Status and Probable Decline of the Southern Dusky Salamander (*Desmognathus auriculatus*) in Georgia

Report to the Georgia State Department of Natural Resources Nongame Division

Final Draft

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9/6/06

Abstract— Despite evidence of worldwide declines in amphibian populations, the southeastern U.S. has apparently been spared from many of the unexplained declines reported from other regions. However, the southern dusky salamander (*Desmognathus auriculatus*) has reportedly undergone a range wide, rapid decline since the 1970's, and is now absent from seemingly pristine habitats, making this the first reported unexplained amphibian decline in the southeast U.S. Time-constrained visual encounter surveys of at least one hour were conducted at 32 historic and 19 newly designated collection localities to address the current status of *D. auriculatus* in Georgia. Only four *D. auriculatus* were located at three of the historic sites, and an additional six were found at a new site, indicating a possible >90% decline and an encounter rate of .13 *D. auriculatus* per hour using the most optimal collection technique for this species known. Though it is concluded that this salamander is at present uncommon in coastal plain habitats in Georgia, it is only speculative at this time whether a decline has taken place, though there is substantial anecdotal and quantitative data that they were much more common in the past (an encounter rate of 8.65 per hour has been reported). Possible reasons for this decline are discussed, and several recommendations for future work are provided.

Introduction

The last sixteen years of research on the worldwide decline of amphibian populations has determined several potential causes and identified alarming new cases of mysterious disappearances (Berger et al., 1998; Alfdord and Richards, 1999; Pounds et al., 2000; Kiesecker et al., 2001; Blaustein et al., 2003). This phenomenon is especially disturbing considering the importance of amphibians to many ecosystems in terms of vertebrate biomass (Burton and Likens, 1975; Petranka and Murray, 2001). Famous cases of amphibian declines or extinction include the golden toad and harlequin frog of Costa Rica, the mouth-brooding frog of Australia, and the Yosemite toad of California; in each case the population decline occurred in areas of high elevation and in seemingly pristine and protected habitat. To date, most amphibians of the southeastern U.S. have fared well compared to other regions, with habitat loss obviously responsible for those species with declining populations (e.g., the flatwoods salamander and gopher frog), and mysterious declines unreported. However, at least one species has apparently undergone massive declines in areas with little obvious habitat degradation. If substantiated, this decline represents the first case of an unexplained amphibian decline in the southeastern U.S., and one of only a few known cases of an unexplained decline of a salamander species (Means, in Lannoo, 2005; Beamer, 2004, unpubl. MS thesis; for an example of another salamander decline, see Bank et al., 2006).

The southern dusky salamander (*Desmognathus auriculatus*) once ranged from southwestern Virginia through eastern Texas, in lowland Coastal Plain blackwater creeks and swamps. Means (in Lannoo, 2005) reported a range wide decline of this species, suggesting population declines or crashes took place sometime after the mid 1970's. The species is apparently absent in many of the localities in Florida where Means collected them in great numbers (average encounter rate 8.65/hr) for his PhD research in the early 1970's (Means, 2005; Means and Travis, submitted). Others have commented on the rarity of this species in parts of its range (e.g., the Carolinas—Harrison, in Dodd, 1998), and Beamer (2005, unpubl. MS thesis) resurveyed several sites in the eastern and western periphery of this species' range and concluded that most historic sites were devoid of salamanders. Museum records from Louisiana (Boundy, in Lannoo, 2005) also suggest that *D. auriculatus* has undergone a severe decline there, though museum records must be scrutinized due to possible collection bias or collection effort confounds. The only published quantitative data of the status of *D. auriculatus* is that of Dodd (1998) who resurveyed a single site in Florida (Devil's Millhopper Geologic Area) and determined that *D. auriculatus*, which had once been collected there in great numbers, was no longer present. Thus, there is growing anecdotal and empirical evidence that *D. auriculatus* is far less common that it was in the past.

There is inherent difficulty in determining the status of a poorly studied animal, in that often there is little quantitative information on population numbers or sampling methods, and thus it is difficult to determine the current status of an animal when there is little information on how common they were previously. In addition, many researchers have warned of possible sampling bias in some of the purported cases of amphibian declines due to surveys being conducted during population fluctuations (Pechman et al., 1991) Nonetheless, population status surveys are very important for developing a baseline for future studies or determining the current status of historic collection sites.

The purpose of this study was to determine the present status of *D. auriculatus* in Georgia. First, quantitative counts of transformed individuals were made using time-constrained surveys at historical collection localities provided by Williamson and Moulis (1994). These surveys were used to determine the proportion of presence/absence of this salamander in historic locales, as well as a relative abundance statistic in terms of salamanders/time. These data were compared to encounter rates of other salamanders in its habitat to determine the relative abundance of *D. auriculatus*.

Methods

Time-constrained surveys of at least one hour were conducted at 32 historic collection localities and 18 newly designated localities from March 2006 through September 2006 (see table #1 and appendix). Sites were scattered across the Georgia Coastal Plain in most major drainages; these were chosen to determine the statewide status of the salamander. Spring and early summer were considered by Means (1975) optimal for collecting *D. auriculatus*, though they have been collected in all months in Florida and Georgia (Means, 1974; Williamson and Moulis, 1994; Dodd, 1998; Means, 2005). New sites were chosen for habitat suitability based on descriptions in Petranka (1998) and Means (1974,1975), and where locality data from historic collection sites were too vague (for example, Laura Walker State Park is listed as a collection locality, but the exact location in the park is unknown, so likely habitat was searched there and designated a new site). Certain localities (see table #1) were visited more than once, or for more than one hour for various reasons (easy access, apparently pristine habitat, recent or more precise collection data). Visual encounter surveys were conducted, with the observer(s) walking through suitable habitat rolling logs and sorting through leafy muck. All additional observers (B. Timpe, L. Giovanetto, D. Stevenson) were trained by and accompanied the author, or had more experience with this species than the author. Previous papers by Means (1974, 1975) and a biologist with experience collecting *D. auriculatus* (D. Stevenson, pers. comm.) were consulted to determine optimal collection techniques. These include raking muck with the hands, spreading muck "with a scrape of the boot (Means, 1974)," turning leaf muck with a hard rake, and rolling logs and other coarse woody debris (CWD—5-150cm in diameter). Rolling CWD was quickly determined to be the most ideal method (and all *D. auriculatus* captured during the survey were located using this method), though all methods were used during the survey. Over 100 logs and other CWD per site (per hour) were turned during most sampling periods (S. Graham, unpubl. data). The general habitat of each site was estimated from brief habitat descriptions taken in the field and was subsequently categorized (see appendix) according to the key and criterion of Wharton (1979).

When found, at least one *Desmognathus* sp. specimen (transformed individuals) in any coastal plain locality was collected from each site as a voucher. *D. auriculatu*s were identified based on the following combination of features: tail heavily keeled for most of its length, dorsal surface dark with indistinct pattern, ventral surface dark and remaining dark until preservation, large, distinct portholes along tail and along sides between legs, 4-5 costal grooves between adpressed limbs, and base of tail at posterior vent taller than wide (Means, 1974; Conant and Collins, 1991).

Tail clips or other tissues were stored in 95% EtOH for future phylogenetic analyses. Additional specimens were counted and released. Snout-vent length (SVL) and tail length (TL), tail base (at posterior vent) width (TW), tail base (at posterior vent) height (TH), and coastal grooves counted between adpressed limbs (CGAL) were measured for all collected coastal plain *Desmognathus*, and digital photographs of most specimens were taken prior to preservation. For TW and TH, the mean of 5 measurements was determined for each specimen to the nearest .1 mm. Other amphibian or reptile species were also identified and counted and released at each site. Larvae of three species were counted since they are easy to identify (*Eurycea quadridigitatta*, *Pseudotriton ruber*, and *P. montanus*) and may assist in comparisons of relative abundance. Toward the end of the survey a few specimens of salamanders and frogs were swabbed to determine the presence of Chytrid fungus, a pathogen implicated in the decline of amphibians worldwide (Berger et al., 1998). Samples were sent to a PCR lab through collaboration with the Atlanta Botanical Garden frog lab.

Percentage of historical localities presently occupied by *D. auriculatus* and ratio of salamanders per search hour was determined for each amphibian species to determine the relative abundance of *D. auriculatus* to other species under the above sampling regime. These data were compared to anecdotal information and quantitative data found in the literature to determine the likelihood of a decline.

Results

32 historic *D. auriculatus* collection sites (see table 1) were revisited for a total of 47 person hours and 19 newly designated sites (see table 1) were visited for a total of 30 person hours, resulting in a total study effort of 77 person search hours at 51 sites. In comparison, Beamer (2004, unpubl. MS thesis) surveyed 75 sites range wide using a similar 1-1.5 hr. time constrained survey for his Master's research, whereas this study was conducted out-of-pocket as preliminary research.

27 amphibian species were identified during the survey, with total individuals encountered ranging from one to >150. Total individuals counted for the study per species and per collection effort is given in Table 2. A total of four *D. auriculatus* were located at three historic collection sites, and six were located at a newly designated site at Fort Stewart, Georgia, resulting in 10 *D. auriculatus* located in 77 person hours of searching (.13 *D. auriculatus* per search hour). The minimum encounter rate was 0.0 per hour, with a maximum encounter rate of 3.0 *D. auriculatus* per hour at Fort Stewart, Georgia. Of the sites where *D. auriculatus* was located, the average encounter rate was 1.75 salamanders per hour. A few historic localities contained *Desmognathus* not referable to *D. auriculatu*s; either *D. conanti* or *D. apalachicolae* (See table #1).

Despite limited swabbing (N=5), a sample from the Reedy Creek site in Jefferson County came back from PCR analysis positive for the chytrid fungus.

Table 1:

***Desmognathus* in coastal plain localities**.

Location *	**County**	***D. auriculatus* Present**	***D. conanti* present**	***D. apalachicolae* Present**
Ogeechee trib.	Bulloch			
Billy's Island	Ware			
Riceboro (Leconte's)	Liberty			
Plains	Sumter			
Oscewichee springs	Wilcox			
Altamaha River bluff	Wayne		X, 3	
Penholloway creek	Wayne			
Suwanoochee Creek	Clinch	X, 1		
Suwanoochee Creek	Clinch			
Little creek	Wayne			
Kinchafoonee Creek	Marion			X, 5≅
Goose Run Creek	Long			
McKinney's Pond	Emanuel			
Little Ebenezer Creek	Effingham			
Run Br./Springfield	Effingham			
Run Br./Clyo	Effingham			
Little Ogeechee Pond	Chatham	X, 1		
Midway	Liberty			
Quacco Road	Chatham			

Kolomoki Park	Early			X, 3≅
Magnolia Bluff	Camden			
West St. George	Charlton			
McBean Creek	Burke		X, 4	
Little Sweetwater Cr.	Burke	X, 2		
Gillionville Rd. Albany	Dougherty			
Osierfield	Irwin			
Reedy Cr.	Jefferson		X, 1	
Mill Cr.	Bryan			
Belle Vista	Wayne			
Kneeknocker swamp	Brantley			
Camp Branch Cr.	Ware			
Baker Swamp	Liberty			

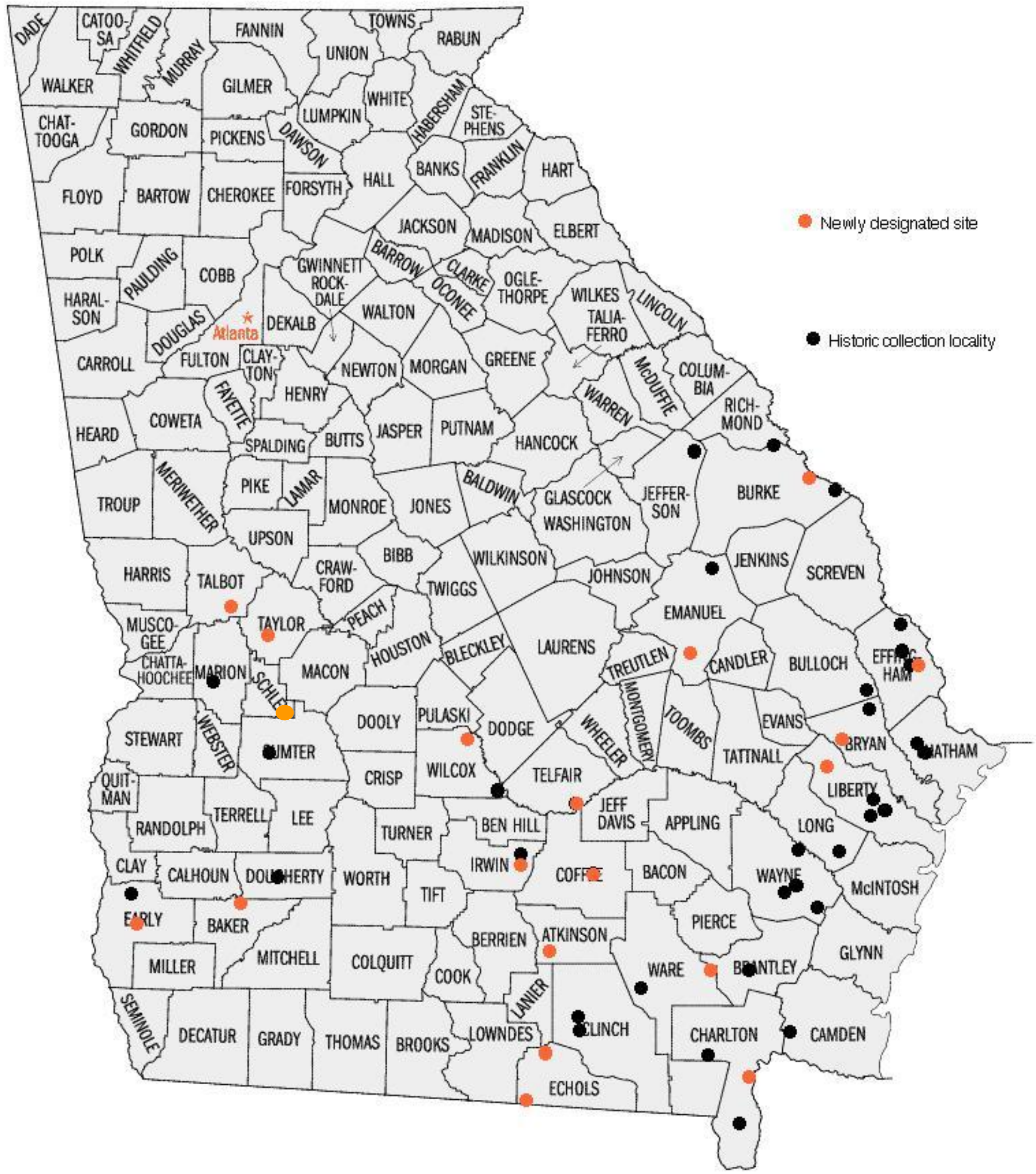
Newly designated collection sites with suitable habitat.

Gen Coffee S.P.	Coffee			
Fort Stewart	Bryan			
Fort Stewart	Liberty	X, 6		
Blue Creek	Early			
Spanish Cr.	Charlton			
Alapaha trib	Echols			
Oakgrove	Talbot			
Cedar Cr.	Wilcox			

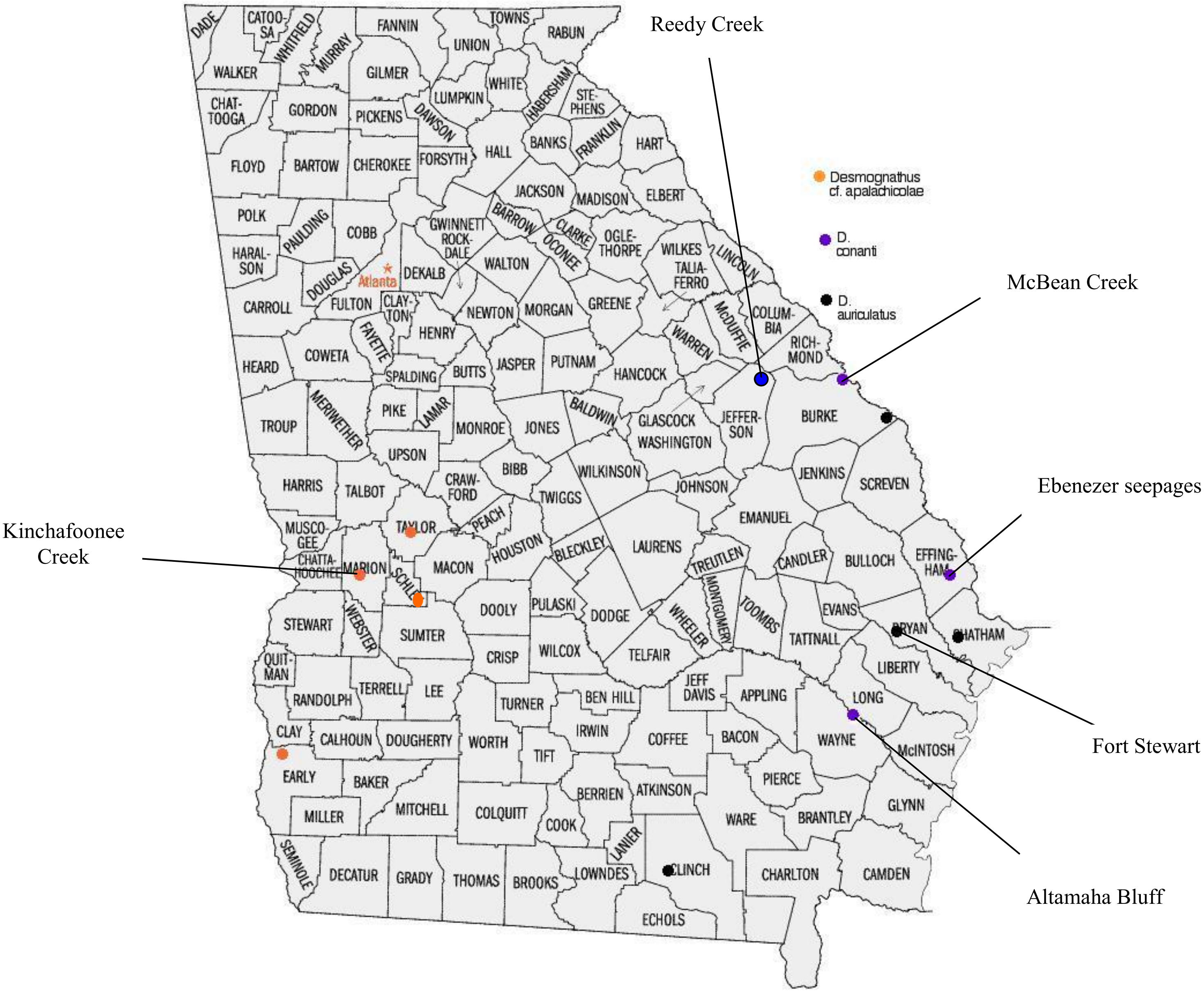
Satilla headwaters	Irwin			
Atkinson bays	Atkinson			
Ohoopee dunes	Emanuel			
Whitewater Cr.	Taylor			X, 2≅
Ebenezer seepages	Effingham		X, 22	
Laura Walker S.P.	Ware			
Alapahoochee trib	Echols			
Tobler Cr.	Burke			
Horse Creek WMA	Telfair			
Chickasawhatchee Cr.	Baker			
Sweetwater Cr.	Schley	X, 1?H		X, 5≅
Total		10	30	15

* see appendix for precise locality data

≅ *Desmognathus* specimens from these localities had the following key characteristics in common with *D. apalachicolae*: Large males with sinuate jaw commisure; tails long and round in cross section, tapering to a fine compressed tip; and base of tail width wider than tail height. A juvenile at the Kinchafoonee Creek site had a bold chestnut zigzagging stripe bordered by black and silvery white (see fig. 9).
H This specimen contained some but not all morphological features common to *D. auriculatus*— moderately keeled tail, "portholes" along tail but not sides, and dark ventral surface.



Map 1. Sites visited during this survey.



Map 2. Sites where *Desmognathus sp*. where located. Significant locations discussed in text labeled.

Table 2:

Amphibians encountered, all sites inclusive

Species	total (trans.)	larvae	per hour (trans.)	per hour larvae incl.
Rana heckscheri	7		.09	
R. clamitans	21		.27	
R. catesbieana	6		.08	
R. sphenocephala	19		.25	
Hyla squirella	3		.04	
H. avivoca	3		.04	
H. cinerea	2		.03	
Bufo terrestris	5		.06	
Eurycea cirrigera	78		1.01	
E. quadridigittata	40	34	.52	.96
E. guttolineata	52		.67	
Pseudotriton ruber	22	40	.29	1.24
P. montanus	3	20	.04	.30
Desmognathus auriculatus	10		.13	
D. conanti	30		.39	
D. apalachicolae	15		.19	
Amphiuma means	5		.06	
Siren intermedia	2		.03	

Stereochilus marginatus	2		.03	
Plethodon glutinosus	28		.36	
Ambystoma maculatum	1		.01	
A. opacum	1		.01	
Pseudacris crucifer	3		.04	
P. ocularis	1		.01	
Acris crepitans	19		.25	
A gryllus	~187		~2.43	

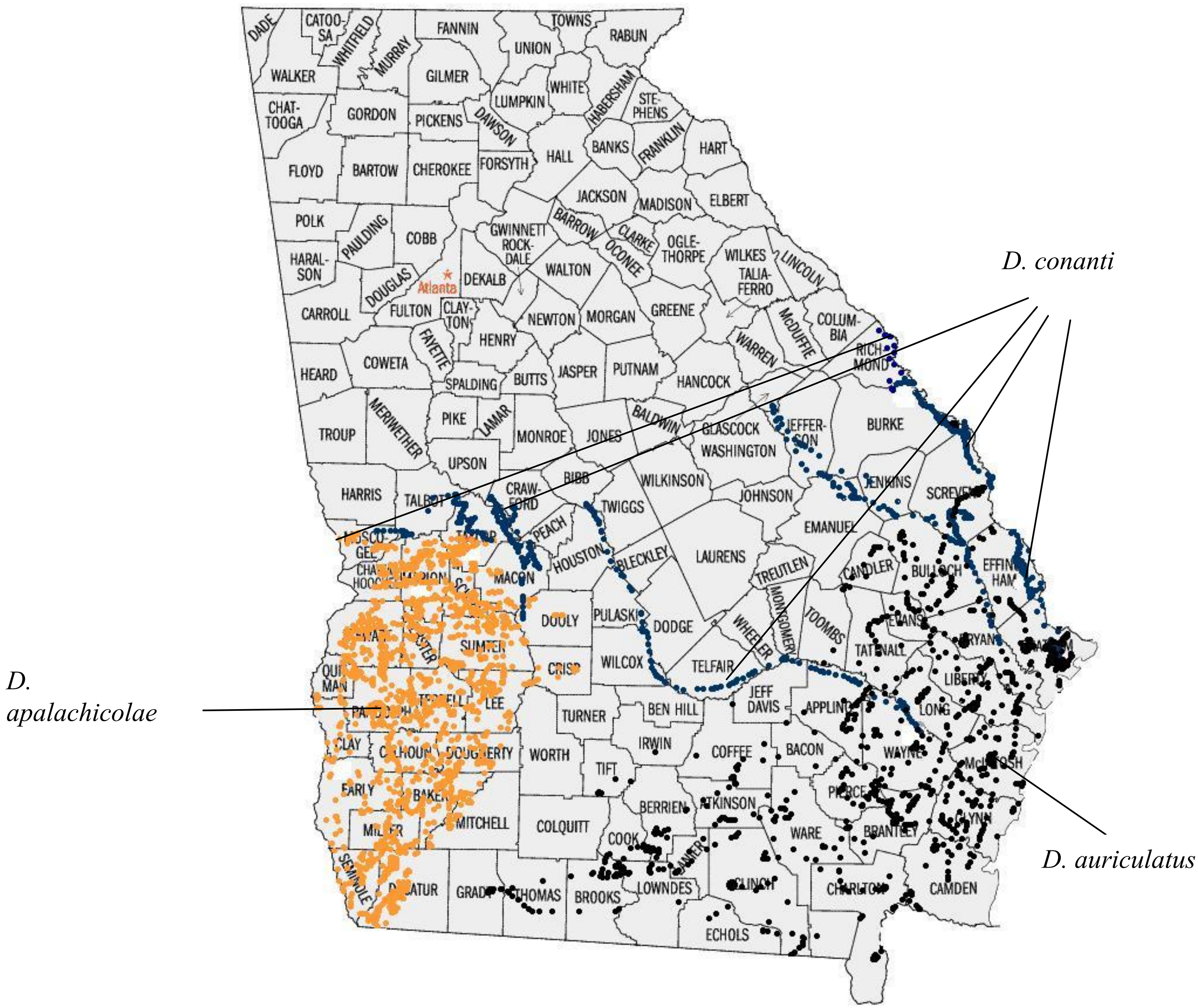
Discussion

Only ten southern dusky salamanders were encountered during this survey, and only four of these were located at three historic collection localities where they had been collected in the past. All ten southern dusky salamanders were located in blackwater branch swamps (for complete description, see #8 of Wharton, 1979, see also fig. 11), which was the most common habitat searched (see appendix). It is unlikely that many salamanders were missed during this survey due to the observer(s) overlooking them, since many species much smaller than *D. auriculatus* were located and counted during this survey (e.g., larval and metamorphosing *Eurycea quadridigittata*, and *Pseudacris ocularis* were located). It is possible that a few (~4) *D. auriculatus* were missed during this survey due to escape, as a few unidentified salamanders of the approximate size of *D. auriculatus* escaped before capture. Since the majority of historic sites were at bridge crossings (see appendix), I am fairly certain that the exact historic collection locality (within 50-100m) was located in most cases.

Several historic sites were located with dusky salamanders not referable to *D. auriculatus* and were probably catalogued by Williamson and Moulis (1994) incorrectly due to the difficulty of identifying *Desmognathus* species and the preponderance of relying on habitat type or region of origin as a diagnostic feature of identification. For example, several individuals referable to *D. conanti* were located at the McBean Creek site in Burke County, in a lowland mucky area. In addition, a few historic sites in the Middle Flint River drainage tentatively referable to *D. apalachicolae* were found in blackwater swamps or seepages (see fig. 11) near the fall line in the headwaters of Kinchafoonee, Sweetwater, and Whitewater Creeks (see fig. 1-4, 12,13; compare to fig. 8-10; fig. 14). These specimens shared key morphological features (sinuate jaw commisure in males (fig. 4), long, round tail tapering to fine tip (fig. 1-3), tail base wider than tail height; Means and Karlin, 1989—see table #3, bright juvenile pattern, see fig 13.) in common with *D. apalachicolae*, a member of the "*ochrophaeus*" group of dusky salamanders (see fig. 14), and probably represent a significant range extension for this narrowly endemic salamander.

In addition, certain major rivers (e.g., Altamaha, Savannah, Flint) apparently serve as corridors for the more northern form of *Desmognathus*, *D. conanti*, as seepages along these rivers contained these salamanders as far south as southern Effingham (see fig. 5-6; compare to fig.7-11), Wayne, and Macon Counties near the Savannah, Altamaha, and Flint Rivers, respectively. Any bluff or ravine collection locality for *D. auriculatus* near major alluvial rivers in Georgia should be viewed with suspicion, as these habitats often contained *D. conanti*. Beamer (2004,unpubl. MS thesis) presented phylogenetic data to support this contention, as previous collections made by him from the Savannah drainage and the Altamaha Bluff site were phylogenetically nested within *D. conanti* from Piedmont localities. More collection effort is necessary to better ascertain the distribution and taxonomic affiliation of Coastal Plain *Desmognathus* in Georgia.

Tentatively, it appears that the distribution of *D. auriculatus* in Georgia more closely follows the map in Means (1999) than the broad Coastal Plain distribution suggested by Williason and Moulis (1994) or Means (in Lannoo, 2005), with *D. auriculatus* found mostly in the lower Atlantic Coastal Plain in Georgia. *D. conanti* possibly exists along major rivers throughout their descent into the Coastal Plain, and can be found in swampy lowland sites (probably as long as they are adjacent to spring seeps, see fig.3)—as they are often found in the Piedmont of Georgia (pers. obs.). Finally, records of *D. auriculatus* in Williamson and Moulis (1994) from ravines along the Chattahoochee River and its tributaries (Kolomoki Cr., and the Ft. Gaines, GA record from Williamson and Moulis, 1994) are certainly referable to *D apalachicolae*.



Map 3. Hypothetical historical distribution of Georgia Coastal Plain *Desmognathus*. Each dot represents a hypothetical locality. There are probably far fewer extant *D. auriculatus* localities today.

I also present the first evidence of a possible range extension of *D. apalachicolae* into the Middle Flint Drainage of Georgia (Kinchafoonee, Sweetwater, and Whitewater Creeks), raising the possibility that *D. auriculatus* does not occur in these Gulf drainages and possibly others that are historic localities for *D. auriculatus* according to Williamson and Moulis (1994). However, at least one specimen (from Sweetwater Creek, Schley County) did not completely key out as *D. apalachicolae*, so it is possible that both *D. apalachicolae* and *D. auriculatus* are sympatric at this site. Samples taken from these localities will be sent to and processed by D. Beamer to determine their molecular phylogenetic relationships to other southeastern *Desmognathus* (D. Beamer, pers.

Fig. 1 Detail of tail of Kinchafoonee Creek, Marion County *D. cf. apalachicolae.* Note rounded base and long taper.

Fig. 2 Ventral surface of same specimen; note white overall color

Fig. 3 Dorsal surface; note long tail tapering to fine compressed tip

comm.), and preserved specimens will be analyzed by experts (C. Camp, B. Means) to verify their morphological similarity to extant described species.

Southern dusky salamanders were one of the least frequently encountered amphibians of this survey. A few species that are generally acknowledged to be uncommon in Coastal Plain habitats were encountered with roughly the same frequency as *D. auriculatus* (*Pseudotriton montanus* and *Stereochilus marginatus;* Petranka, 1998), while salamanders considered common were encountered far more frequently (*Eurycea guttolineata*, *E. cirrigera*, and *E. quadridigittata*; Wharton, 1979; Petranka, 1998). A few salamanders that are difficult to obtain using the collection techniques employed during this study (i.e., *Amphiuma means*, *Siren intermedia*, and *Stereochilus marginatus* are much more effectively captured by seining or dip netting—pers. obs.) were encountered generally as frequently as *D. auriculatus*. Oddly, I encountered the “Piedmont” salamander forms *D. conanti* and *P. ruber* more frequently in the Coastal Plain of Georgia than the "Coastal Plain" form *D. auriculatus*. Relative to other salamanders in the Coastal Plain, *D. auriculatus* should be considered rare, uncommon, or locally common at best.

Though I conclude that *D. auriculatus* is uncommon relative to other Coastal Plain salamanders and as rare as some of the acknowledged uncommon species, to determine if a decline has occurred we must know something about how common they were historically. Unfortunately, there is little quantitative data from Georgia to compare

Fig. 5 *Desmognathus conanti* from Ebenezer Creek seepages. Note flecking along tail, not distinct "portholes"

Fig.6 Dorsal aspect of *D. conanti* from Effingham County

Fig. 7 Ebenezer Creek seepages, Effingham Co. Seepages along ravines feed into deep mucks

Fig. 8 *Desmognathus auriculatus* from Fort Stewart, Bryan County. Note heavily keeled tail and distinct "portholes" along tail.

Fig. 9 Dorsal aspect of *D. auriculatus* from Fort Stewart, Bryan County.

Fig. 10 Detail of large "portholes" along the tail of *D. auriculatus*, Bryan County.

Fig. 11 Habitat of *D. auriculatus*: blackwater branch swamp. Notice large amounts of course woody debris, dark black muck, and lack of understory herbaceous or shrub vegetation. Author’s footprint at lower left. This branch swamp was bound on both sides by mature longleaf pine forest. More *D. auriculatus* were located at this site than any other during the survey (6).

Fig. 12 *Desmognathus cf. apalachicolae*, Kinchafoonee Creek, Marion County. Duskies from this site have many characteristics in common with *D. apalachicolae* from the nearby Chattahoochee drainage.

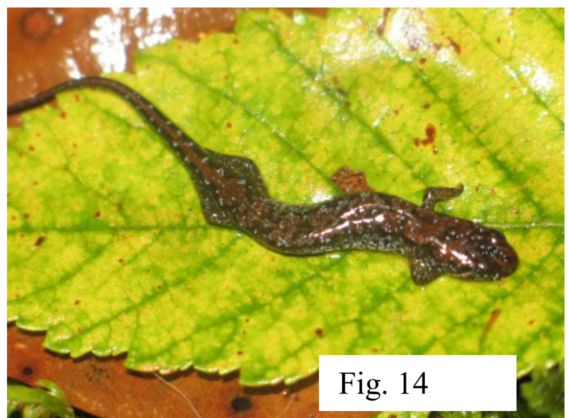


Fig. 14

Fig. 13

Fig. 13 *D. cf. apalachicolae*, Kinchafoonee Creek, Marion County. Juvenile with distinctive "mountain dusky" dorsal pattern. Compare with Fig. 14, juvenile *D. ocoee* from Union County, Georgia.

Fig. 15 Kinchafoonee Creek, Marion County. Habitat of *D. cf. apalachicolae*. This area contained the small headwaters of Kinchafoonee Creek, and thick mucks associated with seepages.

Site	**County**	**Species**	**N**	**CGAL**	**TH**	**TW**	**TH/TW**
Ebenezer Seepages	Effingham	*D. conanti*	7	3.28	4.25	3.87	1.1
Kinchafoonee Creek	Marion	*D. cf. apalachicolae*	4	3.25	4.82	5.14	.94
Sweetwater Creek	Schley	*D. cf. Apalachicolae*	4	3.24	3.55	3.60	.99
Fort Stewart	Bryan	*D.. auriculatu*s	4	4.75	5.39	4.76	1.13
Bluff Springs Branch	Stewart	*D. apalachicolae*	2	2	4.34	4.56	.95

Table #3. Comparative morphology of four coastal plain *Desmognathus* populations. CGAL- Number of costal grooves between adpressed limbs. *D. auriculatus* has 4-5; *D. conanti* or *D. apalachicolae*, 2-3. TH- mean tail height at posterior of vent; TW- mean tail width at posterior of vent; TH/TW- ratio of tail height to tail width at posterior vent; those with values over 1 have tails taller than wide and thus fit the "*fuscus*" morphology type (*conanti* and *auriculatus*), whereas those with values lower than 1 fit the "*ochropheus*" morphology type (*ocoee*, *apalachicolae*). The Bluff Springs Branch site in Stewart County was visited 8/27/06 for comparative material that was definite *D. apalachicolae*, and was not included in any of the results or discussion involving *D. auriuculatus*.

to the present study other than the collection localities of Williamson and Moulis (1994) that I used for this study. Assuming that absence of salamanders at a historic collection site during this study indicates their extirpation, *D. auriculatus* has indeed undergone a massive decline (>90%) in Georgia. However, this is to be taken as a worst-case estimate, as Means (1975) stated that non-detection of this species at a site is not sufficient evidence of their absence. At least two localities (Suwanoochee Creek and Fort Stewart) contained recently metamorphosed individuals, indicating breeding populations in at least two drainages (Suwannee and Ogeechee) in Georgia.

There is some anecdotal and empirical evidence that *D. auriculatus* is far less common than it was in the recent past (e.g., pre-1970). Though it is difficult to estimate the actual (quantitative) abundance of these salamanders from literature reports, a general picture emerges. In the Carolinas and Virginia, this species was considered "abundant under leaf litter and fallen logs in swamps and bottomland forests throughout the Coastal Plain" by Martof and others (1980). Eaton (1953) considered *D. auriculatus* common and widely distributed in the North Carolina Coastal Plain based on work done in Pitt County, and stated it "locally outnumbers all other salamander species combined." Beamer (2004, unpubl. MS thesis) resurveyed them same area and concluded they were absent from many localities and that *Eurycea cirrigera* was now them most common salamander.

Wharton (1979) considered the southern dusky a "dominant" in Georgia cypress ponds, and "common" at spring seeps along bluff forests in the Coastal Plain. Wharton (1979) specifically referred to Magnolia Bluff along the Satilla River, where I was unable to find dusky salamanders despite finding suitable seepage habitat. Wharton (1979) lists the southern dusky among other salamanders found in blackwater branch swamps but does not give an indication of abundance in this habitat.

Means (1974) collected >15 specimens of *D. auriculatus* from the type locality near Riceboro, Georgia (LeConte's Woodmanston historic site) for his PhD analysis of Coastal Plain *Desmognathus*. Visits during this study, Beamer's (2004, unpbl. MS thesis), and others (D. Stevenson, pers. comm.) have failed to collect specimens there again.

In Florida, Means (in Lannoo, 2005) considered the southern dusky salamander the most abundant salamander in its habitat historically. Means and Travis (submitted) suggest a dramatic decline in Florida and a complete extirpation of this species from the 185,600-ha Eglin Air Force Base. Means and Travis (submitted) also provides comparative quantitative data, with an average capture rate of 8.65 salamanders per hour during the 1970s compared to none found during his recent resurvey of his old collection sites. Dodd (1998) provides the only published quantitative data on *D. auriculatus*, with his rigorous survey of the Devil's Millhopper site in Florida. He concluded that the salamanders once common there were completely extirpated sometime during the 1970s.

In Louisiana, Dundee and Rossman (1989) considered *D. auriculatus* "locally abundant" in seeps and swamps of the Florida Parishes, though it is unclear whether they are referring in this case to *D. auriculatus* or *D. conanti*, as the statement follows a lengthy discussion of the taxonomic problems posed by these salamanders in Alabama, Mississippi, and Louisiana. Chaney (1949, unpubl. MS thesis) was able to collect >1500 *D. auriculatus* in only six days from one site in Louisiana. Despite the inherent difficulty of interpreting museum data, Boundy (in Lannoo, 2005) determined that *D. auriculatus* had declined from the Florida Parishes, and from the data he presented we can infer that >1700 *D. auriculatus* were collected from this region before the 1960's, and less than 20 were collected after that time.

There is limited evidence that the present status of *D. auriculatus* in Georgia is unchanged from its original status. Means (1975) compared the relative abundance of *D. fuscus* (= *D. apalachicolae*) to *D. auriculatus*, and mentioned that "the latter species does not seem to maintain the high population densities…" of the former. Means (1975) explained, "the greater tendency of *D. auriculatus* to burrow into the substrate (personal observations; corroborated by a stronger burrowing morphology in *D. auriculatus*—see Means, 1974) makes this species less amenable to surface collecting." He did clarify his statement, indicating that experience in searching for these animals led to the ability to determine their presence in almost all sites with suitable habitat (Means, 1975). Others (Gibbons and Semlitch, 1991) have also commented on the lower relative population sizes attained by *D. auriculatus* compared to other *Desmognathus*, stating that they are "not particularly abundant anywhere on the (Savannah River) site…" though no indication was given as to when or how this was determined.

Beamer (2004, unpubl. MS thesis) conducted the only range wide survey for *D. auriculatus*, and also determined that they were absent from most historic collection sites in the Carolinas, Georgia and Florida, and completely absent from the Texas portion of its range. Beamer (2004, unpubl. MS thesis) also reported similar taxonomic complications such as those I mention above, as most coastal plain *Desmognathus* located by him were not closely related to *D. auriculatus* according to his molecular phylogenetic analysis (i.e., they were *D. conanti* in coastal plain habitats or undescribed *Desmognathus* species). This pattern (also observed in the present study) leads me to suggest with some irony a fairly dependable way to identify coastal plain *Desmognatus*: if you find *Desmognthus*, it's either a *D. conanti* or *D. appalachicolae* site. If you don't, it's a *D. auriculatus* site.

Potential causes of the decline of *D. auriculatus* include invasive species, anthropogenic pollution, emerging infectious diseases (Means, in Lannoo, 2005), over collection, and habitat alteration. Means and Travis (submitted) mention a complicated trophic alteration due to the activity of nonnative pigs in the ravine habitats of Florida. I find this possibility unlikely to explain the declines across the range of *D. auriculatus* (i.e., hogs are not restricted to the coastal plain), though I did discover signs of hog activity at many historic *D. auriculatus* sites. Boundy (in Lannoo, 2005) mentioned that the lowland sites where *D. auriculatus* was once found are potential sinks for biotoxins. The lower pH of the blackwater sites may also contribute to accumulation of toxins, as certain toxins become bioavailable at low pH (e.g., aluminum—Beattie and Tyler-Jones, 1992; Bradford et al., 1992).

Though *D. auriculatus* does not fit predictions of amphibians likely to be affected by chytridiomycosis (e.g., highland, cool-climate forms; Berger et al., 1998), the single chytrid positive sample collected from the Jefferson County site during this survey should be cause for concern, as wholesale losses of amphibian faunas have resulted from chytrid epidemics (Berger et al., 1998). Means (in Lannoo, 2005) suggested the widespread and sudden nature of the *D. auriculatus* decline is perhaps best explained by an infectious disease. It may also be significant that the only other unexplained salamander decline of which I am aware concerns a close relative of *D. auriculatus* (e.g., *D. fuscus* in Maine, Bank et al., 2006).

It is unlikely that over collection lead to the decline of *D. auriculatus* in all cases, as both Means (submitted), Beamer (unpubl. MS thesis, 2004), and the current study also surveyed sites that had not been visited historically and found them devoid of salamanders. It is possible that over collection contributed to some declines, such as the Devil's Millhopper site (see Dodd, 1998 for the large sample collected by R. Highton), and the sites in the Florida Parishes in Louisiana (Boundy, in Lannoo, 2005).

Habitat alteration could be responsible for the observed declines. Though Means (in Lannoo, 2005) mentioned *D. auriculatus* was absent from seemingly pristine habitat, I noticed during this survey a qualitative difference between sites with and without *D. auriculatus*. Three of the sites that contained *D. auriculatus* appeared to have a more mature overstory and well-developed, open, muddy bottoms with little shrub cover (see fig. 7). It may be significant that the site where I found the most *D. auriculatus* was at Fort Stewart, a large military reservation long managed for native ecosystems and the last stronghold in Georgia for many imperiled amphibian and reptile species (e.g., indigo snakes, flatwoods salamanders, gopher frogs, and striped newts). Many of the other historic sites were possibly logged since the original collection took place, as I surveyed many second-growth branch swamps with dense shrub cover. However, at least one branch swamp with well-developed mature hardwood forest canopy did not contain *D. auriculatus* (Seventeen Mile Creek at General Coffee State Park).

Recommendations

Obviously, more work must be done to better determine the status and seek causes to the apparent decline of *D. auriculatus* in Georgia. I recommend the funding of more thorough sampling (including chytrid swabbing) at historic sites and newly determined sites in the Coastal Plain of Georgia, which will have the indirect benefit of delineating the ranges of two other *Desmognathus* species (*D. conanti* and *D. appalachicolae*—a regional endemic and species of special concern in Georgia) and possibly others (*Eurycea chamberlaini, Pseudotriton ruber*, *P. montanus*, *Stereochilus marginatus*, *Amphiuma pholeter*). These surveys should include seining and dipnetting surveys for *D. auriculatus* larvae, as these may prove more fruitful in determining the presence or absence of this species. The trophic position, function, and impact of *D. auriculatus* larvae and adults should be determined by removal experiments and biomass/dietary analysis, so the importance of these salamanders to blackwater creek ecosystems can be determined. Sites that contain these salamanders versus historical sites without them could serve as "natural experiments" to determine the impact and consequences of the disappearance of this species. Museum collections should be analyzed to better determine the past abundance of *D. auriculatus*. Laboratory experiments on *D. auriculatus* should be conducted on captive populations to determine susceptibility of these salamanders to pesticides, endocrine disruptors, and chytrid fungus. Finally, habitat information at *D. auriculatus* sites should be quantified, and GIS techniques should be used to determine if the apparent decline of *D. auriculatus* is simply a subtle case of anthropogenic habitat alteration. A well-funded PhD candidate could probably address most of these recommendations in 4-5 years.

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