The influence of habitat modification on the distribution of the cave salamander.

***Eurycea lucifuga*, in southern Illinois.**

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Habitat modification and other anthropogenic impacts have affected the populations of many species of animals, leading to an increased rate of extinction in the past several decades (Meffe and Carroll, 1994). Destruction of habitats, such as clear cutting of mature forests, are the most obvious form of modification, and can have dramatic effects. Less visible mechanisms of habitat modification such as the pollution of streams, rivers, and the air can also have damaging consequences to organisms (Alford and Richards, 1999). Amphibians are frequently considered to be more vulnerable to these anthropogenic impacts and habitat modification because their biphasic life cycle exposes them to pollutants in both terrestrial and aquatic habitats (Alford and Richards, 1999). Amphibian declines have been occurring around the world since at least the 1950's (Houlahan et al. 2000). Frogs seem to be more heavily affected than salamanders (Alford and Richards, 1999), however, some salamander species have been declining as well (Corser, 2001). Appalachian clear cutting, for example, is thought to have reduced salamander populations there by as much as 9% (Petranka et al., 1993). The specific causes of many of the declines are unknown, but research is currently underway to determine major culprits. Some of the potential causes of amphibian decline are: Ultraviolet radiation, predation, habitat modification, acidity and toxicants, diseases, climate and weather, and interactions among these (Alford and Richards, 1999).

In order to document a decline it is necessary to have baseline data demonstrating the geographic range of the species and the size of individual populations. Unfortunately in some cases a species may be discovered only a very short time before a decline drives the species extinct (Alford and Richards, 1999). Long term monitoring of populations and the distributions of populations across the range of a species are especially important in catching the declines before or as they happen. Understanding how a species disperses or recolonizes extirpated populations may be crucial in the conservation of amphibian species.

Obligate cave species are often considered to be at high risk to habitat modification due to their specialized habitat requirements (Culver et al., 2000). However, little research has been done to determine the status of species that may use the cave for only a portion of their lifecycle. The cave salamander, *Eurycea lucifuga,* is one such species. Cave salamanders spend their early development in caves (Ringia, unpub. data), and many inhabit cave mouths and other karstic areas as adults. The combined risks of the biphasic amphibian life cycle and cave habitat may have synergistic consequences to their vulnerability to anthropogenic influences.

The cave salamander is not currently listed as an endangered or threatened species anywhere across its range. However, researchers working with endangered species are often faced with a distinct lack of information on the species that they are trying to conserve or save. This makes the development of species recovery plans difficult. Although *Eurycea lucifuga* is not thought to be declining currently, similar species, such as the green salamander, *Aneides aeneus*, declined in the southern Appalachians in the 1970's, despite the lack of any obvious habitat modification (Corser, 2001). Corser

(2001) indicated that the type of decline experienced by the green salamander was most similar to that caused by a chytrid fungus in montane anuran species.

Habitat destruction is one of the leading causes of species and population loss (Meffe and Carroll, 1994). Over the past 70 years southern Illinois has experienced population growth, and the increased number of inhabitants has influenced land cover. Additionally, the increase in the use of pesticides in croplands increases the presence of those chemicals in the regions waters. I predict that sites with more visible of habitat modification will be less likely to have cave salamanders than sites where habitat destruction is not visible.

Species information

Cave salamanders are widely distributed across the central eastern United States, concentrated mostly in karstic regions (Petranka, 1998). They are typically found in association with moist caves, and similar habitats such as rock crevices and outcrops (Banta and McAtee, 1906;Hutchinson, 1958). They can also occasionally be found in swamps, especially in spring fed areas (Petranka, 1998). Cave salamanders have a bright orange dorsum with black spots and white ventral surface. Adults can be distinguished from the long-tail salamander, *Eurycea longicauda longicauda,* by the lack of black chevrons on the tail, and from the dark-side salamander, *E. longicauda melanopleura,* by the lack of black mottling on the tail, the cave salamander also has a brighter red orange coloration, compared to the more yellow orange of the long-tail and dark sided salamanders (Petranka, 1998). Larval cave salamanders can be distinguished from larval long-tail salamanders by the larger size of melanophores present on the throat (Brandon

1964). The eggs of cave salamanders are found in cave pools and streams, and are distinguished from those of the long-tail salamander by their smaller size (Myers, 1958).

Methods:

Cave salamanders have been collected at 52 sites in 9 counties across Southern Illinois since 1928 (Illinois Natural History Survey, SIU Herpetology collection; Figure 1). This haphazard collection of locality data over 72 years may not adequately represent the distribution of cave salamanders at any one point in time. Some locations have not been sampled in decades. To address the lack of current presence and absence locality data concerning the cave salamander I resurveyed the known historic sites in southern Illinois at which cave salamanders have been collected and documented in the Illinois Natural History Survey Collection, or the SIU Herpetology Wet Collection.

I determined the location of each site using the description written on specimen tags or INHS collection printouts, and then using topographic maps to determine likely areas. I then visited the sites and searched for probable habitat, including rocky outcrops, springs, rocky crevices and rocky streams, as mentioned by Petranka (1998). Once I had found suitable habitat I conducted a visual encounter survey for the presence of cave salamanders. All visual encounter surveys were conducted between June 2000, and March 2001 during the day or evening. During the visual encounter survey, I examined rock crevices, turned over stones, and looked in pools, and small streams, as well as observing open areas for the presence of cave salamanders in any life stage. The presence of any stage of cave salamander was counted as population existence. Each site was surveyed for four hours or until a cave salamander was found. I sampled surface sites during the spring and summer in order to reduce error resulting from seasonal effects. Cave sites are not affected by seasonal effects due to a less variable year round temperature, and were surveyed in the fall and winter. After I detected the presence of a cave salamander I did not continue surveying at that site, therefore population estimates are not available.

I qualitatively assessed the impact of human activity at each site, designating the quantity (low, medium, high) of visible modification, and the proximity of the modification to the location (near, far). I considered high modification to be indications of high traffic, such as highways, graffiti covered caves, and excess garbage. Moderate modification areas had lower traffic areas such as agricultural fields. Low modification areas had little or no indication of human impact, such as light hiking trails, or wooded areas. Proximity of impact was assessed by considering anything within 100 meters of a site to be "near", and anything between 100 meters and a kilometer to be "far". Beyond a kilometer is probably too far to influence the cave salamander population at a given site.

I recorded whether the site was in immediate proximity to water, such as a spring or stream, because cave salamanders deposit their eggs in subterranean water filled pools (Ringia, unpub. data). I also recorded the type of habitat (cave, rock bluff (>2 m high and >10 m long), and other (including rock outcrops (<2 m high or <10 m long), streams, fields, etc.), to determine cave salamanders were more associated with a particular habitat type.

I used a Garmin GPS 12 global positioning system to map the location of each site, if salamanders were found on the surface, and the location of the entrance to the cave if the salamander was found underground. I used Universal Transverse Mercator (UTM) coordinates in conjunction with Geographic Information Systems (GIS) data and the ArcView GIS program to construct a map overlaying historic and present salamander locations on southern Illinois and its kart regions.

Analysis:

I used a chi-squared test to compare the distribution of salamanders among disturbance categories (low, medium, high) and proximity of modification categories (near, far) and combined disturbance and proximity groups, in order to determine if salamanders were less likely to be found in areas with higher levels of disturbance, or which were closer to disturbed areas.

I also compared the distribution of salamanders among habitat types (cave, bluff, other) using chi-squared test, to determine preference for a particular habitat type. I report the presence of water (yes, no), but small sample size prevents the use of chi-squared analysis of distributions of wet and dry habitat types.

I weighted the number of sites at which salamanders were not detected by the proportion of the particular site type, and used the weighted absence values as expected values. Similarly weighted presence values were used as expected presence.

Results:

I mapped the locations of historic populations on a GIS generated map which included the presence of known karst formations. I overlaid current salamander populations over the historic populations on the same map (Figure 1).

I found cave salamanders at twenty-four of forty-eight locations, and could not obtain landowner permission to survey five of the original fifty-three sites (Table 2). Thirty-three of the forty-eight locations were relatively near habitat modifications, of which fourteen were lightly modified, eight moderately and eleven heavily modified. Fifteen of the locations were relatively far from disturbance, of those eight were lightly modified, five moderately and two heavily modified (Table 2).

There were no statistical differences among categories for the combined degree and proximity of modification (d. f. =5, χ^2=3.08), the degree of modification alone (d. f. =2, χ^2=2.73), or the proximity of modification alone (d. f. =1, χ^2=. 097) (Table 2).

Cave salamanders were found in 71% of 21 caves, 63% of 16 rocky bluffs, 10% of 9 habitats of other varieties, but the difference in distribution was not significant (d.f. = 5, X^2 = 10.8, Table 2)). 55% of the time water was available in the immediate vicinity of the site and was not a significant predictor of the presence of salamanders (d.f. = 1, X^2 = 3.18, Table 2).

Discussion:

Population declines occur for a variety of reasons including natural fluctuations, diseases, pollutants, climatic variation and habitat modification. Amphibians are particularly vulnerable to these factors, due to their reliance on multiple habitat types over their lives (Alford and Richards, 1999). Habitat modification, although not always the most important cause of population declines has the advantage of being highly visible, but is difficult to quantify. Also, not all of the effects of habitat modification are felt in the immediate vicinity of the location of modification, for example, a deforested area that is turned into fields will have greater runoff, and can influence nearby water-systems (Niemi et al, 1990).

Cave salamanders deposit eggs in water filled depressions in caves, which are influenced by pollutants in run-off from fields and roads (Boyer and Pasquarell, 1999). As adults they move more freely to cave mouths, bluffs, or other surface locations (pers. obs). This association with rocky areas (79% of vouchered sites) may help them in avoiding some of the major habitat changes that face more forest oriented species. However, the association with rocky, and karstic regions may also hamper surveying efforts. The historic records cover seventy years of haphazard surveying efforts, but do not adequately cover the likely cave salamander habitat. In my efforts to map cave salamander distribution in southern Illinois, I noticed that large areas of karst have no vouchered specimens of cave salamanders. These areas are readily visible in Figure 1, as being shaded, but not having dots for historic or current surveying efforts. I recommend greater survey efforts in the large areas of karstic terrain in southern Illinois where cave salamanders are likely to be found.

I was only successful at finding cave salamanders at 55% of the historic sites (Figure 1, Table 2), but there was no pattern to my success, supporting the null hypothesis that the habitat modification is not significantly influencing cave salamander populations. I found that habitat modification, as I measured it, did not have a significant effect on my success at finding salamanders. There was no difference in either the amount of modification, or the proximity of the modification. Cave salamanders were equally distributed among the historic sites regardless of habitat type, although a higher proportion of sites were caves and bluffs than other habitat types. The immediate availability of water sources also had no influence on the distribution of cave salamanders. None of these findings supported my predictions. For future studies, I would recommend measuring humidity at research locations, because as amphibians, moisture should be highly important to their survival. I would also recommend the analysis the available water for chemical runoff from agricultural fields that could potentially damage embryonic salamanders (Boyer and Pasquarell, 1999).

It is unknown whether salamander populations are connected through caves and underground waterways that are not passable to humans, which would allow the recolonization of locally extinct populations. Salamander larvae are susceptible to movement by floodwaters, and may be carried for some distance, although this has never been documented, and could also allow recolonization of both extinct populations and new regions. Cave salamanders may exist as a metapopulation connected by surface and cave waterways, although no evidence for this currently exists. Additional research into the methods of dispersal in the cave salamander, and the genetic differentiation among populations would elucidate the extent to which this medium of exchange can be utilized by organisms.

Local cave salamander populations appear to be very tolerant to human impacts with only a few broad restrictions to their distribution. However, it is currently unclear whether or not the species is declining, as are so many other amphibians, and other species. I have determined the gaps in the current knowledge of the distribution of cave salamanders in southern Illinois, and determined that visible disturbance is not a major factor in the loss of cave salamander populations. Additional research is necessary to fill in the gaps in the distribution of the cave salamander, to determine how the populations fluctuate over time.

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Figure 1: Historic and Current Cave Salamander Distribution in Southern Illinois

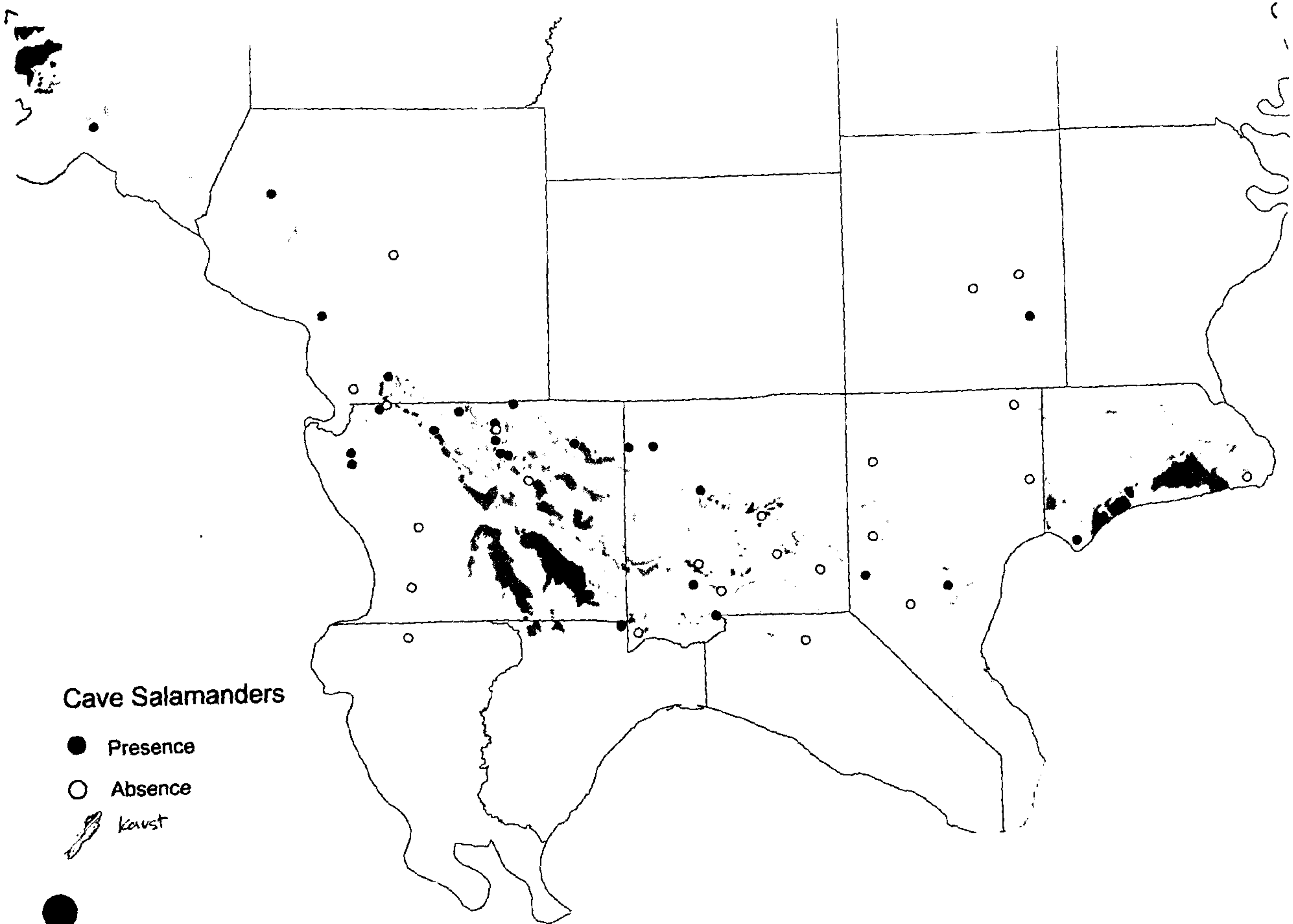


Table 1. Survey locations and degree of habitat modification

Listings without disturbanace data could not be surveyed due to lack of landowner permission.
Habitat coding cave=1 bluff=2 outcrop=3 other=4

County	Site	GPS Location E	N	Pres/Abs	stage	Disturbance Proximaty	Quantity	Water	habitat
Alexander	3m W Mclure	291018	4132731	n		near	light	n	3
Hardin	Rosiclare	380359	4142129	y	a	near	hvy	y	1
Hardin	3.5m E Cave-in-Rock	402813	4142129	n		far	light	y	2
Hardin	Eichorn	374361	4150482	n		near	moderate	n	3
Jackson	Giant City S.P.	306402	4163471	y	a	near	hvy	n	1
Jackson	Black's Cave	289978	4167802	y	a	far	light	y	1
Jackson	Clear Creeek Spring	285210	4166316	n		far	light	y	2
Jackson	Fountain Bluff	281504	4176212	y	a	far	light	y	2
Jackson	Murphysboro	291311	4183868	n		far	moderate	y	3
Jackson	Ava Cave	275484	4192643	y	a	near	hvy	y	1
Jackson	Stearn's Cave	289530	4163975	n		far	moderate	n	1
Johnson	Cedar Bluff Cave	321382	4156967	y	a	near	light	y	1
Johnson	Cypress Swamp Spring	346069	4139650	n		near	hvy	y	4
Johnson	Dutchman Creek	330018	4140973	n					
Johnson	Forman	332075	4134011	n	a	near	light	n	2
Johnson	Jug Spring	330752	4150800	y	a	near	hvy	y	1
Johnson	Little Black Slough	329261	4138247	y	a	near	light	n	2
Johnson	Mason Cave #1	319504	4133305	y	a	far	light	n	1
Johnson	Pipistrellus Pit Cave	319365	4133140	y	a	far	light	n	1
Johnson	Procyon Cave	321625	4132150	n				n	1
Johnson	Sink-Joint Cave	338620	4147040	n		far	moderate	y	1
Johnson	Teal's Cave	332900	4137270	n					
Johnson	5m east Vienna	340472	4141900	n		near	heavy	n	4
Johnson	Cache River/Forman	332075	4134011	y	a	near	light	y	2
Johnson	Ferne Clyffe	324709	4157010	y	a	near	hvy	y	2
Massac	New Columbia	343730	4130278	n		near	hvy	n	2
Pope	Dixon Springs S.P.	352115	4138651	y	j	near	light	y	2
Pope	Bell Smith Springs	353669	4153712	n		near	moderate	y	2
Pope	4m W Golconda	362926	4136838	y	a	far	hvy	n	2
Pope	Brownfield	357779	4134512	n				n	2
Pope	Herod	372715	4160543	n		near	hvy	n	2
Pope	1m S .5E Glendale	353261	4143752	n		far	light	y	4
Randolph	Indian Cave	252420	4202500	n					
Saline	Equality Cave	375351	4172265	y	a	near	heavy	y	1
Saline	4-5m east Harrisburg	374107	4177802	n		far	heavy	n	4
Saline	2mE, 1mS Harrisburg	367917	4176212	n		near	moderate	n	4

Union	Apis Annex	303846	4160037	n		near	moderate	n	1
Union	Bluff Lake-bluff base	291754	4139410	n		near	moderate	y	1
Union	Cave Spring Cave	288601	4163471	y	a	near	light	y	1
Union	Guthrie Cave	303849	4160959	y	a	near	light	y	1
Union	Honeycomb Hole	303937	4160117	n		near	moderate	n	1
Union	Lilly Cave	314273	4157800	y	a	far	moderate	n	1
Union	Pine Hills	284568	4157784	y	a	near	light	y	2
Union	Rich's cave	304429	4156887	y	a,j	near	light	y	1
Union	Saratoga Cave	307902	4153092	n		near	light	y	1
Union	Shilly-Shally	303810	4158600	y	a	near	moderate	y	1
Union	Twilight Cave-LRPH	284568	4157784	y	a	near	light	y	2
Union	Union Point Cave	299120	416276	y	a,j	far	light	y	1
Union	Wolf Lake	284649	4156262	y	a	far	light	n	2
Union	Alto Pass	295699	4160350	y	a	near	light	n	2
Union	3m E Ware	293012	4147418	n		near	heavy	n	3
Union	2m E Rich's Cave	305441	4156553	y	a	near	moderate	n	3

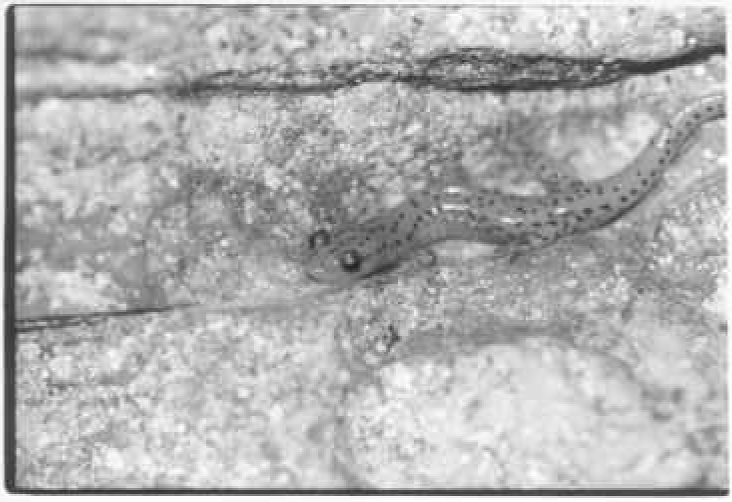
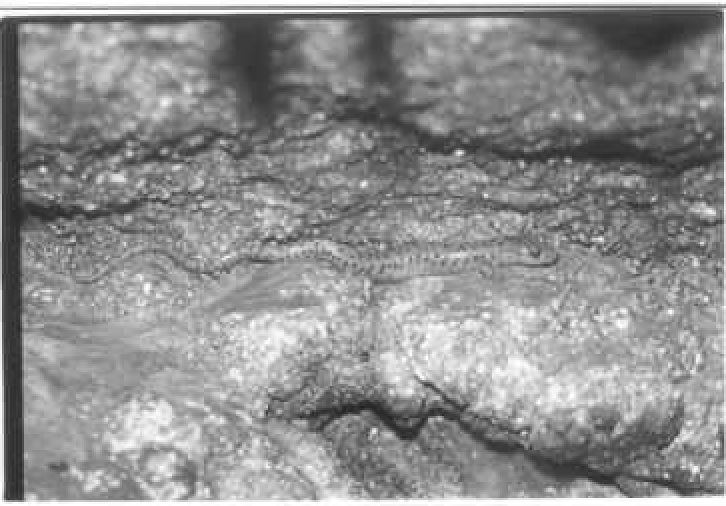
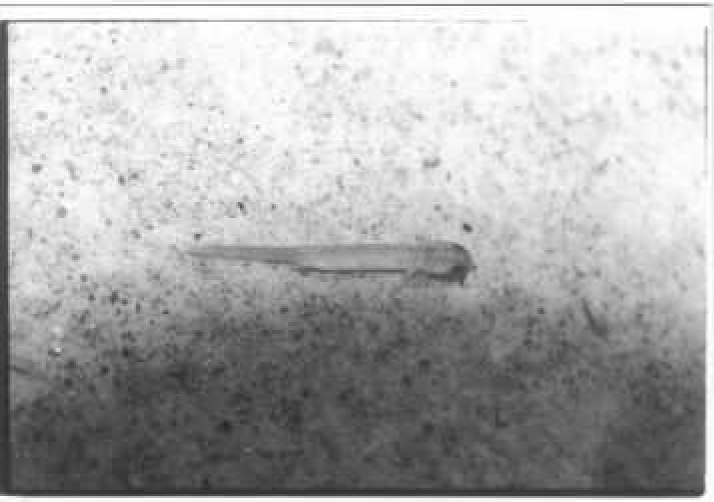
Table 2. Distribution of Historic and Current Cave Salamander locations, and the surveying success associated with habitat and disturbance variables.

# Historic Sites	53
Current populations	24
No population found	24
Unable to survey	5

Disturbance	Light Disturbance	Moderate	Heavy	total
Sites Surveyed	22	13	13	48
Near Habitat Modification	14	8	11	33
Distant Habitat Modification	8	5	2	15

Habitat	Caves	Rock Outcrops	Other
Present	15	10	1
Absent	6	6	8
total	21	16	9

Moisture	Water nearby	No Water
Present	17	9
Absent	9	13
Total	26	22


Rosiclare, Hardin Co., Illinois

Eichorn, Hardin Co. Illinois

3 Miles east of Mclure, Alexander Co., Illinois

Fountain Bluff, Jackson Co. Illinois

Stearns Cave, Jackson Co., Illinois

Murphysboro, Jackson Co., Illinois

Ava Cave, Jackson Co., Illinois

Forman, Johnson Co., Illinois

Cedar Bluff Cave, Johnson Co., Illinois

Jug Springs, Johnson Co., Illinois

Cypress Swamp Spring, Johnson Co., Illinois

Little Black Slough, Johnson Co., Illinois

New Columbia, Massac Co., Illinois

Fern Clyffe, Johnson Co., Illinois

5 Miles E. of Vienna, Johnson Co., Illinois

Mason Cave, Johnson Co., Illinois

Bell Smith Springs, Pope Co., Illinois

Golconda, Pope Co., Illinois

4 miles E. Cobden, Union Co., Illinois

Alto Pass, Union Co., Illinois

Dixon Springs, Pope Co., Illinois

Equality Cave, ~~Pope~~ Co., Illinois
SALINE

Shilly Shally Cave, Union Co. Illinois

Saratoga Cave, Union Co., Illinois

Guthrie Cave, Union Co., Illinois

La Rue Pine Hills, Union Co., Illinois

Wolf Lake, Union Co., Illinois

Lilly Cave, Union Co., Illinois