^2 study area in the northwestern corner of Georgia. We randomly sampled 3–4 waterways, including ponds, lakes, streams, and rivers, within 4 km of each grid intersection ($n = 69$). We monitored bat activity at each site ($n = 213$) once for 20 minutes between 2115 and 0200 hours (3–10 sites per night).

We used Analook 4.7j software (Corben 1999) to identify search-phase echolocation passes by comparing structure and frequency of recorded passes to a library of 273 identified echolocation passes recorded from hand-released bats in the southeastern United States. Gray myotis echolocation calls were distinguished from congeners by slope of the call body (<80 octaves per second) and a characteristic drop in frequency at the end of each pulse (Murray et al. 2001, Britzke et al. 2002).

We measured 23 variables (18 habitat and 5 landscape) at each sampling site that we believed influenced presence of gray myotis based on previous studies of gray myotis and other bat species (Decher and Choate 1995). We classified land surrounding each sampling site as flat peneplain, rolling hills, knobs, linear ridges, or mountains (Surrland) to assess if gray myotis were most frequently detected along a topographic gradient ranging from mountains to riverine areas. We classified waterways as wide alluvial bottom, narrow bottom, terraced bottom, or incised stream (Immland) to assess if gray myotis were detected more often over waterways of a particular physical structure. Because some bats may avoid structural clutter (e.g., vegetation, tree limbs) when foraging over water (Mackey and Barclay 1989), we estimated amount of clutter over waterways by separating streams or pond banks into 20 1-m segments across the waterway; 10 upstream and 10 downstream from the sampling site (Shrub). We scored each segment a 1 if clutter was present <3 m from the water surface or 0 otherwise, resulting in a potential score of 0–20 for each sample site. Brady et al. (1982) recommended retaining forest canopy cover over riparian areas for gray myotis foraging. Therefore, we visually estimated percent canopy cover at 5 points (5-m spacing): one at the sampling site, two upstream and two downstream (or to the left or right along the pond bank) from the sampling site (%Canopy). We estimated the percent canopy cover as 0, 25, 50, 75, or 100 and averaged the values for the 5 points. We noted if stream or pond banks were forested (Forest). We classified water surfaces as pool, run, riffle, or rapid (Actflow) because some bat species may avoid rapids and riffles of lotic waterways (Mackey and Barclay 1989). We measured width of each waterway (Actwid) with a laser range finder (Leica Camera Inc., Solms, Germany) or tape measure because bat activity may be less at smaller waterways (LaVal et al. 1977).

We determined geographic position and elevation (Elev) of each sampling site with a GeoExplorer II global positioning unit (Trimble Navigation, Ltd., Sunnyvale, California) and entered them into a GIS. We used ArcView 3.2 and Spatial Analyst 2.0 (Environmental Systems Research Institute, Inc., Redlands, California) to acquire and analyze 16 spatial variables. To determine if presence of gray myotis was associated with distance to nearest roost cave, we calculated straight-line distances from each sampling site to the nearest roost cave (Distnear). We determined stream order (Sorder) for each stream segment in the digital line graph (DLG) using the Strahler method (Strahler 1964). We determined percent of land use/land cover types (e.g., %Forest) in a 1-ha area (56.4 m radius) surrounding each sampling site (USGS 2003). A 1-ha area was chosen to examine the land use/land cover types surrounding each sampling site while retaining independence among sampling sites. The 2001 National Land Cover Dataset (30 × 30 m resolution) consisted of the following land use/land cover types in our study area: developed open space, low-intensity developed, medium-intensity developed, high-intensity developed, open water, coniferous forest, deciduous forest, mixed forest, barren land, unconsolidated shore, scrub or shrub, pasture or hay, woody wetland, forested wetland, and emergent herbaceous wetland (USGS 2003).

We developed a buffer (GISbuffer) to predict spatial activity patterns of gray myotis. Anecdotal radiotelemetry data, light-tagging data, and acoustic data collected in the area in 1999 and 2000 indicated that four bachelor/maternity colonies occurred in northwestern Georgia (Menzel et al. 2000). Data for two of these colonies suggested gray myotis foraged in the largest riparian waterways near their roost caves. Therefore, we predicted gray myotis would use the largest stream near their roost cave and associated stream tributaries to some threshold minimum width. We divided the study area into four zones, one for each gray myotis colony, based on probable topographic barriers such as Lookout Mountain, drainage basin delineations, and mid-point distances between caves. For each zone, we determined shortest riparian corridor distance (km) from the point of the main foraging stream nearest the cave to the farthest sampling site where a gray myotis was detected. The maximum riparian corridor distance (MaxDist) among the four zones was applied it to all zones. We also believed that gray myotis would use any size stream within a certain distance of their roost cave for traveling to the main foraging stream. In GIS, we created a 3.5-km buffer (Buffer function in ArcView) around each cave, which included the maximum proportion of sample sites where gray myotis were detected within the least amount of area. Further, we created a 150-m buffer around the largest foraging stream near each roost and its tributaries within the MaxDist, and all streams within 3.5 km of each cave. A 150-m buffer was an arbitrary value used to include sampling sites that may have differed from their true geographic position due to GPS error or DLG inaccuracies. We visually confirmed that sample sites within GIS were adjacent to the appropriate waterways. For each sampling site, we determined which sampling sites were within the buffer to create a binary variable (i.e., 1 = inside or 0 = outside the buffer) to include in the landscape analysis. We determined the threshold minimum stream order where gray myotis foraged by excluding all first-order streams from the GIS buffer and determining the proportion of sites where gray myotis were detected within the GIS buffer. Iteratively, we excluded all second-order and smaller streams, all third-order and smaller streams, and so forth, until maximum proportion of sites where gray myotis were detected was retained with the largest, minimum stream order included. All stream orders within 3.5 km of each cave were retained per iteration. We calculated the proportion of streams in the study area that were included in GISbuffer.

We used a chi-square test to determine if presence of gray myotis was disproportionately at lentic or lotic waterways. We used stepwise logistic regression to construct landscape and micro-habitat-scale foraging models. For the landscape model, we used the following variables: Immland, Surrland, Elev, Distnear, and GISbuffer. We entered the remaining variables into the micro-habitat model. Prior to analyses, we tested explanatory variables for collinearity using Pearson's product-moment correlation coefficients and determined that collinearity among all variable pairs was <0.6, requiring no remedial action for dataset (SAS Institute 1990, Grewal et al. 2004). To determine if presence of gray myotis could be predicted on a landscape scale (i.e., study area), we examined landscape-scale variables measured in 2000. To predict presence of gray myotis on a micro-habitat scale (i.e., within areas predicted by the landscape model) with logistic regression analysis, we sampled 114 sites within GISbuffer in summer 2001 (Neter et al. 1989). None of the sites sampled in 2000 were re-sampled in 2001. We examined data from sites sampled in 2000 (to increase sample size) that were predicted by the landscape model as sites where gray myotis would be detected and data from all sites sampled in 2001. We used a bootstrap procedure to assess classification accuracy (i.e., model sensitivity and specificity) of the landscape and micro-habitat models. In our landscape analysis, a liberal predictive threshold of >0.25 rather than >0.50 probability level was used in the bootstrap procedure because preliminary analysis showed that, at a threshold of >0.50, gray myotis presence was not predictable at the landscape scale. In the micro-habitat analysis, we used a more conservative predictive threshold of >0.50 to better refine our understanding of gray myotis requirements within determined foraging areas. We computed Hosmer and Lemeshow goodness-of-fit tests, generalized coefficients of determination, and adjusted generalized coefficients of determination to assess model performance (SAS Institute 1990).

Results

In summer 2000, we recorded 6,314 bat echolocation passes at 213 sampling sites, ranging from 1.2 km to 46.3 km from the nearest gray myotis cave. We identified 237 echolocation passes of gray myotis at 34 sites, ranging from 1.6 km to 28.0 km from the nearest gray myotis cave. The maximum riparian corridor distance (MaxDist) was 66.0 km. Therefore, we presumed that any gray myotis in northwestern Georgia could travel as much as 66.0 km of riparian corridor distance from its cave while foraging. Gray myotis used lotic waterways in greater proportion to lentic waterways ($df = 1$; $\chi^2 = 4.15$; $P = 0.040$). Gray myotis were detected at only 1 of 30 (3%) pond or lake sites and at 33 of 183 (18%) stream or river sites. Therefore, 30 sampling sites at lentic waterways, comprising 22% of water surface area in northwestern Georgia, were excluded from further analyses.

The four roost caves were within 12 km of their respective nearest large stream. The GISbuffer we selected for use in further analyses contained third-order and larger streams, resulting in retention of 82.4% of sample points where gray myotis were detected and 14.4% of all streams and rivers in northwestern Georgia. GISbuffer predicted ($P < 0.001$) gray myotis presence at the landscape scale in 2000. The landscape model predicting gray myotis presence:

$$1/1+\exp^{(-2.965-(2.327*\mathrm{GISbuffer}))}$$

had a Nagelkerke's maximum-rescaled R^2 value of 0.235. The bootstrap method indicated that 68.3% of observations were correctly classified (predictive threshold of 0.25). Model sensitivity (correct classification of gray myotis presence at sample sites) was greater (84.8%) than model specificity (correct classification of gray myotis absence at sample sites; 64.7%) and false positives outweighed false negatives. In 2000, we detected gray myotis at 28 of the 81 (34.6%) sites the bootstrap method predicted and all were within GISbuffer.

We recorded 5,124 bat echolocation passes at 114 sampling sites in summer 2001, and 620 echolocation passes of gray myotis at 87 sites. Further, feeding buzzes of gray myotis were recorded at 50 sites. We used 195 sample sites (81 from 2000 and 114 from 2001) for micro-habitat logistic regression analyses. Significant variables were forest ($r^2 = 0.08$; $P = 0.004$), shrub ($r^2 = 0.05$; $P < 0.001$), and percent pasture ($r^2 = 0.05$; $P < 0.001$). The micro-habitat model predicting gray myotis presence:

$$1/1+\exp^{(-0.760-(1.463*\mathrm{forest})-(-1.641*\mathrm{shrub})-(1.335*\mathrm{percent\ pasture}))}$$

had a Nagelkerke's maximum-rescaled R^2 value of 0.18. An analysis of the percent of land cover in a 56.4-m buffer around streams included in GISbuffer revealed that deciduous forest was the most frequent land cover (27%), followed by pasture/hay (26%) across the study area. The bootstrap procedure indicated that 69.2% of observations were correctly classified and gray myotis presence could be predicted more reliably than absence (86.1% vs. 45.0%).

Discussion

Conservation of gray myotis foraging areas in northwestern Georgia potentially could include all waterways because of the large distances travelled while foraging. However, our GIS buffer indicated that a large proportion (82%) of priority foraging areas could be conserved by focusing management and protection efforts on just 14% (1,235 km) of all streams despite low explanatory power of our models. The accuracy of prediction based on the GIS buffer is supported because gray myotis presence was detected at only 16% of sampling sites in 2000 when sampling was systematic across the landscape; whereas gray myotis were detected at 76% of sampling sites within the buffer in 2001. Our GIS buffer contained third-order and larger streams (>5.8 m width). If second-order streams were included in the GIS buffer, percent of streams across the study area included in the model would increase from 14% to 23% (2,029 km), though not increasing number of sampling sites where gray myotis were detected. We caution that our landscape model did not suggest first- and second-order streams were not important foraging habitat for gray myotis. We sampled each site only once, therefore, we may not have detected gray myotis in areas where foraging was less frequent. Moreover, we potentially detected absence when there may have been presence, as evinced by the low specificity of our models. Further, the robustness of our models, particularly at the micro-habitat scale, is weakened by the low explanatory power of model variables.

Similar to several studies in the eastern United States that have used an acoustic sampling approach to broaden understanding of bat species-habitat associations, we used an efficient combination of acoustic sampling and GIS to elucidate gray myotis spatial patterns across the landscape (Johnson et al. 2002, Ford et al. 2006, Schirmacher et al. 2007, Johnson et al. 2008, Brooks 2009). Moreover, the results of our study corroborated findings of radiotelemetry studies in Georgia (Menzel et al. 2000) and in other parts of the Southeast that showed gray myotis foraged over larger waterways and to a lesser extent over land between riparian areas (Best and Hudson 1996, Choate and Decher 1996). We did not detect gray myotis in riparian areas on the Lookout Mountain massif, indicating that they did not cross over this geologic feature, which may be a barrier between foraging areas of colonies from different watersheds. Within their respective bottomland riparian areas, gray myotis were detected more frequently on main stems than on first- and second-order reaches.

Gray myotis probably cannot efficiently forage in narrow, upstream portions of streams because of increased vegetative clutter over stream surfaces that may decrease prey detection and increase flight difficulty (Mackey and Barclay 1989, Owen et al. 2004, Johnson et al. 2010). Indeed, gray myotis have long, narrow wings and have high wing-loading, morphologically suiting them for maneuvering in open areas, rather than narrow, cluttered first- and second-order riparian corridors (Farney and Fleharty 1969). However, all streams, including first- and second-order, within 3.5 km of gray myotis roost caves should be considered for conservation as they may be important travel corridors to larger streams and rivers where they forage (Choate and Decher 1996, Tuttle 1979). We recorded search-phase echolocation passes of gray myotis at these larger streams and rivers, indicating that these areas were being used as foraging areas. Moreover, we recorded feeding "buzzes" at 57% of sites in 2001, supporting the notion that these areas are serving as foraging areas. Larger streams within our GIS buffer will be affected by sedimentation, pollution, and deforestation of the first- and second-order streams that flow into them (Phillips et al. 2000). In the nearby Etowah River watershed, macroinvertebrate diversity was lower in headwater catchments and within larger basins with >15% urban land cover (Roy et al. 2003). Ensuring quality of upstream reaches may benefit the relative quality and productivity of larger, downstream reaches where gray myotis are primarily foraging (Kalcounis-Rüeppell et al. 2007). Gray myotis may select larger portions of waterways where macroinvertebrate production may be higher and more consistent (Vannote et al. 1980).

Gray myotis foraged in large riparian areas with uncluttered travel corridors and forested edges that were adjacent to pastures. Our findings support research by Brack and LaVal (2006) in Missouri where diet analysis of gray myotis indicated they selectively foraged over wooded riparian habitats. Bat activity typically is lower in deforested areas of riparian corridors (Ober and Hayes 2008). Forested stream banks may provide gray myotis with some protection from predators, and also may buffer streams against sedimentation and pollution (Brady et al. 1982, Phillips et al. 2000). Residential and industrial development can affect water chemistry and sedimentation, reducing macroinvertebrate production in gray myotis foraging areas (Roy et al. 2003, Kalcounis-Rueppell et al. 2007). Research into stream quality and productivity within gray myotis foraging areas and subsequent prioritization of streams and rivers for conservation may be warranted. Indeed, a fuller understanding (and perhaps model improvement) of gray myotis foraging habitat requirements would be gained by incorporating assessments of water quality and aquatic and aerial macroinvertebrates at sampling sites.

The rapid expansion of the Chattanooga, Tennessee, and the Atlanta, Georgia, metropolitan areas near roost caves of gray myotis requires conservation efforts that extend beyond roost cave protection. Development near riparian corridors may have negative impacts on gray myotis populations by polluting streams and increasing sediment loads. Moreover, conversion of agricultural or forested lands adjacent to foraging areas for residential or industrial purposes may result in a decrease in alternate gray myotis foraging habitat. Our findings support the need to protect all streams immediately surrounding roost caves and associated nearby large waterways. Our ability to predict spatial activity patterns of gray myotis in a GIS should allow for more strategic conservation of important foraging areas of gray myotis across the landscape. Results from our study should enable land managers to include foraging habitat requirements in gray myotis conservation efforts.

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