STATUS OF THE GREEN SALAMANDER (*ANEIDES AENEUS*) IN THE BLUE RIDGE MOUNTAINS

A Thesis

by

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ABSTRACT

STATUS OF THE GREEN SALAMANDER (ANEIDES *AENEUS*) IN THE BLUE RIDGE MOUNTAINS

(December 2001)

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Populations of the green salamander (*Aneides aeneus*) in the Blue Ridge Mountains declined 98% in abundance between 1970 and 1999 and are being considered for Candidate Species status by the United States Fish and Wildlife Service. The present study was designed to ascertain the current distribution and status of *A. aeneus* populations throughout the Blue Ridge Mountains.

A spatially explicit multivariate model of *A. aeneus* occurrence was developed for a portion of the salamander's range. Ten habitat layers were sampled from 24 *A. aeneus* localities using Geographic Information Systems and 30-m geographic data. Mahalanobis Distance (D^2) was calculated for each pixel within the study area to assess the likelihood of *A. aeneus* occurrence across the landscape. Diagnostic tests and field-truthing surveys demonstrated that, while the model was very coarse, it was significantly better than random at delineating and sub-dividing *A. aeneus* habitat into categories of suitability.

Status surveys of *A. aeneus* were conducted during 2000 and 2001. In all, 38 occupied sites and eight breeding populations were confirmed throughout the Blue Ridge Mountains. Across all sites, densities were dramatically lower than those reported in 1970. Among 20 historic sites visited, 15 (75%) were occupied and seven (35%) showed evidence of reproduction. Although statistically insignificant, fewer than expected breeding populations were observed ($0.10 > P > 0.05$) and the number of breeding populations decreased between 1991 and 2001 ($P = 0.07$), suggesting that a biologically relevant decline is still in progress. Based on criteria provided in the current World Conservation Union Red List Categories, this study indicates that populations of *A. aeneus* are at a high risk of extinction in the Blue Ridge.

The data and analyses presented here will provide critical information needed to assess the legal status of *A. aeneus* populations in the Blue Ridge Mountains. Additionally, the occurrence model should provide a valuable tool for directing future field surveys and conservation efforts.

Key words: *Aneides aeneus*, status, GIS habitat modeling, amphibian decline

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The first reports of major amphibian declines and local extinctions accumulated through the 1970s and 1980's. At a two-day workshop convened in Irvine, California in 1990 scientists agreed there was substantial evidence that populations of amphibians have declined or become locally extinct on a global scale (Phillips, 1990; Vitt et al., 1990)

Early critics pointed out that declines may actually be a natural part of amphibian population dynamics (Blaustein, 1994). Additionally, much of the supporting evidence of declines was derived from short-term studies at small geographical scales (Blaustein et al., 1994*a*; McCoy, 1994; Pechmann et al., 1991; Pechmann and Wilbur, 1994). However, recent studies demonstrated declines above "natural" levels and provided convincing evidence of a global amphibian decline (Alford and Richards, 1999; Houlahan et al., 2000).

A number of factors at the local and regional scales have been invoked as causes for amphibian declines. Site-specific factors included habitat destruction (Petranka et al., 1993), over-collecting (Gorzula, 1996; Hairston and Wiley, 1993), and introduced predators (Gambrandt and Kats, 1996). Regional factors included acid deposition (Beebe et al., 1990), UV-B radiation (Blaustein et al., 1994*b*), pathogens (Daszack et al., 1999), and extreme weather (Crump et al., 1992). Synergistic combinations of factors have also been implicated as causes of amphibian declines (Carey, 1993; Drost and Fellers, 1996).

While most reported declining amphibians were frog and toad species, a significant number of salamanders have declined as well (Vial and Saylor, 1993). Salamanders are amphibians in the order Caudata (Petranka, 1998), which includes approximately 400 species worldwide (Petranka, 1998). Salamanders are the most abundant forest floor vertebrate in some forest types and may equal or exceed the biomass of birds and small mammals (Burton and Likens, 1975; Hairston, 1987). Terrestrial salamanders consume detritivores on the forest floor and, due to their abundance and biomass, likely play a major ecological role by influencing litter decomposition and nutrient cycling (Wyman, 1998). Over 75 species and 19 genera occur in the southeastern United States, giving this region the highest taxonomic diversity of salamanders in the world (Petranka, 1998).

The southern Appalachians were believed to have escaped the “global” amphibian decline with respect to salamanders (Hairston and Wiley, 1993). However, recent studies reported declines of several salamander species within this region (Highton, 2000), the most dramatic being the green salamander, *Aneides aeneus* (Corser, 2001; Snyder 1991).

The green salamander is a member of the tribe Plethodontini, of the lungless family Plethodontidae, and is the only representative of the genus *Aneides*, or "Climbing Salamanders", in the eastern United States (Petranka, 1998). Adults measure 8 - 14 cm long and can be easily identified by the presence of greenish lichen colored patches on a black dorsum, a flattened body, long legs, and squared toe-tips (Petranka, 1998). They are observed (during the warmer seasons) primarily in shaded crevices of rock outcrops by day, or on rock faces at night (Hafer, 1992*a*). Crevices used are typically horizontal and moist, but not wet, and must be clean, without sediment or moss (Gordon, 1952). Rock outcrops occupied by *A. aeneus* in the Blue Ridge Mountains range from $42m^2$ to $3800m^2$ in area (Bruce, 1992) and are usually located within associations of the Mixed Mesophytic forest type between 290m and 1340m elevation (Gordon, 1952; Bruce, 1992). Appropriate habitat is patchily distributed and tends to occur in ravines. In addition to rock crevice habitat, there are also scattered accounts of woody and arboreal habitat use (Bruce 1968; Canterbury, 1991; Gordon, 1952).

During the spring, individuals emerge from overwintering crevices to breed or disperse. Females begin breeding during the second or third year of life and breed on a biennial basis thereafter (Canterbury and Pauley, 1994). During May and early June, breeding females suspend their eggs from an overhead substrate in horizontal crevices or narrow chambers, which provides the specific micro-climate necessary for embryonic development (Gordon, 1952; Snyder, 1971). Clutches contain 10 - 26 eggs and the brooding period lasts approximately 90 days (Gordon, 1952; Snyder, 1971). In fall, individuals of all age-classes congregate near the deep rock crevices they use during winter hibernation. A second bout of breeding may occur during the fall congregation (Canterbury, 1991; Gordon, 1952; Snyder, 1971). Although scattered individuals can be observed throughout the spring and summer, the fall congregation produces the highest numbers of observable individuals and possibly represents the total population (Gordon, 1952).

The green salamander is distributed from northeastern Mississippi to southwestern Pennsylvania along the Appalachian Plateau Geologic Province. A large disjunct population occurs in the southern Blue Ridge Mountains of northeast Georgia, northwest South Carolina, and southwest North Carolina (Figure 1; Petranka, 1998). Smaller disjuncts are reported from central Tennessee, northeast West Virginia, southern Ohio, southern Indiana, eastern Maryland, and Great Smokey Mountains National Park (Petranka, 1998).

The Blue Ridge Mountain disjunct population of *A. aeneus* experienced a dramatic decline during the 1970's (Snyder, 1991). Snyder (1971) reported nearly 200 clutches from 13 sites in 1970, with one site containing 55 clutches. Snyder (1971) described *A. aeneus* as “common and sometimes dense”. In the late 1980's, only eight of 37 known sites were occupied and densities within those sites were a fraction of their former abundance (USFWS, 1987). Populations along the Appalachian Plateau, although rare (Petranka, 1998), have apparently remained stable (USFWS, 1987; Snyder, 1991). The causes for the decline in the Blue Ridge Mountains are unknown but proposed reasons included chaotic deterministic processes, acid precipitation, habitat loss, climate change, over-collecting, and susceptibility to pathogens (Snyder, 1991; Corser, 2001).

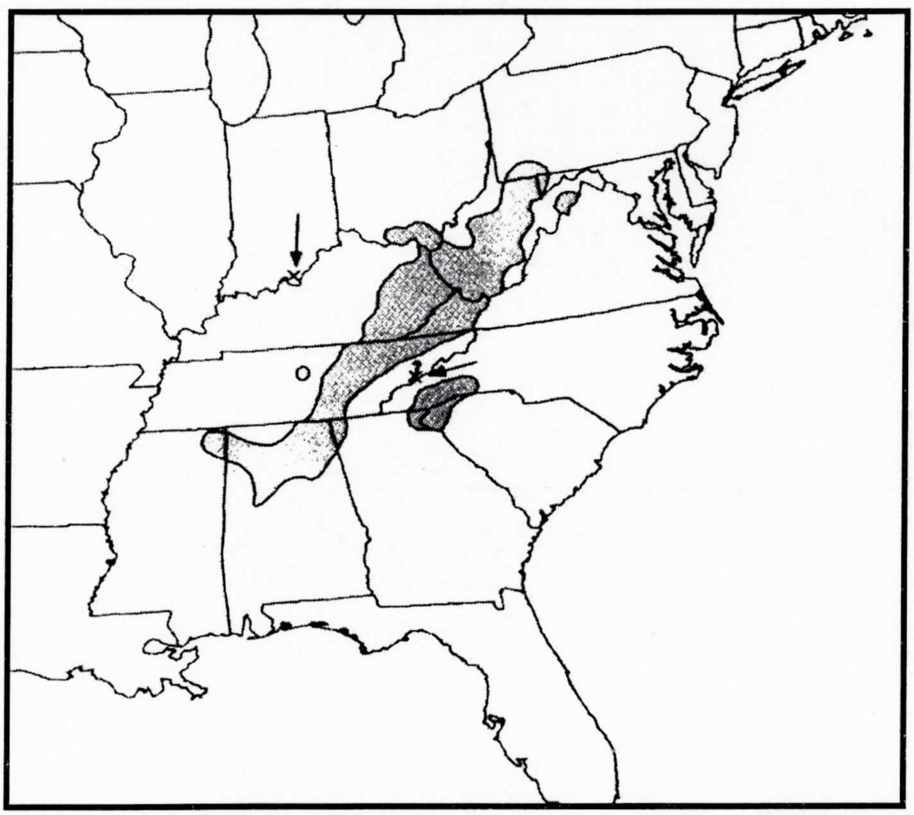

Figure 1. Geographic range of the green salamander, *Aneides aeneus*, in eastern North America. (Reprinted from Petranka, 1998).

The population crash prompted a status review by the USFWS to determine if Blue Ridge Mountain populations qualified for listing under the Federal Endangered Species Act (USFWS, 1987). As a result of the status review, the Blue Ridge population was designated a Federal Species of Concern (FSC) indicating that, while protection under the Act may be warranted, there is insufficient information on the status and threats to the species to warrant designation as a "Candidate" for federal listing (Federal Register, 1996; LeGrand and Hall, 1999). In 1990, populations of *A. aeneus* in North Carolina were listed as endangered by the North Carolina Wildlife Resources Commission (Harry LeGrand, pers. comm.). Populations in other states received lower status: *A. aeneus* was listed as a "Species of Concern" by the South Carolina Wildlife and Marine Resources Department and "Rare" by the Georgia Department of Natural Resources. While the designations assigned by the Federal Government, South Carolina, and Georgia provided little legal protection to *A. aeneus*, the state Endangered designation in North Carolina provided protection from collecting throughout the state and from incidental take on state-owned lands (Harry LeGrand, pers. comm.).

The Blue Ridge disjunct population has been reported for nine counties along the Blue Ridge Escarpment including: Transylvania, Henderson, Rutherford, Jackson, and Macon in North Carolina; Greenville, Pickens, and Oconee in South Carolina; and Rabun in Georgia. Most populations were within, or near, the Savanna watershed of North Carolina, an area known as the "Embayment" (Bruce, 1968). However, a small cluster of populations have been found in Hickorynut Gorge to the northeast (Corser and Gaddy, 1991; Figure 2).

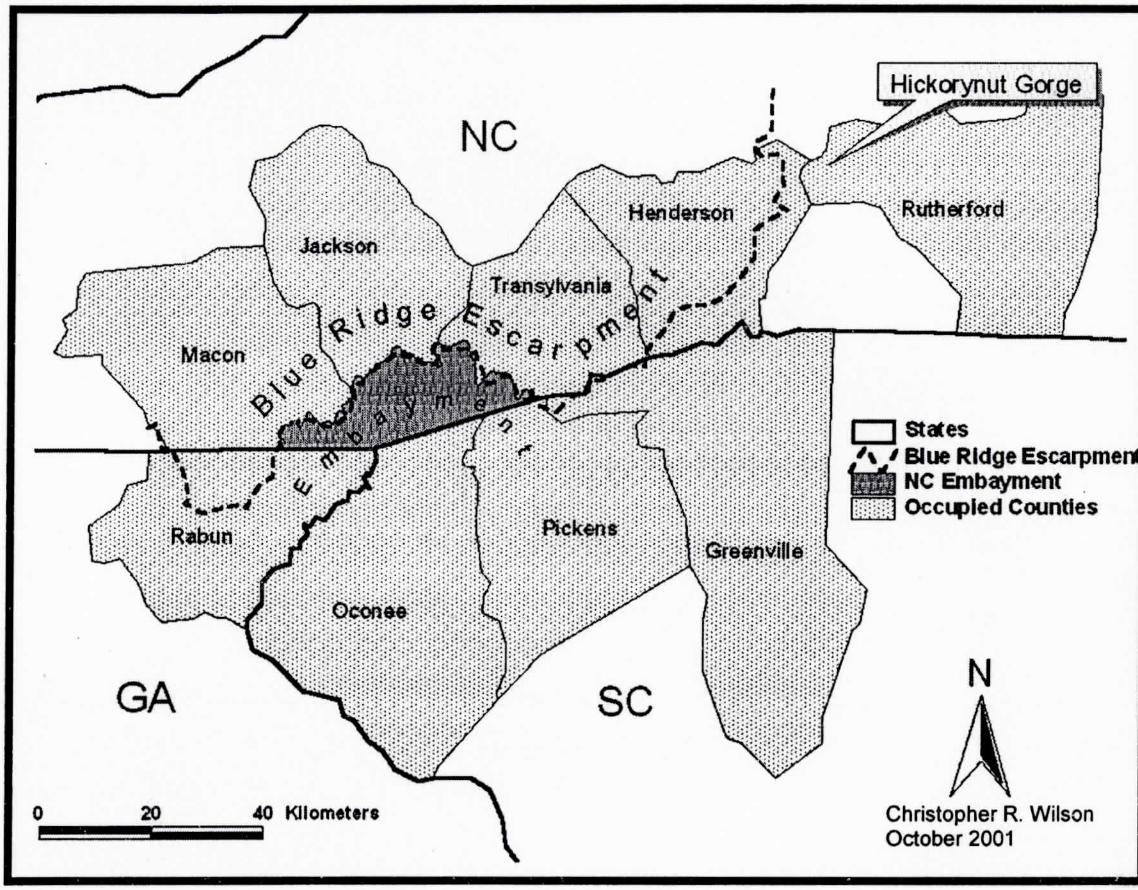

Figure 2. Map of the Blue Ridge Escarpment and counties known to have populations of the green salamander.

The Blue Ridge Escarpment, particularly in the embayment, receives the highest annual precipitation in the eastern United States (Cooper and Hardin, 1971). Elevations range from 275 to 1524m and the topography is characterized by ravines, coves, and deep gorges. The area is dominated by Mixed Mesophytic and chestnut oak (*Quercus prinus*) forests (Cooper and Hardin, 1971). Lands within the eastern third of the Escarpment are mostly private, while lands in the western portion are mostly National Forest or State-owned. Private lands throughout the region are being rapidly developed into second homes, resorts, and golf courses (White et al., 1998).

Populations of *A. aeneus* within the Escarpment of North Carolina have not recovered from the decline of the 1970's. Corser (2001) monitored 13 sites annually between 1990 and 1999 and found no more than 4 clutches from a single site and no more than 13 clutches in a single year. Seven of these sites contained a total of 95 clutches in 1970 (Snyder, 1971) but averaged only 1.67 clutches between 1990 and 1999, demonstrating a 98% decline. Ongoing genetic research regarding the phylogeny of *A. aeneus* shows that the species actually consists of at least two, or possibly four, separate species (Joseph Bernardo, pers. comm.). Of these four, two occur in NC; one within the Escarpment and the other within Hickorynut Gorge. Due to the severe decline of Escarpment populations and the extremely limited distribution within Hickorynut Gorge, Blue Ridge Mountain populations are currently being considered again for elevation to Candidate Species status by the U.S. Fish and Wildlife Service (Allen Ratzlaff, pers. comm.). In addition, conservation advocacy groups, such as the Southern Appalachian Biodiversity Project, intend to petition the USFWS to list Blue Ridge populations of *A. aeneus* as Endangered or Threatened (Marty Bergoffen, pers. comm.).

The World Conservation Union, or International Union for the Conservation of Nature (IUCN), publishes a set of "Red List Categories" which provide objective criteria for the classification of species according to their extinction risk (IUCN, 2001). In order to determine the present status of *A. aeneus* in the Blue Ridge under the IUCN Red List Categories, techniques must be developed to determine the amount and distribution of potential and occupied habitat. Status surveys are also needed to compare current populations to past studies.

Hafer (1992*a*) developed a systematic method for locating potential *A. aeneus* habitats in three counties of South Carolina. She subdivided 7.5' topographic maps into 0.16-km^2 sections by superimposing a grid lattice of 400m x 400m cells over the study area. A list of criteria to predict *A. aeneus* locations was developed by characterizing the topographic features of 14 grid cells containing *A. aeneus* sites. Her topographic features included elevation, slope, aspect, and distance to stream. Hafer rated (by hand) 952 grid cells for each of twenty-four 7.5' topographic maps covering Greenville, Pickens, and Oconee counties. Grid cells were rated as having a low, moderate, or high probability of containing suitable *A. aeneus* habitat and 65 cells were randomly chosen to receive status surveys. Of the 20 high probability cells, 19 contained potential habitat (moist shaded rock outcrops with crevices) and one contained marginal quality habitat (too wet). Of the 19 potential habitat sites, four contained *A. aeneus* individuals. These four new sites extended the salamander's range 32 km eastward in South Carolina. Because 4 (20%) of the high probability sample cells contained *A. aeneus*, Hafer was able to estimate that 134, out of 670 high probability cells in the study area, contained *A. aeneus*.

In 1992, Hafer was contracted by the North Carolina Wildlife Resources Commission to identify high probability sites in the Brevard 7.5' quadrangle and survey those sites for the presence of *A. aeneus* (Hafer 1992*b*). She rated 110 of 952 cells as high probability. Of these high probability sites, five were not surveyed, 57 contained no rock outcrops, 31 contained rock outcrops of moderate quality (too wet or not shaded), and 18 contained rock outcrops of high quality. However, no *A. aeneus* were detected in the surveys. These findings were in contrast to the more successful results obtained when her method was applied to South Carolina. Habitat criteria developed for South Carolina were not appropriate for use in North Carolina but a similar methodology should develop better criteria if based on North Carolina *A. aeneus* sites (Hafer, 1992*b*).

Hafer's geographically based method is perfectly suited for automation using Geographic Information Systems (GIS) software and available geographic data. GIS is a computer-based framework that allows the creation, analysis, and display of large geographic datasets. A GIS database contains separate layers corresponding to specific geographic features such as elevation, slope, aspect, streams, and forest type. These features can be overlaid and queried to locate areas meeting specific combinations of features. GIS-based habitat models can be powerful and efficient methods to assess the distribution of a target species across the landscape (Hunter, 1996). GIS can use high resolution data (30m as opposed to 400m grid cells) to delineate habitat at a much finer scale than Hafer's manual technique. In addition to the simple measures of topography used by Hafer, such as elevation, slope, and aspect, GIS also allows the creation and use of derived topographic variables that measure features such as site exposure and moisture. Because GIS is an automated system, it allows the practical application of multivariate statistical analysis to large sets of geographic data. Although GIS-based, multivariate habitat models have been created for a variety of vertebrate taxa such as Black Bear (Clark et al., 1993), songbirds (Dettmers and Bart, 1999), and Black-tailed jackrabbits (Knick and Dyer, 1997), no such models have been published for an amphibian.

Since the decline reported by Snyder (1991), a number of researchers have conducted field surveys to assess the status of *A. aeneus* populations in the Blue Ridge. Corser and Gaddy (1991) censused populations across the range of *A. aeneus* in North Carolina and Bruce (1992) censused populations in Nantahala and Pisgah National Forests. Using her standardized survey method, Hafer (1992*b*) surveyed for new populations within the Brevard 7.5' quadrangle of North Carolina. As part of their master theses research, Corser (1991) studied the ecology and status of populations in the embayment of North Carolina and Hafer (1992*a*) surveyed populations in South Carolina. Between 1990 and 1999, Corser (2001) monitored 13 populations in the North Carolina embayment.

In a monitoring program developed for the Nantahala National Forest, Bruce (1992) recommended monitoring known sites on a five-year cycle. Other than the 13 populations monitored by Corser (2001) in the NC embayment, most populations in the Blue Ridge have not been censused since the early 1990s. A current census of populations throughout the Blue Ridge is overdue and necessary to assess the current status of *A. aeneus.* Status surveys will provide abundance and occupancy data needed to make comparisons to previous surveys and determine the current distribution of populations in the Blue Ridge.

The present study was designed to ascertain the status of *A. aeneus* populations in the Blue Ridge. A spatially explicit multivariate occurrence model of *A. aeneus* was developed for the North Carolina embayment using GIS. Standardized field truthing surveys were conducted to determine the model's predictive abilities. Status surveys of *A. aeneus* populations were conducted throughout the Blue Ridge. Survey results from historic sites were compared to past surveys. Existing *A. aeneus* occurrence records and status survey results were reviewed to estimate the total number of occurrences in the Blue Ridge, develop an updated range map, and calculate the extent of occurrence for both

Hickorynut Gorge and Escarpment populations. Results of this study were then used to determine the status of Blue Ridge populations as defined by the IUCN Red List Categories.

METHODS

GIS Occurrence Model

Study area

The segment of the Blue Ridge modeled in this study was the embayment of North Carolina, a portion of the southeast Escarpment bounded to the north by the Blue Ridge Divide and to the south by the South Carolina and Georgia state lines (Figure 2). The study area was approximately 47km X 18km. It held elevations ranging from 356m to 1489m and was predominately south facing with many steep slopes and deep incised gorges.

Determination of Sample Sites

The occurrence model was based on the geographic attributes of known populations determined from published records in Bruce (1992) and Corser and Gaddy (1991), and with the field assistance of Jeff Corser. Fourteen sites were located in the field and marked with a Garmin III+ Global Positioning System (GPS). The coordinates of an additional five sites were derived from the 7.5' United States Geological Survey (USGS) quadrangle maps provided in Bruce (1992) and Corser and Gaddy (1991).

The total area of sites varied and some sites occupied multiple 30m pixels. Thus, 19 sites provided 24 pixels, or sample sites, for use in the model (see Table 1)

GIS Database

A GIS database of 11 variables was developed to characterize habitat of *A. aeneus* from the 24 sample sites. Each variable, or map layer, consisted of a grid lattice containing 30m X 30m pixels in ARC / INFO. Variables chosen were limited to those available in GIS. For example, the resolution of the 30m GIS data could not measure microsite features such as appropriate rock crevices. Thus, the available variables measured mesoscale, rather than micoscale, habitat features.

Five variables were known to be important predictors of *A. aeneus* sites in past studies (Hafer 1992*a*). These were elevation, slope, aspect, distance to stream, and landcover type. Elevation (m) was derived from USGS digital elevation models (DEMs) gathered from the Southern Appalachian Man and the Biosphere GIS database (SAMAB 1996). Slope (degrees) was calculated from Elevation in ARC / INFO GRID using the SLOPE command. Aspect (degrees) was calculated from Elevation using the ASPECT command. Because continuous variables are needed for statistical analysis, Aspect (degrees), a circular variable, was converted into a continuous variable using the Beers Transformation (Beers et al., 1996),

$$\text{Aspect Beers} = 1 + \cos(45 - \text{Aspect degrees}).$$

Distance to stream (STDIST) was generated from stream coverages provided in SAMAB (1996) using the DISTANCE command. Landcover data was generated from the 1996 Landuse / Landcover (LU/LC) grid available from the North Carolina Center for Geographic Information and Analysis. The (LU/LC) grid applies 22 classifications to LandSat Thematic Mapper data. Landcover data were converted from one categorical variable to two design variables for the two most common (21/24) classifications of *A. aeneus* sites. Presence (1) or absence (0) of each LU/LC classification of Deciduous Forest (6) and Mountain Conifer (9), respectively, were used in the model.

Five remaining variables were chosen to provide additional measures of site insolation and moisture, and for their potential ability to characterize geologic features such as cliffs (Bockoven, 1999) and outcrops (van Manen, pers. comm.). Curvature (CURVE) measured the convexity or concavity of the individual pixel and was generated from Elevation using the CURVE command. Slope position (SLPOS) provided an index of the pixel's position between the nearest ridge top and nearest valley bottom. Terrain shape index (TSI) measured the convexity or concavity of the surrounding terrain (McNab, 1989). Weighted landform index (WLFI) evaluated the average slope from each pixel to the visible horizon and weighted this value by aspect. This variable provided an index of site exposure or protection (McNab, 1993). Topographic Convergence Index (TCI) simulated the accumulation of water by assessing the number of pixels draining into the target pixel and its convexity or concavity (Wolock and McCabe, 1995). SLPOS, TSI, WLFI, and TCI were generated from Elevation using ARC Macro Language, a programming language for ARC / INFO.

Statistical Analysis

Statistical methods used to develop GIS-based habitat models include linear regression analysis, logistic regression, discriminant function analysis, principle component analysis, canonical correlation analysis, and classification and regression tree (CART) analysis (Dettmers and Bart, 1999). These methods required either "abundance data", indicating the number of individuals present per plot, or "presence-absence data", indicating whether the species occurs, or does not occur, within the plot. In the case of *A. aeneus*, counts of individuals at a rock outcrop, or "plot", were notoriously low and it was impossible to declare the species absent from a plot if no individuals were detected. Therefore, neither "abundance" nor "presence-absence" data were available for model development. Point locations where *A. aeneus* has been observed, or "presence data", provided the only reliable data. The methods of Clark et al. (1993), a modeling approach specifically designed for “presence data”, was used to calculate the Mahalanobis Distance statistic.

Mahalanobis Distance (D^2) was a multivariate statistic expressed as

$$D^2 = (\underline{x} - \underline{\hat{u}})'\Sigma^{-1} (\underline{x} - \underline{\hat{u}}),$$

where $(\underline{x} - \underline{\hat{u}})$ is the vector for a pixel of differences between each of its variables and the means for the 24 known *A. aeneus* sites

and

Σ^{-1} is the inverse of the variance-covariance matrix for the same variables at the known sites.

D^2 represented the standard squared distance (or dissimilarity) between a set of sample variates, $\underline{x}$, and “ideal habitat”, $\underline{\hat{u}}$, where large values represented conditions less like the conditions of the sampling points (known *A. aeneus* locations). SAS (SAS Institute, 1989) was used to calculate $\underline{\hat{u}}$ and Σ^{-1}, then Arc/ Info GRID was used to determine $\underline{x}$ and calculate D^2 for each pixel in the study area.

Since D^2 values for the whole study area had a wide range, they could not be used directly to categorize habitat suitability for *A. aeneus*. D^2 values were sorted in ascending order and separated into three categories, with each category representing twice the total area (number of pixels) as the category before it, according to the following formula,

$$\text{Total pixels in study area} = n + 2n + 4n,$$

where n = 1/7 of the pixels in the study area. These groups are referred to as habitat categories one, two, and three, respectively. Habitat category 1 (best habitat) contained the lowest D^2 values and represented conditions closely approximating the sample sites. Habitat category 3 (worst habitat) contained the highest D^2 values and represented conditions least like the sample sites. Stratifying D^2 values in this way provided more efficient field validation by directing higher sampling intensity into areas with lower D^2 values.

<u>Diagnostic Tests</u>

To determine if the model was actually designating habitat for *A. aeneus*, D^2 values from the 24 known sites were compared to D^2 values of 1000 randomly chosen points. Because D^2 values were not normally distributed, a Mann-Whitney U test was performed using SPSS (SPSS Inc., 1999). In addition, the number of known *A. aeneus* sites within each habitat category was compared with the expected number if salamanders were using habitats without regard to suitability (based on the proportion of the study area contained in each habitat category). Chi-square was used as the test statistic (Zar, 1974).

Determination of Important Habitat Variables

To determine which habitat variables were most important to *A. aeneus* site selection, Mann-Whitney U tests were used to compare the attributes of known *A. aeneus* sites to 1000 random sites for each habitat variable (SPSS Inc., 1999). While no formal methods exist for determination of significant variables in a given Mahalanobis Distance model (Dettmers et al., in press), the Mann-Whitney U tests used here should indicate which variables had the most influence on the model (Dettmers, pers. comm.)

Field-Truthing

To determine the predictive ability of the model, it was necessary to visit a series of random sites belonging to each habitat category and evaluate site occupancy by *A. aeneus*. To minimize sampling bias in site selection, a stratified sampling design was used to select 20 test pixels from each habitat category. Since land ownership and access were important considerations for site selections, field-truthing was limited to pixels within 30m -150m from a public road and located on U.S. Forest Service property within the Highlands Ranger District (SAMAB, 1996). Coordinates corresponding to pixel centers were downloaded into a Garmin III+ Handheld GPS. The GPS unit and a customized 1:100,000 topographic map generated from SAMAB (1996) GIS data were used to locate site centers. Test sites were visited without knowledge of the associated habitat categories.

Field truthing was conducted between 13 October 2000 and 1 November 2000, a period that coincides with the fall congregation of *A. aeneus* and it's highest detectability (Corser, 1991; Hafer, 1992*a*). Once located, each test pixel was searched for the presence of rock outcrops, favorable habitat, and *A. aeneus*. Favorable habitat was loosely defined as a shaded rock outcrop, >1m^2 in area, containing clean, dry to moist, horizontal crevices 3cm – 5cm wide, and >5cm deep (Gordon, 1952). All rock crevices were searched with a high-power flashlight for the presence of individual *A. aeneus*.

Due to inaccuracies in the GIS data used to choose test pixels (property boundaries and roads), many pixels fell on private land or required private road access. Additional test pixels fell within rugged and inaccessible areas. Consequently, many of the originally chosen test pixels were not visited. Rather, field truthing became an iterative process where a new set of pixels were selected for each bout of visits, with only partial success during each attempt. Additionally, early confusion regarding field truthing methodology lead to over sampling of category 1 test pixels. Therefore, habitat categories were not sampled evenly.

Status Surveys

Field Techniques

While the model focused on the North Carolina embayment, status surveys sampled populations across the entire range of *A. aeneus* in the Blue Ridge. Between 2 January 2000 and 8 August 2001, as many previously known *A. aeneus* sites as possible were visited and searched. Site localities were determined from the literature (Bruce, 1992; Corser and Gaddy, 1991), communications with other workers, and with the field assistance of Jeff Corser and Chris McGrath. In addition, several areas with high potential for containing *A. aeneus* were identified by studying topographic maps and using the occurrence model described above. Rock crevices within located sites were searched with a high-power flashlight during daylight hours (Corser, 2001; Gordon, 1952; Snyder, 1971). Number of adults, hatchlings, and broods were recorded during each visit. Hatchlings were in their first calendar year or "young-of-the-year". Age-class of an individual was determined visually without removing them from crevices. Hatchlings only appeared in late summer and were very distinctive. Presence of broods or hatchlings was evidence of reproduction.

Statistical Tests

Chi-square analysis was used to compare number of breeding populations observed during this study with those reported from the same sites between 1991 and 1999 by Corser (2001). Liner regression analysis (SPSS Inc., 1999) was used to test for a trend in the number of breeding populations between 1991 and 2001.

Number, Distribution, and Extent of *Aneides aeneus* Occurrences in the Blue Ridge

To update the total number of *A. aeneus* observations in the Blue Ridge, all available records were obtained from the North Carolina Natural Heritage Program, South Carolina Wildlife and Marine Resources Department, and Georgia Department of Natural Resources. These records and new records reported in this study were tallied and mapped in ARC / VIEW using SAMAB (1996) data. Extent of occurrence was determined for both the Escarpment and Hickorynut Gorge populations from the area of a minimum convex polygon; the smallest polygon containing all occurrences and no internal angle exceeding 180 degrees (IUCN, 2001).

RESULTS

GIS Occurrence Model

Statistical Analysis

Table 1 presents habitat attributes, and associated D^2 values, for the 24 sample sites used to build the model. D^2 values for the sample sites ranged 6.942 to 51.889 with a mean = 16.05 (SD = 11.073). D^2 values for the study area ranged 0.533 to 1102.825 with a mean of 30.4 (SD = 28.034, n = 441,817). Habitat category 1 contained D^2 values between 0 – 8.897; category 2 between 8.898 – 18.028; and category 3 between 18.029 – 1102.825. Each habitat category was widely distributed throughout the study area (Figure 3).

Diagnostic Tests

Known *A. aeneus* sites had D^2 values significantly lower than random, indicating that the model was able to delineate habitat (Table 2). More *A. aeneus* sites fell into categories one and two, and fewer in category 3, than expected based on random usage (Table 3). This demonstrated that habitat categories divided the study area into meaningful classifications and that categories one and two represented better habitat than category 3.

Table 1. Green Salamander sample sites used to build GIS habitat model and their attributes.

Name	Elevation	Slope	Aspect	Beers	LU/LC=6	LU/LC=9	STDIST	CURVE	WLFI	SLPOS	TSI	TCI
Ammons Branch	3002	51	186	0.22	1.00	0.00	141.4	0.26	0.16	0.69	-40	-0.09
Chatooga Gorge	2508	90	241	0.04	0.00	1.00	400.0	0.52	0.21	0.20	-33	-1.58
Coley Creek	2013	34	163	0.74	1.00	0.00	223.6	-0.34	0.20	0.39	-6	0.91
Ellicot Mnt	2977	42	223	0.00	1.00	0.00	100.0	-0.07	0.15	0.78	-23	0.09
Granite City	3114	45	86	1.76	1.00	0.00	948.7	-0.08	0.23	0.30	-23	0.04
Heady Mountain Gap	3386	72	257	0.15	1.00	0.00	509.9	0.07	0.17	0.16	-25	-0.66
Hogback	3515	35	253	0.12	1.00	0.00	761.6	0.13	0.11	0.00	-27	-1.33
Little Creek	3189	25	79	1.83	1.00	0.00	100.0	-0.36	0.22	0.74	-6	1.49
Pleasant Grove	2785	33	240	0.04	1.00	0.00	200.0	-0.09	0.18	0.68	-23	-0.16
Rainbow Falls	2635	36	202	0.08	1.00	0.00	100.0	-0.42	0.35	0.81	-6	0.59
Round Mnt1	3232	43	71	1.90	1.00	0.00	538.5	-0.37	0.28	0.27	-18	0.25
Round Mnt2	3226	40	34	1.98	1.00	0.00	141.4	-0.38	0.31	0.59	-19	1.86
Round Mnt3	3235	36	66	1.94	1.00	0.00	0.0	-0.17	0.29	1.00	-21	3.22
Scottsman Creek	2461	50	140	0.90	1.00	0.00	282.8	0.20	0.22	0.51	-28	-0.99
Slick Rock	3225	48	165	0.51	0.00	1.00	608.3	-0.20	0.16	0.14	-22	-0.54
Thompson Falls	2426	102	258	0.16	0.00	0.00	200.0	0.24	0.28	0.72	-40	-0.60
Thompson Falls 3	2266	99	249	0.08	0.00	1.00	200.0	0.09	0.29	0.67	-26	-2.36
Thompson Falls 4	2372	71	212	0.03	1.00	0.00	538.5	0.53	0.12	0.29	-33	-1.33
Thompson Falls2	2413	96	265	0.23	0.00	0.00	200.0	0.63	0.22	0.71	-59	-1.24
Whitewater Falls	2605	19	75	1.87	0.00	1.00	0.0	-0.59	0.26	1.00	7	9.72
Wilson Gap	3192	42	16	1.88	1.00	0.00	100.0	-0.07	0.32	0.67	-23	-0.40
Windy Falls	1664	78	248	0.08	1.00	0.00	223.6	0.09	0.40	0.69	-26	-1.03
Windy Falls2	1547	81	227	0.00	1.00	0.00	141.4	-0.07	0.42	0.74	-21	-0.56
Zacharys Gap	3925	54	155	0.66	0.00	0.00	282.8	0.16	0.17	0.44	-26	-1.07

Figure 3. Map of Mahalanobis Distance categories overlaid with the sample sites used to build the model.

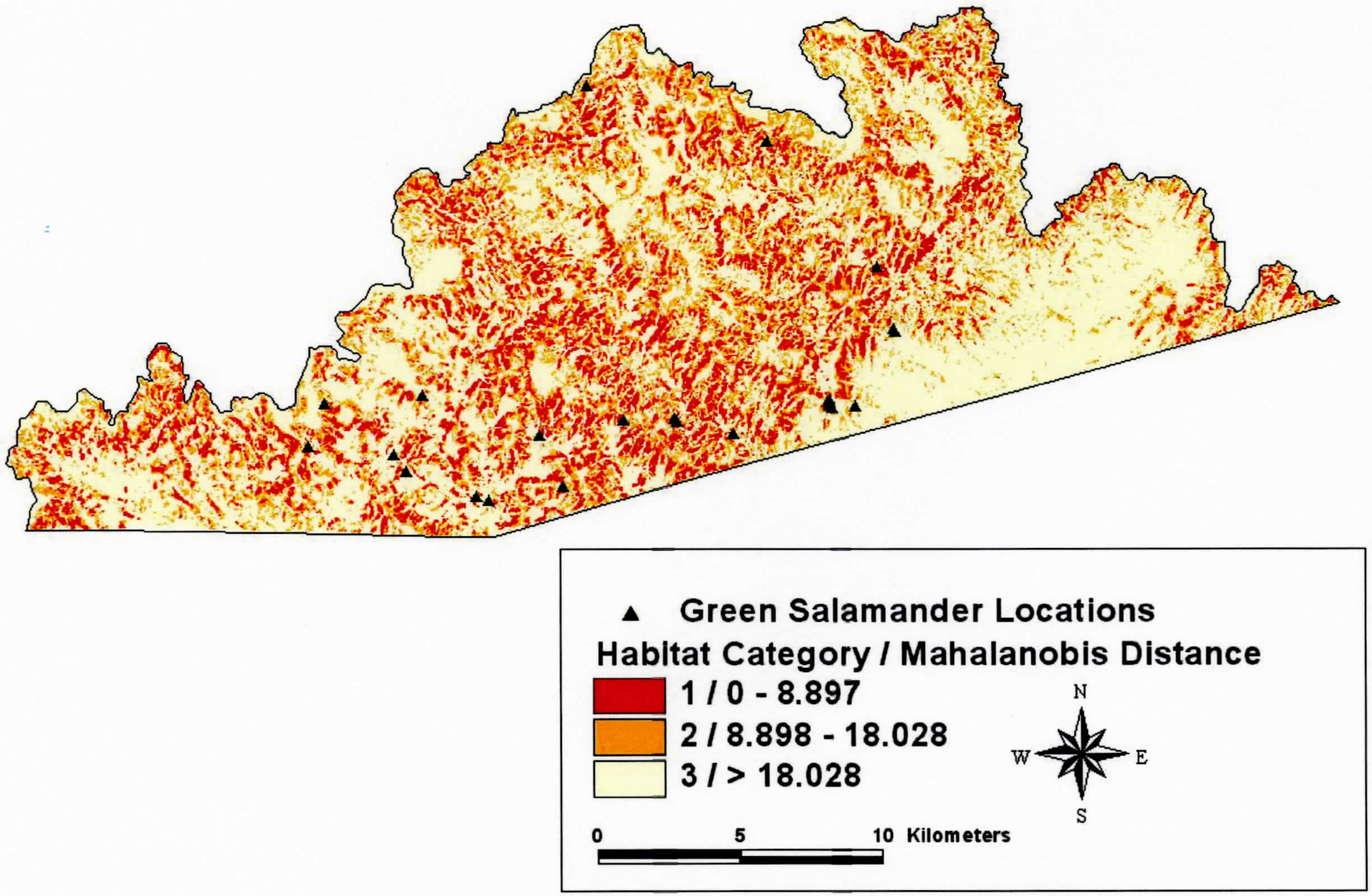
Green Salamander Locations
Habitat Category / Mahalanobis Distance
1 / 0 - 8.897
2 / 8.898 - 18.028
3 / > 18.028
N
W
E
S
0
5
10 Kilometers

Table 2. Test of GIS model's ability to distinguish green salamander sites from random. Mahalanobis Distance (D^2) values for known sites are compared to random sites (Mann-Whitney U test, U = 7609.500, Z = -3.066, P = 0.002).

	N	Mean D^2	SD	Mean Rank	Sum of Ranks
***A. aeneus* Sites**	24	16.05	11.07	329.56	7909.50
Random Sites	1000	32.62	31.27	516.89	516890.50
Total	1024				

Table 3. Green salamander use of habitat categories at 24 sample sites. Expected values are based on the proportion of the study area contained in each habitat category (X^2 = 13.929, df = 2, P < 0.001).

Habitat Category	Observed	Expected	Proportion of total study area within category
1	6	3.43	0.14
2	13	6.86	0.29
3	5	13.71	0.57
Total	24	24	1.00

Determination of Important Habitat Variables

When examined separately, two attributes of *A. aeneus* sites were significantly different from those of 1000 random sites (Table 4). *A. aeneus* sites were on steeper slopes and had higher (more protected) weighted landform indexes. Three additional variables had P-values less than 0.10 (Table 4). For these variables, *A. aeneus* sites were closer to streams, higher up the canyon walls, and were dryer.

Field-Truthing

A total of 66 pixels was visited and evaluated for *A. aeneus* and their habitat. (Table 5). Rock outcrops were most common in category 1 pixels (8 of 38) and least common in category 3 pixels (1 of 16), but the sample size was too small to test this difference for statistical significance. Similarly, no suitable habitat was found in a category 3 pixel, but sample size was even smaller. Observation of *A. aeneus* in only one site made it impossible to test

Table 4. Test for important habitat variables in green salamander site selection. Attributes of known green salamander sites are compared to random sites for each variable using Mann-Whitney U tests.

	Elevation	Slope	Beers	LU/LC=6	LU/LC=9	STDIST	CURVE	WLFI	SLPOS	TSI	TCI
Green Salamander Sites (n = 24)											
Min	1547	19.4052	0.0004	0	0	0	-0.59	0.1121	0	-59	-2.3632
Max	3925	101.7007	1.9821	1	1	948.6833	0.63	0.423	1	7	9.7228
Mean	2788.042	55.05593	0.7162	0.708333	0.166667	289.2765	-0.01208	0.238375	0.5497	-23.625	0.176667
SD	583.6168	24.56978	0.798907	0.464306	0.380693	243.3158	0.317777	0.08347	0.274	13.11094	2.368375
CV	20.93286	44.62694	111.5481	65.54903	228.4161	84.11185	-2629.88	35.01639	49.8453	-55.496	1340.59
Random Sites (n = 1000)											
Min	1170	0	0	0	0	0	-0.89	0.0247	0	-58	-2.0478
Max	4285	106.7034	2	1	1	1702.939	0.87	0.4601	1	9	12.2801
Mean	2953.589	27.38806	0.954846	0.796	0.106	393.9807	-0.00195	0.16422	0.37639	-22.784	0.6289
SD	587.6785	16.48772	0.710238	0.40523	0.309667	290.9362	0.247029	0.071906	0.309964	11.43618	2.156449
CV	19.8971	60.20041	74.38251	50.90826	292.1387	73.84531	-12668.2	43.7862	82.3518	-50.1939	342.892
Mann-Whitney U Test											
U	9880.5	3935.5	9737	10948	11272	9331.5	11499.5	2534.5	9602	11883.5	9557
Z	-1.48033	-5.6325	-1.58055	-1.0488	-0.94803	-1.86847	-0.34961	-6.611	-1.68252	-0.08151	-1.70627
P	0.133	<0.001	0.1139	0.294	0.343	0.0616	0.7266	<0.001	0.092	0.935	0.087

whether categorization of sites had predictive value or to project probability of occurrence across the study area. It was clear that a huge number of test pixels would be required to finish a meaningful field truthing, so the effort was terminated at 66 sites.

Table 5. Results of field truthing. Habitat category 1 was the relatively rare, high quality habitat. No statistical analysis was possible.

Habitat Category	Pixels Visited	Rock outcrops	Suitable Habitat	*A. aeneus*
1	38	8	5	0
2	12	2	2	1
3	16	1	0	0
Total	66	11	7	1

Status surveys

Twenty sites, known before 2000, and 12 of 18 newly discovered sites were visited during this survey (Table 6). Four of these sites were in Georgia, four were in South Carolina, and 24 were in North Carolina. Since one possible cause for the decline in green salamanders was over collecting (USFWS 1987), only general location data were reported in Table 6. Further locality data for these sites were presented to the USFWS field office in Asheville, North Carolina (Wilson, 2001*a*)

Depending on logistics, sites were visited from one to eight occasions, mostly during spring, summer, and fall. A total of 80 site visits produced 230 observations of *A. aeneus* individuals during this study (Table 7). Between 0 and 21 individuals were observed during each site visit (mean = 2.88, SD = 4.56). Fifteen broods were found and each clutch was attended by a single female. The earliest eggs were observed on 25 May 2001 at Biscuit Rock (Jason Robinson, pers. comm.). Visible eggs ranged from 2 to 20 per clutch, but succesive observations of clutches revealed noticeable egg mortality.

Table 6. Summary of thirty-two green salamander sites visited during status surveys.

Site Code	Site Name	County	State	Ownership
28	Highway 28	Macon	NC	USFS
74	Route 74	Henderson	NC	PRIVATE
AB	Ammons Branch	Macon	NC	USFS
BF1	Burrell's Ford #1	Oconee	SC	USFS
BF2	Burrell's Ford #2	Oconee	SC	USFS
BB	Brooks Branch	Highlands	NC	USFS
BR	Biscuit Rock	Highlands	NC	USFS
BT	Bartram Trail	Rabun	GA	USFS
CG	Chatooga Gorge	Jackson	NC	USFS
CR	Canyon Road	Macon	NC	USFS
DP	Dupont	Transylvania	NC	PRIVATE
EM	Ellicott Mountain	Jackson	NC	USFS
FC	Falling Creek Camp	Henderson	NC	PRIVATE
GC	Granite City	Jackson	NC	USFS
GF	Glen Falls	Macon	NC	USFS
HC1	Hedden Creek #1	Rabun	GA	USFS
HC2	Hedden Creek #2	Rabun	GA	USFS
HB	Hogback	Jackson	NC	PRIVATE
HM	Heady Mountain Gap	Jackson	NC	USFS
LC	Little Creek	Highlands	NC	USFS
PG	Pleasant Grove	Jackson	NC	USFS
PR1	Persimmon Road #1	Greenville	SC	USFS
PR2	Persimmon Road #2	Greenville	SC	USFS
RF	Rainbow Falls	Transylvania	NC	USFS
RM1	Round Mountain	Jackson	NC	USFS
RQ	Rock Quarry Road	Transylvania	NC	PRIVATE
RT	Rhododendron Trail	Highlands	NC	HBS
SC	Scotsman Creek	Jackson	NC	USFS
SR	Slick Rock	Macon	NC	USFS
SW	Sherwood Forest Cave	Transylvania	NC	PRIVATE
WG	Wilson Gap	Macon	NC	USFS
WW	Warwomen	Rabun	GA	USFS

Table 7. Census results from status surveys.

Date	Site	Adults	Hatchlings	Broods	Total Individuals
10/7/00	28	4	0	0	4
1/2/00	74	3	0	0	3
10/5/00	74	2	0	0	2
5/23/01	74	2	0	0	2
5/7/00	AB	1	0	0	1
8/8/00	AB	0	0	0	0
5/17/01	AB	2	0	0	2
8/7/01	AB	0	0	0	0
6/14/00	BF1	1	0	0	1
6/15/00	BF2	1	0	0	1
5/7/00	BB	6	0	0	6
8/7/00	BB	3	0	1	3
11/1/00	BB	4	2	0	6
5/17/01	BB	3	0	0	3
8/7/01	BB	0	0	0	0
5/7/00	BR	18	0	0	18
5/28/00	BR	7	0	1	7
6/16/00	BR	7	0	2	7
8/9/00	BR	5	0	3	5
10/8/00	BR	11	1	0	12
10/13/00	BR	17	1	0	18
5/17/01	BR	21	0	0	21
8/8/01	BR	5	0	3	5
5/7/00	BT	0	0	0	0
8/7/00	BT	0	0	0	0
5/31/01	BT	0	0	0	0
8/7/01	BT	0	0	0	0
8/9/00	CG	1	0	0	1
10/13/00	CR	6	0	0	6
5/25/00	DP	1	0	0	1
8/8/00	EM	0	0	0	0
8/8/01	EM	0	0	0	0
5/24/01	FC	2	0	0	2

Table 7 (continued). Census results from status surveys.

Date	Site	Adults	Hatchlings	Broods	Total Individuals
3/25/00	GC	1	0	0	1
8/9/00	GC	1	0	0	1
10/13/00	GC	2	3	0	5
5/17/01	GC	1	0	0	1
8/7/01	GC	0	0	0	0
10/14/00	GF	1	0	0	1
6/8/01	HC1	0	0	0	0
6/8/01	HC2	1	0	0	1
5/17/00	HB	0	0	0	0
8/8/00	HB	0	0	0	0
10/13/00	HM	9	0	0	9
11/2/00	HM	15	6	0	21
5/17/01	HM	3	0	0	3
6/8/01	HM	3	0	0	3
8/8/01	HM	2	0	2	2
5/7/00	LC	3	0	0	3
8/7/00	LC	0	0	0	0
8/7/01	LC	1	0	1	1
5/17/00	PG	6	0	0	6
8/8/00	PG	0	0	0	0
11/2/00	PG	5	0	0	5
8/7/01	PG	0	0	0	0
6/9/01	PR1	1	0	0	1
6/9/01	PR2	1	0	0	1
3/25/00	RF	0	0	0	0
8/7/01	RF	0	0	0	0
5/17/00	RM	1	0	0	1
8/8/00	RM	0	0	0	0
8/8/01	RM	2	0	2	2
5/25/00	RQ	1	0	0	1
5/17/00	RT	0	0	0	0
10/13/00	RT	2	0	0	2
5/17/00	SC	0	0	0	0
8/9/00	SC	0	0	0	0
8/7/01	SC	0	0	0	0

Table 7 (continued). Census results from status surveys.

Date	Site	Adults	Hatchlings	Broods	Total Individuals
3/25/00	SR	1	0	0	1
8/8/00	SR	0	0	0	0
10/13/00	SR	3	0	0	3
8/7/01	SR	0	0	0	0
8/20/00	SW	6	1	0	7
10/30/00	SW	5	0	0	5
6/8/01	SW	1	0	0	1
4/21/00	WG	2	0	0	2
5/7/00	WG	1	0	0	1
8/7/00	WG	0	0	0	0
8/7/01	WG	1	0	0	1
6/8/01	WW	1	0	0	1
	Total	216	14	15	230
	Min	0	0	0	0
	Max	21	6	3	21
	Mean	2.70	0.18	0.19	2.88
	SD	4.20	0.79	0.62	4.56

Thirty occupied and eight breeding populations of *A. aeneus* were confirmed in the Blue Ridge in this study. Six additional occupied populations were visited by other workers during this period. Among 20 historic sites visited, 15 (75%) were occupied and seven (35%) showed evidence of reproduction through the presence of hatchlings or clutches. One of twelve new sites (8%) showed evidence of reproduction.

Twenty-four site visits were comparable to the standardized monitoring procedures of Corser (2001); twelve of Corser's 13 sites were visited during August of both 2000 and 2001. Breeding (presence of clutches) was confirmed at two sites in 2000 and three sites in 2001 (Table 8). Breeding populations were fewer than expected during this study and number of breeding populations decreased between 1991 and 2001. However, the difference was not significant in the Chi-square analysis ($X^2 = 3.83$, df=1, $0.10 > P > 0.05$; Table 9) and the trend was not significant in the linear regression ($F_{1,9} = 4.04$, $P = 0.07$, $r^2 = 0.31$; Figure 4).

Table 8. Breeding success at twelve green salamander monitoring sites. A "+" indicates egg clutches were observed. Results for 1991-1999 were taken from Corser (2001).

Site	AB	BR	HB	RM	SR	WG	BB	BT	EM	LC	PG	SC	# Breeding Populations
1991	-	-	+	+	-	-	-	+	+	+	+	+	7
1992	-	-	-	-	-	-	+	-	+	+	-	-	3
1993	-	-	+	-	-	-	+	+	+	+	-	+	6
1994	-	+	-	-	-	-	+	+	+	-	-	-	4
1995	-	-	-	-	-	-	+	-	+	+	-	+	4
1996	-	+	-	-	-	-	+	+	+	+	+	+	7
1997	-	+	-	-	-	-	+	-	-	-	+	-	3
1998	-	+	-	-	-	-	+	-	-	+	+	-	4
1999	-	+	-	+	-	-	+	-	-	-	+	-	4
2000	-	+	-	-	-	-	+	-	-	-	-	-	2
2001	-	+	-	+	-	-	-	-	-	+	-	-	3

Table 9. Comparison of the numbers of breeding populations observed during this study to those at the same sites between 1991 and 1999 (Corser, 2001). ($X^2 = 3.83$, df = 1, $0.10 > P > 0.05$).

Broods Present	Present Study	Corser (2001)	Total
+	5	42	47
-	19	66	85
Total	24	108	132

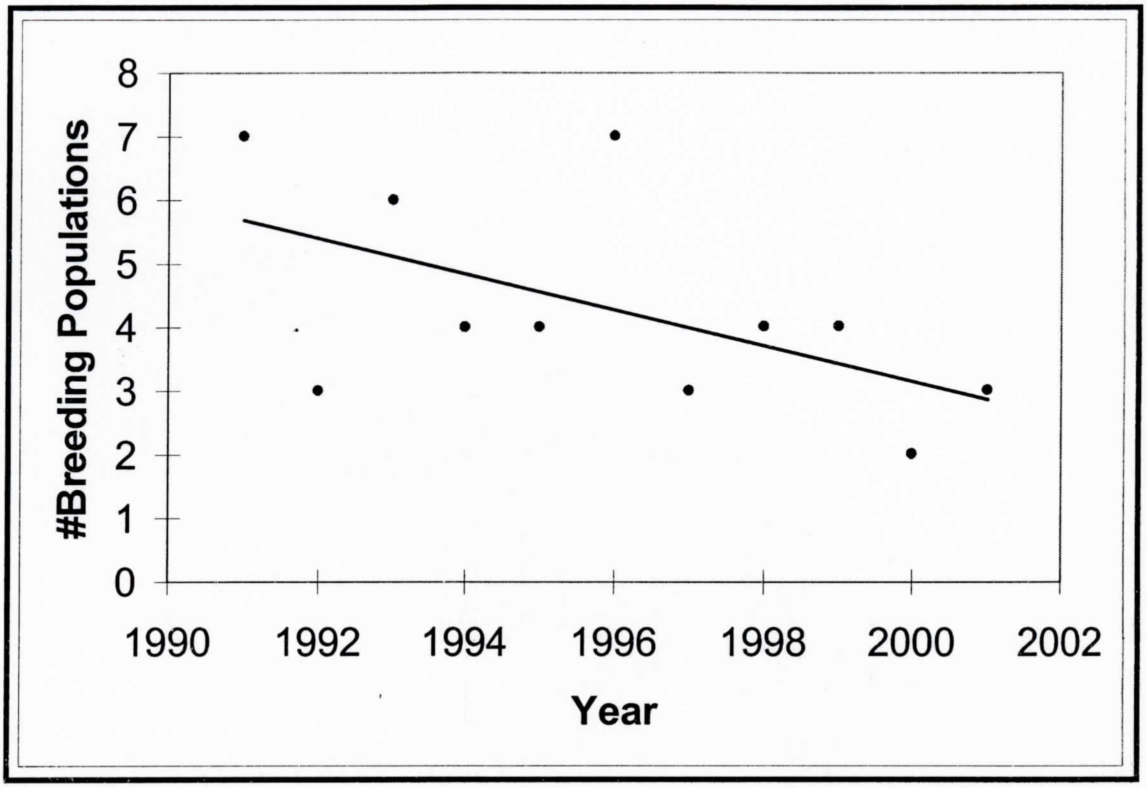

Figure 4. Number of twelve green salamander populations showing breeding between 1991 and 2001 ($y = -0.281x+566.7$; $F_{1,9} = 4.04$, $P = 0.07$, $r^2 = 0.31$).

As of the summer of 2001, green salamanders have been reported at 92 sites in the Blue Ridge (Figure 5), of these 52 (57%) occur in North Carolina, 35 (38%) in South Carolina, and 5 (5%) in Georgia. The extent of occurrence for Hickorynut Gorge and Escarpment populations equaled 15.70 km^2 and 2037.84 km^2, respectively (Figure 6).

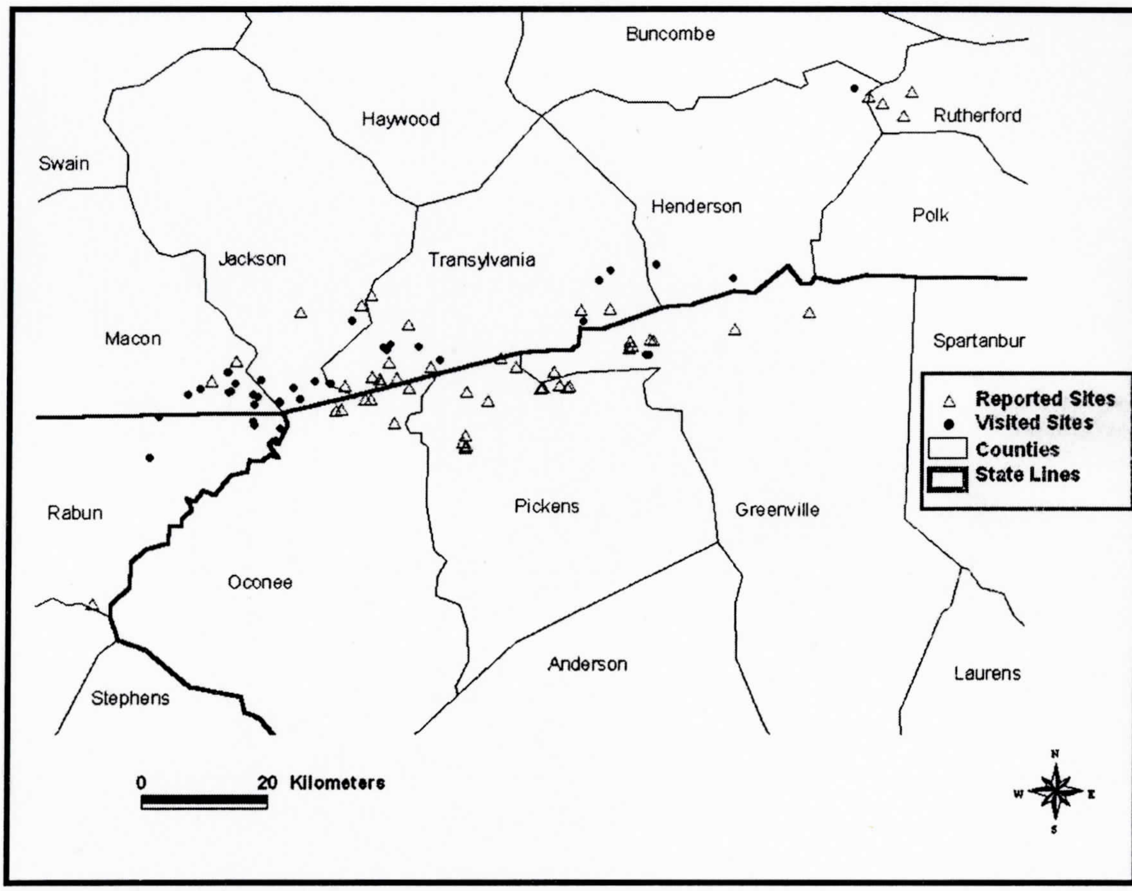

Figure 5. Updated range map of the green salamander in the Blue Ridge.

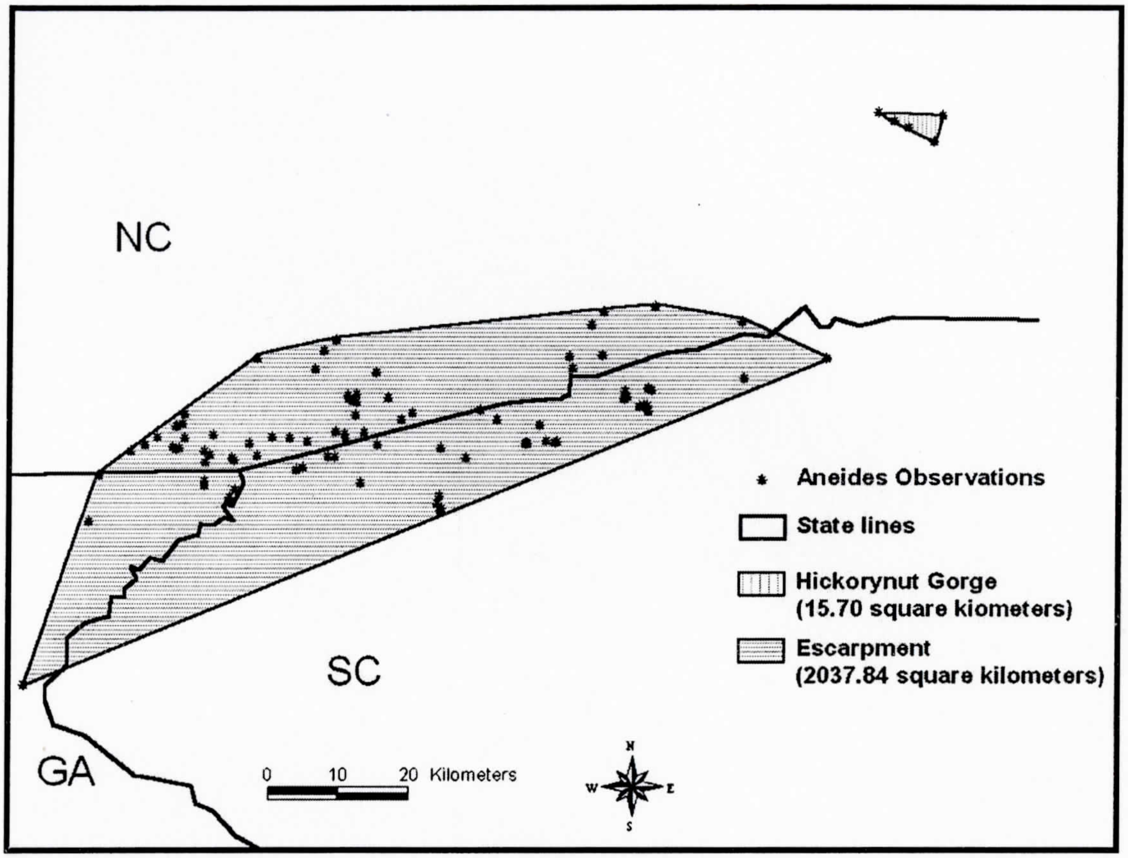

Figure 6. Extents of occurrence of Hickorynut Gorge and Escarpment populations. Extents were determined from the area of minimum convex polygons.

DISCUSSION

GIS Model

The GIS model was able to distinguish and sub-divide habitat and increasing D^2 values and habitat categories correspond to decreasing green salamander occurrence. The habitat attributes of known *A. aeneus* sites were significantly different from random for two variables and three additional variables had P-values less than 0.10, indicating that *A. aeneus* selected habitat at the scale of the geographic data used in the model. These five habitat variables suggested that *A. aeneus* is selecting sites that are dry, located mid-slope near a stream, in steep protected ravines. This habitat description agreed with personal field observations and those of other workers (Corser, pers. comm.)

Among the test pixels visited during field truthing, increasing habitat categories corresponded to a decreasing frequency of rock outcrops, and the model seemed to respond to meso-scale topographic features associated with outcrops. This pattern was not observed for suitable habitat, which was a micro-scale feature that could not be modeled with 30m geographic data.

While the observations of rock outcrops and suitable habitat within test pixels are suggestive, the model was of *A. aeneus* occurrence rather than rock outcrops or suitable crevices. The only test pixel visited during fieldtruthing with *A. aeneus* fell within Category 2 habitat even though three times as many Category 1 pixels were sampled. This result may suggest a weakness in the model to predict the relative occurrence frequency of *A. aeneus* within the three habitat categories. The low detection frequency of *A. aeneus* within the test pixels also suggests the model is very general which seems reasonable given the rarity of the animal, specific micro-habitat requirements (appropriate crevices), the 30m resolution of the data, and the limited number of available samples used to build the model (typical of a rare species). However, the sample of 66 test pixels was simply too small to draw any conclusions. To generate robust predictive abilities using three habitat categories, at least 20 pixels, with *A. aeneus* should be detected during field truthing (van Manen, pers. comm.). Given that 1 pixel in 66 contained *A. aeneus*, 1320 pixels would be necessary to find 20 occupied sites. Such a sample would allow one to calculate realistic probabilities of a given pixel containing *A. aeneus,* and a reasonably estimate the total number of occupied pixels in the study area. Such information would be valuable for status assessment purposes. However, the large sampling effort required with the current model is impractical and likely unjustified.

Because *A. aeneus* is associated with rock outcrops, the model's performance could be dramatically enhanced if variables were included that better indicate rock features. Corser (1991) inspected leaf-off infrared aerial photographs to determine if rock outcrops occurred in locations suspected of containing habitat and located five new *A. aeneus* sites in North Carolina. Rock outcrops maintain a different thermal regime than the surrounding substrate and should produce unique signatures in the infra-red spectrum. Color Infra-red (CIR) Digital-orthophoto-quarter-quads (DOQQs) provide infra-red spectral imagery data with a pixel resolution less than $1m^2$ and can be analyzed with GIS. Using such data, and imagery analysis software, the spectral signatures of rock outcrops could be used to classify the entire study area into a grid of pixels, with values indicating the presence or absence of rock. This grid could be an additional variable in the habitat model. At the time of this study, CIR DOQQs were not available for the southern Blue Ridge but were expected within the next several years.

While the current model is broad and its predictive abilities are not known, its ability to show distribution and density of habitat should be useful for conservation purposes. Given that increasing habitat categories correspond to decreasing frequencies of *A. aeneus* locations, the model will be useful in targeting status surveys for *A. aeneus* or assessing the relative impacts of various management or development alternatives.

Status Surveys

Across all sites visited, densities of individuals and clutches are dramatically lower than those reported by Snyder (1971) and are consistent with those reported in Corser (2001). Fifteen of 20 historic sites were occupied during this study which indicates some recovery since the crash of the late-1970s when only eight of 37 sites were occupied (USFWS, 1987). However, the number of individuals observed per site was generally low (mean of 2.88, SD = 4.56) and site occupancy does not necessarily constitute a reproducing population. Over two breeding seasons, only 8 of 32 sites exhibited evidence of breeding. Although not significant at the strict α=0.05 level, there was a lower number of breeding populations observed during this study (2000 - 2001) compared to those reported from 1991 through 1999 (X^2 = 3.83, df=1, 0.10 > P >0.05). There was also a negative trend in the number of breeding populations from 1991 through 2001 (P = 0.07). These results strongly suggest that a biologically significant decline has occurred over the last eleven years at a rate of –0.281 breeding populations per year, and is still in progress. Continued annual monitoring sould generate statistical significance.

Status surveys attempted to sample *A. aeneus* populations across their range in the Blue Ridge, however South Carolina and Hickorynut Gorge were under-sampled. Known populations in South Carolina typically contain much lower densities than those in North Carolina (Mae Lee Hafer, pers. comm.) and are unlikely to improve the findings reported here. The low densities recorded at the 1 site visited in Hickorynut Gorge are consistent with sites across the Blue Ridge.

While green salamanders have been recorded at 92 sites in the Blue Ridge, this information could be used only to assess the distribution of *A. aeneus* and does not imply 92 viable populations. Some records are of single individuals, some are questionable (Bruce, 1992), and some sites have been destroyed (Corser and Gaddy, 1991). Most of the 92 sites have not been revisited in many years or have never been verified.

Status Assessment

IUCN Red List Categories

According to the IUCN Red List Categories (2001) a taxon is "Critically Endangered" when it is considered to be facing an extremely high risk of extinction in the wild. In addition, a taxon is considered "Endangered" when it is not Critically Endangered, yet faces a very high risk of extinction in the wild. Several of criteria provided in the IUCN Red List Categories (2001) to determine the extinction risk of a taxon were applicable to *A. aeneus* in this study.

Criteria for Critically Endangered

CR B1ab(iv); Extent of occurrence is less than 100 km^2, individuals occur in small semi-isolated subpopulations, and there is an inferred or projected decline in the number of subpopulations.

Criteria for Endangered

EN B1ab(iv); Extent of occurrence is less than 5000 km^2, individuals occur in small semi-isolated subpopulations, and a continuing decline is observed or inferred in the number of subpopulations.

Status of Blue Ridge populations

The extents of occurrence for Hickorynut Gorge and Escarpment populations are 15.7 km^2 and 2037.84 km^2, respectively. Green salamanders occur in small semi-isolated subpopulations in the Blue Ridge (Corser 1991). Because Hickorynut Gorge is largely private, a decline in the number of subpopulations within the gorge is projected due to likely future development. A continuing decline was inferred in the number of breeding subpopulations within the Escarpment ($y = -0.281x + 566.7$; p=0.07, r^2 =0.31). For these reasons, it appears that Hickorynut Gorge populations qualify as Critically Endangered and the Escarpment populations qualify as Endangered under the IUCN Red List Categories (IUCN, 2001).

Conservation

The data and analyses presented here will provide critical information needed to assess the legal status of *A. aeneus* in the Blue Ridge under the Endangered Species Act. Additionally, the occurrence model should provide a valuable tool for directing future status surveys and conservation efforts.

However, this study doesn't bring us any closer to understanding the causes of global amphibian declines or the causes for the decline of *A. aeneus*. Regional decline factors such as chaotic deterministic processes, acid precipitation, climate change, and susceptibility to pathogens are difficult to address and even harder to act upon. In the face of uncertainty, a conservative approach would be to identify and act on potential decline factors that are obvious and immediately controllable. Among the suspected factors mentioned by Snyder (1991) and Corser (2001) for the decline of *A. aeneus*, the two most obviously damaging and immediately controllable are habitat destruction and over collecting.

In the current global extinction crisis, habit loss is the primary cause of extinction because it leads to the direct destruction of populations and reduces the likelihood of recolonization in the remaining habitat (Tilman et al., 1994). In the case of *A. aeneus*, direct habitat destruction from development and loss of shading due to logging has caused previously occupied outcrops to become abandoned (Snyder, 1991). Additionally, disturbance to upslope areas may cause an increase in the surface flow of moisture over the face of an outcrop, depositing sediments into otherwise suitable crevices. Many non-rock observations of *A. aeneus* report individuals under exfoliating bark or in the hollows of trees (Barbour, 1949; Pope, 1928). Such features are more abundant within temperate hardwood old-growth forests relative to logged stands (Hale and Rusterholz, 1999; Hardt and Swank, 1997). Loss of mature forest, containing appropriate woody debris habitat, may impede the dispersal of *A. aeneus* between rock outcrop habitats.

A. aeneus is a strikingly beautiful and mysterious animal much coveted by collectors. Collecting, both scientific and hobby / pet-trade oriented, may destabilize already vulnerable populations. The majority of collecting is likely concentrated during the summer months when collectors are free for vacations or research. Because the female remains stationary with a clutch for the entire summer, she and her eggs represent the demographics most vulnerable to collecting. Females begin breeding during the 2^{nd} or 3^{rd} year of life and breed on a bienniel basis thereafter (Canterbury and Pauley, 1994). Orphaned clutches have zero survivorship (Snyder, 1971). Without recruitment from outside sources, removal of brooding females over several consecutive years from the same site could eliminate the entire breeding population.

Recommendations

Based on the criteria provided in the IUCN Red List Categories (2001), this study indicates that green salamanders are at a high risk of extinction in the Blue Ridge. Therefore, I recommend that the IUCN assess Blue Ridge populations of *A. aeneus* for incorporation into the IUCN Red List of Threatened Species. I also recommend that the U.S. Fish and Wildlife Service seriously consider listing Blue Ridge populations of *A. aeneus* as "Threatened" or "Endangered" under the Endangered Species Act.

In addition to studies of regional and local decline factors, research recommendations include further development and testing of the GIS occurrence model, continued and expanded annual monitoring, and more status surveys of *A. aeneus* populations. The occurrence model will likely benefit from the incorporation of color infra-red, digital-orthophoto-quarter-quads (CIR-DOQQs). When these data becomes available, the model should be refined and evaluated with field truthing. Study sites used for future monitoring should be located across the entire range of *A. aeneus* in the Blue Ridge. The field survey results presented in Table 7 will provide necessary baseline data. Federal and state agencies should take financial and organizational responsibility for future monitoring efforts. Additional status surveys are currently needed in under-sampled areas such as South Carolina, and especially Hickorynut Gorge.

General conservation recommendations include limiting habitat disturbance, providing outreach and conservation incentives to private land owners, and strengthening and enforcing restrictions on collecting throughout the Blue Ridge.

Developers and land managers should survey for *A. aeneus* populations and potential habitats during the project planning stages and avoid disturbance to rock-outcrops in general. The occurrence model presented here should be used to direct status surveys and assess the impacts of proposed project alternatives. Status surveys for *A. aeneus* should target, and disturbances should avoid, areas within the lower habitat categories. Public land management agencies, such as the USFS, can use the model to assess the relative benefits of various land management scenarios. For instance, the amount of category 1 habitat affected by each plan alternative can be compared.

Wilson (2001*b*) reported that 54% of *A. aeneus* habitat within the embayment occurs on private lands. Private lands throughout the Escarpment are rapidly being developed and there are currently no requirements to take the precautionary measures mentioned above. The only way to conserve *A. aeneus* habitat on private lands may be through a combination of public outreach and financial incentives. The new landowner is typically affluent, educated, and appreciates the natural beauty of the area. These landowner attributes may present unique opportunities for habitat conservation. The steep and rocky areas used by *A. aeneus* are often problematic for building and development. Unused portions of land can create large tax burdens due to high land values in the area. A developer or landowner may benefit by conveying portions of their land, containing *A. aeneus* habitat, to a land trust as a conservation easement. The establishment of such an easement would benefit a suite of other rare species, dramatically reduce income taxes, protect the land's aesthetic attributes, and increase the value of adjacent parcels. With proper outreach and guidance, easements can be incorporated into the design of a development in such a way that a host of biological and financial benefits are achieved (pers. obs.). Land trusts should use the occurrence model to target areas containing high amounts of *A. aeneus* habitat for acquisition. Category 1 habitat can be overlaid with digitized parcel maps to identify which areas contain the most *A. aeneus* habitat. If appropriate, the respective landowners can then be approached with conservation options and incentives.

While *A. aeneus* is protected from collecting in North Carolina, additional restrictions are needed in South Carolina and Georgia. Legal restrictions on collecting may only increase the value and desirability for the animal, thus increasing the demand by collectors. Therefore, enforcement of restrictions is also necessary.

Ultimately, the only way to recover Green Salamander populations will be through increased research into the cause for decline and through public education and involvement.

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