Red Hills Salamander Habitat Delineation, Breeding Bird Surveys, and Habitat Restoration Recommendations on Commercial Timberlands

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Abstract

Twenty-seven sites known to support the Red Hills salamander (Phaeognathus hubrichti) were surveyed to estimate burrow density, delineate and quantify habitat, map slope habitat, and at selected sites perform breeding bird surveys. Additional data analysis included Red Hills salamander habitat associations with the underlying geological and soil layers. Information was collected on a suite of other rare species as identified in the Alabama Comprehensive Wildlife Conservation Stategy and known to occupy habitats of the Red Hills physiographic province: two lizards, one snake, one tortoise, and 19 birds.

Stepwise logistic regression analysis indicated that the probability of having Red Hills salamders on a site increases with the presence of American beech, American holly, deciduous magnolia species, mountain laurel, and yellow poplar, yet the probability declines with the additons of additional woody species. Burrow density estimates were calculated for 18 sites with estimates ranging from 0.030 to 0.202 burrows/m^2.

The majority of Red Hills salamander habitat mapped occurred in tracts less than 10 ha in area. Habitat association, with the Tallhahatta and Hatchetigbee formations, was > 75%, as expected. Major soil associations with Red Hills salamander habitat were Arundel fine sandy loam and Luverne sandy loam. These two soil types comprised >76% of the total.

Generalized management recommendations pertaining to Red Hills salamander slope habitat and adjacent ridgetops and based on scale and interval of perturbation events and effect upon species suites have been included. For sites deemed to be important for conservation of the Red Hills salamander and representative of this unique physiographic province specific management recommendations have been provided

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Introduction

Description of Red Hills

The Red Hills Physiographic Province lies within the East Gulf Coastal Plain, or the Hilly Coastal Plain of Miller and Robinson (1995), and extends from southern Georgia, across Alabama, and into Mississippi. Age of the parent material of this region ranges from 5.5 to 22 million years and is rock composed of unconsolidated water-, ocean-, and wind-deposited sediments. These ancient marine sediments of gravel, sand, silt, clay, and chalk underlying the Hilly Coastal Plain were deposited at a time when the oceanic shoreline was located along the Fall Line (Miller and Robinson, 1995).

Distinguishing characteristics of the province include the geological formations (which are primarily of Eocene age) and the highly variable topography, which ranges from rolling hills to steep bluffs and ravines. Various geological belts occur throughout the province but in Alabama the most prominent substratum that crops out in portions of the province is the Tallahatta Formation. A second substratum, underlying the Tallahatta and surfacing in some locales is the Hatchetigbee Formation (Harper 1920 and 1943; Dodd 1991). The Tallahatta Formation, with its steep, north-facing escarpment, gives the Red Hills, between the Alabama and Conecuh rivers, its characteristic features of precipitous height and topographical sinuosity. The third geological formation to be mentioned is the Nanafalia which is the lowest of the Eocene strata, and separated from the Hatchetigbee by Tuscahoma Sand.

The Hatchetigbee Formation is comprised of brownish-gray sandy clays, silt, and fine-grained sand, with alternating bands of dark brown or purple sediments. This formation is thickest in western Alabama, and thinner in the east, ranging from 10 - 75 m (35 - 250 feet) in thickness. Spheroidal concretions and abundant fossils can be found within the Hatchetigbee stratum. The presence of *Turritella gilberti*, *Venericardia hatcheplata*, and *Venericardia turneri* may be used in the identification of this formation. In contrast, the Tallahatta Formation contains more hard rock in the form of quartzite, glauconitic sandstone, porous claystone, plus loose sand. In general the coloration is greenish-gray, light-gray, or nearly white. The Tallahatta Formation has been estimated to range from 60 – 90m (200 - 300 feet) in thickness. In contrast to the Hatchetigbee Formation, the Tallahatta tends to be fossil-poor, although the presence of the oysters *Cubitostrea perplicata* and *Alectryonia johnsoni* aid in the identification of the Tallahatta (Adams et al. 1926; Toulmin 1977).

Both marine and non-marine deposits comprise the Nanafalia Formation, with nonmarine littoral sands and clays, in places, overlying the limestone stratum. The Nanafalia Formation, reaching a maximum thickness of 150m (500 feet), has sediments of kaolinitic crossbedded sand, gray clay, marine glauconitic marly sand, and Clayton limestone. Fossil remains used in the identification of the Nanafalia Formation include *Odontogryphaea thirsae*, *Ostrea arrosis*, *Ostrea sinuosa*, *Turritella postmortoni*, *Turritella praecincta*, and *Venericardia planicosta*. The description of the Nanafalia Formation has been included in light of the recent discovery of a population of *Phaeognathus hubrichti* within this geological stratum (Bailey and Miller 2006).

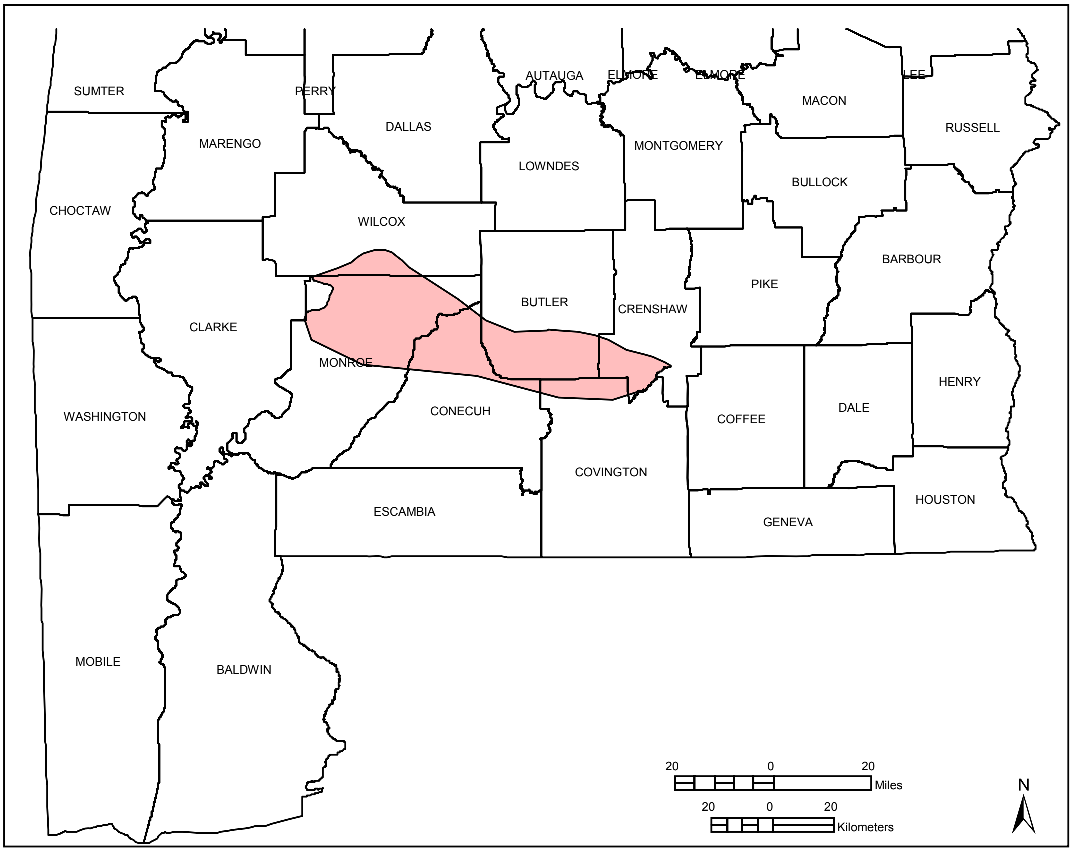
Toulmin (1977) provides a listing of invertebrate fossils known from the Nanafalia, Hatchetigbee, and Tallahatta formations, with 68 taxa having been reported from the Nanafalia, 117 from the Hatchetigbee, and 49 from the Tallahatta (Appendix 4). Of these totals none have been found across all formations. The largest group of the Hatchetigbee, with 67 taxa, is the gastropod, while only 12 taxa have been reported from the Tallahatta. For the Tallahatta the pelecypods, with 33 taxa, are the most numerous, while 39 have been reported from the Hatchetigbee. A nearly equal number of taxa of pelecypods and gastropods have been reported from the Nanafalia with 31 and 35, respectively (Table 1). Based on the number of shared taxa the Nanafalia and Hatchetigbee are more similar than either the Nanafalia or Hatchetigbee are to the Tallahatta. Eleven taxa are shared between the Nanafalia and Hatchetigbee, while the Tallahatta shares three taxa with both the Hatchetigbee and Nanafalia.

Table 1. The major invertebrate fossil groups reported from the Nanafalia, Hatchetigbee, and Tallahatta formations of Alabama.

Group	Nanafalia Formation	Hatchetigbee Formation	Tallahatta Formation
Coral	2	7	3
Pelecypods	31	39	33
Scaphopods		2	
Cephalopods		2	
Gastropods	35	67	12
Echinoid			1
Total	68	117	49

In Alabama, the Red Hills province encompasses approximately 1.4 million ha (3 ½ million acres). Across the province elevations range from 45 to over 450 m (150 - 500 feet), and many areas have local relief extremes approaching a 60 m (200 foot) difference from the top of a steep slope or bluff to the lowest point of the adjacent floodplain. In Alabama, the region between the Alabama and Conecuh rivers has the most impressive topographical features of the province. Throughout much of this area, sinuous bluff-lines, steep hillsides, deeply incised ravines, and narrow to moderately broad ridges characterize the landscape. Habitats vary markedly and form an ecological heterogeneous matrix with the steep slopes and mesic ravines supporting dense forests of mixed southern hardwoods and the drier ridges (historically) supporting pine-oak woodlands and stands of longleaf pine. From a conservation perspective, this ecological matrix of dry, pine-oak woodlands and mesic hardwoods support a diverse array of wildlife. One inhabitant of this province that has received great attention since its discovery in 1960 and has since been designated as the state amphibian for Alabama is the endemic Red Hills salamander (*Phaeognathus hubrichti*); the area of the Red Hills between the Alabama and Conecuh rivers defines the latitudinally narrow global range for this species (Figure 1).

Figure 1. Distribution of the Red Hills physiographic province corresponding to the range of the Red Hills salamander is between the Alabama and Conecuh rivers.



Red Hills: Historical Perspective and Biological Importance

Unfortunately little information is available on the natural forest cover and vegetation of the Red Hills of Alabama. What little we do have has come from Charles Mohr and Roland Harper. Mohr (1901) provides a generalized description of the "upper division of the coast pine belt" which would encompass much of the Red Hills. At the time of his observations, the late 1800s, longleaf pine was the dominant forest cover of the sand-and-gravel capped ridges. Atop the ridges longleaf pine dominated and down slope, toward the protected ravines and floodplains, a transition in forest cover occurred whereby shortleaf pine and spruce pine replaced longleaf and the frequency of mesophytic species such as beech, basswood, and magnolias increased.

Harper (1920; 1943) described the ridges of the Red Hills as supporting open longleaf woodlands. Historically, these longleaf pine forests upslope of the mesic ravines supported wildlife that was indicative of longleaf pine woodlands elsewhere in the East Gulf Coastal Plain. Species of conservation concern such as the gopher tortoise (*Gopherus polyphemus*), Bachman's sparrow (*Aimophila aestivalis*) and possibly the endangered red-cockaded woodpecker (*Picoides borealis*) occurred in these open, ridgetop woodlands. However, since the publications of Harper, the ridges have undergone dramatic change and alteration. The majority of the land base in the Red Hills is in private ownership and commercial timber is a key economic factor in the region. Accordingly, most of the open, longleaf woodlands and pine-oak habitats have long been removed and replaced with extensive pine plantations. Locally, in a few open patches, primarily along logging roads, gopher tortoises continue to persist on the ridges in the Red Hills. The status of the Bachman's sparrow is not known but very likely only a few populations exist due to the short duration of open habitats (e.g., recently planted pine stands to within five years of growth) and a paucity of open, park-like woodlands and grasslands. The red-cockaded woodpecker has been virtually extirpated from the Red Hills in Alabama.

The monotypic Red Hills salamander (*P. hubrichti*) is listed as threatened by the U.S. Fish and Wildlife Service with habitat destruction and alteration cited as the primary impacts to this species. While overcollection has been cited as having harmed some populations, this would not have the degree of impact as habitat disturbance (Schwaner and Mount 1970; Jordan 1975; Jordan and Mount 1975; French 1976; French and Mount 1978). An Alabama endemic, *P. hubrichti* is confined to the Red Hills physiographic province between the Alabama and Conecuh rivers. The presence of this fossorial salamander is easily determined by the identification of its characteristic burrows (Figure 2). The salamander is confined to the well-forested, mesic ravines where outcrops of the Tallahatta geologic formation provide optimal Red Hills salamander habitat. The species has also been reported to occur within outcroppings of the Hatchetigbee formation, but this substratum is used secondarily to the former (Dodd 1991). One recently discovered outlying population in southern Wilcox County is associated with the Nanafalia formation (Bailey and Miller 2006). The vast majority of the salamander's habitat is found on private lands, and much of this habitat is on commercial timberlands.

Figure 2. Photographs which illustrate several characteristic burrows of the Red Hills salamander and a sequence of an individual partially emergeing from a burrow.

In addition to supporting the threatened Red Hills salamander, a rich assemblage of terrestrial vertebrates occurs in the deciduous forests of the slopes, ravines, and adjoining floodplains. One taxonomic group that extensively utilizes and depends upon the forested habitats of the province is songbirds, particularly Neotropical migrants. The hardwood-dominated slopes and ravines provide habitat for transients during spring migration in addition to supporting extensive habitat for breeding birds. Unfortunately, quantitative data are lacking concerning songbird use of the habitats in the Red Hills. Based on qualitative records and accounts of breeding activity (see Gardella, 2003), several bird species of conservation concern are either known or thought to breed on the forested slopes and adjoining bottomland forests (Table 2). Additionally, the dry piney ridges also provide important bird habitat and species of conservation concern are known to breed in these areas as well.

Table 2. Terrestrial vertebrates of conservation concern occurring in the Red Hills Physiographic Province. (Status categories include federal protection – Threatened or Endangered – and state status with state status codes as follows: P1 = Highest Conservation Concern—taxa critically imperiled; P2 = High Conservation Concern—taxa imperiled due to rarity, limited distribution, and/or questionable viability; Watch List = Moderate Conservation Concern—research and/or conservation action recommended.)

Species	Common Name	Status
Phaeognathus hubrichti	Red Hills salamander	P2, Threatened
Eumeces anthracinus	coal skink	P2
Eumeces inexpectatus	southeastern five-lined skink	P2
Lampropeltis getula holbrooki	speckled kingsnake	P2
Gopherus polyphemus	gopher tortoise	P2
Picoides borealis	red-cockaded woodpecker	P1, Endangered
Hylocichla mustelina	wood thrush	P2
Helmitheros vermivorus	worm-eating warbler	P2
Limnothlypis swainsonii	Swainson's warbler	P2
Oporonis formosus	Kentucky warbler	P2
Aimophila aestivalis	Bachman's sparrow	P2
Elanoides forficatus	swallow-tailed kite	P2
Columbina passerina	common ground-dove	Watch List
Otus asio	eastern screech-owl	Watch List
Bubo virginianus	great horned owl	Watch List
Caprimulgus carolinensis	Chuck-will's-widow	Watch List
Ceryle alcyon	belted kingfisher	Watch List
Melanerpes erythrocephalus	red-headed woodpecker	Watch List
Picoides pubescens	downy woodpecker	Watch List
Picoides villosus	hairy woodpecker	Watch List
Parula americana	northern parula	Watch List
Dendroica discolor	prairie warbler	Watch List
Protonotaria citrea	prothonotary warbler	Watch List
Seiurus motacilla	Louisiana waterthrush	Watch List

Habitat Conservation Plans

To reduce impacts from timber activities upon this unique salamander Habitat Conservation Plans (HCP) have been arranged between the U.S. Fish and Wildlife Service and private landowners. While HCPs have been demonstrated to afford a degree of protection for the salamander, they do not ensure long-term protection, needing to be rewritten periodically, nor do they provide protection to species not directly associated with the mesic slopes occupied by the Red Hills salamander.

One prominent landowner in this region owns approximately 1823 ha (4,500 acres) (at the initiation of this project, recent land sales have reduced this total) of Red Hills salamander habitat distributed across the five counties from which the salamander is known. (A recent observation of *P. hubrichti* at a single and isolated locality in southern Wilcox County increases the number to six counties (Bailey and Miller 2006.) These landholdings encompass all major habitat types ranging from broad floodplains to forested slopes and ravines to xeric, piney ridges. Under their HCP the corporation has designated the unique habitat occupied by the salamanders as a stream-side management zone (SMZ). In this case the SMZ begins along the upper line of the slope, encompasses the steep forested salamander habitat, and continues to the nearby stream channel. This approach provides a level of inclusive protection to floodplains lying between salamander slope habitat and streams.

But long-term protection for the unique Red Hills biota will need to be done with conservation easements or outright acquisition, coupled with proper management with the restoration of ecological processes as the primary goal. Prior to entering into a conservation easement, several key activities must be undertaken. These include the delineation of salamander habitat for accurate acreage determination, estimation of density of salamanders for sites which have not been sampled, and assessment of adjacent ridgetops for management recommendations and restoration potential. Developing an understanding of the salamander's population size and distribution within the easement or acquisition boundaries will lay the foundation for assessing future population trends and will provide insights toward an adaptive management approach to sustain and potentially enhance local populations. This approach will require a quantitative as well as a qualitative description of salamander habitat.

By restoring selected ridges to the historical condition of open, longleaf pine woodland, a tremendous opportunity will arise for the creation and enhancement of wildlife habitat for a number of species that are representative of this vanishing coastal plain ecosystem. Through the implementation of appropriate management strategies, the potential exists for augmentation in both areal extent and population size for those species that continue to persist in some portions of the ridgetops (e.g., gopher tortoise). Additionally, a foundation will be established for the potential re-establishment (or recolonization) of some species of wildlife that were formerly extirpated due to habitat alteration (e.g., red-cockaded woodpecker). Restoration and habitat management directives on the ridgetops will require two principal approaches. One, selected ridges considered for conservation action will require delineation and description of current habitat conditions. Two, long-term management goals and benchmarks for reaching the desired habitat condition must be provided in a management plan.

Objectives

The stated objectives of this project are: 1) to accurately delineate Red Hills salamander habitat on former International Paper properties; 2) provide a status of the Red Hills salamander by estimating burrow density for each of the sites delineated; 3) assess and quantitatively describe the forest cover of the Red Hills salamander habitat; 4) assess the ridgetops and provide restoration recommendations; 5) conduct bird surveys to document neotropical migrant use of the forested slopes, stream bottoms, and ridgetops.

During the course of the study three sub-objectives, under objective 3) above, emerged relevant to habitat and burrow densities. These were: 1) increase knowledge of micro-site ecological factors influencing the presence of Red Hills salamander burrows, 2) develop quantitative tools that will enable individuals and conservation agencies to assess the probability of Red Hills salamander occurrence given site-specific data, 3) and evaluate potential differences in Red Hills salamander burrow density across study sites.

Methods

Site Selection

Sites were selected based on the known presence of *P. hubrichti*, localities which have been entered into the Alabama Natural Heritage Biological Conservation Database. With this dataset and the GIS coverage of International Paper's landholdings, a subset of sites was generated for the study. A total of 25 sites were sampled including Haines Island which has the only Red Hills salamander population under federal ownership. Sites were distributed throughout the range of the salamander (Figure 3), but the majority of sites were found toward the central and eastern portions of the ranges. No sites were available in either Crenshaw or Wilcox counties (Table 3). Sites were generally named using the following convention of topographical quad, section, and, if needed, a unique qualifier of cardinal direction.

Figure 3. Distribution of Red Hills salamander study sites sampled on commercial timberlands.

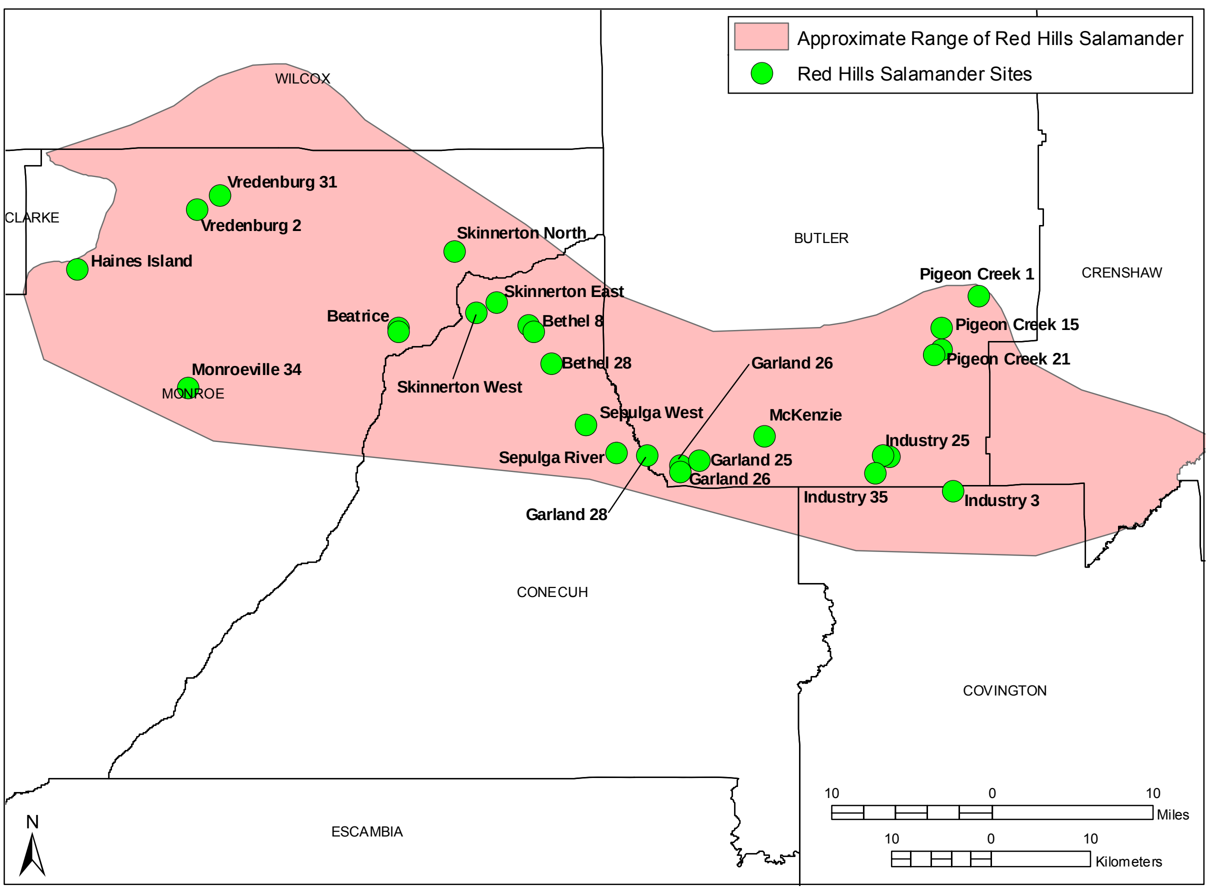


Table 3. A listing of the study sites as identified by name and county of occurrence.

Site	County		Site	County
Garland 25	Butler		Sepulga River	Conecuh
Garland 26	Butler		Sepulga West	Conecuh
Garland 28	Butler		Skinnerton E	Conecuh
Garland 35	Butler		Skinnerton W	Conecuh
Industry 25E	Butler		Industry 3	Covington
Industry 32	Butler		McKenzie 3N	Covington
Industry 35	Butler		Beatrice	Monroe
McKenzie	Butler		Haines Island	Monroe
Pigeon Creek 1	Butler		Monroeville 34	Monroe
Pigeon Creek 15	Butler		Skinnerton N	Monroe
Pigeon Creek 21E	Butler		Vredenburg 2	Monroe
Bethel 28	Conecuh		Vredenburg 31	Monroe
Bethel 8	Conecuh			

Habitat Delineation

The boundaries of the occupied salamander habitat were delineated with an experienced observer walking the perimeter of the slope habitat and recording a track with a handheld Garmin GPS. This technique was the most feasible available. While the employment of the handheld unit introduced an element of error, which could be several meters, it did exhibit improved satellite reception over the backpack unit and longer battery life allowing for the collection of track data, and downed trees, shrub thickets, and other natural obstacles were easier to negogiate with the handheld unit than with the backpack unit. Data gathered was then imported into ArcGIS from which maps were produced and acreages calculated. Once a track was imported into the GIS program the boundary delineation was smoothed and the adjusted track overlain on a topographical, geological, soils, and aerial layer to determine which layer yields the best potential method for remote identification of Red Hills salamander habitat. While the concept of physically walking the perimeter and delineating habitat is straightforward, obstacles were encountered in the field which forced routing deviations away from salamander habitat. Most commonly these obstacles were blown down trees, thickets of Florida anise, or gradations into submarginal habitat.

Woody Vegetation of Slopes

Forest cover of the slopes and ravines typical of Red Hills salamander habitat has only been described in general terms; therefore, to provide more descriptive data on the canopy and shrub layer of the Red Hills belt, transects were used to collect data. A predetermined width of 6 m was chosen because, on many slopes, the collector was anchored by a rope at the top of the slope and 3 m on either side of the transect was the maximum lateral distance which could be adequately surveyed. Transects were set at the top of the slope and ran to the bottom; thus, transect lengths varied accordingly. Within each transect the data collected included species, number of individuals, and with the trees, diameter at breast height (DBH). Trees less than 2.5 cm DBH were categorized as saplings. Woody species not a component of the canopy were categorized as shrubs.

Data collection of trees and shrubs was emphasized because woody species are most likely the primary biotic factor influencing the microclimate of the slopes, are easily identified, compose the greatest vegetation biomass of the slopes, and are the source of the leaf litter. Grasses, forbs, ferns, and bryophytes have not been included because of difficulty of positive identification in the field, and low densities observed on the slopes. While the importance of these groups is recognized, adequate data collection on these groups was beyond the scope of this project.

Line Transects for Salamander Burrow Density and Habitat Analysis

Previous investigators (Dodd, 1991, Bailey, 1992, 1994, 1995) have used time constraint counts converted to number of burrows observed/hour. Problems exist with this technique and include: 1) the methodology has not been explicitly stated. [Did the observer walk perpendicular to slope, i.e. upslope, while counting, or when a burrow was encountered did the observer then follow the burrow distribution along the slope? When did timing start? Was it at the same point each time, i.e., at bottom of the slope, or did timing start when the first burrow was encountered? What was the determinant for ending the count? Was it when no more burrows were encountered, or at a specified time even if more burrows were within sight?], and 2) no density estimates can be derived because the area sampled was not determined.

HCPs have generally been based on data gathered by time constraint counts (Dodd, 1991, Bailey, 1992, 1994, 1995), but the use of line transect methodology to estimate burrow densities yields a statistically quantifiable estimate on burrows and potentially, on salamanders. Such information provides a baseline for future monitoring and a basis for comparison of salamander populations. Dodd (1990) used a line transect method to estimate burrow density, and this technique has further been effectively employed (Godwin, 2003). Data analysis for density estimation was done with the program Distance (Thomas et al., 1998); Buckland et al. (2001) provide approaches to select models for the best fit. Estimates of individual salamander density were then generated using the conversion factor of salamander/burrow developed by Carroll et al. (2000). Coupling habitat acreage with density estimates, estimates of numbers of individuals can be calculated.

The line transect method initially used by Dodd (1990) to estimate burrow density was used in this study. Four assumptions must be met in using line transects (Dodd, 1990): 1) burrows directly on the transect line are not missed; 2) burrows are not counted more than once; 3) the perpendicular distance from the burrow to the line is measured exactly and without error; and 4) burrow sightings are independent.

Each slope was surveyed by uniquely numbered transects that ran perpendicular to the ridge and whose origin was spaced approximately 20 m apart along the ridge to ensure no overlap between lines. From the top of the slope a 50 or 100 m tape measure was run downhill, and data collection proceeded by the observer starting at the bottom of the slope and ascending to the ridge. Prior to ascent, the observer recorded the transect line length, recorded the angle for the entire slope with a clinometer, and estimated the directional aspect of the slope face. Angle slope was estimated as the angle created by the observer's height at the bottom of the slope and a similar height previously marked on a tree at the top of the slope. These angle and slope aspects are transect-level variables and for the purpose of analysis were ascribed to each sampling point contained within transect. Slope aspect was recorded to the nearest cardinal direction (i.e., N, NNE, NE, ENE, W, etc.). Slope aspect was transformed into its numerical equivalent prior to statistical analysis (e.g., E = 90^o). Aspect is a circular variable (i.e., $0^o = 360^o$) and must be transformed prior to its use in statistical analyses. The technique developed by Jammalamadaka and Lund (2006) to transform slope aspect was used. Briefly, the transformation requires 2 variables to accurately describe slope aspect (i.e., one to account for the "northness" and one to account for the "eastness").

Data were collected systematically and opportunistically along each transect within a 4.047 m^2 (0.001 acre) circular plot. To define the circular plot a small cable 1.13 m long was used which was attached to a spike which served as the plot centrum. The center of the plot was set at the burrow or each 5 m transect interval. Systematic sampling was conducted at 5 m intervals along each transect, while opportunistic sampling was done whenever the observer detected a Red Hills salamander burrow adjacent to the transect. A sampling point is defined for systematic sampling as a point central to each 5 m increment along the transect and for opportunistic sampling as a Red Hills salamander burrow detected adjacent to the transect regardless of the distance increment. The response variable in the analysis is considered to be whether a burrow was present or not at each sampling point.

Several variables were recorded at each sampling point. Micro-site estimates of slope were determined at each sampling point or detected Red Hills salamander burrow. For sampling points without a burrow, micro-site slope was estimated as the slope at the center of the sampling point. When a burrow was detected, micro-site slope was estimated as the angle at the burrow hole. Micro-site slope was estimated with a clinometer. Soil density was estimated within 10 cm of each sampling point with a soil penetrometer and recorded to the nearest 0.1 kg/cm^2. Canopy density above each sampling point was estimated with a densitometer and converted to percentage canopy coverage.

Several aspects of the plant community at each sampling point were estimated. Data included the dominant tree species in the canopy directly above the sampling point, tree and shrub species, and tree DBH for all plant individuals within 1.13 m of the sampling point. The DBH and stem count data per sampling point were summarized. TOTALDBH is the summed DBH of all tree stems within 1.13 m of the sampling point. SHRUBNUM is the total number of shrub stems within 1.13 m of the sampling point.

The hypothesis that several plant species might represent a high quality habitat for the Red Hills salamander was generated. These species are as follows: American beech (*Fagus grandifolia*), American holly (*Ilex opaca*), American hop hornbeam (*Ostrya virginiana*), deciduous magnolia species (*Magnolia* spp.), Florida anise tree (*Illicium floridanum*), Florida maple (*Acer saccharum*), mountain laurel (*Kalmia latifolia*), white oak (*Quercus alba*), and yellow poplar (*Liriodendron tulipifera*). The variable, NUMPLANT, that represents the percentage of these species present at each sampling (e.g., if 2 of the 9 species were present at a sampling point, NUMPLANT = 0.22) was developed. Since NUMPLANT was a percentage, it was arcsine transformed prior to use in statistical analyses (Zar 1984).

Statistical Methodology

Generalized non-linear models with a binomial likelihood to model heterogeneity in the probability of Red Hills salamander burrows as a function of habitat and terrain covariates (Hosmer and Lemeshow 2000) were used. The probability of a Red Hills salamander burrow being present (BURROW) as a function of the following covariates: slope aspect (ASPECT), canopy density above sampling point (CANOPYDENS), dominant tree species in the canopy above a sampling point (DOMTREE), micro-slope at the sampling point (MSSLOPE), angle of the entire slope covered by a transect (OVERALLANGLE), total number of shrubs within 1.13 m of a sampling point (SHRUBNUM), measurement of soil density (SOILPENT), and summed DBH of all trees within 1.13 m of a sampling point (TOTALDBH) was modeled. Inferences made from these results are qualitatively similar to those made from results of patch occupancy analyses (e.g., MacKenzie, et al. 2002); however, attempts to estimate burrow detection rates were not done. Red Hills salamander burrow are conspicuous and detection is neat unity, and a suite of *a priori* models of burrow occupancy based on novel hypotheses, field observations, and other findings in the literature were made.

A priori models of burrow occupancy were incorporated into the binomial likelihood via a logit link function (Hosmer and Lemeshow 2000). Evaluations of model adequacy were done with the test described by Hosmer and Lemeshow (1980). Pigeon and Heyse (1999) and Kuss (2002) suggested this test may not be appropriate when continuous covariates are used; however, our sample sizes were large and this reduces the bias associated with incorporation of continuous covariates (Kuss 2002). Model adequacy was evaluated at the global model (i.e., the most highly parameterized model) and the *a priori* best model selected with our information theoretic approach to model selection.

An information theoretic approach was used for model selection. Because the ultimate interest was in deriving statistical models for use in prediction of burrow occupancy, Akaike's Information Criterion (AIC, Akaike 1973) was used. Model comparisons were made with Δ_i, which is the difference between the AIC value for model *i* and the lowest observed AIC value among the candidate set of models. Models with $\Delta_i < 2$ are considered to have substantial support given the data. The Akaike weight per model which reflects the relative likelihood of the model given the data and the candidate model set (Burnham and Anderson 2002) was computed. Sugiura's (1978) Second-Order form of AIC (frequently referred to as *small sample AIC*; Burnham and Anderson [2002]) in analysis of burrow occupancy was not used because the ratio of sample size to maximum number of parameters was large. Inferential parameters (e.g., estimated maximum likelihood beta values for covariates) came from the AIC best model (i.e., $\Delta_i = 0$) if little uncertainty existed in model selection (i.e., Akaike weight > 0.90 for AIC best model). If uncertainty did exist, inference came from across all models with model averaged parameters and unconditional standard errors (Burnham and Anderson 2002). Estimates of DSR were derived from model averaged betas values for the covariates with substantial support (i.e., Akaike weights > 0.38; White and Burnham 2005). Relative importance of a covariate by summing the Akaike weights for models that contain that covariate was calculated. Covariates that explain considerable heterogeneity in burrow occupancy will have a low AIC value and thus high Akaike weights.

Avian Surveys

Breeding bird surveys followed point count survey methodology as presented in Hamel et al. (1996). Point count stations were conducted in all representative habitats which included forested slopes occupied by Red Hills salamanders, adjoining floodplains, dry ridgetops with restoration potential, and anthropogenic plantation and mixed pine/hardwood stands. General habitat type of each station was described. Survey stations were located approximately 300 m apart to avoid overlap, and coordinates of each station were recorded with a handheld GPS. Because a central goal of the bird survey was to document habitat use within specific habitat types, count stations, if possible, were generally established interiorly to avoid edge effects.

Other Species of Conservation Concern

Reptiles

Gopher tortoise (*Gopherus polyphemus*)

Where it occurs in the Red Hills physiographic province the gopher tortoise typically occupies the higher elevations of the ridgetops which have deposits of deep, loose, sandy soil. Historically such sites would have had a native forest cover of pine and an associated ground cover rich in grasses and forbs. Natural expansive stands of native pine have disappeared from the Red Hills landscape following the conversion of the uplands to plantations of slash and loblolly pine; concomitantly, this has driven the tortoise populations to drastically low numbers.

Robust tortoise populations require an open canopy which is unavailable to tortoises where conversion to pine plantations has occurred, except in the first few years of plantation growth. New plantations which have an open canopy are used by tortoises, but as the trees mature and the canopy approaches closure the tortoises abandon the burrows, generally within 5-7 years (Aresco and Guyer, 1999a). Conversion to plantation also results in poor quality forage which results in protracted maturation of tortoises as compared to those living on sites with a higher quality of habitat (Aresco and Guyer, 1999b).

In Butler County tortoise burrows have been associated with the following soils types: Arundel fine sandy loam, Orangeburg sandy loam, and the Troup-Alaga complex. One ridgetop locality in Conecuh County which previously supported tortoises has Arundel loamy fine sand soil. In a study conducted in southwest Alabama and southeast Mississippi, Jones and Dorr (2004) found that the best habitat on timber company lands had sandy soils > 1 m deep which allowed for good drainage. These sites had a naturally regenerated longleaf or naturally regenerated loblolly-longleaf stand, and were parklike with tree basal areas < 35 m^2/ha. Herbaceous ground coverage of the sites, which was a composition of native legumes, grasses, and forbs, exceeded 20%.

Support of viable gopher tortoise populations requires not only high quality habitat but sufficient acreage. Cox et al. (1987) in their guidelines recommended a minimal area of 10-20 ha to encompass 80 burrows or 50 tortoises. The number 50 was assumed to be the minimal number for a viable population. Eubanks et al. (2002) calculated that an area ranging from 25 – 81 ha would be required to support 50 tortoises, and that nearly twice as many burrows, or 157, are needed within the area. Numbers of burrows encountered on any site during the present study seldom fell far below either recommended minimum.

Reversion of typically closed-canopy ridgetop pine plantations back to a longleaf pine or other native pine forest would benefit tortoise population remnants which are persisting as Red Hills isolates. Management practice approaches used to enhance red-cockaded woodpecker and Bachman's sparrow populations would also improve habitat for the gopher tortoise (see later sections on red-cockaded woodpecker management and ridgetop restoration).

Coal skink (*Eumeces anthracinus*)

The coal skink in Alabama is poorly known, and from the Red Hills physiographic region only one specimen has been collected. In other regions of the state the lizard has been reported to occur in mesic sites near water which have rotting logs and leaf litter. Other habitat types in which the coal skink has been observed include hilly terrains with mixed pine and hardwood forests with sandy to rocky habitats (Mount, 1975; Means, 2004). Within the Red Hills the sites most promising to support coal skinks are moist ravines and slopes in the vicinity of a stream. Maintaining the hardwood forest dominant canopy of the steep slopes and floodplains is the recommended management practice best suited for the coal skink.

Southeastern five-lined skink (*Eumeces inexpectatus*)

The southeastern five-lined skink is a lizard of xeric ridgetops with well-drained soils, dry open woodlands, and ecotones between forests and openings. This skink shuns heavily shaded, mesic ravines, coves, and damp stream margins. Ecological structures of logs and rock piles are used for cover and bask sites, and the species is more terrestrial than arboreal (Mount, 1975; Hughes, 2004). Management practices beneficial for the gopher tortoise, red-cockaded woodpecker, and Bachman's sparrow would also benefit the southeastern five-lined skink.

Speckled kingsnake (*Lampropeltis getula holbrooki*)

Habitat requirements of the speckled kingsnake in Alabama are poorly known. Reportedly the species uses floodplains and the margins of streams and swamps. During the warm months juveniles may occupy space on dead trees between the trunk and slabs of exfoliating bark, as well as lying under logs.

Adults are thought to overwinter in stump holes. The apparent decline of the speckled kingsnake is thought to be due to deforestation (Mount, 1975; Guyer and Bailey, 2004). No specific management practices are recommended for the speckled kingsnake aside from proper ecosystem management.

Birds

Swallow-tailed kite (*Elanoides forficatus*)

Information taken from Meyer (1995).

Relevant Habits & Habitat

The swallow-tailed kite is a gregarious, neotropical migrant which inhabits wetlands, swamps, lowland forests, and freshwater marshes of the southeastern United States. This species requires habitat which has tall accessible trees for nesting and open areas which support sufficient populations of small prey. Food items include flying insects, tree frogs, lizards, snakes, nestling birds, and occasionally bats, small fish, and fruit. Food is gleaned from tree canopies while the bird is in flight. Birds roost communally at night. Nests are constructed in the crowns of trees in woodland sites which have an uneven canopy structure.

Conservation and Management

The greatest threat to the swallow-tailed kite has been the loss and degradation of the nesting, foraging, and roosting habitat. Within south Alabama much of this loss is attributable to logging.

Riparian zones along the base of Red Hills salamander slopes which support a heterogeneous matrix of hardwood vegetation provide needed habitat for the swallow-tailed kite. Conservation measures for this species in the Red Hills simply require the maintenance of quality riparian forest along the stream courses.

Common ground-dove (*Columbina passerina*)

Information taken primarily from Bowman (2002).

Relevant Habits & Habitat

The natural habitat of the common ground-dove is that of relatively dry, open, early successional forests with sandy soils. This is a species of early successional, generally fire-maintained forest types. The common ground-dove feeds upon weed and grass seeds, grains, small berries, insects, and snails, which it gathers by foraging on the ground in sites with bare patches of sandy soil.

Nesting is done on or above the ground. If above the ground the nest may be located in a bush, on a low horizontal tree branch, stump, or among vines (Imhof, 1976; Turcotte and Watts, 1999).

Conservation and Management

While the numbers of the common ground-dove have been in decline, no direct factors have been identified. The decline of this species has been indirectly linked to a loss of successional or shrub type habitats due to habitat degradation and fire suppression. An improvement and increase in habitat for the common ground-dove would be seen with conversion of densely spaced pine plantations, back to naturally occurring native pine forests.

Eastern screech-owl (*Otus asio*)

Information taken from Gehlbach (1995).

Relevant Habits & Habitat

The eastern screech-owl is a non-migratory habitat generalist found in forest types which range from deciduous to mixed to plantations and from early successional to mature. Yet within this broad characterization the owl shows a preference for open canopy space with sparse shrub cover. As with its habitat requirements its food habits also reflect a generalist nature; prey items include a wide variety of terrestrial and aquatic vertebrates and invertebrates.

Nesting takes place in tree cavities and the screech owl is an opportunistic secondary cavity-nester with no selection for height or direction. Natural nest sites include hollow trunks and limbs, stumps, holes in trunks or limbs, and woodpecker cavities, but most are the result from storm damage of trees and are naturally rotted and/or enlarged by squirrels.

Conservation and Management

A reduction of tree density below 50 trees/ha or the removal of natural nest cavities will extirpate this owl from an area. To enhance habitat conditions for the species, reforested habitat requires the placement of nest boxes to replace natural cavities. Nest boxes should be placed 3-4 m above ground, on a straight trunk of a diameter which is wider than the box. The site should be shady and provide an unobstructed flight path to and from the box. Nest boxes should be erected at a distance > 30 m from the nearest box or natural cavity.

The nest box may be constructed from any wood with the following dimensions: $\geq$ 2cm thick; floor 18 x 18 cm with 0.5 cm drain holes in bottom corners; 7 cm diameter entrance hole with its bottom 25 cm above the floor; front-sloping lid 5 cm above the entrance hole, overhanging 3 cm, hinged at back, and hooked at the side. Wood of the box should be painted or stained dark brown on the outside. 2 cm of dry deciduous leaf litter should be placed in the bottom.

Along the hardwood-dominated slopes and forested floodplains of the Red Hills, an abundance of suitable nest cavities may exist. Management for this species within the Red Hills is not likely to be needed.

Great horned owl (*Bubo virginianus*)

Information taken from Houston, et al. (1998).

Relevant Habits & Habitat

Both a habitat and prey generalist, the great horned owl can be found in deciduous, mixed, and coniferous forests, but within these forest types prefers open and secondary growth woodlands, and swamps. Diet of the owl is the most inclusive of any North American raptor which includes rabbits, rodents, waterfowl, other birds, reptiles, fish, amphibians, and arthropods.

This large owl nests in a variety of sites, including tree nests of other bird species, cavities in trees and snags, and artificial platforms, and it will also lay eggs on the ground. Great horned owls do not build their own nests, but rely on abandoned nests of other birds, quite often those of the red-tailed hawk.

Conservation and Management

Great horned owls are susceptible to bio-accumulation of pesticides, organophosphates, organochlorines, and rodenticides. The species is adaptable to habitat alterations as long as nest sites are available, but nest site availability in altered habitats may be affected as nest donors may not be as adaptable. In areas with limited nest availability artificial nest sites encourage breeding.

This is not a species of concern that is considered to require any direct management within restored or managed sites in the Red Hills, at this time.

Chuck-will's-widow (*Caprimulgus carolinensis*)
Information taken from Straight and Cooper (2000).

Relevant Habits & Habitat

The Chuck-will's-widow is a crepuscular species which forages in the evening and early morning, and on nights with a full moon. Using visual cues to capture prey, this species feeds upon moths and beetles, and the occasional bat and smaller bird, all while in the air.

Chuck-will's-widows are found in pine, oak-hickory, and mixed forests which have suitable patches of openings. Forest openings appear to be important foraging habitat. Nesting takes place in early to mid-April, and eggs are laid on dead leaves or bare ground.

Conservation and Management

No specific conservation measures have been identified for this species, but the conversion of dense pine plantation back to open native pine forest would be beneficial as this would increase the open forest patches and in all likelihood diversify the prey base.

Belted kingfisher (*Ceryle alcyon*)

Information taken from Hamas (1994).

Relevant Habits & Habitat

Streams which are not overgrown with vegetation and have clear water and riffles are the preferred habitat of the belted kingfisher. From perches this bird searches for and preys upon fish, crayfish, mollusks, insects, amphibians, and reptiles. Nests are excavated from earthen banks near fishing sites, but banks in sand and gravel pits near streams may also be used.

Conservation and Management

Key habitat variables for the kingfisher include good water quality, lack of vegetative cover over streams, and suitable nest sites. Human disturbance, especially during nesting, may drive kingfishers from an area.

With regard to the occurrence of this species on Red Hills sites surveyed during this project, little can be done to enhance habitat or conditions for the belted kingfisher. Ensuring that stream-side management goals address appropriate water quality issues is the primary management requirement for this species.

Red-headed woodpecker (*Melanerpes erythrocephalus*)
Information taken from Smith, et al. (2000).

Relevant Habits & Habitat

The red-headed woodpecker is a bird of deciduous woodlands, river bottoms, open woods, mixed pine and hardwood, and longleaf pine forests. Necessary within the forests are dead and dying trees, snags, or large dead limbs, as well as open understory or a sparse shrub layer.

This is the most omnivorous of North American woodpeckers, and is an expert flycatcher. Food items include seeds, nuts, berries, insects, bird eggs, nestlings, and mice, and woodpeckers will commonly forage on the ground, as well as on dead trees or dead portions of live trees. Foraging in live trees occurs much less frequently than on dead wood.

Nesting is done in dead trees or dead portions of live trees, whether hardwood or pine. If the nest is in a dead tree, the snag will typically have little bark. Nests are found in sites with little understory.

Conservation and Management

Decline of the red-headed woodpecker has been tied to the removal of dead trees and branches, firewood cutting, and clear-cutting, all practices which eliminate available nest sites. Growth of plantations leads to canopy closure, a condition detrimental to the woodpecker as it needs open areas in forests for aerial foraging.

As pine plantations are converted back to native pine forests any standing snags should be left in place, and these may be either hardwood or pine as red-headed woodpeckers will forage and nest in clearcuts that retain snags. If at all possible snags should be retained in groups as the woodpecker requires multiple snags for roosting and/or foraging.

Prescribed burning may be either beneficial or detrimental for the red-headed woodpecker. Burning removes and thins shrubs of the understory, but may also destroy nest snags. If possible, prior to a controlled burn the snags should be identified and protected. Presence of beavers along streams may also benefit the red-headed woodpecker. As beaver impound stream stretches the backwaters flood and drown trees leading to an abundance of dead standing timber.

Aside from the retention of dead trees and snags within forests, no specific management recommendations for this species in the Red Hills are needed.

Red-cockaded woodpecker (*Picoides borealis*)
Information taken from Jackson (1994).

Relevant Habits & Habitat

The red-cockaded woodpecker is a species that is dependent upon expansive old growth pine forests, composed of longleaf (*Pinus palustris*), loblolly (*Pinus taeda*), slash (*Pinus elliottii*), shortleaf (*Pinus echinata*), plus a few other pine species. Natural ecological processes that maintain the pine forest in a condition suitable for the woodpecker depend upon a 1-5 year summer fire cycle. Historically, these fires were brgun by a lightning strike; today a prescribed burn may be used. Expansive forests are needed since the bird is colonial and requires large areas for foraging.

Larger pine trees are preferred as forage sites, and food items include adults, larvae, and eggs of arthropods taken on the tree surface or subsurface. Some seeds and fruits are also consumed.

Nest cavities are constructed in larger and older trees, and the same nest may be used for several years. The red-cockaded woodpecker is a cooperative breeding woodpecker, in that young birds will assist with the feeding of nestlings.

Conservation and Management

Dramatic loss of old growth pine forest has drastically reduced the viable populations of the red-cockaded woodpecker throughout its range. Restoration efforts within the Red Hills would require a long-term commitment (80+ years). Longleaf or other native pine forest would first need to be reestablished on the ridgetops, frequent fire would have to be reintroduced, and time would be needed for maturation of the trees. Once the trees had reached an appropriate size, translocation of woodpeckers would most likely need to take place.

More detailed management recommendations are presented in the sections pertaining specifically to red-cockaded woodpeckers and ridgetop forest restoration.

Downy woodpecker (*Picoides pubescens*)
Information taken from Jackson and Ouellet (2002).

Relevant Habits & Habitat

Across the Gulf Coast, and in other regions of North America, the downy woodpecker is a non-migratory resident. Habitats occupied by this species include open deciduous forests, particularly riparian zones, and small deciduous tree patches within coniferous forests.

Feeding is done on the surface and subsurface of live and dead trees where the woodpecker searches for insects, other arthropods, seeds, and sap. A dead tree or a dead stub of a living tree is used as a nest site, and the nest is generally associated with trees that have an advanced state of heartrot. Species used include *Pinus*, *Acer rubrum*, and *Liquidambar styraciflua*.

Conservation and Management

The downy woodpecker prefers early successional habitats and the clearing and thinning of forests has, to some extent, been advantageous to the species. Yet extensive clearing and the establishment of intensive, even-aged, forest monoculture has a negative impact as nesting habitat is eliminated. Optimal habitat for the downy woodpecker includes a broad range from virgin bottomlands to sparsely stocked upland woodlands, but a common element is a snag density of $\geq$ 5 snags/0.4 ha which have a minimum 15 cm dbh.

With the large extent of hardwood slopes and hardwood riparian zones within the Red Hills, active management for the downy woodpecker is not needed.

Hairy woodpecker (*Picoides villosus*)
Information taken from Jackson et al. (2002).

Relevant Habits & Habitat

The hairy woodpecker is a bird of mature woodlands, mixed hardwood forests, and open pine forest. This species forages on the surface and subsurface of trees, searching for arthropods. Fruits and seeds are also consumed. The woodpecker opportunistically forages on available trees, with a seeming preference for larger trees, and those that potentially host concentrations of prey items. Both live and dead trees serve as forage substrate.

Live trees are preferred over dead for the construction of nest cavities but either will be used. A nest cavity may be excavated in the trunk of a tree with fungal heart rot or on the underside of a limb that leans out from vertical.

Conservation and Management

Forest fragmentation has been implicated as a cause for declines of hairy woodpecker populations, and clearcutting is one means by which habitat has been destroyed. While the retention of snags in pine plantations is recommended, this has questionable value for hairy woodpeckers.

Mature hardwood forests on the slopes of the Red Hills and along the adjacent stream bottoms provide habitat for the hairy woodpecker, and active management for this species in the Red Hills is not recommended.

Wood thrush (*Hylocichla mustelina*)
Information taken from Roth, et al., (1996).

Relevant Habits & Habitat

The wood thrush is a neotropical migrant which breeds in deciduous and mixed forests of the eastern United States. Within the forest the thrush requires a developed shrub-subcanopy layer, shade, moist soil, relatively open forest floor, and decaying leaf litter.

Foraging on the ground, the wood thrush feeds upon larval and adult insects, millipedes, isopods, arboreal insects, snails, and small salamanders, plus fruit. Foraging takes place in leaf litter or on the ground where herbaceous vegetation is sparse.

Trees and shrubs are used as nest sites and often the nest is placed in American beech (*Fagus grandifolia*) or oak (*Quercus* spp.).

Conservation and Management

Forest destruction and fragmentation are the main threats to the wood thrush. Maintenance of the hardwood forest along the slopes and floodplains is the recommended management strategy for the wood thrush in the Red Hills, recommendations which parallel those for the Red Hills salamander.

Prairie warbler (*Dendroica discolor*)
Information taken from Nolan, et al. (1999).

Relevant Habits & Habitat

The prairie warbler is a neotropical migrant which requires regenerating, early successional stage shrubby habitats for breeding. Sites such as old fields with shrub patches, pine forest with a shrub sub-canopy, or abandoned fields or pastures are favored habitats. Sites with a closed canopy are shunned.

A prey item generalist, the warbler feeds on insects, spiders, small soft-bodied arthropods, mollusks, and occasionally fruit.

Nests are typically placed in trees and shrubs which have numerous branches, twigs, and leaves. The nest site is often within a small clump of trees.

Conservation and Management

During the course of the deforestation of the eastern forests, an abundance of breeding habitat for the prairie warbler was produced. The warbler responded with an increase in its range. Factors which are now impacting the warbler include habitat destruction, such as urbanization, and forest regeneration.

Active management of this species in the Red Hills is not recommended. The prairie warbler requires shrubby growth which is an ephemeral, early seral stage condition. Shrubby patches will be generated as native pine restoration proceeds, although active maintenance of shrub patches is not recommended.

Worm-eating warbler (*Helmitheros vermivorus*)
Information taken from Hanners and Patton (1998).

Relevant Habits & Habitat

The worm-eating warbler is another neotropical migrant which requires large tracts of mature deciduous forest. In addition the forest must overlap slopes with a moderate to steep pitch and a dense but patchy shrub layer should be present. Important shrub species for the warbler include mountain laurel (*Kalmia latifolia*) and rhododendron. Minimal area requirements of quality habitat for the species range from 21 to 340 ha.

This warbler forages primarily on the ground in live leaves and leaf litter by gleaning food from foliage. Major food items are arthropods, spiders, slugs, caterpillars and other insects.

Nesting is also done on the ground, near a stream or wetland, and typically on a hillside or along the bank of a ravine. The nest is placed under a drift of dead leaves, against the roots of a shrub or tree, or in a dense low shrub such as huckleberry (*Gaylussacia*) or low blueberry (*Vaccinium*).

Conservation and Management

Forest fragmentation and degradation are the major threats to the worm-eating warbler, as this species requires large continuous forested areas with a minimum of nonforested edge. Maintenance of the hardwood-dominated slope and adjacent floodplain habitat in the Red Hills is the recommended management strategy for this species.

Swainson's warbler (*Limnothlypis swainsonii*)
Information taken from Brown and Dickson (1994).

Relevant Habits & Habitat

Primarily a bird that breeds in the southeastern United States, the Swainson's warbler is a neotropical migrant that inhabits swamps and river floodplains. Often this species is associated with dense stands of cane (*Arundinaria* spp.) within the bottomland hardwood forest. Other ecological features pertaining to Swainson's warbler include a dense understory, abundant leaf litter, and areas with little herbaceous growth. The vegetative understory parameters of dense cane thicket and sparse herbaceous ground cover may be more important as habitat variables than overstory.

Birds forage along moist, but not saturated, areas, and in sites with dense understory composed of canebrakes, dwarf palmetto (*Sabal minor*), and/or sweet pepperbush (*Clethra alnifolia*) stands. Food items are mainly adult and larval insects and spiders.

Nesting is at the edge or near dense cane thickets, amid vines, or rhododendrons, and the nest is often constructed near water. This is a bird that nests low, generally at a height of 3 m or less. A minimum of 350 ha of intact forest is required by individuals when establishing a territory.

Conservation and Management

The greatest threat to this species has been the degradation and fragmentation of bottomland hardwood forests, and the reduction and fragmentation of expansive canebrakes.

Habitat enhancement management includes selective cutting of trees to mimic tree falls. Selective cutting of individual trees increases the light intensity reaching the forest floor while ensuring a relatively closed canopy. Clearcutting an area that lacks cane but is adjacent to a cane thicket may promote the spread of cane, but the clearcut should be no larger than 4 ha.

Kentucky warbler (*Oporonis formosus*)

Information taken from McDonald (1998).

Relevant Habits & Habitat

The Kentucky warbler is a neotropical migrant which, during the breeding season, inhabits moist, deciduous forests with dense understory. A minimum of 500 ha of unfragmented bottomland hardwood forest with a thick understory is needed for nesting. Nests are constructed on the ground or slightly off the ground and anchored to a shrub.

Food items include insects, caterpillars, and small spiders, plus a small percentage of seeds. Foraging is done on the ground with the bird rummaging through leaf litter, or feeding in shrubs, vines, and the lower portions of trees.

Conservation and Management

Deforestation and the loss of bottomland hardwood forests is the prime factor for declines of the Kentucky warbler. Mature hardwood forests with dense understory lie between streams and the slopes through much of the Red Hills. With the availability of such suitable breeding habitat no direct management is recommended for the Kentucky warbler.

Northern parula (*Parula americana*)
Information primarily taken from Moldenhauer and Regelski (1996).

Relevant Habits & Habitat

The northern parula is a neotropical migrant and on the breeding grounds in the southern United States has a preference for riparian hardwood forests with epiphytic growth, typically Spanish moss (*Tillandsia*). The warbler nests and feeds in the canopy and subcanopy of the forests along rivers and swamps, and to a lesser extent will use forests of mixed pine and hardwood. At the time of writing, Imhof (1976) described the northern parula as common to abundant.

Food items are mainly insects and spiders, but occasionally berries and seeds are consumed.

Hanging bunches of epiphytic plants such as Spanish moss are preferred nest sites, particularly near water. Turcotte and Watts (1999) add that the parula breeds in river swamps and hardwood forests or in uplands where Spanish moss is present. These descriptions fit sites of the Red Hills in which the northern parula has been documented.

Conservation and Management

As a species of mature riparian hardwood forests, clearcutting of the forests is detrimental to the species. With Red Hills salamander habitat being treated as broad streamside management zones under the HCP, optimum habitat for the northern parula is abundant. No direct management of this bird is needed at this time.

Prothonotary warbler (*Protonotaria citrea*)
Information taken from Petit (1999).

Relevant Habits & Habitat

The prothonotary warbler is a neotropical migrant which inhabits low, wet forests. Habitat features needed by this bird include a wooded area near water which has suitable cavity nest sites. Typical habitats include seasonally inundated bottomland hardwood forests, cypress swamps, and small creeks and streams. Occupied areas tend to have low elevation and flat terrain, with a sparse understory. Forested tracts < 100 ha in size and waterways with forested borders < 30 m wide tend to be shunned.

Foods of the prothonotary warbler include insects, mollusks, and isopods. Nesting is done in cavities in trees, dead snags, dead branches of live trees, or in cypress knees. A cavity excavated by the downy woodpecker is often used. Nests are usually over water and moss (bryophyte) is included in the construction.

Conservation and Management

Habitat destruction is the primary factor pertaining to the decline of this bird. Clearing and logging of bottomland hardwood forests removes foraging and nesting habitat, and the removal of dead trees eliminates nest sites. Populations with low levels which are limited by nest sites may be enhanced through the placement of nest boxes.

Adherence to proper stream side management with the protection of bottomland hardwood forests along stream courses in the Red Hills is the appropriate management technique for the prothonotary warbler. Protection of hardwood stands and natural processes along the stream corridors promote the natural cycling of dead wood, thus providing nest cavity sites and foraging habitat.

Louisiana waterthrush (*Seiurus motacilla*)
Information taken from Robinson (1995).

Relevant Habits & Habitat

A member of the group of birds categorized as neotropical migrants, the Louisiana waterthrush is present in the Red Hills only during the warm-season breeding period. Habitats in which the waterthrush are found include cypress swamps, bottomland forests with mud-bottomed streams, and deciduous forests with gravel-bottomed steams.

The Louisiana waterthrush is an insectivore but may also prey upon other invertebrates. Many of the prey items are aquatic insects, but small to medium sized flying insects are also fed upon. Often this warbler will forage entirely within the banks of a stream channel.

Stream channels are also used as nesting habitat with nests being placed in cavities along the banks, under bank overhangs, within root bases of toppled trees, or under fallen logs.

Conservation and Management

Within the Red Hills the Louisiana waterthrush requires no direct management. Protection of riparian zones, stream channels, associated floodplain forest, and nearby Red Hills salamander slope habitat encompasses the ecological needs of the species.

Bachman's sparrow (*Aimophila aestivalis*)
Information taken from Dunning (1993).

Relevant Habits & Habitat

Bachman's sparrow is, preferably, an inhabitant of mature, open pine forest, with an open midstory and dense grassy ground cover. A ground cover with stands of wiregrass, or other bunchgrass, and broomsedge is important. The southern coastal populations of the sparrow are considered to be residents of the region.

As with many sparrows this one forages on the ground and feeds upon seeds, especially *Panicum*, and insects. Nesting is done on the ground and often in association with wiregrass or broomsedge, with nest placement at the base of a grass clump, small shrub, or pine seedling. Ground nesting has its dangers, snakes of the genera *Elaphe* and *Coluber* have been observed to be two important nest predators. While not mentioned in the literature, but probably also important, is predation by the imported red fire ant on eggs and chicks.

Conservation and Management

Preferred habitat of the Bachman's sparrow is a successionally transient one, requiring frequent perturbation in the form of fire. Growing season burns on a 1-3 year cycle appear to be best in order to maintain a midstory clear of dense shrubs and to enhance the growth of the grasses and forbs of the ground layer. Fire suppression within pine forests across the Southeast has exerted a major negative pressure on this species. Fire suppression results in increased midstory shrub density and decrease of the grassy ground layer and leads to local extirpations of the sparrow. Three years following a burn, as the shrubby midstory increases, sparrow numbers will begin to decline.

Native pine forest restoration on ridgetops coupled with proper management, i.e. growing season burns on a 1-3 year rotation, would be required to improve habitat and increase the numbers of Bachman's sparrow within the Red Hills.

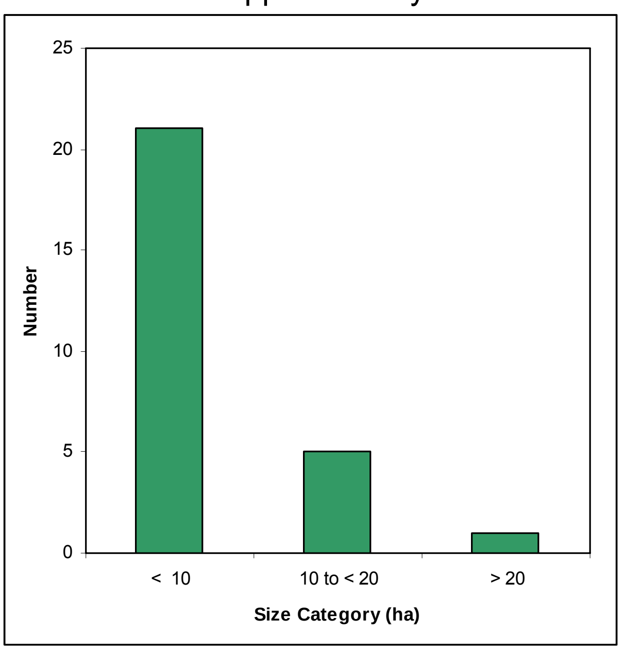
Results and Discussion

Habitat Delineation

GPS Tracks

Twenty-seven habitat tracks were recorded which ranged in size from 0.3 ha (0.7 ac) to 40.8 ha (100.7 ac). Total area delineated was 176.1 ha (435.1 ac) with the average track size being 6.5 ha (16.1 ac) (Figure 4). Majority of the tracks were less than 10 ha in size (n = 21), five were between 10 and 20 ha while only one was greater than 20 ha. Thus, based on these observations, Red Hills salamander habitat across the range is expected to occur in smaller isolated patches, rather than extensive contiguous tracts of habitat.

Figure 4. Size category distribution of delineated tracks of Red Hills salamander habitat. Majority of habitat patches are on the order of less than 10 ha; the largest track recorded was approximately 40 ha in extent.



Topographical & Aerial

Habitat delineation tracks were overlain on USGS topographical maps and DOQQ aerial photographs and the tracks were then assessed as to how well tracks conformed to topographical features or forest imagery on the aerial photographs. A subjective categorization scheme was devised for the evaluation of conformity of the tracks to the two types of mapping layers with each track receiving a score from 0 to 5 with 0 = no conformity and 5 = absolute conformity. Average scores after ranking the 27 tracks yielded were 4.0 for the aerial DOQQ and 3.2 for topographical maps. Tracks often followed forest cover changes, such as distinctions between pine plantation and hardwood forest; thus, scoring with the DOQQs tended to be higher than for the topography. Tracks did not conform to topography as would be expected; for example, tracks were often discontinuous from topographical elevational features relied upon to identify Red Hills salamander habitat.

Geology

The association of the Red Hills salamander with the Tallahatta and Hatcehtigbee formations has long been known, and this association has been supported through the delineation of the habitat tracks. The predominant geological layers found within the delineated tracks were the Tallahatta and Hatchetigbee formations, with the Tallahatta comprising 54% of the total and the Hatchetigbee 27%. Interestingly, four additional geological layers fell within the Red Hills salamander habitat delineations, although in quite low percentages.

The Nanafalia had been previously documented (Bailey and Miller, 2006), but Tuscahoma Sand, Gosport Sand, Lisbon Formation, and alluvial deposits have not been noted as being geological layers known to harbor the Red Hills salamander (Table 4).

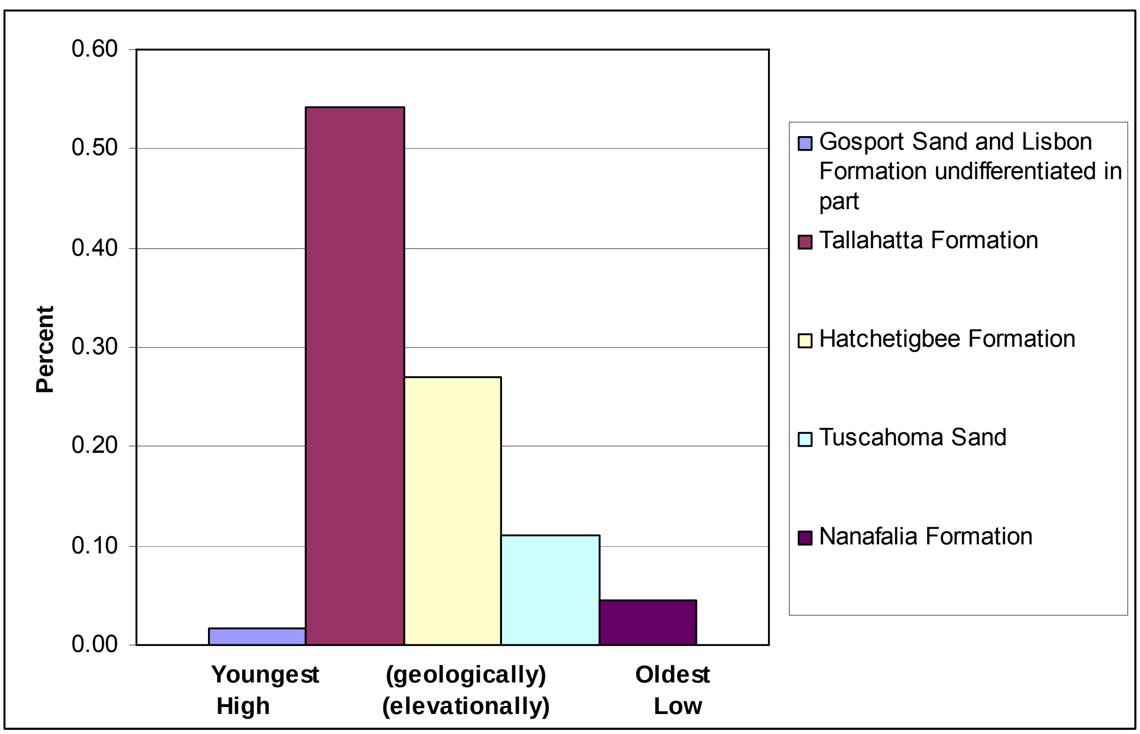
Table 4. Geological layers identified within the boundaries of the delineated Red Hills salamander habitat tracks.

FORMATION	**Hectares**	**% of total**
Tallahatta Formation	95.332	0.54
Hatchetigbee Formation	47.662	0.27
Tuscahoma Sand	19.496	0.11
Nanafalia Formation	7.828	0.04
Gosport Sand and Lisbon Formation undifferentiated in part	3.019	0.02
Alluvial, coastal and low terrace deposits	2.732	0.02
Total	176.069	

Habitat delineation was based on degree of slope and forest cover primarily incorporating the field experience and knowledge of the observer. Thus, the inclusion of the minor geological layers within the track boundaries does not necessarily confirm that Red Hills salamanders utilize these geological layers as burrow media. In walking tracks an observer, at times, had need to route around a dense shrub thicket or impenetrable blowdown and in doing so might veer onto a geological layer which is not used by Red Hills salamanders. Mapping of the geology of the region may have introduced another degree of error reflected by the inclusion of these geological layers which contribute but a small percentage to the total. But it is very probable that Red Hills salamanders do occupy burrows found in the geological layers which are adjacent to the Tallahatta and Hatchetigbee formations. Figure 5 illustrates the physical distribution of the geological layers as they would be within the Red Hills. The

Tallahatta and Hatchetigbee formations compose the core of the geology with the undifferentiated Gosport Sand and Lisbon Formation lying adjacent to, and above, the Tallahatta. Immediately below the Hatchetigbee is the Tuscahoma Sand followed by the Nanafalia Formation. Burrows elavationally higher than the Tallahatta Formation would naturally lie in the undifferentiated Gosport Sand and Lisbon Formation. Red Hills salamanders have been documented in the Nanafalia Formation, and between the Nanafalia and Hatchetigbee formations is Tuscahoma Sand. Therefore the presence of Red Hills salamanders in Tuscahoma Sand is plausible.

Figure 5. The percentage of geological layers identified through habitat delineation with the geological layers arranged across the chart from youngest (highest) to oldest (lowest).



Gopher tortoise burrows were observed on five sites; for four of the sites their location placed them on the Tallahatta Formation. Tortoise burrows on the remaining site were associated with Gosport Sand and Lisbon Formation undifferentiated.

Soils

The influence of soil upon the flora and, directly or indirectly, upon the fauna cannot be overlooked. Soil variables such as permeability, friability, nutrient composition, and degree of slope influence the plant and animal species present or potentially present on any given site. An understanding of the soil is needed with regard to implementation of natural restoration and management actions. Soils distributed across the Red Hills sites are listed below in Table 5, are lumped by county, and are categorized as slope or ridgetop. Soils specific to each site will be given in Appendix 3 which provides detailed information per site.

Table 5. Major soil types found across the Red Hills physiographic province on the slopes or ridgetops of the Red Hills salamander study sites.

Sites	Slope	Ridgetop
Butler County	ArF, LuE	AaB, LgB, LuE,OrB, OrC, OrB, SmD, TaD
Conecuh County	ArE, LuD	ArE, CoC, LuD, TaC, ToE
Covington County	ArE	OrB, OrC, OrE, TrD
Monroe County	ArF, LvE	ArF, LnB, LnC, LvC, LvE, SgF

Butler County (Fox, 1997)

Two soil types are common to the steep slopes of the Butler County Red Hills sites, the Arundel fine sandy loam and a smaller proportion of Luverne fine sandy loam. These soils are moderately to very deep and well drained, and occur on narrow ridges and hillsides. Slopes associated with these soils range from 8 to 35%. Underlying the Arundel is weathered claystone, and areas of rock outcrops, stones, boulders, and surficial cobbles may be found.

A wider variety of soils are found on the ridgetops, but common to all is the characteristic of being well drained. These soils have a gentle slope, typically from 0 to 8%, but in some instances up to 15%, and tend to be deep or very deep. Soil types identified from Red Hills ridgetops in Butler County include the Alaga-Troup complex, Lucy loamy sand, Luverne sandy loam, Orangeburg sandy loam, Smithdale sandy loam, and Troup-Alaga complex (Table 6).

Table 6. Butler County soil types

Alpha code	Soil Name	Slope	Description
AaB	Alaga-Troup complex	0 to 5%	deep, somewhat excessively drained soils, on broad ridgetops and upper parts of side slopes
ArF	Arundel fine sandy loam	8 to 35%	moderately deep, well-drained soil on hillsides of uplands. Substratum is weathered claystone. Includes areas of rock outcrop and small areas with stones, boulders, and cobbles on the surface
LgB	Lucy loamy sand	0 to 5%	very deep well-drained soil on narrow to broad ridgetops
LuE	Luverne sandy loam	8 to 25%	very deep well-drained soil on narrow ridges and side slopes
OrB	Orangeburg sandy loam	1 to 5%	very deep well-drained soil on ridgetops and upper parts of slopes
OrC	Orangeburg sandy loam	5 to 8%	very deep, well-drained soil on narrow ridgetops and side slopes
SmD	Smithdale sandy loam	8 to 15%	very deep well-drained soil on side slopes and narrow ridges
TaD	Troup-Alaga complex	5 to 15%	very deep, somewhat excessively drained soils, on side slopes and narrow ridges

Conecuh County (Fox, 1989)

Soils of the slopes in Conecuh County are comprised for the most part of Arundel loamy fine sand, with slope angles up to 25%. The other soil type found on slopes, but only to a limited degree, is Luverne sandy loam. Each of these is deep and well drained. A soft gray shale lies beneath the Luverne sandy loam, while the underlying material of the Arundel loamy fine sand is moderately hard siltstone bedrock.

Five main soil types occur on the ridges, two of which are shared with the slopes. The soils of the ridges are Arundel loamy fine sand, Conecuh sandy loam, Luverne sandy loam, Troup loamy sand, and the Troup-Orangeburg association. All tend to be deep and moderately to excessively drained, with slope angles ranging from 2 to 25% (Table 7).

Table 7. Conecuh County soil types.

Alpha code	Soil Name	Slope	Description
ArE	Arundel loamy fine sand	4 to 25%	moderately deep, well drained and moderately steep. Underlying material is moderately hard siltstone bedrock to a depth of more than 60 inches
CoC	Conecuh sandy loam	2 to 8%	soil deep and gently sloping and moderately well drained
LuD	Luverne sandy loam	8 to 15%	soil well-drained and sloping
TaC	Troup loamy sand	2 to 8%	deep, excessively drained, and sloping
ToE	Troup-Orangeburg association	8 to 25%	deep, well drained soils

Covington County (Cotton, 1989)

In Covington County only one soil type occurs on slopes, the Arundel loamy fine sand, with 8 to 25% slopes. This is a moderately deep and well-drained soil with underlying bedrock of white fossiliferous claystone, and rock outcrops are common.

On the ridges four soil types have been identified, Troup sandy loam and three types of Orangeburg sandy loam. These soils are all deep and well drained with slope angles ranging from 1 to 20% (Table 8).

Table 8. Covington County soil types.

Alpha code	Soil Name	Slope	Description
ArE	Arundel loamy fine sand	8 to 25%	moderately deep and well drained. Rock outcrops are common. Underlying bedrock is white fossiliferous claystone
OrB	Orangeburg sandy loam	1 to 5 %	soil deep and well drained, on nearly level and gently sloping ridgetops
OrC	Orangeburg sandy loam	5 to 8%	soil is deep and well drained, on sloping ridgetops and side slopes
OrE	Orangeburg sandy loam	8 to 20%	soil deep and well drained, on moderately sloping to moderately steep side slopes
TrD	Troup loamy sand	5 to 15%	soil is deep and well drained, on narrow moderately sloping or moderately steep side slopes

Monroe County (Dungan, 1986)

One primary soil type is found on the slopes in Monroe County, Arundel loam, with an 8 to 35% slope. This is a moderately deep and well-drained soil as is the Luverne sandy loam, the second soil type of the slopes. Within the Arundel loam are areas of cobble and stone piles.

Six soil types may be found on the ridges, including Arundel loam, two types of Lucy loamy sand, two types of Luverne sandy loam, and the Saffell-Lucy complex. All soils are well drained, with slope angles ranging from 1 to 35%. The Saffell-Lucy complex, unlike the other soils, contains gravels (Table 9).

Table 9. Monroe County soil types.

Alpha code	Soil Name	Slope	Description
ArF	Arundel loam	8 to 35%	moderately deep, well-drained soil on narrow upland ridges and side slopes. Areas of cobble and stone piles common
LnB	Lucy loamy sand	1 to 5%	deep well-drained soil on broad ridges
LnC	Lucy loamy sand	5 to 8%	deep well-drained soil on broad ridges and side slopes
LvC	Luverne sandy loam	5 to 10%	deep well-drained soil on ridges and side slopes
LvE	Luverne sandy loam	10 to 25%	deep well-drained soil on narrow ridges and side slopes
SgF	Saffell-Lucy complex	15 to 35%	deep well-drained gravelly and sandy soils on uplands. Landscape a series of convex side slopes with narrow drains and narrow to broad ridges

Soils within Habitat Delineations

Fourteen soil types were identified within the tracks of the habitat delineations, although this number may be collapsed through a comparison of county soil names and descriptions. Although there is an apparent diversity of soil types associated with Red Hills salamander habitat only two stand out and combined constitute 87% of the total amount of soils identified. These are the Arundel fine sandy loam, with 8 to 35 percent slopes and the Luverne sandy loam, with 8 to 25 percent slopes. Percentage totals for these soil types were 71.7% and 15.8%, respectively (Table 10). The obvious characteristics of these two soil types, indicating their favorability for Red Hills salamanders, are the sandy loamy nature which would facilitate burrowing and their occurrence on steep slopes.

Table 10. The diversity and abundance of soil types associated with Red Hills salamander habitat. The majority of the percentage of soils is composed of only two types with one of those being extremely abundant.

Soil Type	**% of Total**
Arundel fine sandy loam, 8 to 35 percent slopes	0.7167
Luverne sandy loam, 8 to 25 percent slopes	0.1579
Saffell-Lucy complex, 15 to 35 percent slopes	0.0341
Troup-Alaga complex, 5 to 15 percent slopes	0.0243
Iuka and Mantachie soils, 0 to 2 percent slopes, frequently flooded	0.0188
Mantachie, Bibb, and Iuka soils, 0 to 1 percent slopes, frequently flooded	0.0127
Orangeburg sandy loam, 8 to 20 percent slopes	0.0114
Rains-Bethera complex, 0 to 2 percent slopes, frequently flooded	0.0092
Bama sandy loam, 1 to 5 percent slopes	0.0058
Lucy-Troup loamy sands, 8 to 25 percent slopes	0.0039
Izagora, rarely flooded-Bethera, occasionally flooded association, 0 to 3 percent slopes	0.0028
Conecuh sandy loam, 2 to 8 percent slopes	0.0019
Smithdale sandy loam, 8 to 15 percent slopes	0.0003
Troup-Orangeburg association, 8 to 25 percent slopes	0.0003

As with the geological layers, the inclusion of the soils of minor percentage may be due to the observer straying onto these soils during the course of habitat delineation, mapping errors which were introduced while soil maps were being digitally converted, or a lack of field checking of the soil distributions. The Arundel fine sandy loam (8 to 35% slope) and Luverne sandy loam (8 to 25% slope) are the key soil types pertaining to Red Hills salamander habitat, nonetheless, Red Hills salamanders may occasionally inhabit burrows which are found in these less abundant soil types.

Within the range of the gopher tortoise an important abiotic determinant of the presence or absence of the tortoise is soil type. Tortoises require a soil in which they can construct burrows. Of the five sites on which the presence of tortoises was noted, eight soil types were identified. These were Alaga-Troup complex, 0 to 5% slope; Alaga-Troup complex, 5 to 15% slope; Arundel loamy fine sand, 4 to 25% slope; Orangeburg sandy loam, 1 to 5 % slope; Orangeburg sandy loam, 5 to 8% slope; Troup loamy sand, 2 to 8% slope; Troup-Alaga complex, 5 to 15% slope; and Troup-Orangeburg association, 8 to 25% slope.

Woody Vegetation of Slopes

Red Hills salamander hardwood-dominated slope forests have been given the following description under NatureServe's community classification scheme along with a Global Rank of G2:

***Fagus grandifolia - Magnolia grandiflora / Ostrya virginiana / Aesculus parviflora* Forest**

Translated Name: American Beech - Southern Magnolia / Eastern Hophornbeam / Bottlebrush Buckeye Forest

Common Name: Red Hills Beech - Magnolia Forest

Unique Identifier: CEGL008554

Classification Approach: International Vegetation Classification (IVC)

Summary: This is a generally circumneutral beech - magnolia association which occurs on slopes in the Alabama Red Hills area. It occurs in mesic conditions on slopes of various aspects. *Fagus grandifolia* and *Magnolia grandiflora* are canopy dominants in most stands, with *Fagus grandifolia* generally more abundant. Other canopy dominants include *Liquidambar styraciflua, Fraxinus americana, Liriodendron tulipifera, Tilia americana var. caroliniana, Magnolia macrophylla, Quercus pagoda, Ostrya virginiana, Carya carolinae-septentrionalis*, and *Quercus alba*. *Carya carolinae-septentrionalis* is a characteristic but not constant species, which occurs in many stands of this association in the Alabama Red Hills, but does not occur in Florida, or west of the Mississippi River. The subcanopy can be dominated by *Magnolia grandiflora, Ostrya virginiana, Halesia diptera, Ilex opaca, Magnolia macrophylla, Fagus grandifolia*, and/or *Cornus florida*. Also of interest are *Magnolia pyramidata* and *Magnolia acuminata* which are found in some stands. The most important shrub for differentiating the type is *Aesculus parviflora*, which is found in nearly all stands and is nearly endemic to Alabama. Other important shrubs are *Ostrya virginiana, Illicium floridanum, Hydrangea quercifolia, Arundinaria gigantea, Halesia diptera, Aesculus pavia, Fagus grandifolia, Magnolia grandiflora*, and *Calycanthus floridus var. floridus*. The herbaceous layer is generally sparse. The most common herbaceous plants include *Polystichum acrostichoides, Laportea canadensis, Smilax hugeri, Carex* spp., *Luzula* spp., *Hexastylis arifolia, Mitchella repens, Solidago caesia, Phegopteris hexagonoptera, Chasmanthium sessiliflorum, Dioscorea quaternata, Sanicula canadensis*, and

Aristolochia serpentaria. Some stands of this association support populations of the threatened *Phaeognathus hubrichti* (Red Hills salamander) (Figure 6).

Figure 6. Two examples depicting optimum habitat of the Red Hills salamander. Illustrated are steep, north-facing, mesic, hardwood-dominated slopes with a forest canopy of near complete closure. Slope faces in the photos lie on the Tallahatta and Hatchetigbee geological formations.

As the available habitat descriptions pertaining to the forest cover are qualitative (Bailey and Means, 2004; Dodd, 1991; French and Mount, 1978; Jordan and Mount, 1975; Mount, 1975), quantitative data is unavailable. Vegetation sampling was done at nine sites with viable *P. hubrichti* populations to generate a reference of quantatitive information.

For the following results the data from the nine sampled sites was pooled. Sixty-eight taxa of woody species were identified with 41 being categorized as trees and 26 as shrubs. A distinction was made with the categorization of the woody species as follows: those species that contributed to the canopy were labeled "tree" and those that formed the sub-canopy were labeled "shrub". Ecologically the forest canopy serves an important role by moderating ambient temperatures and relative humidities on the slopes. The microclimate of a slope under a closed, or nearly closed, canopy will have a cooler temperature and higher relative humidity as compared to a similar exposed slope. Environmentally these conditions are necessary for the existence of *P. hubrichti* because, being a plethodontid salamander, a moist skin surface for respiration must be maintained.

The following canopy-forming species were found on all sites: *Acer saccharum*, *Cornus florida*, *Fagus grandifolia*, *Ilex opaca*, *Magnolia grandiflora*, and species of deciduous *Quercus*. Other widespread canopy species included *Carya* sp., *Liquidambar styraciflua*, *Liriodendron tulipifera*, *Magnolia macrophylla*, *Osytra virginiana*, *Oxydendrum arboretum*, *Pinus glabra*, and *Symplocus tinctoria*. Common sub-canopy species were *Aesculus pavia*, *Hamamelis* *virginiana*, *Hydrangea quercifolia*, *Kalmia latifolia*, *Rhododendron* sp., and *Vaccinium* sp*.* *Illicium floridanum* is a common shrub throughout the Red Hills and was captured in numerous samples. In fact, it was numerically the most abundant species of all, but was dropped for the final analysis. *I. floridanum* is a species more of the floodplain habitat which lies along the slope base, and here *I. floridanum* often occurs in dense stands. Its inclusion in the sampling was based on transects ending at the base of the slopes which is typically uninhabitated by *P. hubrichti*, thus the decision to eliminate *I. floridanum* from the final analysis.

Representative habitat of the Red Hills salamander, in general, has been described as a beech-magnolia slope forest. This description is fitting, because on many sites the visually dominant trees are American beech, and southern and bigleaf magnolia. Other species, such as hop-hornbeam, sugar maple, flowering dogwood, mountain laurel, and rhododendron, are important forest species and at times more abundant than the apparent dominants and as such have not been recognized in that respect. Table 11 is a listing of the numerically more dominant tree species. American beech, Amerian holly, and magnolia are included within this listing of the eight most abundant species, while other important species, which have not been recognized in descriptions, include sugar maple and hop-hornbeam.

Table 11. Abundance of the more common canopy species on sampled Red Hills salamander (*P. hubricthti*) sites.

Species	Relative Frequency	Common Name
Fagus grandifolia	0.169	American beech
Acer saccharum	0.135	sugar maple
Ilex opaca	0.130	American holly
Ostrya virginiana	0.120	hop-hornbeam
Quercus sp.	0.052	deciduous oak
Magnolia deciduous (primarly *macrophylla*)	0.051	big leafed magnolia
Magnolia grandiflora	0.042	southern magnolia
Cornus florida	0.040	flowering dogwood

Important sub-canopy species were mountain laurel and rhododendron, both of which occupy the higher portions of the slopes, often along the steep escarpment of the Tallahatta Formation. Other species, such as cane, oak leaf hydrangea, witch hazel, and viburnum, are scattered along the slope face between the base and the upper brow line. Cane was numerically the second most abundant species because it tends to grow in clumps with numerous shoots. Cane stands on slopes do not achieve the dense stands nor height seen in floodplain stands. Table 12 presents the 10 most abundant sub-canopy woody species.

Table 12. Abundance of the more common sub-canopy species on sampled Red Hills salamander (*P. hubricthti*) sites.

Species	Relative Frequency	Common Name
Kalmia latifolia	0.280	mountain laurel
Arundinaria gigantea	0.189	cane
Rhododendron sp.	0.122	rhododendron
Aesculus pavia	0.084	red buckeye
Vaccinium (probably *arboreum)*	0.062	vaccinium
Hydrangea quercifolia	0.051	oak leaf hydrangea
Hamamelis virginiana	0.044	witch hazel
Carpinus carolinaina	0.032	ironwood
Euonymous americanus	0.028	strawberry bush
Viburnum sp.	0.025	viburnum

Abundance is only one measure of the forest cover; size based on diameter at breast height (DBH) is one other means of generating data on canopy composition. The measurement of DBH is based on the assumption that trees with a large DBH will contribute to a higher degree to the overall canopy, i.e. individuals with a larger DBH will have a broader crown providing more shade in the summer and leaf fall in the winter. Based on an average DBH for trees with > 50 observations, of which there were 13 species, the oaks, yellow poplar, hickory, and spruce pine were the three largest (Table 13). Oak, yellow poplar, spruce pine, and American beech had the largest individuals.

Of the 13 tree species with the larger average DBH figures, 10 are deciduous and three are evergreen. This is an important ecological characteristic of this habitat. Each year in the fall when the trees drop their leaves the deciduous trees will add a top layer to the leaf litter of the slopes. The surficial leaf litter is presumed to be the microhabitat of a large portion of the prey base of *P. hubrichti*.

Table 13. Average diameters of the respective canopy species on sampled Red Hills salamander (*P. hubricthti*) sites.

Species	Average DBH (cm)	Minimum DBH (cm)	Maximum DBH (cm)	Total Number	Common Name
Fagus grandiflolia	14.2	2.0	73.2	583	American beech
Ostrya virginiana	7.3	2.0	46.1	234	hop-hornbeam
Ilex opaca	6.4	2.0	25.0	217	American holly
Magnolia macrophylla	11.2	2.3	35.4	187	bigleaf magnolia
Quercus sp.	25.0	2.0	114.0	179	deciduous oak
Magnolia grandiflora	10.7	2.2	48.5	149	southern magnolia
Pinus glabra	25.7	3.8	73.0	134	spruce pine
Cornus florida	7.9	2.2	19.2	118	flowering dogwood
Carya sp.	22.3	2.7	53.4	116	hickory
Liquidambar styraciflua	13.3	3.2	52.0	79	sweetgum
Acer saccharum	9.0	2.0	34.8	79	sugar maple
Oxydendron arboreum	14.2	3.0	35.0	71	sourwood
Liriodendron tulipifera	25.0	2.7	88.0	66	yellow poplar

Line Transects, Predictive Models, and Burrow Density Estimation

Analysis of data was conducted in several separate analyses. The first analysis estimated the probability of *P. hubrichti* burrow presence or absence with respect to several micro-site habitat features. Hereafter this analysis will be referred to as *burrow occupancy*. The second analysis estimated *P. hubrichti* burrow density across the study sites. An evaluation of burrow density heterogeneity as explained by micro-site features was performed. This analysis will be termed *burrow abundance* hereafter. A third analysis was a re-evaluation of historical data on *P. hubrichti* burrow density. This data is included to better help understand expected densities for *P. hubrichti* burrows across time and space; hereafter, this analysis will be known as *historical burrow abundance*. A fourth analysis is a brief evaluation of the spatial aggregation of burrow on a slope. This analysis may yield information on the clustering tendency on the micro-distribution of burrows.

Results for each separate analysis are reported below. Within the text for each analysis the following information is provided: 1) specific objectives for the analysis, 2) description of data collection and statistical methodology, and 3) results of statistical analysis. The final section of the report contains instructions for the use of statistical analyses in evaluating potential *P. hubrichti* habitat for conservation purposes.

Burrow Occupancy

METHODS

FIELD DATA COLLECTION PROTOCOL

Data on *P. hubrichti* burrows was collected in Butler, Conecuh, Covington, and Monroe counties, Alabama between April and September, 2006 and 2007. Study sites were defined as areas of slope bordering creeks between the Alabama and Conecuh Rivers and were selected on 7.5' USGS topographic quadrangles. The Tallahatta and Hatchetigbee geologic formation emerge in the regions surrounding numerous creeks in the area, and their emergence typically creates an area with average slope of 28.9° (Range: 61.0° to 6.0°).

Each slope was surveyed by uniquely numbered transects that ran perpendicular to the ridge and whose origin was spaced approximately 10 m apart along the ridge. Data collection proceeded by the observer starting at the bottom of the slope and ascending to the ridge. Prior to ascent the observer recorded the angle for the entire slope with a clinometer and estimated the directional aspect of the slope face. Angle slope was estimated as the angle created by the observer's height at the bottom of the slope and a similar height previously marked on a tree at the top of the slope. These angle and slope aspects are transect-level variables and for the purpose of analysis were ascribed to each sampling point contained within transect. Slope aspect was recorded to the nearest cardinal direction (i.e., N, NNE, NE, ENE, W, etc.). Slope aspect was transformed into its numerical equivalent prior to statistical analysis (e.g., E = 90^{o}). Aspect is a circular variable (i.e., 0^{o} = 360^{o}) and must be transformed prior to its use in statistical analyses. The technique developed by Jammalamadaka and Lund (2006) was used to transform slope aspect. Briefly, the transformation requires 2 variables to accurately describe slope aspect (i.e., one to account for the "northness" and one to account for the "eastness").

Data was collected systematically and opportunistically along each transect. Systematic sampling provided randomly selected locations that lacked a *P. hubrichti* burrow, while opportunistic sampling enabled quantification of *P. hubrichti* burrows. This sampling approach ensured that covariates would be collected at points where *P. hubrichti* burrows were present (i.e., opportunistic sampling) and absent (i.e., systematic sampling). Systematic sampling was conducted at 5 m intervals along each transect, while opportunistic sampling was done whenever, along the transect, the observer detected a *P. hubrichti* burrow. A sampling point is defined for systematic sampling as a randomly selected point adjacent to each 5 m increment along the transect and for opportunistic sampling as a *P. hubrichti* burrow detected adjacent to the transect regardless of the distance increment. At each systematic sampling point, a *P. hubrichti* burrow was marked as present if it occurred within 1 m of the randomly selected location. A sampling point in systematic sampling was not taken if it was within 2 m of an opportunistically detected *P. hubrichti* burrow. A sampling point will refer to the randomly selected point associated with systematic sampling and individual burrow opening associated with opportunistic sampling. The response variable in the analysis is considered to be whether a burrow was present or not at each sampling point.

Several variables were recorded at each sampling point. Micro-site estimates of slope were determined at each sampling point or detected *P. hubrichti* burrow. For sampling points without a burrow, micro-site slope was estimated as the slope over an approximate 6 cm section centered on the sampling point. When a burrow was detected, micro-site slope was estimated as the angle at the burrow hole. Micro-site slope was estimated with a clinometer. Soil density was estimated within 10 cm of each sampling point with a soil penetrometer and recorded to the nearest 0.1 kg/cm^2. Canopy coverage above each sampling point was estimated with a densitometer. Densitometer readings return the percentage of unobstructed sky (i.e., 5% indicates a 95% canopy coverage).

Several aspects of the plant community at each sampling point were estimated. Dominant tree species in the canopy directly above the sampling point were recorded, and data on all tree (species and diameter at breast height [DBH] for each stem) and shrub (species and number of stems per individual plant) species for all plant individuals within 1 m of the sampling point. DBH and stem count data per sampling point were then summarized. TOTALDBH is the summed DBH of all tree stems within 1 m of the sampling point. SHRUBNUM is the total number of shrub stems within 1 m of the sampling point.

The hypothesis was generated that several plant species might represent a high quality habitat for *P. hubrichti*. These species are as follows: American beech (*Fagus grandifolia*), American holly (*Ilex opaca*), American hop hornbeam (*Ostrya virginiana*), deciduous magnolia species (*Magnolia* spp.), Florida maple (*Acer saccharum*), mountain laurel (*Kalmia latifolia*), white oak (*Quercus alba*), and yellow poplar (*Liriodendron tulipifera*). The variable, PERCENTSPP, that represents the percentage of these species present at each sampling (e.g., if 2 of the 9 species were present at a sampling point, PERCENTSPP = 0.22) was developed. Since PERCENTSPP was a percentage, it was arcsine transformed prior to use in statistical analyses (Zar 1984).

STATISTICAL METHODOLOGY

Generalized non-linear models with a binomial likelihood to model heterogeneity in the probability of *P. hubrichti* burrows as a function of habitat and terrain covariates (Hosmer and Lemeshow 2000) were used. The probability of a *P. hubrichti* burrow being present (BURROW) as a function of the following covariates: slope aspect (ASPECT), canopy density above sampling point (CANOPYDENS), percentage of plant species present in hypothetical quality habitat (PERCENTSPP), total number of shrubs within 1 m of a sampling point

(SHRUBNUM), measurement of soil density (SOILPENT), and summed DBH of all trees within 1 m of a sampling point (TOTALDBH) was modeled. Inferences made from these results are qualitatively similar to those made from results of patch occupancy analyses (e.g., MacKenzie, et al. 2002); however, burrow detection rates were not estimated. *P. hubrichti* burrows are conspicuous and detection is near unity. A suite of *a priori* models of burrow occupancy based on novel hypotheses, field observations, and other findings in the literature was developed.

A priori models of burrow occupancy were incorporated into the binomial likelihood via a logit link function (Hosmer and Lemeshow 2000). Model adequacy was evaluated with the test described by Hosmer and Lemeshow (1980). Pigeon and Heyse (1999) and Kuss (2002) suggested this test may not be appropriate when continuous covariates are used; however, sample sizes were large and this reduces the bias associated with incorporation of continuous covariates (Kuss 2002). Model adequacy was evaluated at the global model (i.e., the most highly parameterized model) and the *a priori* best model selected with the information theoretic approach to model selection.

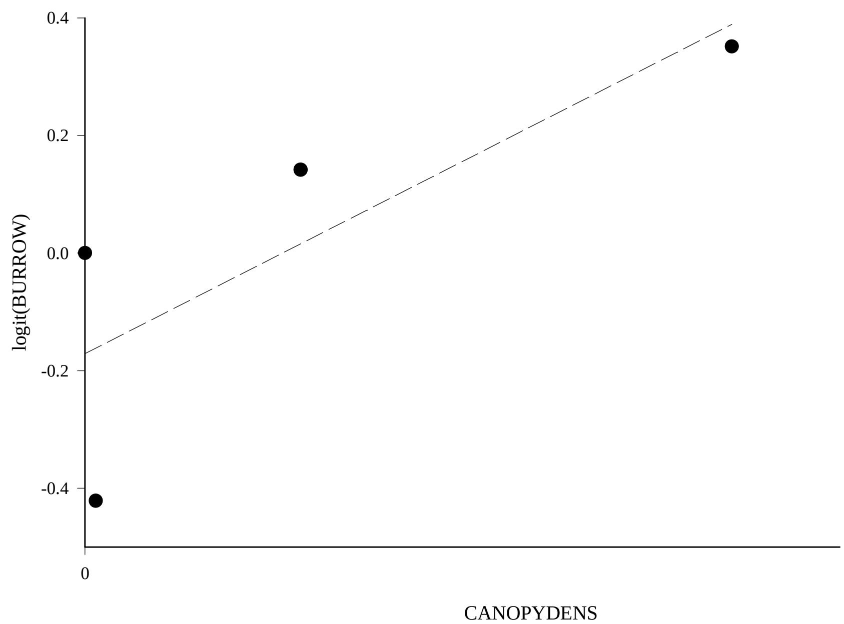
Continuous covariates were used in models of *P. hubrichti* burrow presence. The incorporation of continuous covariates into the logit link function assumes a linear effect between the covariate and the response variable (Hosmer and Lemeshow 2000). Hosmer and Lemeshow (2000: 99) suggest the use of *group smoothed plots* to evaluate this assumption of linearity. In this procedure, the observed values were ranked for a particular continuous covariate by magnitude and categorized observations by deciles. Then a 10-level categorical variable was created to describe classification of the continuous covariate into deciles. The continuous covariate was replaced with its categorical representation in the AIC best model for the particular covariate. Maximum likelihood estimates of model parameters were then recalculated. A group smoothed plot was then developed from the resulting beta values for the categorical variable and midpoints of each decile. The plotted points should be nearly linear if the assumption of linearity in a continuous covariate is appropriate. If the plotted points are not linear, the parametric form of the continuous covariate (e.g., quadratic, sigmoid, etc.) will be discernable from the plot. Parameter transformations were done in Sigmaplot®. The final candidate set of *a priori* models for DSR and DMR are those where continuous covariate(s) is of the appropriate form suggested by group smoothed plots.

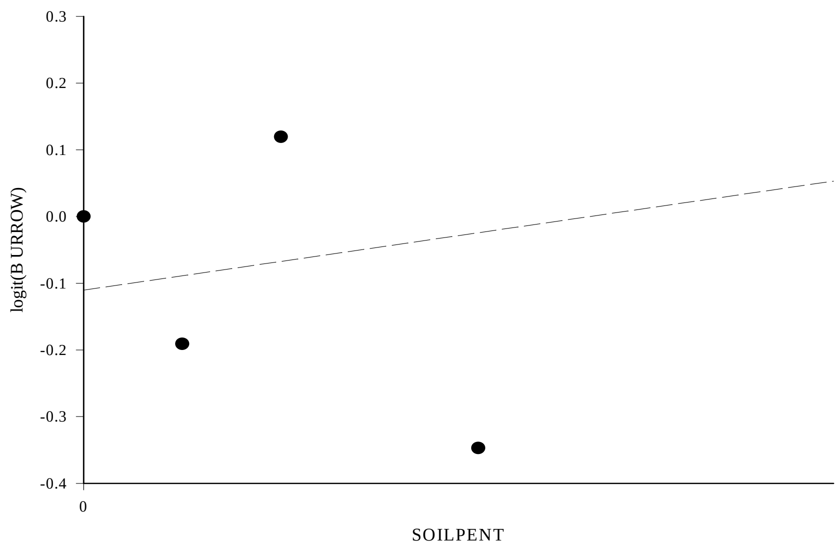
An information theoretic approach to model selection was used. Because the ultimate interest was in deriving statistical models for use in prediction of burrow occupancy, Akaike's Information Criterion (AIC, Akaike 1973) was used. Model comparisons were made with Δ_i, which is the difference between the AIC value for model *i* and the lowest observed AIC value among the candidate set of models. Models with $\Delta_i < 2$ are considered to have substantial support given the data. The Akaike weight per model was computed which reflects the relative likelihood of the model given the data and the candidate model set (Burnham and Anderson 2002). Sugiura's (1978) Second-Order form of AIC was not used (frequently referred to as *small sample AIC*; Burnham and Anderson [2002]) in analysis of burrow occupancy because the ratio of sample size to maximum number of parameters was large. Inferential parameters (e.g., estimated maximum likelihood beta values for covariates) came from the AIC best model (i.e., $\Delta_i = 0$) if little uncertainty existed in model selection (i.e., Akaike weight > 0.90 for AIC best model). If uncertainty did exist, inference came from across all models with model averaged parameters and unconditional standard errors (Burnham and Anderson 2002). Estimates of DSR were derived from model averaged betas values for the covariates with substantial support (i.e., Akaike weights > 0.38; White and Burnham 2005). The relative importance of a covariate was calculated by summing the Akaike weights for models that contain that covariate. Covariates that explain considerable heterogeneity in burrow occupancy will have a low AIC value and thus high Akaike weights.

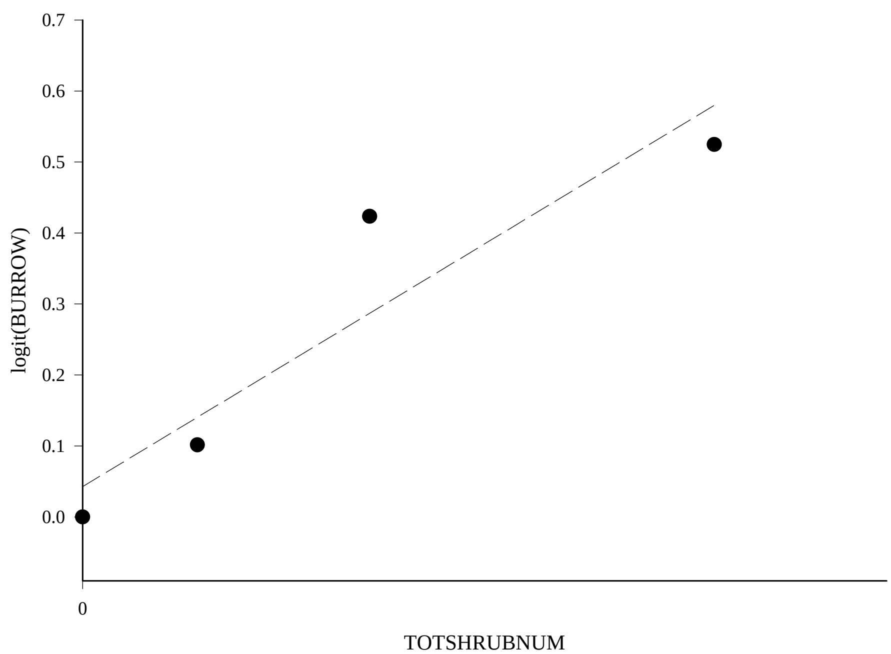
RESULTS

Six continuous covariates (CANOPYDENS, PERCENTSPP, SOILPENT, TOTALDBH, and TOTSHRUBNUM) were used to model heterogeneity in the response variable BURROW. Group smoothed plots for CANOPYDENS, SOILPENT, and TOTSHRUBNUM did not suggest that the relationship to BURROW was nonlinear (Figure 7*a*, *b*, *c*). Because these group smoothed plots did not suggest an alternative form (e.g., quadratic, etc.), we did not transform these continuous covariates in the *a priori* set of models explaining heterogeneity in BURROW. A group smoothed plot was not produced for PERCENTSPP nor TOTALDBH due to the distribution of the observed data. Parsing PERCENTSPP or TOTALDBH into deciles (or any other bin width) was not possible because of the distribution of observations.

Figure 7 a, b, c. Group smoothed plots of continuous covariates CANOPYDENS, SOILPENT, and TOTSHRUBNUM used in analyses of presence of *Phaeognathus hubrichti* burrows (BURROW) in south-central Alabama, 2006-2007. Plots did not suggest a nonlinear form between the continuous covariate and BURROW; therefore, CANOPYDENS, SOILPENT, and TOTSHRUBNUM were not transformed prior to inclusion in the *a priori* model set for BURROW.







Twenty-two *a priori* models were constructed to explain heterogeneity in BURROW (Table 14). These models represented covariate combinations that come from field knowledge of Red Hills salamanders and covariate combinations that would be interpretable in *post hoc* model evaluation. Model selection results indicated the model with CANOPYDENS and PERCENTSPP best explained heterogeneity in BURROW with ΔAIC = 0 (Table 15). The second AIC-best model was ΔAIC = 59.94, and does not support considering all *a priori* models. Therefore, inference was derived from the AIC-best, and subsequent discussion is derived from the estimated model parameters. Analysis indicates that the probability of burrow occurrence increases with increasing canopy density (Figure 8) and decreases with increasing proportion of plant species hypothesized to represent quality habitat (Figure 9). Figure 10 presents a three-dimensional plot of the probability of *P. hubrichti* burrow occurrence with respect to both CANOPYDENS and PERCENTSPP simultaneously.

Table 14. List of all *a priori* models considered in analysis of heterogeneity of the probability of the presence of *Phaeognathus hubrichti* burrows. List does not include the null model which estimates only an intercept value for the logistic equation.

Model number	BURROW models	Model number	BURROW models
1	CANOPYDENS PERCENTSPP	12	ASPECT TOTALDBH
2	PERCENTSPP TOTALDBH	13	SOILPENT TOTALDBH
3	PERCENTSPP SOILPENT	14	TOTALDBH SHRUBNUM
4	PERCENTSPP ASPECT	15	SOILPENT ASPECT
5	PERCENTSPP SHRUBNUM	16	ASPECT SHRUBNUM
6	PERCENTSPP	17	SOILPENT SHRUBNUM
7	CANOPYDENS TOTALDBH	18	TOTALDBH
8	CANOPYDENS SOILPENT	19	ASPECT
9	CANOPYDENS ASPECT	20	SOILPENT
10	CANOPYDENS SHRUBNUM	21	SHRUBNUM
11	CANOPYDENS		

Table 15. AIC Model selection results for models explaining heterogeneity in the probability of *Phaeognathus hubrichti* burrow occurrence (BURROW). All other models not presented were ΔAIC > 98.27.

Model	K^a	-Log(£)	AIC	ΔAIC	Model Weight	Model Likelihood
PERCENTSPP CANOPYDENS	3	2930.0	5866.02	0	1.0	1.0
PERCENTSPP TOTALDBH	3	2960.0	5925.96	59.94	0	0
PERCENTSPP SOILPENT	3	2976.7	5959.33	93.31	0	0
PERCENTSPP ASPECT	3	2977.5	5961.03	95.01	0	0
PERCENTSPP TOTSHRUBNUM	3	2979.1	5964.29	98.27	0	0

[a] Number of estimated parameters.

Figure 8. Probability (and 95% Confidence interval) of the presence of *Phaeognathus hubrichti* burrows (BURROW) plotted with respect to canopy density (CANOPYDENS). Probability was only computed for the range of densities observed in the field.

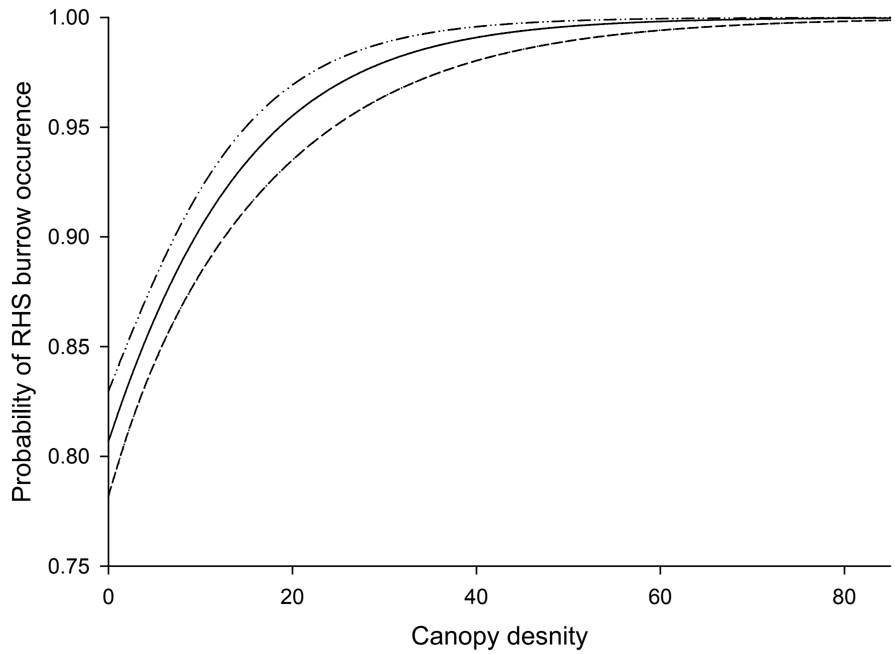


Figure 9. Probability (and 95% Confidence interval) of the presence of *Phaeognathus hubrichti* burrows (BURROW) plotted with respect to percent of plant species hypothesized to represent quality *P. hubrichti* habitat (PERCENTSPP). PERCENTSPP has been back transformed with the arc sine transformation for this figure; therefore, values on the x-axis represent actual percentages.

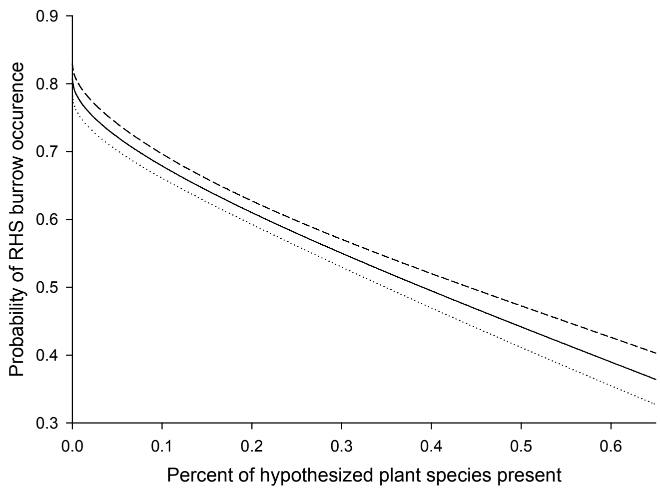
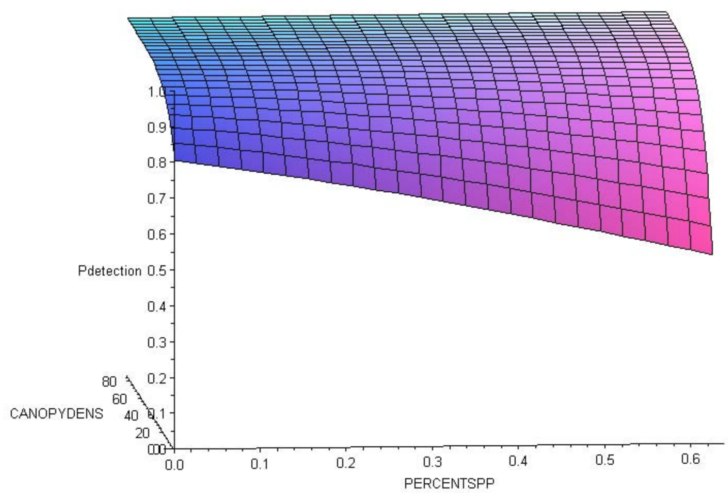
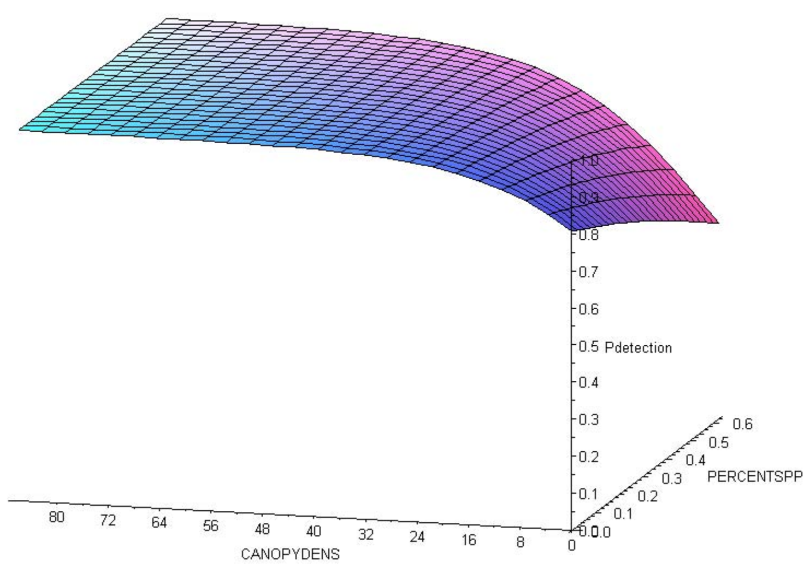


Figure 10. Three-dimensional plot of the relationship of probability of *Phaeognathus hubrichti* burrow occurrence (BURROW) with respect to canopy density (CANOPYDENS) and the percent of hypothesized, indicator plant species present (PERCENTSPP).





The hypothesis that a particular suite of plant species would represent high quality *P. hubrichti* habitat (i.e., we should find a greater percentage of these plant species in concert with *P. hubrichti* burrows as compared to sampling points that lack RHS burrows) was formulated. The presence of PERCENTSPP in the AIC best initially supported this contention, yet Figure 9 suggests that the probability of *P. hubrichti* burrow occurrence declines with increasing proportion of these hypothesized, indicator plant species. This pattern was further investigated by evaluating which of the eight hypothesized plant species may be important for *P. hubrichti*. Because the list of hypothesized, indicator plant species was developed *a priori* to analysis, we used a stepwise logistic regression to parse out which of the eight species was most important for *P. hubrichti* burrow presence. The eight plant species that were initially used to create PERCENTSPP (i.e., American beech, American holly, American hop hornbeam, deciduous magnolia species, Florida maple, mountain laurel, white oak, and yellow poplar) were included. Results of stepwise logistic regression indicate that the probability of detecting *P. hubrichti* burrows is highest with the presence of American beech, American holly, deciduous magnolia species, mountain laurel, and yellow poplar (P[RHS burrow] = 0.995 [0.986-0.997]) as compared to locations with the other species (i.e., American hop-hornbeam, Florida maple, and white oak) (P[RHS burrow] = 0.608 [0.543-0.669]).

Burrow Density

OBJECTIVES

The primary objective of this analysis was to estimate *P. hubrichti* burrow density across sites considered in this project. A secondary objective was to evaluate if *P. hubrichti* burrow density differed substantially between study sites or with respect to other transect level variables. Estimation of *P. hubrichti* burrow density will establish benchmark levels to be compared to future estimates. It will also better elucidate the range of *P. hubrichti* burrow densities on inhabited sites. Comparison to historical data may aid in indentifying trends in population levels.

METHODS

FIELD DATA COLLECTION PROTOCOL

Data used in analysis of *P. hubrichti* burrow density was identical to that used for estimating *P. hubrichti* burrow occupancy; thus, field data collection procedures are identical to those described in the **BURROW OCCUPANCY** section above. In addition to the dataset described above, the perpendicular distance from the centerline of the transect to all detected *P. hubrichti* burrows was recorded.

STATISTICAL METHODOLOGY

P. hubrichti burrow density was estimated with multiple covariate distance sampling protocol similar to that in Marques et al. (2007). Density was estimated at the transect level (i.e., for a given study site and/or slope, multiple transects ran perpendicular to the slope). Data were first fit with several global models that included unique combinations of key functions (i.e., uniform, negative exponential, half normal, and hazard rate) and series expansion terms (i.e., cosine, simple polynomial, and Hermite polynomial). Data was verified that it could be described by different combinations of these functions and expansion terms, and the data as a whole was considered (i.e., we did not evaluate key function and expansion term fit with covariates). For the key function and expansion term combinations that were capable of describing the data, we then evaluated whether heterogeneity in density data could be explained by study site, aspect of transect, and angle of overall slope the transect covered. Several *a priori* models of heterogeneity in *P. hubrichti* burrow density based on statistical considerations (i.e., key functions and expansion terms) and biological hypotheses (i.e., covarites) were constructed.

RESULTS

The data analyzed was appropriately described by a variety of key functions and expansion terms. The following combinations were used in density estimation procedures: half-normal and cosine, uniform and cosine, half-normal and simple polynomial, half-normal and hermite polynomial, negative exponential and cosine, negative exponential and cosine, uniform and simple polynomial, hazard rate and simple polynomial, hazard rate and cosine. For these key function/expansion term combinations, covariates for study site (SITE), slope aspect (ASPECT), and overall angle of slope (SLOPE) were included. At most one covariate per model was included, because interpretation of multi-covariate models would be limited. Table 16 provides results of *a priori* model fitting. The half-normal key function, with cosine expansion term, plus covariate SITE model was the best to explain heterogeneity in the dataset. The next AIC-best model (uniform key function, cosine expansion term, covariate SITE) was ΔAIC > 2.0 and therefore was not a model to be considered for inference (Table 16).

Table 17 and Figure 11 present Red Hills Salamander burrow densities across study sites. All estimated values are within bounds previously documented by other researchers. Estimates of variability with 95% confidence intervals appear consistent across all study sites.

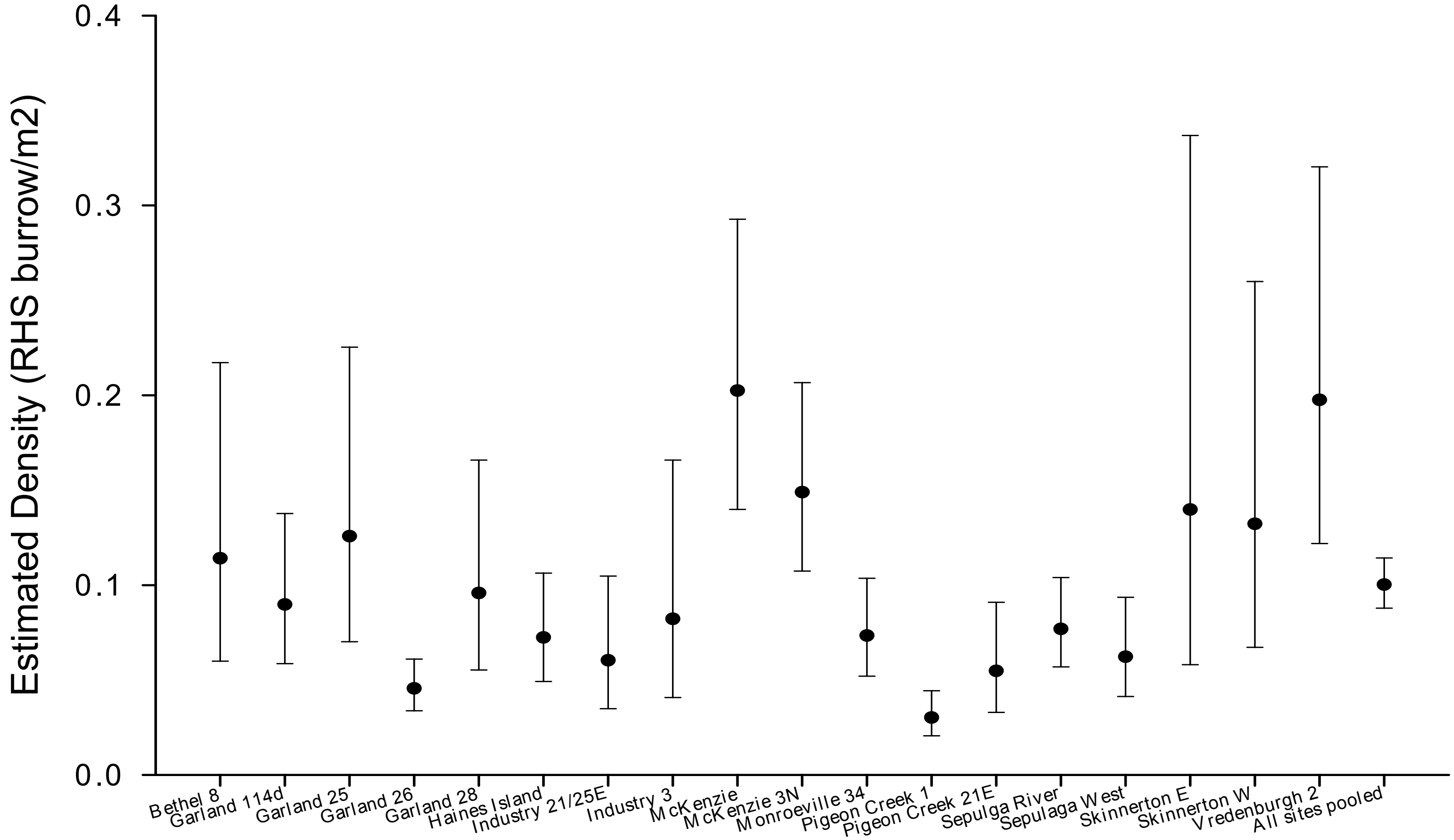
Table 16. Information theoretic model selection results for models explaining heterogeneity in *P. hubrichti* burrow density. Models are ranked by ΔAIC (Akaike's Information Criterion), which is the difference between each candidate model and the model with the lowest AIC value. Key functions are uniform (UNI), negative exponential (NE), half normal (HN), or hazard-rate (HR). Series expansions are cosine (COS), simple polynomial (SP), or Hermite polynomial (HP). Covariates used in models are angle of overall slope (ANGLE), aspect of slope (ASPECT), and study site (SITE).

Model #	Key Function	Series Expansion	Covariate	-Log(£)	*K*	AIC	ΔAIC
1	HN	COS	SITE	-8651.72	25	17353.44	0
2	HN	SP	SITE	-8652.67	26	17357.35	4.25
3	HR	SP	-	-8698.64	5	17407.28	52.12
4	HN	COS	ASPECT	-8689.65	14	17407.30	52.37
5	HN	HP	ASPECT	-8689.65	14	17407.30	52.37
6	HN	SP	ASPECT	-8689.65	14	17407.30	52.37
7	UNI	COS	-	-8702.39	2	17408.79	53.59
8	HN	SP	-	-8704.04	1	17410.08	54.89
9	HN	HP	-	-8704.04	1	17410.08	54.89
10	HN	COS	-	-8704.04	1	17410.08	54.89
11	NE	COS	-	-8702.17	3	17410.34	55.15
12	NE	SP	-	-8701.45	4	17410.91	55.73
13	HN	SP	ANGLE	-8705.97	2	17415.94	60.74
14	HN	HP	ANGLE	-8705.97	2	17415.94	60.74
15	HR	COS	-	-8726.59	2	17457.18	101.98
16	HR	COS	ANGLE	-8733.17	3	17472.34	117.16

Table 17. Density estimates of Red Hills Salamander in south central Alabama, 2006-2007.

Study Site	n	Model	Density Estimate	95% CI
Bethel 8	24	Half normal / cosine	0.1141	0.0599-0.2172
Garland 25	88	Half normal / cosine	0.1258	0.0702-0.2254
Garland 26	100	Half normal / cosine	0.0455	0.0338-0.0611
Garland 28	81	Half normal / cosine	0.0958	0.0553-0.1659
Garland 35	85	Half normal / cosine	0.0898	0.0586-0.1377
Haines Island	108	Half normal / cosine	0.0724	0.0493-0.1063
Industry 21/25E	149	Half normal / cosine	0.0604	0.0349-0.1048
Industry 3	67	Half normal / cosine	0.0822	0.0408-0.1659
McKenzie	88	Half normal / cosine	0.2024	0.1399-0.2928
McKenzie 3N	137	Half normal / cosine	0.1490	0.1074-0.2067
Monroeville 34	88	Half normal / cosine	0.0734	0.0520-0.1036
Pigeon Creek 1	20	Half normal / cosine	0.0302	0.0206-0.0444
Pigeon Creek 21E	106	Half normal / cosine	0.0548	0.0330-0.0909
Sepulga River	85	Half normal / cosine	0.0769	0.0569-0.1040
Sepulaga West	93	Half normal / cosine	0.0622	0.0413-0.0936
Skinnerton E	80	Half normal / cosine	0.1398	0.0581-0.3369
Skinnerton W	65	Half normal / cosine	0.1323	0.0673-0.2599
Vredenburgh 2	131	Half normal / cosine	0.1976	0.1219-0.3203
All sites pooled	951	Half normal / cosine	0.1002	0.0879-0.1143

Figure 11. Graph illustrating the estimated densities (±95% CI) of Red Hills Salamander burrows across study sites in south-central Alabama, 2006-2007. Estimates were generated from AIC-best model in Table 4.



Historical Burrow Density

OBJECTIVES

The primary objective of this analysis was to estimate *P. hubrichti* burrow density from several historical datasets (data collected from 1999 to 2003). Estimates produced in this analysis provide additional benchmarks in which to evaluate *P. hubrichti* burrow densities from the current study.

METHODS

FIELD DATA COLLECTION PROTOCOL

Data used in analysis of *P. hubrichti* burrow density was similar to that used for estimating *P. hubrichti* burrow occupancy; thus, field data collection procedures are similar to those described in the **BURROW OCCUPANCY** section above. In addition to the dataset described above, the perpendicular distance from the centerline of the transect to all detected *P. hubrichti* burrows was recorded.

STATISTICAL METHODOLOGY

We estimated *P. hubrichti* burrow density with multiple covariate distance sampling protocol similar to that in Marques et al. (2007). Density was estimated at the transect level (i.e., for a given study site and/or slope, multiple transects ran perpendicular to the slope). Data were first fit with several global models that included unique combinations of key functions (i.e., uniform, negative exponential, half normal, and hazard rate) and series expansion terms (i.e., cosine, simple polynomial, and Hermite polynomial). We verified that the data could be described by different combinations of these functions and expansion terms, and we considered the data as a whole (i.e., we did not evaluate key function and expansion term fit with covariates). We estimated *P. hubrichti* historical burrow density estimates with the AIC best key function/expansion term model.

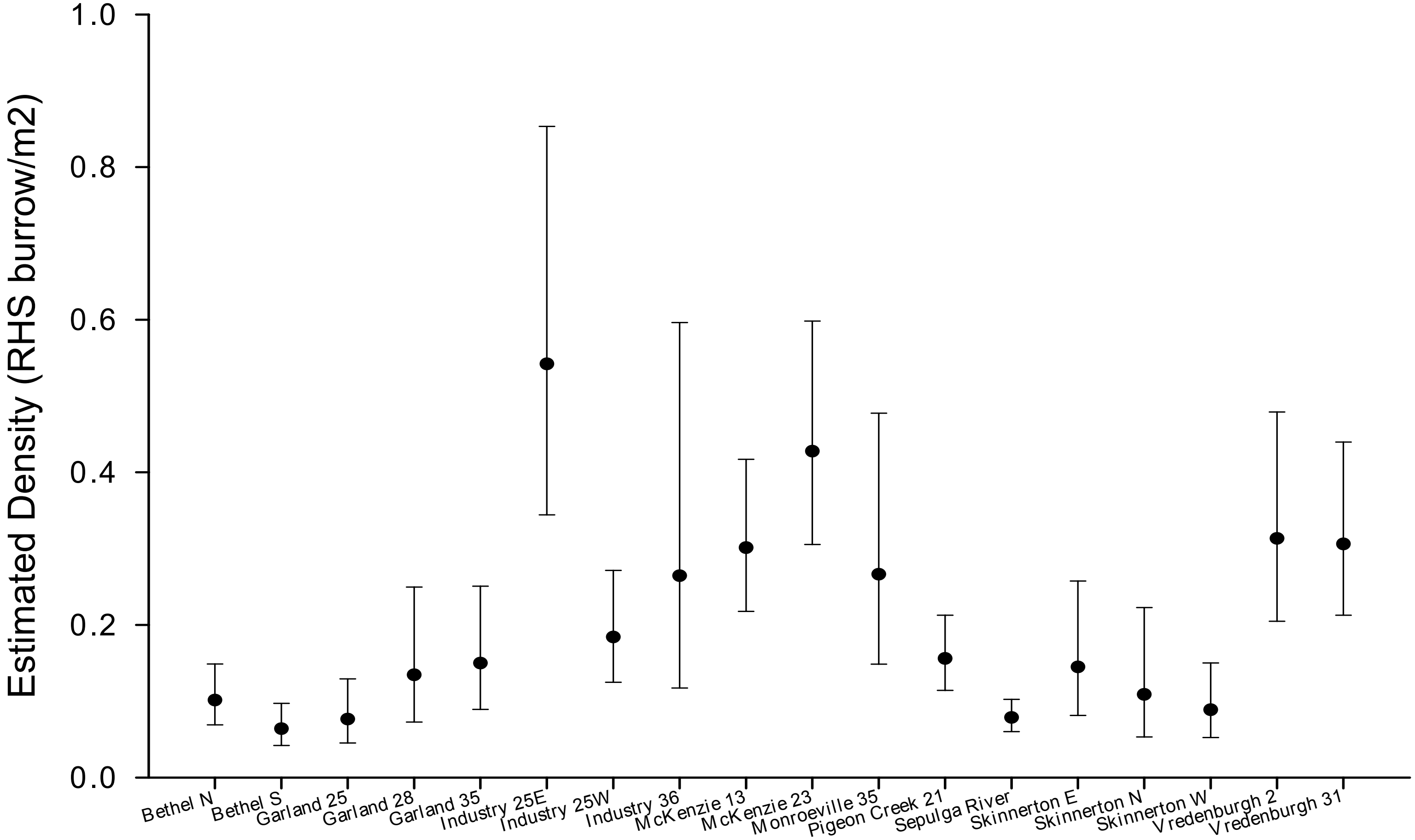
RESULTS

The datasets analyzed were appropriately described by a variety of key functions and expansion terms. Table 18 summarizes estimated densities for historical dataset. Figure 12 presents these results.

Table 18. Historical density estimates of Red Hills Salamander in south central Alabama.

Study Site	Date of data collection	*n*	Model (key function / expansion term)	Density Estimate (*P. hubrichti* burrows / m^2)	95% CI
Bethel N	1999-2003	30	Uniform / cosine	0.1014	0.0691-0.1488
Bethel S	1999-2003	22	Uniform / cosine	0.0639	0.0420-0.0972
Garland 25	1999-2003	75	Half normal / simple polynomial	0.0765	0.0452-0.1294
Garland 28	1999-2003	46	Uniform / cosine	0.1345	0.0726-0.2495
Garland 35	1999-2003	81	Hazard rate / cosine	0.1497	0.0894-0.2508
Industry 25E	1999-2003	146	Uniform / cosine	0.5420	0.3442-0.8534
Industry 25W	1999-2003	101	Half normal / simple polynomial	0.1841	0.1249-0.2714
Industry 36	1999-2003	113	Half normal / cosine	0.2645	0.1173-0.5965
McKenzie 13	1999-2003	152	Hazard / cosine	0.3013	0.2177-0.4169
McKenzie 23	1999-2003	146	Hazard / cosine	0.4275	0.3055-0.5983
Monroeville 35	1999-2003	170	Uniform / cosine	0.2664	0.1486-0.4774
Pigeon Creek 21	1999-2003	244	Half normal / simple polynomial	0.1559	0.1142-0.2129
Sepulga River	1999-2003	211	Half normal / simple polynomial	0.0786	0.0603-0.1025
Skinnerton E	1999-2003	37	Uniform / cosine	0.1448	0.0814-0.2575
Skinnerton N	1999-2003	91	Hazard / cosine	0.1088	0.0532-0.2227
Skinnerton W	1999-2003	35	Uniform / cosine	0.0888	0.0525-0.1502
Vredenburgh 2	1999-2003	122	Half normal / cosine	0.3132	0.2047-0.4790
Vredenburgh 31	1999-2003	105	Half normal / cosine	0.3059	0.2129-0.4397

Figure 12. Graph illustrating the historical (1999-2003) estimated densities (±95% CI) of Red Hills Salamander burrows across study sites in south-central Alabama.



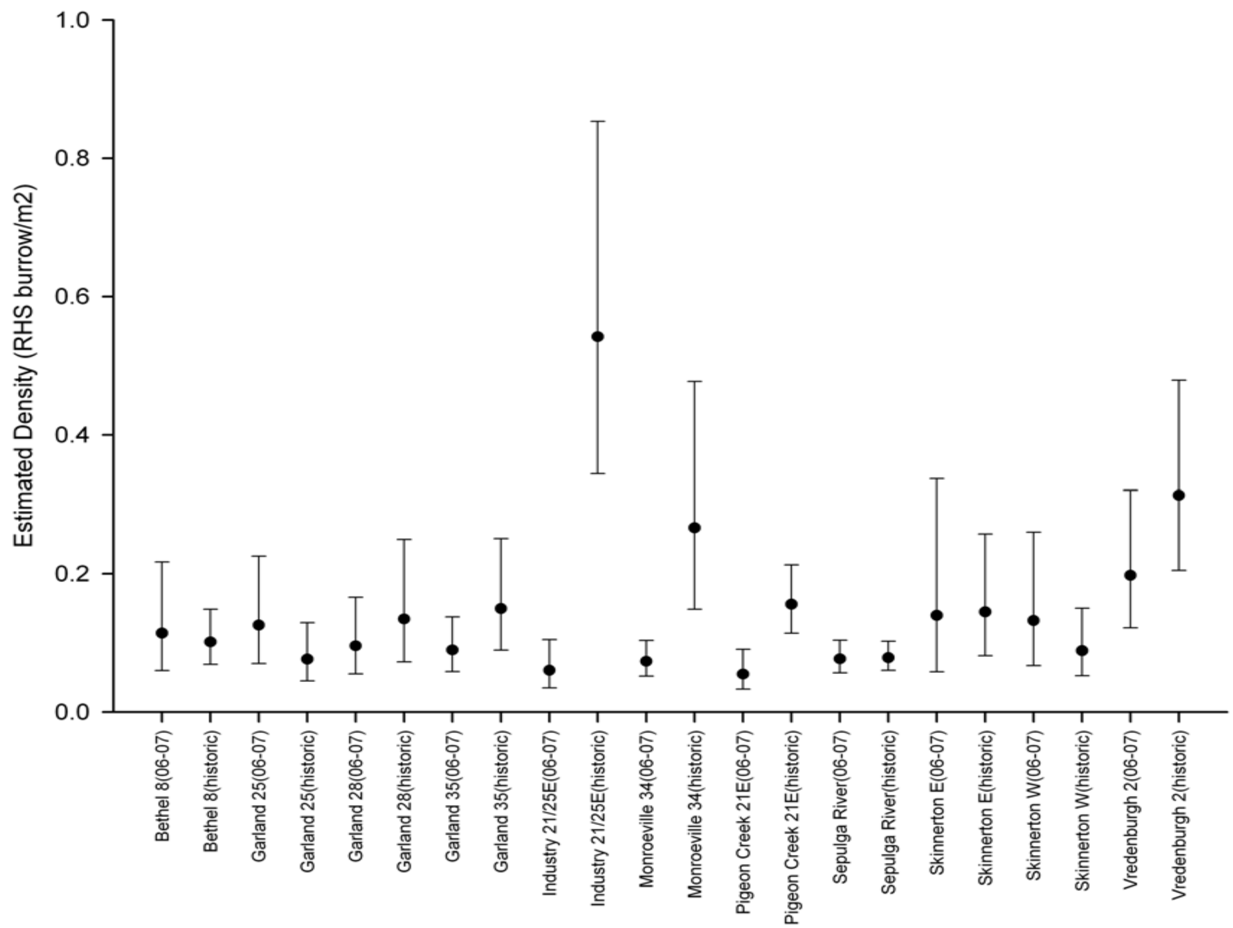
Results of current burrow density estimations generally fall within the range of 0.05 to 0.2 burrows/m^2, while the historical range is 0.06 to 0.5 burrows/m^2. Burrow density estimates presented by Dodd (1990), as calculated by the program Density and recalculated with the program Distance, tended to range lower as compared to the estimates from the above datasets; "Density" estimates ranged from 0.026 to 0.094 and "Distance" estimates from 0.025 to 0.09 burrows/m^2. While, overall, the estimates based on historical data appear to yield higher densities, a site-by-site comparison does not exhibit any dramatic differences between historic and current density estimates (Figure 13). Data was available on 11 sites and of these the historic vs. current densities were within the statistical confidence intervals for eight sites. Three sites (Industry 21/25E, Monroeville 34, and Pigeon Creek 21E) had widely divergent density estimates which, at this time, cannot be explained, but the cause is thought to lie in the data and not that the actual densities have shifted.

Variance in the density estimations, at least regarding the historical dataset, may be due to a violation of data collection assumption which may be resolved through further analysis in which the data is truncated. Variance between the historical and current datasets may also be due to data collection under drought vs. normal conditions, or pre- and post-hurricane/tropical storm events impacting sites. Variances of the estimated densities within each dataset are undoubtably affected by habitat heterogeneity.

Burrow density estimations provide for: 1) statistically valid data upon which to reference a baseline and provide a mechanism for monitoring; 2) a means to compare sites for conservation, although burrow density should not be the only factor considered; 3) data to in preparing delisting critera for the Red Hills salamander and; 4) a technique for tracking climate change.

For simplicity burrow density estimates have been reported at burrows/m^2, thus the representation of burrows is on the order of 0.1+/- burrow/m^2, which corresponds to approximately 1 burrow/10 m^2 or 10 burrow/100m^2. Such densities may appear to be quite low but the densisty estimate is encompassing the entire sampled slope which is a hetertogeneous complex of habitable and uninhabitable slope habitat. Also within the habitable slope patches actual densities will vary depending upon micro-features. Burrow distribution is often stratified along the slope face and exhibits a pattern of clustering, thus where burrows do occur the density within a small area may be quite high. Data collection across slopes was done in order to sample the range of density variation so that a more accurate density estimate could be acquired.

Figure 13. Graph comparing historical (1999-2003) and recent (2006-2007) density estimations on a site-by-site basis for which data is available. Dataset includes 11 sites.



Avian Surveys

Point counts have been combined by habitats across the study sites (Figure 14). The four habitat types recognized were forested slope, forested floodplain, mixed pine and hardwood, and pine plantation. Forested slopes were dominated by a hardwood forest cover, with a steep face, and the slope base often ecotonally graded into a forested floodplain. The forested slopes were the recognized habitat of Red Hills salamanders. The forested slopes and forested floodplain habitats had been set aside by International Paper as stream side management zones. In the floodplain the forest cover was typically hardwood and dominated by oak species. Mixed pine and hardwood habitat, in general, was found on ridgetops and represented a transitional habitat between anthropogenic pine plantation and naturally occurring forest communities. Pine plantation was found on ridgetops or dry lowlands at slope bases.

Forty-four species of birds were documented during point counts with eight falling in the High to Moderate conservation categories as ranked in Alabama Wildlife Volume 1 (Mirarchi, ed., 2004). An additional five High to Moderate ranked species were recorded outside of point counts. The five most abundant species as recorded across all habitats were the northern cardinal, northern parula, hooded warbler, red-eyed vireo, and pine warbler (Table 19); all except the northern parula have a low to lowest ranking. Twenty-one species were recorded in all four habitats, five species in three habitats, and 10 species in two habitats, and eight species were found in only one habitat. These numbers are reflective of the proximity of the habitat types, heterogeneity of ecotones, and movement of birds. Species total was evenly divided between those that reside in the region year round or migrate either elsewhere in North America during the winter or to Central or South America. Regarding the migratory species, 20 of the 22 are Neotropical migrants with the Red Hills providing habitat for nesting and the rearing of young.

Figure 14. Distribution of avian sampling points across the Red Hills study sites.

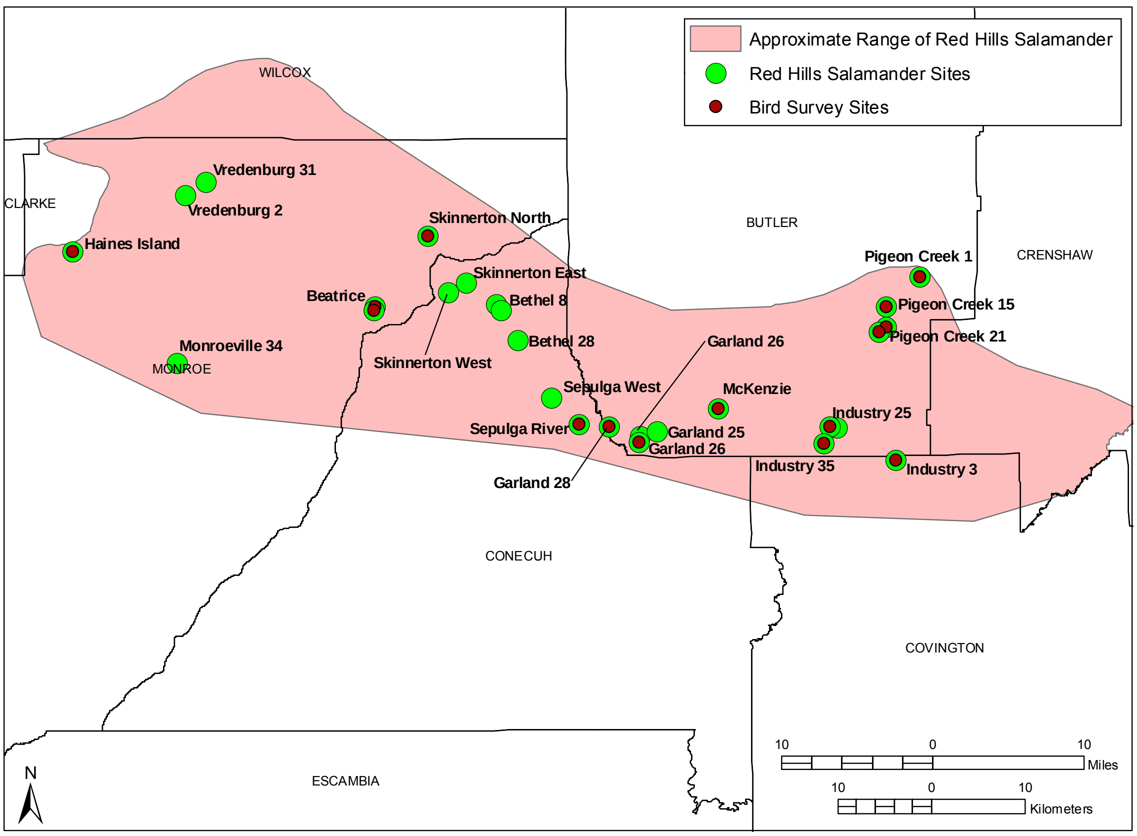


Table 19. A listing of all bird species recorded during point counts and ranked from most abundant to least, with all habitat types combined.

Common Name	Scientific Name	Migration Tendency	Alabama Wildlife Ranking	Overall Relative Frequency
red-tailed hawk	*Buteo jamaicensis*	R	low	0.001
northern bobwhite	*Colinus virginianus*	R	low	0.001
turkey	*Meleagris gallopavo*	R	low	0.001
mourning dove	*Zenaida macroura*	R	lowest	0.011
yellow-billed cuckoo	*Coccyzus americanus*	NM	low	0.019
barred owl	*Strix varia*	R	low	0.005
Ruby-throated hummingbird	*Archilochus colubris*	NM	low	0.009
red-bellied woodpecker	*Melanerpes carolinus*	R	low	0.032
red-headed woodpecker	*Melanerpes erythrocephalus*	R	moderate	0.001
downy woodpecker	*Picoides pubescens*	R	moderate	0.002
hairy woodpecker	*Picoides villosus*	R	moderate	0.001
pileated woodpecker	*Dryocopus pileatus*	R	low	0.028
great crested flycatcher	*Myiarchus crinitus*	NM	lowest	0.004
Acadian flycatcher	*Empidonax virescens*	NM	low	0.043
eastern wood pewee	*Contopus virens*	NM	low	0.009
eastern phoebe	*Sayornis phoebe*	R	lowest	0.003
blue jay	*Cyanocitta cristata*	R	low	0.038
American crow	*Corvus brachyrhynchos*	R	lowest	0.030
tufted titmouse	*Baeolophus bicolor*	R	lowest	0.042
Carolina chickadee	*Poecile carolinensis*	R	low	0.008
Carolina wren	*Thyrothorus ludovicianus*	R	lowest	0.036
blue-gray gnatcatcher	*Polioptila caerulea*	M	low	0.020
wood thrush	*Hylocichla mustelina*	NM	HIGH	0.001
American robin	*Turdus migratorius*	R	lowest	0.001
white-eyed vireo	*Vireo griseus*	M	low	0.014
Yellow-throated vireo	*Vireo flavifrons*	NM	low	0.003
red-eyed vireo	*Vireo olivaceous*	NM	lowest	0.059
prothonotary warbler	*Protonotaria citrea*	NM	moderate	0.001
northern parula	*Parula americana*	NM	moderate	0.149
Yellow-throated warbler	*Dendroica dominica*	NM	low	0.004
prairie warbler	*Dendroica discolor*	NM	moderate	0.002
pine warbler	*Dendroica pinus*	R	lowest	0.057
yellow warbler	*Dendroica petechia*	NM	lowest	0.007
hooded warbler	*Wilsonia citrina*	NM	low	0.071
Louisiana waterthrush	*Seiurus motacilla*	NM	moderate	0.004
common yellowthroat	*Geothlypis trichas*	R	low	0.004
Yellow-breasted chat	*Icteria virens*	NM	lowest	0.033
American redstart	*Setophaga ruticilla*	NM	low	0.022
northern cardinal	*Cardinalis cardinalis*	R	lowest	0.172
blue grosbeak	*Passerina caerulea*	NM	NA	0.004
indigo bunting	*Passerina cyanea*	NM	low	0.017
eastern towhee	*Pipilo erythrophthalmus*	R	lowest	0.007
chipping sparrow	*Spizella passerina*	R	lowest	0.021
summer tanager	*Piranga rubra*	NM	lowest	0.004
44 species overall		2 M		

		20 NM		
		22 R		

Migration tendency categories:

M=migrant – summer in Red Hills, winters elsewhere in North America
NM=neotropical migrant – summer in Red Hills, winters in Central or South America
R=resident – present year round in Red Hills

The forest floodplain habitat had the fewest number of species at 27. Of these species two are of conservation concern, the northern parula and wood thrush. The northern parula was recorded in other habitats but the single sighting of the wood thrush was in the forested floodplain. Within this habitat the six most often recorded species, in descending oreder, were northern parula, northern cardinal, red-eyed vireo, Acadian flycatcher, tufted titmouse, and hooded warbler (Table 20) (Figure 15).

Figure 15. Forested floodplain habitat was the area between the base of slope habitat to the stream. Forest cover ranged from relatively open to relatively dense.

Table 20. A listing of the 27 species recorded in the forested floodplain habitat and ranked from most abundant to least common.

Common Name	Scientific Name	Alabama Wildlife Ranking	Forested Floodplain Relative Frequency
northern parula	*Parula americana*	moderate	0.161
northern cardinal	*Cardinalis cardinalis*	lowest	0.139
red-eyed vireo	*Vireo olivaceous*	lowest	0.108
Acadian flycatcher	*Empidonax virescens*	low	0.076
tufted titmouse	*Baeolophus bicolor*	lowest	0.076
hooded warbler	*Wilsonia citrina*	low	0.063
red-bellied woodpecker	*Melanerpes carolinus*	low	0.049
blue jay	*Cyanocitta cristata*	low	0.045
pine warbler	*Dendroica pinus*	lowest	0.036
American crow	*Corvus brachyrhynchos*	lowest	0.031
blue-gray gnatcatcher	*Polioptila caerulea*	low	0.031
white-eyed vireo	*Vireo griseus*	low	0.022
yellow-billed cuckoo	*Coccyzus americanus*	low	0.022
American redstart	*Setophaga ruticilla*	low	0.018
chipping sparrow	*Spizella passerina*	lowest	0.018
mourning dove	*Zenaida macroura*	lowest	0.018
great crested flycatcher	*Myiarchus crinitus*	lowest	0.013
pileated woodpecker	*Dryocopus pileatus*	low	0.013
eastern wood pewee	*Contopus virens*	low	0.009
Ruby-throated hummingbird	*Archilochus colubris*	low	0.009
Yellow warbler	*Dendroica petechia*	lowest	0.009
Yellow-throated warbler	*Dendroica dominica*	low	0.009
barred owl	*Strix varia*	low	0.004
Carolina wren	*Thyrothorus ludovicianus*	lowest	0.004
red-tailed hawk	*Buteo jamaicensis*	low	0.004
wood thrush	*Hylocichla mustelina*	HIGH	0.004
Yellow-breasted chat	*Icteria virens*	lowest	0.004
27 species			

The forest slope habitat (Figure 16) was the most species rich with 39 recorded species. In descending order, the five most abundant were northern cardinal, northern parula, red-eyed vireo, hooded warbler, and pine warbler. Six of the 41 species have a moderate conservation ranking; these include the northern parula, downy woodpecker, hairy woodpecker, Louisiana waterthrush, prothonotary and prairie warblers (Table 21).

Figure 16. Forested slope habitat typified Red Hills salamander steep slope and ravine habitat.

Thirty species were recorded in the mixed pine/hardwood habitat (Figure 17) which included three species of moderate conservation concern, the northern parula, Louisiana waterthrush, and prairie warbler. The seven most abundant species, using a relative frequency of 0.5 as the cut-off, were northern cardinal, northern parula, hooded warbler, Carolina wren, pine warbler, yellow-breasted chat, and blue jay (Table 22). This habitat is intermediate between the natural hardwood forests of the slopes and floodplains and the pine plantations.

Table 22. A listing of the 39 species recorded in the forested slope habitat and ranked from most abundant to least common.

Common Name	Scientific Name	Alabama Wildlife Ranking	Forested Slope Relative Frequency
northern cardinal	*Cardinalis cardinalis*	lowest	0.182
northern parula	*Parula americana*	moderate	0.138
red-eyed vireo	*Vireo olivaceous*	lowest	0.074
hooded warbler	*Wilsonia citrina*	low	0.070
pileated woodpecker	*Dryocopus pileatus*	low	0.064
Acadian flycatcher	*Empidonax virescens*	low	0.047
red-bellied woodpecker	*Melanerpes carolinus*	low	0.043
tufted titmouse	*Baeolophus bicolor*	lowest	0.043
blue jay	*Cyanocitta cristata*	low	0.039
American redstart	*Setophaga ruticilla*	low	0.035
yellow-billed cuckoo	*Coccyzus americanus*	low	0.031
Carolina wren	*Thyrothorus ludovicianus*	lowest	0.029
American crow	*Corvus brachyrhynchos*	lowest	0.025
blue-gray gnatcatcher	*Polioptila caerulea*	low	0.019
chipping sparrow	*Spizella passerina*	lowest	0.016
yellow warbler	*Dendroica petechia*	lowest	0.014
Carolina chickadee	*Poecile carolinensis*	low	0.012
Yellow-throated vireo	*Vireo flavifrons*	low	0.012
Yellow-breasted chat	*Icteria virens*	lowest	0.012
Ruby-throated hummingbird	*Archilochus colubris*	low	0.010
eastern wood pewee	*Contopus virens*	low	0.010
white-eyed vireo	*Vireo griseus*	low	0.010
common yellowthroat	*Geothlypis trichas*	low	0.010
eastern towhee	*Pipilo erythrophthalmus*	lowest	0.010
eastern phoebe	*Sayornis phoebe*	lowest	0.006
Yellow-throated warbler	*Dendroica dominica*	low	0.006
pine warbler	*Dendroica pinus*	lowest	0.006
northern bobwhite	*Colinus virginianus*	low	0.004
barred owl	*Strix varia*	low	0.004
downy woodpecker	*Picoides pubescens*	moderate	0.004
hairy woodpecker	*Picoides villosus*	moderate	0.004
summer tanager	*Piranga rubra*	lowest	0.004
mourning dove	*Zenaida macroura*	lowest	0.002
American robin	*Turdus migratorius*	lowest	0.002
prothonotary warbler	*Protonotaria citrea*	moderate	0.002
prairie warbler	*Dendroica discolor*	moderate	0.002
Louisiana waterthrush	*Seiurus motacilla*	moderate	0.002
indigo bunting	*Passerina cyanea*	low	0.002
red-tailed hawk	*Buteo jamaicensis*	low	0.002
39 species			

Figure 17. The mixed pine/hardwood habitat was ecotonal between the natural hardwood forests of the Red Hills and the anthropogenic pine plantations commonly established on the ridgetops.

The pine plantation (Figure 18) is an anthropogenic habitat. Thirty-one species were recorded within the habitat with four having a moderate conservation ranking. The four most common species were northern cardinal, northern parula, pileated woodpecker, and yellow-breasted chat. Those species with the moderated conservation ranking were northern parula, red-headed woodpecker, downy woodpecker, and Louisiana waterthrush (Table 23).

Table 22. A listing of the 30 species recorded in the mixed pine/hardwood habitat and ranked from most abundant to least common.

Common Name	Scientific Name	Alabama Wildlife Ranking	Mixed Pine /hardwood Relative Frequencies
northern cardinal	*Cardinalis cardinalis*	lowest	0.163
northern parula	*Parula americana*	moderate	0.158
hooded warbler	*Wilsonia citrina*	low	0.102
pileated woodpecker	*Dryocopus pileatus*	low	0.075
Carolina wren	*Thyrothorus ludovicianus*	lowest	0.075
Yellow-breasted chat	*Icteria virens*	lowest	0.061
blue jay	*Cyanocitta cristata*	low	0.053
pine warbler	*Dendroica pinus*	lowest	0.044
indigo bunting	*Passerina cyanea*	low	0.036
Acadian flycatcher	*Empidonax virescens*	low	0.033
American crow	*Corvus brachyrhynchos*	lowest	0.025
red-eyed vireo	*Vireo olivaceous*	lowest	0.022
chipping sparrow	*Spizella passerina*	lowest	0.019
blue-gray gnatcatcher	*Polioptila caerulea*	low	0.017
tufted titmouse	*Baeolophus bicolor*	lowest	0.014
mourning dove	*Zenaida macroura*	lowest	0.011
red-bellied woodpecker	*Melanerpes carolinus*	low	0.011
eastern towhee	*Pipilo erythrophthalmus*	lowest	0.011
summer tanager	*Piranga rubra*	lowest	0.011
eastern wood pewee	*Contopus virens*	low	0.008
white-eyed vireo	*Vireo griseus*	low	0.008
Louisiana waterthrush	*Seiurus motacilla*	moderate	0.008
barred owl	*Strix varia*	low	0.006
Ruby-throated hummingbird	*Archilochus colubris*	low	0.006
great crested flycatcher	*Myiarchus crinitus*	lowest	0.006
prairie warbler	*Dendroica discolor*	moderate	0.006
American redstart	*Setophaga ruticilla*	low	0.006
Yellow-throated warbler	*Dendroica dominica*	low	0.003
common yellowthroat	*Geothlypis trichas*	low	0.003
30 species total			

Figure 18. Pine plantations represent an anthropogenic habitat of limited plant diversity and structure, as well as short life-span.

Table 23. A listing of the 31 species recorded in the pine plantation habitat and ranked from most abundant to least common.

Common Name	Scientific Name	Alabama Wildlife Ranking	Pine Plantation Relative Frequency
northern cardinal	*Cardinalis cardinalis*	lowest	0.187
northern parula	*Parula americana*	moderate	0.148
pine warbler	*Dendroica pinus*	lowest	0.060
yellow-breasted chat	*Icteria virens*	lowest	0.057
tufted titmouse	*Baeolophus bicolor*	lowest	0.049
American crow	*Corvus brachyrhynchos*	lowest	0.046
red-eyed vireo	*Vireo olivaceous*	lowest	0.039
hooded warbler	*Wilsonia citrina*	low	0.039
pileated woodpecker	*Dryocopus pileatus*	low	0.035
chipping sparrow	*Spizella passerina*	lowest	0.035
indigo bunting	*Passerina cyanea*	low	0.032
red-bellied woodpecker	*Melanerpes carolinus*	low	0.025
Carolina wren	*Thyrothorus ludovicianus*	lowest	0.025
white-eyed vireo	*Vireo griseus*	low	0.025
mourning dove	*Zenaida macroura*	lowest	0.021
Acadian flycatcher	*Empidonax virescens*	low	0.021
American redstart	*Setophaga ruticilla*	low	0.021
yellow-billed cuckoo	*Coccyzus americanus*	low	0.018
Carolina chickadee	*Poecile carolinensis*	low	0.018
blue-gray gnatcatcher	*Polioptila caerulea*	low	0.018
blue grosbeak	*Passerina caerulea*	NA	0.018
blue jay	*Cyanocitta cristata*	low	0.014
Ruby-throated hummingbird	*Archilochus colubris*	low	0.011
barred owl	*Strix varia*	low	0.007
red-headed woodpecker	*Melanerpes erythrocephalus*	moderate	0.007
eastern wood pewee	*Contopus virens*	low	0.007
turkey	*Meleagris gallopavo*	low	0.004
downy woodpecker	*Picoides pubescens*	moderate	0.004
eastern phoebe	*Sayornis phoebe*	lowest	0.004
Yellow-throated vireo	*Vireo flavifrons*	low	0.004
Louisiana waterthrush	*Seiurus motacilla*	moderate	0.004
31 species total			

Avian Species of Conservation Concern

Thirteen species with some degree of conservation concern were recorded either during point counts or outside point counts. All except one species had a very low frequency of occurrence, in other words, these species were very uncommon within the habitats sampled in the Red Hills. Two species, the wood thrush and swallow-tailed kite, have a high ranking, while all others have a moderate ranking (Table 24 and Table 26).

Table 24. Bird species of conservation concern recorded during point counts.

Common Name	Scientific Name	Alabama Wildlife Ranking	Overall Relative Frequency
wood thrush	*Hylocichla mustelina*	HIGH	0.001
downy woodpecker	*Picoides pubescens*	moderate	0.002
hairy woodpecker	*Picoides villosus*	moderate	0.001
Louisiana waterthrush	*Seiurus motacilla*	moderate	0.004
northern parula	*Parula americana*	moderate	0.147
prothonotary warbler	*Protonotaria citrea*	moderate	0.001
prairie warbler	*Dendroica discolor*	moderate	0.002
red-headed woodpecker	*Melanerpes erythrocephalus*	moderate	0.001

Forested slope habitat contained more of the species, six of the eight, than the other habitats. Both the mixed pine/hardwood and pine plantation had three of the species, while the forested floodplain had two (Table 25). These results may be misleading. The hardwood-dominated forested slopes with a mature tree canopy are undoubtably important as nesting habitat to neotropical migrants and other species of birds, but the presence of declining species in pine plantation and mixed pine/hardwood, which is intermediate between the natural forests and plantation, is questionable. The observations were few and may have been of an individual enroute between habitats.

Four species were recorded in only one habitat, the wood thrush in a forested floodplain, the prothonotary warbler at the base of a forested slope (and near a stream course), the hairy woodpecker in forested slope, and the red-headed woodpecker in a plantation. The observation of Louisiana waterthrush in mixed pine/hardwood and plantation is questionable; the presence of the species in forested slope is not. The northern parula was noted in all four habitats but the high percentage of observations in mixed pine/hardwood and plantation is not expected. The species was abundant in the hardwood forests and its presence in other habitats may be due to sighting along the edge of the other habitats.

Table 25. Habitat associations, based on point counts, for species with conservation needs.

Species relative frequency of occurrence for each habitat type				
Common Name	Forested Floodplain	Forested Slope	Mixed Pine/hardwood	Pine Plantation
wood thrush	1			
downy woodpecker		0.667		0.333
hairy woodpecker		1		
Louisiana waterthrush		0.200	0.600	0.200
northern parula	0.175	0.345	0.277	0.204
prothonotary warbler		1		
prairie warbler		0.333	0.667	
red-headed woodpecker				1

Five additional species of conservation concern were documented during the study. Individual swallowtail kites were observed along the Sepulga River and near Persimmon Creek in flight over forested floodplain, ground doves were noted on ridgetops with extensive sandy soils, a screech owl was seen on a forested slope, and great horned owls were heard calling, as were chuck-will's-widow (Table 26).

Table 26. Avian species of conservation concern recorded in Red Hills outside of point counts.

Species	Common Name	Alabama Wildlife Ranking
Elanoides forficatus	Swallow-tailed kite	HIGH
Columbina passerine	ground dove	moderate
Otus asio	eastern screech owl	moderate
Bubo virginianus	great horned owl	moderate
Caprimulgus carolinensis	chuck-will's-widow	moderate
Limnothlypis swainsonii	Swainson's warbler	HIGH

Target Species in the Red Hills

Fourteen of the 19 target bird species, or 74%, were documented within the Red Hills during this study (Table 27). While many of the species were recorded in low numbers, their presence indicates the importance of the Red Hills habitats to the native avifauna.

Table 27. Bird species of conservation concern potentially occurring in the Red Hills and noted as being documented during the study.

Species	Common Name	Documented Y/N
Picoides borealis	red-cockaded woodpecker	N
Hylocichla mustelina	wood thrush	Y
Helmitheros vermivorus	worm-eating warbler	N
Limnothlypis swainsonii	Swainson's warbler	Y
Oporonis formosus	Kentucky warbler	N
Aimophila aestivalis	Bachman's sparrow	N
Elanoides forficatus	swallow-tailed kite	Y
Columbina passerine	common ground-dove	Y
Otus asio	eastern screech-owl	Y
Bubo virginianus	great horned owl	Y
Caprimulgus carolinensis	Chuck-will's-widow	Y
Ceryle alcyon	belted kingfisher	N
Melanerpes erythrocephalus	red-headed woodpecker	Y
Picoides pubescens	downy woodpecker	Y
Picoides villosus	hairy woodpecker	Y
Parula Americana	northern parula	Y
Dendroica discolor	prairie warbler	Y
Protonotaria citrea	prothonotary warbler	Y
Seiurus motacilla	Louisiana waterthrush	Y

Management Recommendations

Recommendations for ridgetop restoration will be provided for each selected site and presented in Appendix 2. The criteria for selecting sites for longleaf pine restoration include but are not limited to the presence of gopher tortoises, presence of soils optimum for longleaf pine, and the persistence of vegetation indicative of a former longleaf pine ecosystem.

Red Hills Salamander and Red-cockaded Woodpecker: Keystones to Red Hills Conservation and Restoration

Conservation and restoration within the Red Hills, at least as addressed with this project, centers on two species, the Red Hills salamander and the red-cockaded woodpecker. Proper conservation and adequate protection of the Red Hills salamander necessitates protecting the hardwood-dominated slope forests which lie in the zone between the ridgetops and the floodplains. But in order to thoroughly protect the slope forests, at the minimum, a buffer is needed along the ridge brow and the adjacent floodplain must also be protected. Only through these measures will adequate habitat protection be achieved for the Red Hills salamander. Protection of the Red Hills salamander is fairly simple. Protect the known extant populations and sites with quality habitat, and for sites which have been disturbed yet still support salamanders, allow the hardwood forest habitat to recover.

Red-cockaded woodpecker conservation is not as simple a task. The woodpecker is all but extirpated from the Red Hills (perhaps functionally extirpated) and to return this species to the Red Hills will require an extensive and expensive long-term commitment to forest restoration. Optimal management of the longleaf pine forest for the red-cockaded woodpecker will yield ecological conditions that are also optimal for Bachman's sparrow and gopher tortoise, i.e. summer burn rotations on a 2 to 3 year cycle with a midstory canopy reduction, and enhanced grass and forb growth.

Management of the hardwood-forested slopes occupied by the Red Hills salamander is best accomplished through an approach of less-is-better. Natural ecological processes of the forest should be allowed to occur unimpeded, but one management action incorporated should be to increase and protect the uppermost buffer along the ridge brow. Species to directly benefit through slope forest protection would be the coal skink, wood thrush, worm-eating warbler, Swainson's warbler, Kentucky warbler, eastern screech-owl, great horned owl, northern parula, and Louisiana waterthrush.

Twenty-four species have been listed as targets of this project including one salamander, two lizards, one snake, one tortoise, and 19 birds. Eleven of the species would directly benefit from Red Hills salamander conservation, including the Red Hills salamander. Ten species, including the red-cockaded woodpecker, would directly benefit from proper ecological restoration to reestablish a historical forest cover on the ridgetops. Three species, being less habitat selective, would benefit from conservation and restoration actions directed toward both the slopes and ridgetops (Table 28).

Table 28. Species associations based on disturbance interval and scale, general habitat, and the species' association to either Red Hills salamander or red-cockaded woodpecker conservation.

Frequent (1-3 yr) disturbance interval (fire) across the habitat				
Species	Common Name	General Habitat	Critical Habitat Needs	Keystone
Picoides borealis	red-cockaded woodpecker	ridgetop	mature pine forest	RCW
Gopherus polyphemus	gopher tortoise	ridgetop	dense grass/forb layer; open midstory	RCW
Aimophila aestivalis	Bachman's sparrow	ridgetop	dense grass/forb layer; open midstory	RCW

Regular (3-5 yr) disturbance interval (fire) across the habitat				
Species	Common Name	General Habitat	Critical Habitat Needs	Keystone
Eumeces inexpectatus	Southeastern five-lined skink	ridgetop	ground structure for shelter, bask sites	RCW
Columbina passerina	common ground-dove	ridgetop	mixed shrubs and open patches	RCW
Caprimulgus carolinensis	chuck-will's-widow	ridgetop	forest with open patches	RCW
Melanerpes erythrocephalus	red-headed woodpecker	ridgetop	dead/dying trees; sparse understory	RCW
Picoides pubescens	downy woodpecker	ridgetop	dead/dying trees	RCW
Dendroica discolor	prairie warbler	ridgetop	brushy second growth, mature pine	RCW

Regular, microhabitat to habitat level, windthrow of individual trees or small groupings				
Species	Common Name	General Habitat	Critical Habitat Needs	Keystone
Hylocichla mustelina	wood thrush	slope/floodplain	dense second growth and shrub layer	RHS
Helmitheros vermivorus	worm-eating warbler	slope/floodplain	dense second growth and shrub layer	RHS
Limnothlypis swainsonii	Swainson's warbler	slope/floodplain	dense second growth and shrub layer	RHS
Oporonis formosus	Kentucky warbler	slope/floodplain	dense second growth and shrub layer	RHS

Table 28 (cont.)

Disturbance not an ecological requirement				
Species	Common Name	General Habitat	Critical Habitat Needs	Keystone
Phaeognathus hubrichti	Red Hills salamander	slope	mature hardwood slope forest	RHS
Eumeces anthracinus	coal skink	slope/floodplain	mesic ravine with shelter	RHS
Lampropeltis getula holbrooki	speckled kingsnake	ridgetop, slope/floodplain	sufficient prey base	RHS & RCW
Otus asio	eastern screech-owl	ridgetop, slope/floodplain	cavity trees for nesting	RHS & RCW
Bubo virginianus	great horned owl	ridgetop, slope/floodplain	available nest sites	RHS & RCW
Ceryle alcyon	belted kingfisher	slope/floodplain	streams with good water quality and riffles, vegetation-free banks for nesting, vegetation-free water	RHS
Picoides villosus	hairy woodpecker	ridgetop	mature pine and hardwoods	RHS
Parula americana	northern parula	slope/floodplain	mature hardwood forest with epiphytes	RHS
Protonotaria citrea	prothonotary warbler	slope/floodplain	extensive mature riparian forest	RHS
Seiurus motacilla	Louisiana waterthrush	slope/floodplain	mature riparian hardwood forest	RHS
Elanoides forficatus	swallow-tailed kite	floodplain	mature riparian forest	RHS

RCW – red-cockaded woodpecker
RHS – Red Hills salamander

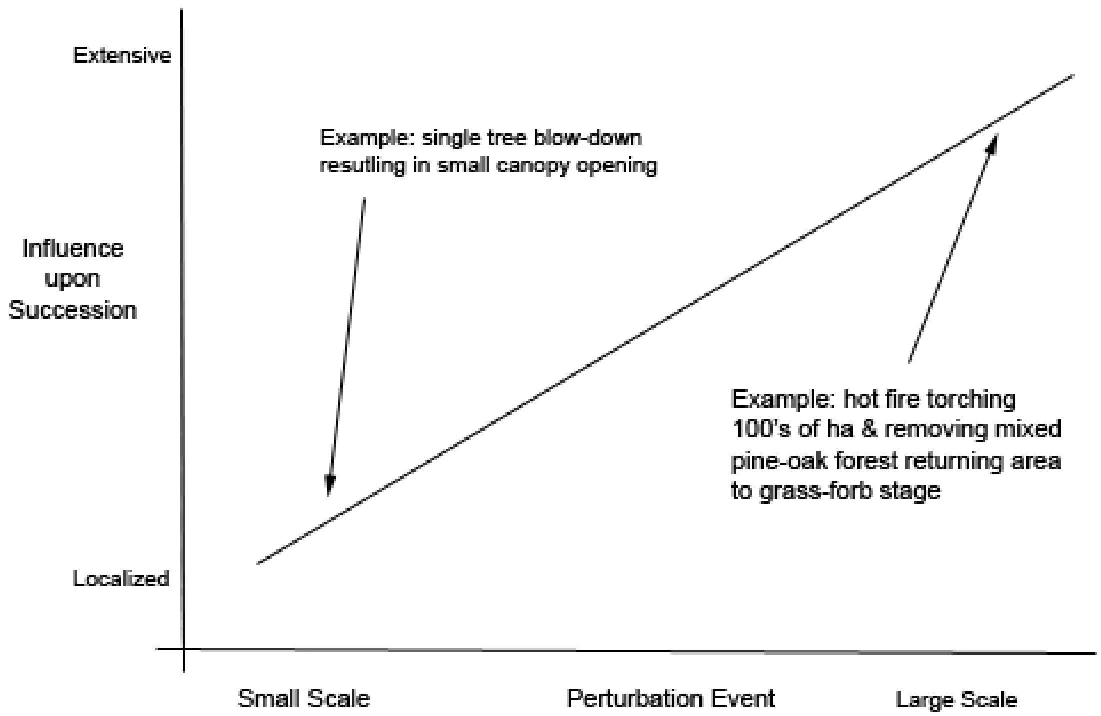
An ecological distinction between the forests of the slopes and ridgetops lies with the degree of spatial, temporal, and intensity of perturbations. Hardwood-dominated slopes experience more stability than the forested ridgetops. On the slopes perturbation events tend to be on a smaller scale as individual trees die and fall, or are blown down in storms, and, on any given site, the individual events may be widely spaced through time. Fire historically swept across the ridgetops every few years, while hurricanes would have a more dramatic impact on the exposed forests. The adaptation to perturbations is seen in the fauna inhabiting the Red Hills. Species which occupy the forested slopes are less tolerant of disturbance, or less tolerant of large-scale disturbance.

Inhabitants of the ridgetop forests, in several instances, require regular and more intense perturbations as they are adapted to a subclimax state of the forest.

Conversion of pine plantation to natural longleaf or other native pine species, or mixed pine-oak forest community will have variable effects upon the birds of the forest community. With this in mind the spatial and temporal shifts across the landscape from plantation to forest may be manipulated to the benefit of many of the species identified in this project. Understanding the ecological needs of the individual bird species and how those needs may mesh or conflict provides information to land managers which may be used for the enhancement of the forest for particular species or suites of species.

Disturbance events retard succession to varying degrees both spatially and temporally. An event such as a large hardwood tree being blown down along the brow of a ridgetop will produce an opening in the forest canopy with a small concomitant retardation of succession. At the opposite end of the spectrum a wide-spread hot fire, which removes dense tree canopy, will shift the successional stage back, in comparison, much further, and on a much larger spatial scale (Figure 19).

Figure 19. A conceptual graph illustrating the influence of perturbation events and scale upon succession.



Hunter et al. (2001) have provided an overview of birds which are dependent upon disturbance events of their habitat and have grouped species which have broadly similar disturbance requirements. The red-cockaded woodpecker and Bachman's sparrow require stands of mature pine, preferably native for the woodpecker, and for the sparrow an open grassy understory. Within the Red Hills, the ridgetops would be the sites with habitats suitable for the red-cockaded woodpecker and Bachman's sparrow. Additionally Chuck-will's-widow and red-headed woodpecker would occupy this habitat; Chuck-will's-widow requires open woodlands whether pine or oak dominated as does the red-headed woodpecker.

Two additional ridgetop occupying species discussed in Hunter et al. (2001) are the common ground-dove and prairie warbler. Both of these species need large (> 5 ha) patches of shrubby habitat which may be found intermixed in mature pine forests. The shrubby habitats may also follow regenerating burns and clearcuts, conditions present following a burn through a heterogeneous landscape.

The wood thrush, worm-eating warbler, Swainson's warbler, and Kentucky warbler are species which require, in general, small (< 4 ha) interior forest disturbances. More specific habitat needs include dense second-growth or dense shrub layer for the wood thrush, brushy ravines with dense undergrowth for the worm-eating warbler, forested wetlands with dense undergrowth or canebrakes for Swainson's warbler, and dense second growth along ravines or swamp edges for the Kentucky warbler (Hunter et al., 2001). Conditions meeting these habitat requirements may be found on the slopes and adjacent floodplains. For example, within a few years following the fall of a large beech tree, a condition of thick shrubby growth around the downed tree will be created. Mountain laurel thickets along the brow of ridges form a dense shrub zone, while along the lower slope-floodplain interface Florida anise occurs in very high density.

Ecological disturbance which provides benefits to those species of the bird community for which optimal habitat is transient may come from either a natural event or a human-directed action. Natural mortality of large hardwoods along slopes and blow-downs of trees create small canopy openings and small scale reversions of succession. Clearcutting of plantations followed by a replanting of longleaf pine provides a short-term grassy-shrubby habitat patch. Fire, whether from a lightning strike or controlled burn, will maintain longleaf forest in a state of low-level disturbance. The mechanism, timing, spatial scale, and projected results of disturbance events must all be considered if they are to be used to enhance habitats for the bird species addressed in this project.

Species that would benefit as ridgetop restoration shifts woody cover from dense pine plantation to open, mature longleaf stands include the red-cockaded woodpecker, Bachman's sparrow, chuck-will's-widow, and prairie warbler. Each species has particular habitat requirements and an attempt to incorporate the needs of all species may introduce management conflicts into restoration endeavors.

Red-cockaded woodpeckers and Bachman's sparrows may occupy the same mature longleaf pine habitat which is a fire-maintained subclimax. While both species need the same general habitat, their niche requirements differ. Red-cockaded woodpeckers nest in large, old trees, while Bachman's sparrows require a dense ground cover of grasses and forbs in which to nest. Red-cockaded woodpeckers may tolerate a dense midstory yet this has a very deleterious effect upon Bachman's sparrows; Bachman's sparrows prefer an open midstory (Plentovich et al., 1998). A 2 to 3 year burn rotation, with fires during the growing season, is the most beneficial management technique for both red-cockaded woodpecker and Bachman's sparrow as this both removes the midstory and enhances the ground cover (Plentovich, et al. 1998; Shriver and Vickery, 2001), although Tucker et al. (2004) reported little effect from burning based on season in their study. Other management techniques which have been examined include hardwood reduction using herbicides and felling-girdling. Regarding hardwood reduction only all three techniques were effective and produced essentially the same results. But overall, fire is the best management tool as it is the only one which also yields a positive benefit to the ground cover, and Bachman's sparrow nests are often associated with wiregrass or broomsedge clumps (Provencher et al., 2002).

Red-cockaded woodpeckers live in family groups which typically range in numbers from 2 to 5, but greater if fledglings are present. Family groups are composed of a breeding pair and 1 to 4 helpers, which are male offspring from the previous year. Parents and helpers contribute to the feeding of chicks. When foraging the family group moves through the forest as a group (Jackson, 1994).

USFWS recovery plan for the red-cockaded woodpecker (USFWS, 2003) recommends a minimum of 250 breeding groups for long-term viability, and if possible, to have groups clustered so that no individual group is > 3.2 km from any other group. Home range size has been estimated to range from approximately 40 – 162 ha per group, dependent upon quality of the foraging habitat. Clusters in high-quality old-growth longleaf have smaller home ranges than those in lesser quality habitat. Therefore with natural pine restoration in the Red Hills and ultimately reintroduction of red-cockaded woodpeckers, clusters initially would have larger foraging ranges but as the pine approaches maturity and habitat quality rises the foraging ranges would contract.

In Apalachicola National Forest Porter and Labisky (1986) found that the red-cockaded home range of clans (family groups) ranged from 85 to 157 ha., but in other studies in which the woodpeckers occupied poor habitat the home range was as high as 400 ha (Jackson, 1994). Again in Apalachicola National Forest, researchers observed red-cockaded woodpeckers foraging in flatwoods and sandhills which have longleaf pine stands of 30 to 60 years of age (Hess and James, 1998). Nearly all foraging was done on living pine (99%), either on longleaf (77%) or slash (22%), and the pines selected were a minimum of 20 m high with a dbh at least 20 cm (Porter and Labisky, 1986). Based on the results of Porter and Labisky (1986), in good habitat the woodpeckers require at least 82 ha of primary foraging habitat. Thus to successfully reestablish viable populations of the red-cockaded woodpecker in the Red Hills will require extensive tracts of mature, open pine stands.

Primary food item of red-cockaded woodpeckers is arthropods, and Hanula et al. (2000) determined that the best predictors of arthropod abundance were stand age, tree diameter, and bark thickness. Of the 3 predictors bark thickness is the most biologically important as this is the direct substrate on which the arthropods live, but stand age may be the easiest to obtain. Arthropod biomass and numbers were shown to increase with bark thickness up to a thickness of 2 cm. Trees with a diameter of 30 to 35 cm supported the highest arthropod biomass, and trees which were 60 to 80 years old were the optimal foraging habitat.

Hess and James (1998), through stomach flushing, determined that the ant *Crematogaster ashmeadi* comprised over 50% of the diet of adult red-cockaded woodpeckers. Other adult food items included ants, beetles, hemiptera, spiders, centipedes, and fruits and seeds of *Magnolia virginiana* and *Myrica inodora*. Nestlings received a wider variety of arthropod prey items which included ants, beetles, hemiptera, spiders, centipedes, carpenter bees, roaches, lepidoptera, and tabanid flies. In Georgia and South Carolina, Hanula and Engstrom (2000) found that nestlings were fed predominantly wood roaches (32.9 to 56.8%).

Red-cockaded Woodpecker Prey: the Acrobat Ant, *Crematogaster ashmeadi*

Crematogaster ashmeadi has been identified as the major prey item of the red-cockaded woodpecker (Hess and James, 1998). *C. ashmeadi* is an arboreal ant that ranges across the southeastern United States, living in colonies on pine trees, both longleaf (*Pinus palustris*) and slash (*Pinus elliotti*). Typically the dominant species, up to 90% of the individual ants on a tree will be *C. ashmeadi* (Tschinkel, 2002).

Colonies of this acrobat ant inhabit chambers within the dead branches or bark of pine, but seldom do the ants excavate the chamber. Founding queens establish new colonies through the occupation of abandoned chambers made by bark-mining caterpillars, woodboring beetles, or termites. Often the cossid moth, *Givira francesca*, is the common species which constructs the galleries in the bark of pine trees. The caterpillar excavates a gallery in the bark but feeds on the phloem of the tree. Once successful pupation takes place and a moth emerges, an empty gallery remains which *C. ashmeadi* may then inhabit. Estimates of colony size range from 15,000 to 80,000; thus a tree with a colony potentially could have 80,000 individual ants. Up to 50% of available trees in an area may support a colony, and up to 90% of arboreal ants represented on trees may be *C. ashmeadi*. Any given tree will only have one colony, but a colony may occupy up to 3 trees (Tschinkel and Hess, 1999; Tschinkel, 2002).

The abundance of *C. ashmeadi* may explain its importance in the diet of the red-cockaded woodpecker. It is the most abundant arboreal ant in the pine forests of panhandle Florida. Colonies may be established even in sapling pines but colonization of longleaf saplings does not occur until the tree has at least one dead branch. With slash the saplings must be older because the thin branches are less suitable for gallery formation by woodboring beetles (Tschinkel, 2002). The red-cockaded woodpecker may not be dependent upon *C. ashmeadi* for its main prey item; other insect species may be substituted, but *C. ashmeadi* is dependent upon the woodboring insects that initially form the galleries that it uses. *C. ashmeadi* queens colonize longleaf as small as 3 m in height, and colonies of the ant decrease as the trees grow larger, with the larger trees less likely to have *C. ashmeadi* colonies (Hahn and Tschinkel, 1997; Tschinkel 2002). Thus with longleaf pine restoration to Red Hills sites *C. ashmeadi* should become established many years before the pine have reached sufficient size to support red-cockaded woodpeckers. Secondly, as restoration advances multilple size classes of longleaf should be available to *C. ashmeadi* for the colonization and establishment of new colonies.

The true dependence of the red-cockaded woodpecker on *C. ashmeadi* is unclear as the abundance of the ant, at this time, is not a limiting factor. Woodpeckers feed upon the fat-rich sexual broods of the ants during the bird's breeding season. If absent other species of arboreal ants could fill the void left by *C. ashmeadi* but these species may not be able to fully replace *C. ashmeadi* in the diet of the red-cockaded woodpecker (Tschinkel and Hess, 1999).

Management actions that would enhance ecological conditions favorable for Bachman's sparrows and red-cockaded woodpeckers would also be favorable for arboreal ant species such as *C. ashmeadi* (Tschinkel and Hess, 1999). Simple monitoring methods are available and as longleaf pine restoration progresses monitoring of the arboreal ant community should be incorporated.

Additional Comments Regarding Longleaf Pine Restoration and Ant Communities

Ants in longleaf forests can be placed into one of three ecological categories: arboreal, those that live in trees, ground-foraging, those that move actively over the forest surface, and subterranean, those that live below the surface. In longleaf pine flatwoods of Apalachicola National Forest a total of 72 species of ants have been identified, although 8 are non-native to the area. In a study by Lubertazzi and Tschinkel (2003) the ground-foraging ant community was the most diverse with 30 species, including *Solenopsis invicta*, the red imported fire ant. Arboreal and subterranean communities were represented by 13 and 20 species, respectively. These two categories contain species specialized for particular ecological habitats, while the ground-foraging group contains, to some degree, more generalized species.

As lower level vegetation shifts from a predominantly shrubby state to a more grassy state the ground-foraging ant community shifts. Unfortunately in this study, with an increase in wiregrass, *S. invicta* became the dominant ground-foraging species (Lubertazzi and Tschinkel, 2003). The prevalence of *S. invicta* has deleterious effects upon the native ant species and other native fauna whether invertebrate or vertebrate.

Longleaf restoration would have little effect upon the arboreal or subterranean species of native ants, but with the management goal objective to attain an ecological state favorable to Bachman's sparrow, for example, an unwelcome outcome may be an increase of *S. invicta*. A normal expected outcome in a shift from a shrubby ground layer to one that is predominantly herbaceous is a decrease in overall ground-foraging ant diversity (Lubertazzi and

Tschinkel, 2003). But along with the decrease in ant diversity may be an increase in overall numbers and density of *S. invicta*, which may prey upon eggs and fledglings of ground-nesting birds such as Bachman's sparrow and chuck-will's-widow.

Fall-Line Sandhills of Georgia have vegetation similarities to the Red Hills, with mixed pine, including loblolly and longleaf, and hardwoods of oak and hickory. Fort Benning has active red-cockaded woodpecker colonies that live in stands of longleaf with an understory of perennial forbs and grasses (but not wiregrass, *Aristida stricta*). A 3-year burn cycle is in effect which yields habitat conditions quite favorable for both red-cockaded woodpeckers and gopher tortoises (Graham, et al., 2004). Graham, et al. (2004) also found that *S. invicta* was common in disturbed areas (but not the most prevalent species), and that arboreal species such as *C. ashmeadi* were less affected by ground disturbance.

Extreme disturbance of the soil, clearcutting, or other types of habitat disturbance favor the spread of *S. invicta* (Tschinkel, 1987), and these are actions which may be unavoidable during restoration of plantation back to longleaf. Thus, one component of longleaf restoration may be to reduce or eradicate, if possible, the red imported fire ant from restoration sites.

Ridgetop Restoration

Longleaf pine forest ecosystem has been in decline for approximately 250 years as forests have been cut for timber, cleared for agriculture, converted to pine plantations and undergone urban development. Along with loss of the forests, remaining stands have been impacted as natural ecological factors have been altered, especially through the suppression of wildfire. Historically, the longleaf forests covered over 25 million ha of the southeast (Gilliam and Platt, 2006), although other authors (Sorrie and Weakley, 2006) place the total acreage figure at 38 million ha. While total historical acreage figures may be questioned, what is undeniable is the dramatic loss of this ecosystem, which now covers < 3% of the original area (Gilliam and Platt, 2006; Sorrie and Weakley, 2006).

A disturbance-dependent ecosystem, longleaf pine forests of the Gulf Coastal Plain have a high rate of plant endemism, and overall high diversity. Ecological viability requires a large landscape, frequent fires, proper timing of fires, and a heterogeneous burn patchwork ranging from thorough burning to patchy to no burning. While many species depend on fire, the survival of others, particularly subcanopy shrubs and hardwoods, are less tolerant of fire, and patchy burning promotes high diversity. Patchy burning is also better for the insect assemblages, and the importance of insects to pollination cannot be overstated (Sorrie and Weakley, 2006).

In the Red Hills the establishment of conservation areas of substantial size would add to the current state and federal landholdings where longleaf conservation and restoration is being practiced. While the Red Hills physiographic province lies within the historical range of *P. palustris*, it is immediately north of the core region of coastal plain endemism. Plant endemism of the Red Hills, and floristics in general, have been poorly studied and documented. Ecological conditions pertaining to longleaf do not seem to conform to the conditions of the Fall Line Hills longleaf communities in western Georgia, nor do they conform to the conditions of the lower coastal plain longleaf communities. Perhaps the longleaf pine communities of the Red Hills represent a unique botanical association.

Little historical information is available detailing the vegetation of the natural forests of the ridgetops of the Red Hills, but Harper (1920; 1943) depicted an open longleaf pine forest. Descriptions by Mohr (1901) covered the general Red Hills region plus geologically similar areas outside of the present study area, and he mentioned that buhrstone ridges with deep sand and gravel deposits were dominated by forests of longleaf pine. Yet his statement "East of Patsaliga Creek the hills become less prominent, the softer strata of Eocene Tertiary spread out into undulating table-lands, and the generous brown soil supports the mixed growth of xerophile and mesophile woody species, evergreen and deciduous, characteristic of the region" leads one to conclude that longleaf was not dominant across the entire region. A second view, based on Ware et al. (1993) is that the forests of the Red Hills are in a longleaf pine shortleaf-pine loblolly-pine hardwood transitional zone. This community would have a canopy of the following dominant trees, *Pinus palustris*, *Pinus echinata*, *Pinus taeda*, *Quercus stellata* (post oak), *Quercus alba* (white oak), *Quercus falcata* (southern red oak), and *Carya* spp. (hickories). A savanna-like grass-forb layer formed the understory. Ware et al. (1993) are postulating that this was the pre-settlement (> 400 years ago) forest condition as this community has never been adequately described. While we may not have a description of the historical longleaf community of the Red Hills, nor know the full extent of coverage, we can make some assumptions regarding longleaf in the Red Hills, namely that what was present, at least to some degree, would have been an upland savanna-type of predominantly evergreen forest.

Mohr (1901) stated that the narrow valleys with their mesic conditions had the common species of *Magnolia grandiflora*, *Magnolia macrophylla*, *Fagus grandifolia*, *Pinus glabra*, *Quercus nigra*, and *Quercus laurifolia*, a listing of species presently found in the protected slopes and ravines of the Red Hills. Of note also is the statement by Ware et al. (1993) referring to the true southern mixed hardwood forest which is dominated by beech, southern magnolia, semi-evergreen oaks, and other hardwoods; this vegetative mix may have been confined to very limited habitats within the primary range of longleaf. Slope forests overlying habitat of the Red Hills salamander conform to these descriptions.

Without an accurate historical description or research to piece together the natural floristics of the uplands of the Red Hills the best estimate will have to be made using the above references. Longleaf pine was undoubtedly present and a dominant tree of the forest. Some stands may have been exclusively composed of longleaf, others may have been a mix of longleaf and shortleaf, while other stands may have been a more heterogeneous mix of longleaf, shortleaf, a variety of oaks, and hickory. The complex interaction of soils, slope, perturbation events, natural fire barriers, seed source, etc. would have, over time, shaped the community of each site, and consequently each site will present a set of unique management issues. The presence of longleaf and shortleaf in the narratives of Mohr (1901) and Harper (1920; 1943) is strong evidence that fire was a major ecological force in shaping the natural communities of the ridgetops of the Red Hills. In the lower coastal plain wiregrass (*Aristida beyrichiana*) is an important understory species. This bunch grass traps fallen pine needles, contributes its leaves as a fine fuel source, and serves to carry fire across the forest floor. *Aristida* species are not present in the Red Hills but other bunch grasses, which do occur in the Red Hills, such as *Andropogon glomeratus* (bushy beardgrass), *Andropogon virginicus* (broomsedge), *Muhlenbergia capillaris* (hair grass), *Schizachyrium scoparium* (little bluestem), *Sporobolus junceus* (piney woods dropseed), and *Sorghastrum secundum* (lopsided Indian grass) may fill the ecological role of *Aristida*.

With longleaf pine natural communities along the Gulf and Atlantic coasts, and the Florida peninsula, fire has been identified as perhaps the single most important ecological process to the existence of the longleaf pine community. The natural longleaf pine community is a fire sub-climax, and without the regular perturbation introduced by fire, succeeds to a hardwood-dominated community type. Longleaf pine, and many of the herbaceous species which compose the ground cover, depend upon periodic burning. Fortunately fire is an ecological tool which has been well studied and has the advantage of simplicity of application once the longleaf have achieved a minimum size.

The herbaceous ground cover under a closed pine canopy may be virtually eliminated. An example using sand pine will be used assuming this is a parallel, but not necessarily, exact situation to a dense stand of planted slash pine. Sand pine (*Pinus clausa*) forms dense stands with a closed canopy and beneath the canopy native perennial grasses may be reduced to < 5% of the ground cover (Provencher et al., 2000). Removing the canopy of sand pine releases herbaceous species, primarily generalist species, but this also allows an avenue for the invasion of exotics. Complete restoration of a site formerly dominated by a closed pine canopy may require supplemental plantings or translocation of key species such as bunch grasses. Species expected to be on site but absent is likely due to mechanical site preparation involved with pine removal (or perhaps the initial plantings if the pine did not become naturally established) (Provencher et al., 2000).

As slash pine plantations are cut, and as an initial step, a replanting with longleaf should be done on the site. Each site would need to be evaluated regarding the presence (or absence) of expected herbaceous species important to the target fauna, for example gopher tortoises and Bachman's sparrows. If needed bunch grasses should be planted to re-establish this physiognomic group. Removal of the dense canopy cover of the pine plantation may allow dormant seeds to sprout, but sprouting will be hampered by mechanical soil disturbance which is detrimental to the herbaceous ground layer. Once the longleaf has reached an appropriate size and fire has been reintroduced to the site, seeds of some species that have lain dormant in the seed bank may sprout.

Three major questions need to be considered when approaching restoration, (1) what was the historical forest community type, (2) what is the desired community type, and is it the equivalent to the historical condition, and (3) what ecological processes are in operation, how may they be manipulated, and how will this affect the restoration outcome? Restoration should be based on a solid scientific understanding of the ecological functions involved and how they will influence the desired community. In the Red Hills the major factor in the loss of longleaf forests, or longleaf mixed forests, has been conversion of the natural forests to pine plantations. Assuming the open, park-like forest of Harper's time was the dominant forest across the ridgetops and that the desired forest is this type, the first two questions have been dealt with. Historically the longleaf forests had widely-spaced mature trees with an overall low basal area and the herbaceous ground cover had a high diversity of native grasses (including bunch grasses), forbs, and shrubs. Ecological processes which are typically recognized as being most influential upon the longleaf pine forest are disturbance factors, and these disturbance factors influence the forest on differing scales (Gilliam and Platt, 2006). In old-growth forests over half the canopy trees exceed half of the maximum life span while some trees are nearing the maximum life span. With natural old-growth or older second-growth stands of longleaf, canopy openings are created by lightning strikes killing trees, wind-throw knocking down one or a few trees, severe wind or tornadoes creating large canopy openings, or hurricanes generating even larger openings. For longleaf seedling growth an increase in light intensity is needed, yet the gap openings may release hardwoods which may out-compete and overshadow longleaf seedlings. Hurricanes and tropical storms stochastically impact the forest canopy, and the scale of the affected area may range from small to large; hurricanes and tropical storms exert a minor influence on the ground layer. Fire, under normal conditions, has little effect on the established canopy of longleaf pine, but exerts a strong effect upon the species composition of the ground layer (Gilliam and Platt, 2006).

Unlike storm events, fire may be used as an ecological tool. The effect of fire is to enhance the herbaceous ground cover, limit the expansion of shrubs, and suppress hardwoods, with a desired condition being one in which the patterns of vegetation conform to historical patterns. For example, in old-growth that has been frequently burnt a patch structure with trees of varying ages and sizes, plus open space, would exist. The natural openings are created by lightning, windthrow, and hurricanes and these forest openings allow an increase of light intensity to reach the ground. Plant diversity within these forest openings may increase as much as 20% within 5 years; the diversity increase may be maintained over several decades. On a small scale overstory trees may be managed ecologically through selective felling (Platt et al., 2006), if natural events are not yielding the desired result.

The seasonal timing of fire is crucial to accomplish longleaf restoration. Fire, even at the frequency of 2 – 4 years but during the cool season, may not eliminate oaks to the desired degree. Cool season burns may not burn as hot as needed because fuel may be somewhat moist; hence oaks may become established and be allowed to reach a larger fire-tolerant size. While oaks may be top-killed, rootstocks are rarely killed by the cool season burns (Jacqmain et al., 1999). Frequent and hot fires enhance the herbaceous understory which provides an increased availability of palatable resprouts for up to 3 years. Insect response is evident in that arthropod numbers increase also. Fresh growth attracts herbivorous insects, flowering attracts pollinators, and predators are attracted to the herbivores, pollinators, and other predators (Provencher, et al., 2003).

While overstory age may be irrelevant to ground cover condition, ground cover condition may be indicative of an old-growth condition of the forest. Wiregrass (*Aristida stricta*) dominance suggests a history lacking root disturbance, and ground cover vegetation not subjected to root disturbance or intense grazing has higher diversity than that of a disturbed site (Kirkman and Mitchell, 2006). A ground cover dominated by wiregrass indicates a history of frequent fire; fire as a management tool serves two purposes by enhancing the herbaceous vegetation and suppressing hardwood growth. Attainment of old-growth stands in the Red Hills would not be achieved for several hundred years, but steps toward this goal can be initiated.

Overstory condition is most important to red-cockaded woodpeckers, but for most other species condition of the ground cover is more important. Even though the northern range of wiregrass (*A. stricta* or *Aristida beyrichiana*) is south of the Red Hills, examples of optimal condition ground cover will be taken from studies done on wiregrass. The importance of wiregrass to fire ecology in longleaf forests has been well documented, as has the role of fire in the life cycle of wiregrass. As pine needles fall, the wiregrass leaves intercept the needles, and along with the wiregrass needles this flammable biomass may reach a peak of 6160 to 7840 kg/ha in 3 to 4 years. Wiregrass clumps serve as a mechanism to carry fire through the longleaf forest understory, and fire stimulates the flowering of wiregrass (Outcalt, et al., 1999).

Most longleaf ground cover research has been done in the Florida Panhandle, and central Florida within the range of wiregrass, but other bunch grasses are found in the Red Hills. Once wiregrass is eliminated from a site it will not readily become reestablished. If having bunchgrass species as understory components is critical, transplanting may need to be done to supplement or re-establish the grasses. Wiregrass transplantation may serve as a model in this regard. Wiregrass can be successfully transplanted using containerized plugs, but for best results the grass should be at least 6 months old, which increases survivorship potential. Site burning prior to planting also increases the probability of survivorship, while transplanting during a drought period increases mortality. If wiregrass is planted on sites where competition is reduced wiregrass may reach a mature size in 8 years. A minimum density of one clump centrally planted in 1 x 1 m plots is needed for good establishment and to reach fire-carrying capacity numbers more quickly, but the natural density of 5 clumps/m^2 would be optimal (Outcalt, et al., 1999). An alternative technique is to collect native grasses with a Flail-Vac and distribute seeds with a Grasslander. Native seed stock can be collected using an agricultural implement known as the Flail-Vac and spread using a second implement which is the Grasslander. Bryan Kreiter (pers. comm.) with The Nature Conservancy of Florida provided information on seed collection with the Flail-Vac; his communication follows.

Wiregrass Seed Collection in a North Florida Sandhill
Bryan Kreiter, The Nature Conservancy

The availability of seed is one of the greatest bottlenecks in the effort to restore groundcover in North Florida sandhill communities. This article is a collection of our experiences with wiregrass collection and the ATV-mounted Flail-Vac seed collector.

The Woodward Flail-Vac is manufactured by Ag-Renewal, Inc. The basic design is a rotating brush that strips the seed and sucks it into a hopper. Ag-Renewal offers three different sizes of collector. The 6 and 12 foot models are intended for mounting on the loader of a tractor and the 4 foot model is designed for mounting to an ATV via the Groundhog loader system. The 4 foot collector, loader and hydraulic power package can be purchased complete from Ag-Renewal. The 4 foot collector can yield over 100 lbs of wiregrass seed per day.

Equipment

ATV used must be at least 500cc, 4-wheel drive, liquid-cooled and have stout racks. Our recommendation is Polaris or Arctic Cat. The Arctic Cat needs slight modification in order to mount the loader system. I prefer the Arctic Cat because of its stout frame and suspension. Yamaha, Kawasaki, and Suzuki racks are far inferior to Polaris and Arctic Cat.

Suspension blocks come with the seed collector and should be used. Clamped on to the front suspension springs, they keep the front end from sagging and bouncing due to the weight of the collector/loader. Install them prior to mounting the collector to support the weight and keep the machine level. They tend to get knocked off occasionally. Take care to mount them tightly.

On the top of the collector is an air vent that is important for sufficient suction in the collector. The amount of air moving through this vent blows wiregrass right out. A wood or metal frame screen MUST be added for wiregrass collection or any other small or fuzzy seed. This screen will periodically plug with seed and chaff and needs to be kept clean for proper air flow.

The operator handles that come with the machine are short and hard to reach from the operator's seat. New handles can be made inexpensively with steel round stock. I have constructed 18" handles that angle toward the operator for both of our collectors.

The upper lip of the brush housing on the Flail-Vac tends to push over the seed stalks and can prevent them from making contact with the brush. It is also susceptible to collision damage. To mitigate this, cut the lip on either end and fold the lip back against the brush housing. Then install a ¾" iron pipe using pipe flanges on either end. This brings the leading edge of the machine back and prevents the lip from pushing over the stalks. It also adds strength and protects against the inevitable collision. The lower lip of the collector is also somewhat susceptible to damage and could be strengthened.

Timing

Environmental factors influence how early or late wiregrass will ripen. In a North Florida Sandhill, wiregrass is generally ripe by mid-November. Once ripe, the seed becomes more easily broken from the plant. Wind and rain will knock seed off the plants; therefore, the collection window is short and needs to be taken advantage of. Depending on environmental factors, the collection window usually lasts until mid-December, or occasionally longer.

Technique

Adjust the aggressiveness of the collector head by tilting it forward or backward. Tilting forward is more aggressive and yields more chaff. In wiregrass, this position exacerbates the problem of the leading edge pushing over the plant before it makes contact with the brush. Tilting the brush back exposes more of the brush face and yields clean seed but leaves much on the plant. In wiregrass it is best to run the machine level to the ground. This removes the most seed without excess chaff. Aggressiveness can also be adjusted with groundspeed. Groundspeed affects how long the brush is in contact with the plant. Higher groundspeeds (4-5 mph) produce cleaner seed but leave much on the plants. Slow speeds (1-2 mph) produce chaffy seed leaving little on the plant. 2-4 mph is ideal. Run the machine on the low end of this range when in dense stands.

The height of wiregrass seed heads is variable so, obviously, keep the collector at the height where it will come in contact with the most seed heads. In areas where wiregrass is dense, it is sometimes necessary to make multiple passes in different directions and/or heights to get as much seed as possible.

Wind above 10 mph can be troublesome for collecting because the plants are leaned over and the collector doesn't make contact with the seed heads. Driving perpendicular to or diagonal to the wind direction and lowering the collector head mitigates this problem.

Once seed has been collected it must be distributed, and Kreiter (pers. comm.) recommends the Grasslander as opposed to using a hay blower. Hay blower operation requires four staff, one to drive, one to feed seed, one to aim the blower, and one to roll the seed into the soil. Proper rolling of seed is critical for optimum contact between the seed and soil and can mitigate for poor soil and moisture conditions. Operation of the Grasslander requires only one staff person plus it scarifies the soil, drops an accurate amount of seed, and rolls the seed into the soil as it passes. The Grasslander is more efficient with seed also requiring ¼ of the seed mix per acre than that of hay blower usage. Thus, four times the acreage with ¼ of the staff can be planted with a Grasslander.

While the Flail-Vac and Grasslander are being used successfully in north Florida sandhills for wiregrass restoration these techniques may be transferable to Red Hills ridgetop restoration keeping in mind that native bunch grasses would be substituted for wiregrass. Minor modifications of technique may be required depending upon the species on site.

Additional points on restortation:

1) Characterize historical, pre-settlement condition, if possible.
2) Define desired community type, historical or otherwise and what fauna are expected to benefit.

3) Identify important or critical ecological processes which will influence the desired community type, and identify as to whether the processes may be used as an ecological tool (less management the better).

4) Identify methods of conversion of plantation back to natural forest such as cutting of plantation, and the planting of longleaf pine and bunch grass.

5) Identify appropriate management regarding burn frequency, timing of burn, burn patchiness, and expected outcome.

6) Do not plow firebreaks around ridgetop if possible; use natural firebreaks; do not plow firebreaks between ridge and slope; allow slope to serve as firebreak, fire will not travel down slopes > 15 degrees; firebreak plowing between slope and ridge may alter natural surface (and subsurface) hydrology to detriment of interior slope flora and fauna.

Natural (or restored) vs. Altered Ridgetop Tree Cover: A Postulated Linkage to Slope Habitat

The most species-rich family of salamanders in North America is the Plethodontidae and the singular defining character for this group is their lack of lungs. With the absence of lungs respiratory functions have been assumed by the integument. A basic environmental requirement for cutaneous respiration is that the surface of the skin must be moist, but not necessarily wet; dry skin reduces the effectiveness of gaseous exchange potentially to the point of mortality. *Phaeognathus hubrichti*, being a plethodontid salamander, is dependent upon living in an environment with some form of available moisture.

The burrow system of the Red Hills salamander provides several benefits, protection from predation, a communal system promoting social interaction, suitable microclimate for egg laying, and a moderated microclimate for continued physiological existence. The postulated connection between ridgetop condition and slope habitat is based on the physiology of the Red Hills salamander. Individuals of Red Hills salamanders require an environment which has some minimum degree of relative humidity or soil moisture, and the assumption is being made that the overlying habitat influences soil moisture. A natural stand of longleaf pine or longleaf-shortleaf pine mix experiencing a regular fire regime would consist of well-spaced trees with an overall low density as compared to a pine plantation. Conversely, the plantation is a monoculture of closely planted trees forming a dense closed canopy. Transpiration rates and soil moisture content undoubtably differ between these divergent states of tree cover. The critical difference being presented is that less soil moisture will be available under plantation conditions than under natural conditions. Rainfall is the primary source of moisture across this region. With the natural forest much of the rain will pass between trees and be absorbed into the ground. The dense canopy of the plantation will intercept much of the rain and it may collect on leaves, branches, and trunks and run to the ground or remain on the tree surfaces and evaporate. Once in the ground the moisture may be drawn out at a higher rate in the plantation than in the natural forest assuming plantation transpiration rates exceed natural forest transpiration rates.

Studies in hydrology provide evidence supporting this postulation. The water budget for a catchment includes rainfall (input) balanced by output, which includes runoff, groundwater recharge, and evapotranspiration. Evapotranspiration is further subdivided into ponded water held in depressions and on plant canopies, from the soil surface, and water use (transpiration) by plants. Differential evapotranspiration rates have been measured between native forests and plantations as compared to pastures and crops, with 1) native forests and plantations having a higher rainfall interception and transpiration rate, 2) native forests and plantations, with a deeper rooting system, having better access to soil water, 3) native forests and plantations having a greater ability to extract moisture from soil under dry conditions, and 4) mean annual recharge is lower under forest and plantation than crop or grass. Additionally, trees may use a significant amount of groundwater as compared to crops or grasslands, and some evidence indicates that evapotranspiration rates in mature pine stands are lower than in vigorously growing ones, with decreases becoming apparent after 30-35 years (Vertessy 2001).

The influence of forests, from a hydrological standpoint, has been approached from opposite directions (Allen and Chapman 2001), clearcutting increases water yield (Hibbert 1967) and reforestation results in a reduction in water yield (Bosch and Hewlett 1982, McCulloch and Robinson 1993). Several factors contribute to the water yield equation. Interception of rainfall by forest canopy reduces the water quantity reaching ground surface which then results in a reduction in surface runoff (Calder and Newson 1980; Farrell et al. 1998; Horton 1919). The process of interception loss, or the evaporation of intercepted rainwater directly back to the atmosphere, reduces the amount of water reaching the ground (Stewart 1968). For a coniferous forest the interception loss rate may be twice that of grassland. About one-half of the loss occurs during precipitation with the remainder taking place in the hours following precipitation (Calder and Newson 1979; Hall et al. 1996; Harding et al. 1992). Once in the ground, water may also be lost through transpiration as water is transferred from the soil to the atmosphere through tree roots, trunk, and leaves, and within a coniferous plantation this is a main mechanism of loss (Hall et al. 1996). The removal of soil water leading to evaporation, especially during dry periods, results in a soil-moisture deficit and the establishment of a zero flux plane (ZFP), a zone which separates the upward capillary-moisture movement from downward movement (Richards et al. 1956). Forests generate a greater deficit than grasslands; thus, the depth of the ZFP is generally greater under trees than grass, and may at times reach the water table. Under such conditions groundwater may be lost through both transpiration and evaporation leading to a lowering of the water table (Cooper 1980).

While the above examples are based on comparisons between forested and unforested lands an extrapolation to compare a dense young pine plantation to a natural mature longleaf forest can be made. Consider that the longleaf stand has a moderately open canopy with a grass-forb understory, thus placing it intermediate between the plantation and treeless grassland. Therefore the evapotranspiration rates seen in the natural longleaf forest would be lower than that of the plantation which would result in a higher groundwater recharge rate.

How is this important to the Red Hills salamander? As moisture moves downward through the porous sands of the ridgetops the moisture eventually contacts the underlying Tallahatta and Hatchetigbee formations, where it is absorbed. The retention of water in the soils and rocks in which *P. hubrichti* has its burrows is vital to establishing conditions which are physiologically favorable for the salamander, i.e. maintain a level of humidity conducive to cutaneous respiration. Reduced soil moisture content may stress individuals and lead to delayed or impaired reproduction, unsuccessful egg development, or increased mortality, which may be size dependent. Additionally prey availability may be reduced. These, and others, are potential inhibitory outcomes from reduced soil moisture within slopes inhabited by Red Hills salamanders. During years with above normal, or perhaps normal, rainfall soil moisture content may not fall below critical levels, but during drought periods biological thresholds of the salamander may be crossed because of reduced soil moisture content.

Embedded Habitats

Encompassed within the Red Hills landscape matrix are a number of smaller, yet biologically important, habitats such as ephemeral floodplain ponds, seepage areas, marshes, and swamps (Figure 20). With a comprehensive approach to conservation which includes the dominant habitats of ridgetops and slope forests these smaller habitats would fall under that protective umbrella. Salamanders, such as the *Ambystoma*, *Eurycea*, and *Desmognathus* which have aquatic larvae, winter, spring, and summer breeding frogs, and crayfish would benefit. Wading birds, snakes, crayfish, turtles, aquatic insects, and frogs would benefit with marsh and swamp protection.

Figure 20. Examples of small, yet important, embedded habitats include ephemeral ponds and swampy seepage sites.

Comprehensive Red Hills Conservation for the Red Hills Salamander and Gopher Tortoise

At the time of this writing only one tract supporting a population of the Red Hills salamander is under any degree of long-term protection. This site is under federal ownership; no populations are under state or private conservation organization ownership; therefore, a proposed Red Hills conservation framework is being put forth. The primary target species will be the Red Hills salamander but in order to accomplish complete conservation across the region ridgetops must be addressed and through this the gopher tortoise will be included.

Conservation Need:

Red Hills Salamander has minimal protection and no significant Red Hills salamander conservation is currently underway. Gopher tortoise (*Gopherus polyphemus*) populations in the Red Hills have no protection; only remnant populations remain and extirpation of these is imminent. (Even with intervention of federal listing these populations will not survive without a concerted conservation effort). Therefore, restoration of xeric-adapted ridgetop forest communities are needed to improve ecological conditions for the gopher tortoise in the Red Hills. Secondarily, ridgetop restoration may confer benefits to the Red Hills salamander but research in this area is needed. Primary protection of Red Hills salamander would be achieved through acquisition of large acreage tracts which support viable and sustainable salamander populations.

Goal:

Secure 3 large tracts with viable and sustainable Red Hills salamander (*Phaeognathus hubrichti*) populations, one in the eastern, western, and central portion of the range. Tracts should also have suitable habitat or restorable habitat for the gopher tortoise (*Gopherus polyphemus*), and of sufficient acreage to support a viable tortoise population(s).

Site Needs:

Large acreage (size to be determined) tract with mosaic of slopes, ravines, and extensive ridgetops as well as other habitats such as seepage areas and floodplain forests are needed. Presence of good Red Hills salamander population (= good habitat) is a requirement. Presence of restorable gopher tortoise habitat is a requirement. Presence of gopher tortoise population is not necessary but would be an added benefit.

Pilot Restoration Study:

As restoration of natural pine forest has not been attempted in the Red Hills a pilot restoration study is proposed. The objective of the study would be to convert a ridgetop pine plantation to an ecologically functional longleaf or longleaf-shortleaf mix forest capable of supporting a viable gopher tortoise population(s). This site would serve as a demonstration and research site.

Research and Monitoring:

Research goal will be to identify the ecological response of restoration actions both biotically and abiotically. A question to be answered is, "What significant, or measurable, changes occur following restoration that result in positive (or negative) affects upon the Red Hills communities?"

An approach would be to establish long-term monitoring stations from ridgetop to stream to document community response to restoration. Natural community factors to monitor or measure would be the ridgetop and slope forest canopy, shrub layer, and ground cover. Zoological components would include monitoring of Red Hills salamanders, gopher tortoises, birds, and invertebrates such as ground cover orthoptera, slope-inhabiting trap door spiders, ridgetop-inhabiting ants, and terrestrial snails.

Abiotic factors which may be included would be for air and soil temperature, rainfall, relative humidity, and solar insolation and how these factors influence ecological processes. The importance of soils should be investigated and the role of transpiration rates as it affects, or whether it affects, the soil/subsurface water storage and movement.

And finally, what has been the historical role of fire in the Red Hills and how should it be reintroduced as an agent of conservation management?

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