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CAVE AND SPRING FISHES OF THE SOUTHERN BEND OF THE TENNESSEE RIVER[1]

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ABSTRACT

Forty-seven species, representing 12 families and 30 genera, were collected from 68 springs, many of which had been developed for various purposes. Development usually destroys the constant spring environment, endangering organisms restricted to the spring habitat. Three species (*Typhlichthys subterraneous; Chologaster agassizi;* and *Etheostoma tuscumbia*) collected during this survey are apparently restricted to caves and springs in the survey area. Three additional species known only from caves and springs in the survey area were not collected during this study. The 6 species most frequently collected were *Campostoma anomalum, Notropis c. chrysocephalus, Semotilus atromaculatus, Lepomis cyanellus, Rhinichthys atratulus,* and *Cottus carolinae.* The number of species collected at a given locality ranged from 1 to 11 with an average of 5 species per station.

INTRODUCTION

Little is known about the ichthyofauna of springs in the Southeastern United States. In Agassiz's (1854) account of the fish fauna of the southern bend of the Tennessee River near Huntsville, Alabama, he included two species, *Chondrostoma prolixus=Campostoma anomalum and Rhinichthys obtusus=Rhinichthys atratulus,* from the Spring Branch in Huntsville. Gilbert and Swain (in Gilbert, 1887) described *Etheostoma tuscumbia* from Tuscumbia Spring, Tuscumbia, Alabama. Gilbert (1891) reported collections from several springs in Tennessee and Alabama and described *Fundulus albolineatus* from Spring Creek, Huntsville, Alabama. Evermann (1918) summarized some of the earlier work on the fishes of Kentucky and Tennessee and mentioned some 20 springs collected. Later, Hubbs and Allen (1943) and Herald and Strickland (1948) reported on Silver Springs and Homosassa Springs, both in Florida. Caldwell (1965) reported on fishes from limestone springs in the Valley and Ridge Province of the Mobile Basin and suggested that springs of the Southeastern United States may serve as places for relicism and endemism, as do those of the desert southwest (See Hubbs and Miller, 1948). Indeed, Howell and Caldwell (1965), Ramsey and Suttkus (1965), and Williams (1968) have each described new species of fish from springs of the Mobile Basin.

The southern bend of the Tennessee River is defined herein as the area from Walden Ridge near Chattanooga, Tennessee in the northeast, downstream through the northern part of Alabama to the area of the Tennessee state line in the northwest. This portion of the Tennessee River drains parts of two physiographic sections, the Highland Rim Section of the Interior Low Plateau Province and the Cumberland Plateau Section of the Appalachian Plateau Province. Within the study area, the Highland Rim Section embraces all of Giles and Lincoln counties and parts of Wayne, Lawrence, and Franklin counties in Tennessee. In Alabama it includes all of Lauderdale and Limestone counties and parts of Madison, Colbert, Lawrence, and Morgan counties. Rocks of the Highland Rim Section are primarily early and middle Mississippian in age. Much of the Highland Rim Section is plateau-like, although along major streams there is marked dissection. Highest summit elevations are slightly above 1,000 feet and Apparently represent remnants of the Highland Rim Peneplain (Thornbury, 1965). The Cumberland Plateau Section embraces parts of Franklin, Grundy, and Marion counties in Tennessee, parts of Colbert, Franklin, Morgan, and most of Marshall, Jackson, and DeKalb counties in Alabama. The plateau is at an altitude of approximately 2,000 feet at Sewanee near the eastern edge of Franklin County, Tennessee and declines somewhat toward the south. In Tennessee the Cumberland Plateau consists of a cap of Pennsylvanian shales and conglomerate sandstones overlying limestones of late Mississippian age. Where the Pennsylvanian cap is removed large sinks are formed in the underlying soluble limestones (Theis, 1936). In Alabama, the Plateau is developed largely upon the rocks of Pennsylvanian age and contains anticlinal valleys of older Paleozoic limestones and dolomites (Johnston, 1930). In general, the surface of the Cumberland Plateau is higher than that of the adjoining provinces.

The ground-water resources of this region are best shown by the omnipresent springs. Springs flowing several hundred gallons per minute are found in every county along the escarpment of the Highland Rim Plateau and along the Tennessee River.

Gratitude is due Dr. Herbert T. Boschung, Jr. who offered many constructive suggestions during the course of this study. Thanks are also due the other members of the senior author's graduate committee, Dr. George A. Rounsefell and Dr. Joab L. Thomas. Appreciation goes to Ben R. Wall and Thomas S. Jandebeur who assisted on several field trips. The manuscript was typed by Anna Williams, the wife of the junior author.

METHODS

This study is based primarily on specimens from 68 collections made between April 1966 and May 1967. Specimens are deposited in the University of Alabama Ichthyological Collection (UAIC). Several pertinent collections present in the UAIC at

[1]Based on a thesis submitted by the senior author in partial fulfillment of the requirements for the MS degree at the University of Alabama, Tuscaloosa, Alabama.

the beginning of this study are included herein. Unless otherwise stated, all collections were made with a minnow seine.

The location of each station in Alabama is given by township (T), range (R), and section (Sec). For some stations the section was further divided into quarters and, in some cases, these quarters were divided again into quarters. For example, a station cited as SW ¼ Sec 12, T 1 S, R 1 E, Madison Co., Ala. is located in the southwest one-fourth of section 12, township 1 south, range 1 east, Madison County, Alabama. Since Tennessee is not divided into sectionized townships, Tennessee collection stations were located in relation to permanent landmarks and major highways. Collection stations are generally numbered from west to east and are shown in Fig. 1. Elevations were determined either *in situ* with a Type MB-1 Kollsman altimeter or taken from USGS topographic maps (scale 1:250,000) to the nearest contour.

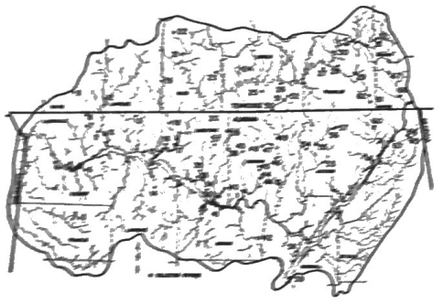

Fig. 1. Location of collection stations in the southern bend of the Tennessee River.

When available, the following data are given for each station: station number; spring name; location; elevation; approximate flow in gallons per minute; aquifer; water temperature in degrees Centigrade; bottom type; depth and width; vegetation present; date collected; UAIC number; and a list of species collected. These species are referred to by numbers assigned to them in the annotated list of species. The following abbreviations are used in station descriptions: el.=elevation; approx.=approximately; gpm.=gallons per minute; aqf.=aquifer; temp.=temperature; ft.=feet; hwy.=highway; mi.=mile.

Families are arranged phylogenetically according to the classification proposed by Greenwood, Rosen, Weitzman, and Myers (1966). In this annotated list, pertinent comments are given about selected species. Station numbers are listed for each species to indicate the presence of that species at a particular station or stations. Counts and measurements were made according to the methods described by Hubbs and Lagler (1958) and common names of fishes are in accordance with those published by the American Fisheries Society (1960). Lengths, when shown, are in standard lengths (SL).

Annotated List of Species

Petromyzontidae. Lampreys

1. *Lampetra aepyptera* (Abbott). Three specimens were collected during this survey. A female 105 mm total length and a male 110 mm total length were collected on 23 March over gravel in a spring run. The female had apparently spawned, as no eggs were present. One adult male was collected from a subterranean stream. Stations: 8, 41.

Clupeidae. Herrings

2. *Dorosoma cepedianum* (Le Sueur). The gizzard shad was collected from springs which had been dammed up to form small ponds. The seven specimens from Station 44a ranged from 260 to 305 mm SL. Stations: 6, 44a.

Esocidae. Pikes

3. *Esox americanus vermiculatus* Le Sueur. The grass pickerel was collected amid dense mats of *Myriophyllum* at Station 6. *E. a. vermiculatus* appears to be absent from the Tennessee River system above Colbert and Lauderdale counties in Alabama (See Fig. 1, Crossman, 1966). Station: 6.

4. *Esox niger* Le Sueur. Three specimens were collected in still water beneath dense mats of watercress. Station: 40.

Cyprinidae. Minnows

5. *Carassius auratus* (Linnaeus). Goldfish were seen in Big Spring, downtown Huntsville, but were not collected. Station: 44.

6. *Cyprinus carpio* Linnaeus. The specimen collected at Station 6 was the large scale or mirror carp variety. Stations: 6, 34, 36, 44a.

7. *Notemigonus crysoleucas* (Mitchill). The golden shiner is widely introduced as a bait minnow. It was collected from large springs in close proximity to impoundments. Stations: 5, 35, 43, 59.

8. *Clinostomus funduloides* Girard. The rosyside dace was collected in open water of large springs north of the Tennessee River. A heavily tuberculate male was collected 15 April 1967 (Station 59). Stations: 8, 9, 13, 22, 25, 27, 28, 30, 59.

9. *Semotilus atromaculatus* (Mitchill). Burton and Odum (1945) classified the creek chub as a typical headwaters fish. It was collected at 26 of the 68 stations. Stations: 1, 2, 9, 10, 12, 13, 14, 17, 20, 21, 22, 23, 25, 27, 35, 37, 39, 40, 44, 46, 49, 51, 52, 53, 58, 59.

10. *Hemitremia flammea* (Jordan and Gilbert). The flame chub is depicted by Jordan and Evermann (1896) as common in clear streams in nothern Alabama. Due to increasing agricultural development and to the practice of denuding stream banks, few streams in north Alabama are clear. *H. flammea* is associated with springs and clear, cold spring-fed creeks in the survey area. Stations: 8, 14, 29, 40, 43, 46, 47, 48, 50, 52, 53, 55.

11. *Chrosomus erythrogaster* Rafinesque. The southern redbelly dace was found in a variety of springs. Stations: 1, 2, 7, 9, 10, 12, 13, 25.

12. *Hybopsis amblops* (Rafinesque). One specimen (41 mm SL) of the bigeye chub was collected at Station 62.

13. *Rhinichthys atratulus* (Hermann). The blacknose dace, present at 29 of the 68 stations, was the most common minnow collected. Stations: 2, 8, 11, 13, 15, 20, 22, 23, 25, 27, 37 38, 40, 42, 43, 44, 45, 46, 49, 51, 52, 53, 54, 55, 57, 59, 62, 66, 67.

14. *Notropis ardens* (Cope). The rosefin shiner is a popular bait minnow in southern Tennessee. The three specimens collected at Station 30 were reportedly introduced by owners of several bait farms using this system of springs. Stations: 30, 62.

15. *Notropis chrysocephalus chrysocephalus* (Rafinesque). The striped shiner was collected at 25 stations. Stations: 4, 5, 6, 10, 15, 16, 17, 22, 23, 24, 27, 28, 29, 30, 40, 41, 46, 51, 53, 54, 55, 56, 57, 58, 62.

16. *Notropis telescopus* (Cope). The telescope shiner was collected at one station, a spring branch with deep pools. Station: 27.

17. *Notropis spilopterus* (Cope). Four specimens of the spotfin shiner were collected with a dip net from an underground stream (Station 31). Stations: 15, 31.

18. *Pimephales notatus* (Rafinesque). Stations: 14, 23, 24, 26, 29, 30, 53.

19. *Pimephales promelas* Rafinesque. Two specimens of the fathead minnow were collected from a single station, a limnokrene with a flow of approximately 3,000 gallons per minute. Trautman (1957) described the habitat of *P. promelas* as muddy brooks, ponds, and small lakes, where population pressure from other fishes is not great. Station: 59.

20. *Campostoma anomalum* (Rafinesque). The stoneroller was usually taken in riffle areas over sand and gravel. Stations: 4, 6, 8, 9, 10, 14, 15, 20, 21, 22, 23, 27, 29, 35, 43, 44, 46, 51, 52, 54, 55, 56, 57.

Catostomidae. Suckers

21. *Ictiobus bubalus* (Rafinesque). A single smallmouth buffalo was collected with a dip net from a subterranean stream. Station: 41.

22. *Catostomus commersoni* (Lacepede). The white sucker was collected in five springs with a higher than average flow and an average temperature of 15° C. Two strongly tuberculate males (140-145 mm SL) were collected at Station 54, 16 April 1966. Stations: 42, 43, 44, 44a, 54.

23. *Hypentelium nigricans* (Le Sueur). The northern hog sucker prefers clear, swift waters and was collected from two of the larger springs. Stations: 28, 30.

24. *Minytrema melanops* (Rafinesque). Two spotted suckers (410-450 mm SL) were collected from Brahms Spring (Station 44a) which had been dammed up forming a small pond.

Ictaluridae. Catfishes

25. *Ictalurus melas* (Rafinesque). Stations: 28, 34, 41.

26. *Ictalurus natalis* Le Sueur. One yellow bullhead (85 mm SL) was collected from a subterranean stream. Station: 41.

27. *Ictalurus punctatus* (Rafinesque). One channel catfish (295 mm SL) was collected from Station 44a.

Amblyopsidae. Cavefishes

28. *Chologaster agassizi* Putnam. Woods and Inger (1958) give the range of *C. agassizi* as swamps, caves, and springs of the limestone region from southern Illinois to central Kentucky and north central Tennessee. Two specimens (22 — 33 mm SL) were collected from a small spring 0.3 miles east of Cowan, Franklin County, Tennessee (Station 29). This is the first record of *C. agassizi* from south central Tennessee. The specimens were taken amid roots and debris beneath an overhanging bank. The bottom was mud and the water was approximately two feet deep.

29. *Typhlichthys subterraneus* Girard. Woods and Inger (1958) delimit the range of the southern cavefish from the limestone region of northeastern Oklahoma through southern Missouri and northern Arkansas to central Kentucky and Tennessee and into northern Alabama. Boschung (1961) reported 10 specimes from the Coosa River drainage, expanding its range to include the Mobile Basin. From field observations it is apparent that this species prefers a lentic habitat. Solitary fish may be seen lying motionless near the edge or bottom of subterranean pools. When disturbed, they swim off a short distance then stop. Two specimens were seen at Station 32 but were not collected. Stations: 31, 45.

Cyprinodontidae. Killifishes

30. *Fundulus catenatus* (Storer). Stations: 22, 23.

31. *Fundulus olivaceus* (Storer). Although most of the early workers considered *Fundulus olivaceus* and *Fundulus notatus* to be conspecific, more recent work indicates that the two are valid species (Brown, 1956; Braasch and Smith, 1965). The latest work to date (Thomerson, 1966) defines the range of *F. olivaceus* as overlapping that of *F. notatus*. In the Mississippi Valley, *F. olivaceus* ranges north to southern Missouri and Illinois, west to eastern Oklahoma, and east to Kentucky and eastern Tennessee (Anderson County). During this study only *F. olivaceus* was collected. Stations: 6, 10, 35, 37.

Poeciliidae. Livebearers

32. *Gambsia affinis* (Baird and Girard). Stations: 3, 6, 14, 26, 28, 33, 34, 35, 36, 40, 42, 47, 49, 50, 59.

Cottidae. Sculpins

33. *Cottus carolinae* (Gill). The banded sculpin was collected at more stations than any other species (37 of the 68 stations). Stations: 4, 6, 9, 12, 13, 19, 20, 21, 25, 27, 28, 29, 30, 32, 39, 40, 42, 43, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 66, 67.

34. *Cottus bairdii* Girard. With the exception of Station 65, the mottled sculpin was found to be sympatric with *Cottus carolinae*. *C. bairdii* was collected only from the northeastern part of the area surveyed, primarily from springs flowing from cavernous openings. These springs are typically colder than other springs (Johnston, 1933). Stations: 61, 62, 65, 66, 67.

Centrarchidae. Sunfishes

35. *Micropterus salmoides* (Lacepede). Two specimens (26-36 mm SL) were collected from Station 38 in a spring which feeds a pond into which *M. salmoides* and other centrarchids may have been introduced.

36. *Chaenobryttus gulosus* (Cuvier and Valenciennes). Stations: 5, 33.

37. *Lepomis cyanellus* Rafinesque. The green sunfish was collected at 26 stations and was the most common centrarchid collected. Stations: 4, 5, 6, 14, 15, 16, 21, 24, 26, 28, 29, 34, 35, 36, 37, 38, 40, 41, 42, 47, 48, 49, 50, 52, 59, 63.

38. *Lepomis macrochirus* Rafinesque. The bluegill was the second most common centrarchid collected. Stations: 5, 15, 21, 33, 34, 38, 40, 41, 47, 49, 51, 52, 60.

39. *Lepomis megalotis* (Rafinesque). Stations: 15, 17, 56.

Percidae. Perches

40. *Percina sciera* (Swain). One specimen was collected in a moderate current over a sand and gravel bottom. Station: 42.

41. *Etheostoma caeruleum* Storer. The rainbow darter was the most abundant darter present in the study area. Stations: 4, 5, 10, 16, 30, 46, 51, 52, 53, 55, 57.

42. *Etheostoma chlorosomum* (Hay). One specimen was collected in a slow current over a clean sandy bottom. Station: 53.

43. *Etheostoma flabellare lineolatum* (Agassiz). Stations: 8, 9, 29.

44. *Etheostoma duryi* Henshall. The blackside snubnose darter was collected at 13 localities. Stations: 23, 29, 42, 46, 52, 53, 55. 56, 59, 61. 62, 63, 66.

45. *Etheostoma simoterum* (Cope). The Tennessee snubnose darter was collected at six localities. It was taken sympatrically with a closely related species, *E. duryi*, at four localities. Stations: 27, 29, 46, 52, 60, 62.

46. *Etheostoma squamiceps* Jordan. The spottail darter exhibited more variation in morphology and color than any other percid collected. Stations: 8, 13, 19, 23, 24, 26, 29, 44, 50, 52, 57.

47. *Etheostoma tuscumbia* (Gilbert and Swain). This darter was described by Gilbert and Swain (in Gilbert, 1887) from Tuscumbia Spring, Tuscumbia, Alabama. The habitat of the Tuscumbia darter is dense mats of aquatic vegetation such as *Nasturtium* or *Myriophyllum*. In the early spring of 1967 the vegetation was dredged from the spring pool at Tuscumbia Spring and part of the bank filled in. Were it not for the fact that *E. tuscumbia* is well established in several other springs it would be in danger of extinction. However as a result of such practices as damming and dredging in other large springs, *E. tuscumbia* and other fishes restricted to springs have been placed on the U. S. Department of Interior's list of endangered wildlife (Bureau of Sport Fisheries and Wildlife, 1968). *E. tuscumbia* is restricted to springs, particularly those with dense growths of aquatic vegetation. Stations: 6, 14, 34, 40, 43, 47.

Discussion

A survey of 68 springs located in the drainage basin of the southern bend of the Tennessee River revealed the presence of 47 species of fishes, represnting 12 families and 30 genera. Although the majority of these fishes are also found in streams, several species collected are apparently restricted to caves and springs. In a similar study of the springs in the Valley and Ridge Province of the Mobile Basin Caldwell (1965) collected 40 species from 58 springs. Four of these species were found to be restricted to springs.

The spring habitat is generally characterized by constant temperatures and clear water. Odum (1957) noted that runoff water at Silver Springs, Florida dropped only 1° C in five miles, when sampled during a winter night, and rose 1° C in five miles on a June day, when the air temperature was over 37° C. The water temperature of springs in this area is close to the average regional air temperature (Causey, 1961). The clarity of spring water was reported by Odum (1957) in Silver Springs

from a horizontal Secchi disc reading of about 105 m, using an underwater observer with a face mask. Some of the large solution channel springs are exceptions and may be slightly muddy following prolonged rains.

Since springs are a constant source of clean, unpolluted water, many have been developed for various purposes. A number of the springs have been used as water supplies for individual families and municipalities. This is usually accomplished by constructing retaining walls around the edge of the spring and a low dam across the spring run. Smaller springs (up to 25 feet in diameter) used for water supply are often covered by a pump house. Some of the larger springs in rural areas have been modified for commercial growing of watercress (*Nasturtium officinale*), the dominant plant in springs of the survey area. Reservoirs have inundated many springs in the Tennessee Valley. For example, Mooresville Spring, which flows over 3,000 gallons per minute, is covered by the backwaters of Wheeler Lake (McMaster and Harris, 1963). Several springs have been dammed up forming ponds stocked with fish, usually rainbow trout (*Salmo gairdnerii*). The growing demands on springs as a source of unpolluted water and the subsequent alteration have greatly endangered the survival of organisms restricted to the spring habitat.

Several species reported by early ichthyologists (early 1900's) as being common in the area covered by this study were found to be totally absent during the course of this investigation. Two of the more noteworthy species not collected were *Fundulus albolineatus*, the whiteline topminnow, and *Lagochila lacera*, the harelip sucker. *F. albolineatus* was described by Gilbert (1891) from three specimens collected in Spring Creek, the outflow of Big Spring, in Huntsville, Alabama. In addition to the type specimens in the United States National Museum, a collection of five specimens was found, which had been catalogued as *Fundulus catenatus*. This collection (USNM 63133) is from Huntsville, Alabama and was collected by P. H. Kirsch, who collected the type specimens in the summer of 1889. Big Spring and Spring Creek have been drastically altered by the city of Huntsville so that they apparently no longer offer a suitable habitat for *F. albolineatus*. The changes that have essentially destroyed the spring habitat include: (1) a concrete retaining wall around the margin of the spring and its immediate run; (2) a dam on the spring run which forms a pond (for ducks, carp, and goldfish) in which the water temperature fluctuates with the air temperature; (3) the ditching of the stream below the dam. Although specimens were not collected from the study area, eight small specimens were collected and tentatively identified as *F. albolineatus*, from a spring in Coffee County, Tennessee, a tributary of the Cumberland River system.

Lagochila lacera was described by Jordan and Brayton (1877) from specimens collected from Chickamauga Creek near Ringgold, Georgia. Jordan and Brayton (1877) reported one specimen from the Elk River near Estill Springs, Tennessee (Station 30). Clay (1962) and Moore (1957) suggested that since it has not been reported for many years, *Lagochila lacera* is probably extinct. This species has two morphological features which could contribute to its extinction should environmental conditions change. One is its highly specialized mouth which suggests a specific diet; the second is its small opercle suggesting a clear water habitat on bottoms relatively free from silt (Clay, 1962). A reduction in either the abundance of food or the availability of a suitable habitat or a combination of the two could lead to the extinction of a highly specialized organism.

Three species collected during this study are apparently restricted to caves and springs in the area surveyed. They are: *Typhlichthys suterraneus Chologaster agassizi*, and *Etheostoma tuscumbia*. In addition to these species three additional species are restricted to caves and springs in the survey area, but were not collected during this study. One of these forms represents a new genus of cave fish (family Amblyopsidae) presently known only from a cave in Franklin County, Alabama. Less than 10 specimens have been collected by John Cooper and Robert Kuehne, who are presently preparing a description of this new cavefish. Another species is an undescribed pygmy sunfish, genus *Elassoma*, known only from Pryor Spring (Station 34). This species was first collected by the TVA during their preimpoundment surveys of the Tennessee River. Recent attempts by ichthyologists to collect this species in Pryor Spring have been unsuccessful. A description of this species is being prepared by James E. Bohlke of the Academy of Natural Sciences of Philadelphia. The third species is *F. albolineatus* from Big Spring and Spring Creek in Huntsville, Alabama.

Of the three species restricted to caves and springs collected during this study, a single species, *Typhlichthys subterraneus*, was found only in subterranean streams. Woods and Inger (1958) report this cave-limited amblyopsid from the physiographic provinces of the central United States designated by Fenneman (1938) as the Interior Low Plateau and the Ozark Plateau. Boschung (1961) reported a collection of *T. subterraneus* from the adjoining Cumberland Plateau. The Interior Low Plateau and the Ozark Plateau have in common a thick series of almost horizontal Mississippian limestone formations perforated by many ground water solution channels and noted for caves, springs, and sink holes. The limestone formations pass beneath the present surface drainage, including the Tennessee, Cumberland, and Mississippi Rivers and ground water has been found circulating through solution channels 100 feet below the present bed of the Tennessee River (Moneymaker and Rhoades, 1945). With such an elaborate system of dispersal, there are probably no truly isolated populations of *T. subterraneus*. This is undoubtedly one of the contributing factors to the absence of speciation in this genus.

Another amblyopsid, *Chologaster agassizi*, is less restricted to subterranean waters than *Typhlichthys*. Although individuals have been collected from surface streams and swamps (Woods and Inger, 1958), this species appears to be restricted to springs and caves in the area drained by the southern bend of the Tennessee River.

Of the eight percid fishes collected, *Etheostoma tuscumbia* is the only one restricted to springs. *E. tuscumbia* is typically found in lentic waters, under mats of *Nasturtium* or *Myriophyllum*. Judging from its present pattern of distribution, *E. tuscumbia* was probably once widespread although presently it is known only from isolated spring populations in the lower Tennessee drainage in northern Alabama and southern Tennessee. It is thought that the average summer temperature of northern Alabama was lowered by about 10° F during the height of the Wisconsin glacial stage (Dillon, 1956). This lowering of stream temperatures could enable temperature-limited species to live in such streams throughout the year.

Two species, *Hemitremia flammae* and *Cottus bairdii*, were found to be associated with springs in the survey area but not restricted to them. A few specimens of both species were taken in clear, cold spring-fed streams which were relatively undisturbed. Agricultural practices in the survey area have resulted in increased turbidity and silting of streams and have undoubtedly eliminated populations of these species in some areas.

In the 68 springs surveyed the six species most frequently collected were (Table I): *Campostoma anomalum, Notropis c. chrysocephalus, Semotilus atromaculatus, Lepomis cyanellus, Rhinichthys atratulus,* and *Cottus carolinae*. These six species are widely distributed in the Tennessee River System and other drainage basins of the Mississippi Valley. With the exception of *Notropis c. chrysocephalus*, Caldwell (1965) reported these same species to be most frequently collected in springs of the Moblie Basin. The apparent absence of *Notropis c. chrysocephalus* in springs of the Upper Coosa Drainage (Caldwell, 1965) is surprising since this species is common in creeks of this area (Gilbert, 1964).

The number of species of fishes taken at a given station ranged from a low of one species at six stations, to a high of 11 species at two stations. Most stations yielded three to seven species per station, with an average of five species per station. Springs in the Valley and Ridge Province of the Mobile Basin surveyed by Caldwell (1965) ranged from a low of one species to a high of 15 species with an average of four species per station. The lack of species diversity in springs, as compared to streams of equal flow, is due primarily to the absence of a variety of ecological niches. The reduced number of ecological niches found in springs is due to the constant or more stable environmental factors characteristic of most springs.

TABLE I. Frequency of Occurrence of the 47 Species Collected

Species	Number of Times Collected 1-2	3-9	11-14	23-37
Esox americanus	1			
Esox niger	1			
Carassius auratus	1			
Hybopsis amblops	1			
Notropis telescopus	1			
Pimephales promelas	1			
Ictiobus bubalus	1			
Minytremia melanops	1			
Ictalurus natalis	1			
Ictalurus punctatus	1			
Chologaster agassizi	1			
Micropterus salmoides	1			
Percina sciera	1			
Etheostoma chlorosomum	1			
Lampetera aepyptera	2			
Dorosoma cepedanium	2			
Notropis ardens	2			
Notropis spilopterus	2			
Hypentelium nigricans	2			
Tiphlichthys subterraneus	2			
Fundulus catenatus	2			
Chaenobryttus gulosus	2			
Ictalurus melas		3		
Lepomis megalotis		3		
Etheostoma flabellare		3		
Cyprinus carpio		4		
Notemigonus crysoleucas		4		
Fundulus olivaceous		4		
Catostomus commersoni		5		
Cottus bairdii		5		
Etheostoma simoterum		6		
Etheostoma tuscumbia		6		
Pimephales notatus		7		
Chrosomus erythrogaster		8		
Clinostomus funduloides		9		
Etheosioma caeruleum			11	
Etheostoma squamiceps			11	
Hemitremia flammae			12	
Lepomis macrochirus			13	
Etheostoma duryi			13	
Gambusia affinis			14	
Campostoma anomalum				23
Notropis chrysocephalus				25
Semotilus atromaculatus				26
Lepomis cyanellus				26
Rhinichthys atratulus				29
Cottus carolinae				37

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Appendix

STATION 1. Newsome Springs, SW ¼, SE ¼ Sec 4, T 5 S, R 13 W, Colbert Co., Ala.; el. 700 ft.; flow approx. 3 gpm.; aqf. probably Tuscumbia Limestone (Harris, 1957); temp. 20° C; bottom sand, organic detritus; depth to 2 ft.; width to 2 ft.; no vegetation; 30 July 1966. Pools formed by water dripping from limestone shelves. UAIC 1965. Species: 9, 11.

STATION 2. Unnamed spring branch, SW¼, SE ¼ Sec. 27, T 6 S, R 12 W, Franklin Co., Ala.; el. 800 ft.; flow undetermined; aqf. Tuscoloosa Group (Peace, 1964); temp. 20° C; bottom gravel, sand; depth to 1 ft.; width to 2 ft.; watercress in patches; 29 July 1966. UAIC 1963. Species: 9, 10, 13.

STATION 3. Unnamed spring, SE ¼, NW ¼ Sec 30, T 6 S, R 11 W, off Ala. Hwy. 24 within city limits of Russellville, Franklin Co., Ala.; el. 840 ft.; flow undetermined; aqf. Bangor Limestone (Peace, 1964); temp. 18° C; bottom organic detritus, gravel; depth to several ft.; width to 80 ft.; surface completely covered with watercress; 29 July 1966. UAIC 1962. Species: 32.

STATION 4. Parker Spring, SE ¼, SE ¼ Sec 28, T 3 S, R 13 W, Colbert Co., Ala.; el. 600 ft.; flow approx. 0.3 million gallons per day; aqf. probably Tuscumbia Limestone (Harris, 1957); temp. 16° C; bottom chert; depth to 6 inches; width to 2 ft.; watercress abundant along margin of spring run; 29 July 1966. UAIC 1964. Species: 15, 20, 33, 37, 41.

STATION 5. Gravelly Spring, NW ¼, NE ¼ Sec 32, T 3 S, R 12 W, Lauderdale Co., Ala.; el. 500 ft.; flow approx. 2,500 gpm.; temp. 14° C; bottom gravel, sand; depth to 3 ft.; width to 10 ft.; watercress abundant in quiet spots, some *Riccia;* 22 March 1967. UAIC 1988. Species: 7, 15, 36, 37, 38, 41.

STATION 6. Tuscumbia Spring, downtown Tuscumbia, Colbert Co., Ala.; el. 550 ft.; flow averaged 44.2 million gallons per day; aqf. Tuscumbia Limestone (Warman and Causey, 1961); temp. 16° C; bottom sand, gravel; depth to 3 ft.; width to 120 ft.; devoid of vegetation on 5 March 1967. This is one of the three largest springs in Alabama. 21 September 1962, UAIC 861. 30 July 1964, UAIC 1351. 2 April 1965, UAIC 1588. Species: 2, 3, 6, 15, 20, 31, 32, 33, 37, 47.

STATION 7. Unnamed spring, SW ¼, NE ¼ Sec 28, T 1 S, R 11 W, Lauderdale Co., Ala.; el. 600 ft.; flow approx. 20 gpm.; temp. 14° C; bottom sand; organic detritus; depth to 1 ft.; width to 3 ft.; no vegtation; 23 March 1967. Water issues from beneath pump house. UAIC 1990. Species: 11.

STATION 8. Unnamed spring complex, NW ¼, NE ¼ Sec 4, T 1 S, R 11 W, Lauderdale Co., Ala.; el. 650 ft.; flow approx. 800 gpm.; temp. 15° C; depth to 1 ft.; width to 10 ft.; mint along margin of spring; 23 March 1967. Water issues from ground over area approx. one acre in size. UAIC 1991. Species: 2, 8, 10, 13, 20, 43, 46.

STATION 9. Unnamed spring branch, about 0.8 mi. S. Natchez Trace on unpaved road to Cypress Inn Post Office, Wayne Co., Tenn.; el. 900 ft.; flow approx. 500 gpm.; aqf. probably Fort Payne Chert (Theis, 1936); temp. 14° C; bottom chert; depth to 1 ft.; width to 3 ft.; no vegetation; 23 March 1967. UAIC 1992. Species: 8, 9, 11, 20, 33, 43.

STATION 10. Bailey Spring, SW ¼ Sec 10, T 2 S, R 10 W, Lauderdale Co., Ala., el. 600 ft.; flow approx. 5 gpm.; aqf. chert (Harris, 1957); temp. 16° C; bottom rock, sand; depth to 2 ft.; width to 4 ft.; no vegetation; 2 April 1965. UAIC 1590. Species: 9, 11, 13, 15, 20, 31, 41.

STATION 11. Lawson Spring, NE ¼, NE ¼ Sec 6, T 2 S, R 10 W, Lauderdale Co., Ala.; el. 600 ft.; flow approx. 500 gpm.; temp. 15° C; bottom chert, sand; depth to several inches; width to 3 ft.; watercress abundant; 23 March 1967. UAIC 1989. Species: 13.

STATION 12. Unnamed spring complex at Wayland Springs, Lawrence Co., Tenn.; el. 575 ft.; flow approx. 150 gpm.; aqf. probably Decatur Limestone (Theis, 1936); temp. 14° C; bottom soft sand, chert, organic detritus; depth to 1 ft.; width to 50 ft.; watercress abundant, some mint; 23 March 1967. Water issues from several sources and flows into a common basin. UAIC 1993. Species 9, 11, 33.

STATION 13. Needmore Spring, NE ¼, NW ¼ Sec 9, T 1 S, R 7 W, Lauderdale Co., Ala.; el. 600 ft.; flow approx. 900 gpm.; aqf. Tuscumbia Limestone (Harris, 1957); temp. 14° C; bottom chert; depth to 1 ft.; width to 3 ft.; *Fontinalis* abundant in spring run; 5 March 1967. UAIC 1987. Species: 8, 9, 11, 13, 33, 46.

STATION 14. Wheeler Spring, NE ¼, SE ¼ Sec 36, T 4 S, R 7 W, Lawrence Co., Ala.; el. 750 ft.; flow approx. 400 gpm.; aqf. Tuscumbia Limestone (Harris and McMaster, 1965); temp. 16° C; bottom sand, gravel; depth to 2 ft.; width to 20 ft.; watercress abundant; 3 April 1965. UAIC 1592. Species: 9, 10, 18, 20, 32, 37, 47.

STATION 15. Moore Spring, SE ¼, SE ¼ Sec 10, T 3 S, R 7 W, Lauderdale Co., Ala.; el. 600 ft.; flow approx. 800 gpm.; aqf. Fort Payne Chert (Harris, 1957); temp. 15° C; bottom chert, rock; depth to 1 ft.; width to 12 ft.; watercress abundant along margin of spring run; 5 March 1967. UAIC 1984. Species: 13, 15, 17, 20, 37, 38, 39.

STATION 16. Unnamed spring, SE ¼, NE ¼ Sec 29, T 2 S, R 6 W, Limestone Co., Ala.; el. 600 ft.; flow approx. 200 gpm.; aqf. Fort Payne Chert (McMaster and Harris, 1963); temp. 14° C; bottom chert, rock; depth to 1 ft.; width to 2 ft.; watercress abundant in spring run; 5 March 1967. UAIC 1985. Species: 15, 37, 41.

STATION 17. Cave Spring, NW ¼, NE ¼ Sec 26, T 2 S, R 6 W, Limestone Co., Ala.; el. 600 ft.; flow approx. 200 gpm.; aqf. Fort Payne Chert (McMaster and Harris, 1963); temp. 14° C; bottom rock, silt; depth to 10 ft.; width to 25 ft.; no vegetation; 5 March 1967. Water issues from cavernous opening. UAIC 1986. Species: 9, 15, 39.

STATION 18. Unnamed spring branch, SE ¼, NW ¼ Sec 21, T 1 S, R 6 W, Limestone Co., Ala.; el. 600 ft.; flow approx. 500 gpm.; aqf. Chickamauga Limestone (McMaster and Harris, 1963); temp. 14° C; bottom gravel; depth to 1 ft.; width to 6 ft.; some watercress; 25 January 1967. UAIC 1982. Species: 9, 11, 13, 20, 38, 46.

STATION 19. Unnamed spring in Fall River, Lawrence Co., Tenn.; el. 900 ft.; flow approx. 100 gpm.; aqf. probably Fort Payne Chert (Theis, 1936); temp. 14° C; bottom chert; depth to several inches; width to 3 ft.; watercress and *Fontinalis* abundant; 23 March 1967. UAIC 1994. Species: 33, 46.

STATION 20. Unnamed spring on Tennessee-Alabama State Line on Hwy. 31, Giles Co., Tenn.; el. 700 ft.; flow approx. 450 gpm.; aqf. probably Fernvale Formation (Theis, 1936); temp. 14° C; bottom chert; depth to 2 ft.; width to 8 ft.; some watercress; 17 December 1966. UAIC 1968. Species: 9, 13, 20, 33.

STATION 21. Unnamed spring, 1.5 mi. N. Wales, on Mt. Pleasant Road, Giles Co., Tenn.; el. 700 ft.; flow approx. 300 gpm.; aqf. probably Fernvale Formation (Theis, 1936); temp. 14° C; bottom chert, sand; depth to 1 ft.; width to 3 ft.; watercress and *Fontinalis* abundant; 24 March 1967. Water issues from cavernous opening. UAIC 1995. Species: 9, 20, 33, 37, 38.

STATION 22. Unnamed spring near trout farm, approx. 4.0 mi. N. Campbellsville on Mt. Pleasant Road, Giles Co., Tenn. el. 800 ft.; flow approx. 1,700 gpm.; aqf. probably Fernvale Formation (Theis, 1936); temp. 14° C; bottom sand, gravel; depth to 4 ft.; width to 20 ft.; no vegetation; 24 March 1967. UAIC 1996. Species: 8, 9, 13, 15, 20, 30.

STATION 23. Unnamed spring branch, 1.2 mi. S. junction U. S. Hwy. 64 and Interstate 65, Giles Co., Tenn.; el. 700 ft.; flow approx. 200 gpm.; aqf. probably Fernvale Formation (Theis, 1936); temp. 12° C; bottom solid rock, chert, sand; depth to 2 ft.; width to 6 ft.; some watercress; 17 December 1966. UAIC 1969. Species: 9, 13, 15, 18, 20, 30, 44, 46.

STATION 24. Unnamed spring complex, W. Little Swan Creek on Tenn. Hwy. 64, Lincoln Co., Tenn.; el. 700 ft.; flow approx. 200 gpm.; aqf. probably Fernvale Formation (Theis, 1936); temp. 14° C; bottom chert; depth to 1 ft.; width to 2 ft.; some watercress; 17 December 1966. Spring run fed by several springs, one with remains of pump house covering it. UAIC 1970. Species: 15, 18, 37, 46.

STATION 25. Unnamed spring, 3.0 mi. S. Fayetteville, Lincoln Co., Tenn.; el. 800 ft.; flow approx. 125 gpm.; aqf. Cannon Limestone (Theis, 1936); temp. 12° C; bottom gravel, chert; depth 6 inches; width to 3 ft.; watercress abundant along margin of spring run; 17 December 1966. Formerly a municipal water supply for Fayetteville. Water flows from beneath ruins of pump house. UAIC 1971. Species: 8, 9, 11, 13, 33.

STATION 26. Unnamed spring, 0.2 mi. E. Kelso Community on Tenn. Hwy. 64, Lincoln Co., Tenn.; el. 700 ft.; flow approx. 15 gpm.; aqf. Fernvale Formation (Theis, 1936); temp. 12° C; bottom solid rock, organic detritus; depth to several inches; width to 3 ft.; watercress abundant; December 1966. UAIC 1981. Species: 18, 32, 37, 46.

STATION 27. Unnamed spring branch, behind Bethel Methodist Church, 4.1 mi. W. of Winchester off Tenn. Hwy. 50, Franklin Co., Tenn.; el. 900 ft.; flow approx. 500 gpm.; aqf. probably Warsaw Formation (Theis, 1936); temp. 15° C; bottom gravel, sand; depth to 3 ft.; width to 8 ft.; watercress abundant at source of springs; 19 December 1966. UAIC 1980. Species: 8, 9, 13, 15, 16, 20, 33, 45.

STATION 28. Sharp Spring, 2.0 mi. N. of Winchester, left off U. S. Hwy. 41A, Franklin Co., Tenn.; el. 900 ft.; flow approx. 2,500 gpm.; aqf. probably Warsaw Formation (Theis, 1936); temp. 16° C; bottom sand, chert; depth to 4 ft.; width 40 ft.; watercress and *Fontinalis* abundant in spring run; 19 December 1966. Used as public water supply for Winchester. UAIC 1979. Species: 8, 15, 23, 25, 32, 33, 37.

STATION 29. Unnamed spring, 0.3 mi. E. of Cowan on U. S. Hwy. 64, Franklin Co., Tenn.; el. 1,000 ft.; flow approx. 250 gpm.; aqf. probably Pennington Shale (Theis, 1936); temp. 16° C; bottom sand, gravel, and mud along bank; depth to 3 ft.; width to 6 ft.; some watercress; 19 December 1966. UAIC 1978. Species: 10, 15, 18, 20, 28, 33, 37, 43, 44, 45, 46.

STATION 30. Estill Spring complex, W. of L & N Railroad, Estill Springs, Franklin Co., Tenn.; el. 800 ft.; flow undetermined; aqf. probably Fort Payne Chert (Theis, 1936); temp. 14° C; bottom chert; depth to 1 ft.; width to 4 ft.; watercress abundant; 18 December 1966. This area has many springs combining to form a branch which runs through the community. UAIC 1975. Species: 8, 14, 15, 18, 23, 33, 41.

STATION 31. Underground stream in Crystal Cave, 0.5 mi. from Wonder Cave attraction near Monteagle, Grundy Co., Tenn., el. 1,100 ft.; flow approx. 10 gpm; temp. 16° C; bottom sand, gravel, rock; depth to 3 ft.; width to 6 ft.; 19 December 1966. Crystal Cave is an abandoned attraction owned by proprietors of Wonder Cave. This station was collected with a dip net. UAIC 1977. Species: 17, 29.

STATION 32. Wonder Cave Spring, Wonder Cave tourist attraction, near Monteagle, Grundy Co., Tenn.; el. 1,100 ft.; flow approx. 1,400 gpm.; temp. 16° C; bottom chert, rocks; no vegetation; 18 December 1966. Station sampled where flow emerges from cave. UAIC 1976. Species: 30. Two specimens of *Typhlichthys subterraneus* (Species 29) were seen in cave but not collected.

STATION 33. Unnamed spring, NE ¼ Sec 18, T 4 S, R 4 W, Limestone Co., Ala.; el. 700 ft.; flow approx. 75 gpm.; aqf. Tuscumbia Limestone (McMaster and Harris, 1963); temp. 17° C; bottom sand, silt; no vegetation; 16 July 1966. Water issues from a series of connected pot holes in wooded area. UAIC 1954. Species: 32, 36, 38.

STATION 34. Pryor Spring, SW ¼ Sec 22, T 4 S, R 4 W, Limestone Co., Ala.; el. 600 ft.; flow 2,500 gpm.; aqf. Tuscumbia Limestone (McMaster and Harris, 1963); temp. 18° C; bottom sand, gravel; depth to 8 ft.; width to 150 ft.; watercress abundant in spring with Eelgrass and *Myriophyllum* in spring

run; 16 July 1966. UAIC 1952. 6 April 1967, UAIC 1997. Species: 6, 25, 32, 37, 38, 47.

STATION 35. Unnamed spring, NE ¼ Sec 18, T 4 S, R 4 W, Limestone Co., Ala.; el. 700 ft.; flow approx. 75 gpm.; aqf. Tuscumbia Limestone (McMaster and Harris, 1963); temp. 14° C; bottom gravel, sand; depth to 6 inches; width to 3 ft.; no vegetation; 16 July 1966. Water issues from pump house. UAIC 1953. Species: 7, 9, 20, 31, 32, 35, 37.

STATION 36. Unnamed spring, SE ¼ Sec 3, T 5 S, R 4 W, Limestone Co., Ala.; el. 620 ft.; flow approx. 75 gpm.; aqf. Tuscumbia Limestone (McMaster and Harris, 1963); temp. 14° C; bottom sand, organic detritus; depth to 6 ft.; width to 20 ft.; *Salix* in and around series of connected pot holes; 16 July 1966. UAIC 1951. Species: 6, 32, 37.

STATION 37. Unnamed spring, SE ¼ Sec 19, T 2 S, R 3 W, Limestone Co., Ala.; el. 650 ft.; flow approx. 500 gpm.; aqf. Fort Payne Chert (McMaster and Harris, 1963); temp. 17° C; bottom chert, sand; depth to 3 ft.; width to 4 ft.; some watercress; 16 July 1966. UAIC 1955. Species: 9, 13, 31, 37.

STATION 38. Unnamed spring, NE ¼ Sec 36, T 2 S, R 3 W, Limestone Co., Ala.; el. 700 ft.; flow approx, 3,000 gpm.; aqf. Fort Payne Chert (McMaster and Harris, 1963); temp. 17° C; bottom chert, sand; some watercress; 16 July 1966. Water issues from a modified opening (pipe) and flows into a series of ponds. UAIC 1956. Species: 13, 35, 37, 38.

STATION 39. Wooley Spring, NW ¼ Sec 36, T 1 S, R 3 W, Limestone Co., Ala.; el. 600 ft.; flow 20 gpm.; aqf. Fort Payne Chert (McMaster and Harris, 1963); temp. 17° C; bottom sand, chert; depth to several inches; width to 2 ft.; some organic detritus; some watercress; 16 July 1966. Used as a source of water for health resort until 1900. UAIC 1957. Species: 9, 33.

STATION 40. Unnamed spring, NE ¼ Sec 2, T 5 S, R 3 W, Limestone Co., Ala.; el. 620 ft.; flow approx. 500 gpm.; aqf. Tuscumbia Limestone (McMaster and Harris, 1963); temp. 16° C; bottom sand, gravel; depth to 4 ft.; width to half an acre; watercress abundant in spring with some eelgrass in spring run; 16 July 1966. Formerly a watercress farm. UAIC 1950. Species: 4, 9, 10, 15, 32, 33, 37, 38, 47.

STATION 41. Cave Spring, NW ¼, SE ¼ Sec 4, T 6 S, R 3 W, Morgan Co., Ala.; el. 600 ft.; flow approx. 2,000 gpm.; aqf. Tuscumbia Limestone (Dodson and Harris, 1965); temp. 14° C; bottom sand, rock; depth to 4 ft.; width to 15 ft.; no vegetation; 11 June 1966. The collection inside the cave was made with a dip net. Species: 1, 15, 21, 25, 26, 37, 38.

STATION 42. Unnamed spring, NW ¼ Sec 24, T 7 S, R 1 W, Morgan Co., Ala.; el. 620 ft.; flow approx. 500 gpm.; aqf. Pottsville Formation (Dodson and Harris, 1965); temp. 14° C; bottom sand, gravel; depth to 6 ft.; width to 6 ft.; no vegetation; 16 July 1966. Water issues from a cavernous opening. UAIC 1949. Species: 13, 22, 32, 33, 37, 40, 44.

STATION 43. Indian Spring, NW ¼ Sec 2, T 3 S, R 2 W, Madison Co., Ala.; el. 600 ft.; flow approx. 3,500 gpm.; aqf. Fort Payne Chert (Malmberg and Downing, 1957); temp. 16° C; bottom sand; depth to 6 ft.; width to 12 ft.; watercress abundant; 17 July 1966. Formerly a watercress farm, water flows through a series of boarded up pits. UAIC 1960. Species: 7, 10, 13, 20, 22, 33, 47.

STATION 44. Huntsville Big Spring, downtown Huntsville, Madison Co., Ala.; el. 600 ft.; flow fluctuates from approx. 5 to 28 million gallons per day; aqf. Tuscumbia Limestone (Malmberg and Downing, 1957); temp. 17° C; bottom gravel, sand; depth to 3 ft.; width to 20 ft.; eelgrass abundant. Supplies park area with water for ponds. Formerly a municipal water supply. 17 July 1966, UAIC 1961. 10 September 1966, UAIC 1966. Species: 5, 9, 13, 20, 22, 46.

STATION 44a. Brahms Spring, in Huntsville, Madison Co., Ala.; el. 600 ft.; flow undetermined; aqf. Tuscumbia Limestone (Johnston, 1933); temp. not taken; bottom mud; depth to 3 ft.; width approx. 60 ft.; vegetation abundant around the margin; 19 October 1968. Spring has been dammed up to form a pond in a municipal park. UAIC 3237. Species: 2, 6, 22, 24, 27, 47.

STATION 45. Underground lake in Shelta Cave, between Cave and Linx Avenues, Huntsville, Madison Co., Ala.; temp. 18° C; bottom solid rock, silt; depth to 4 ft.; width to 100 ft; cave excavated in Warsaw Limestone and probably its water is discharged through Huntsville Big Spring, Station 44, or Brahm's (Merrimack) Spring, Station 44a (Johnston, 1933). The collections were made with a dip net. 29 November 1964, UAIC 2148. 7 April 1967, UAIC 1999. Species: 29.

STATION 46. Acuff Spring, NE ¼ Sec 14, T 3 S, R 1 E, Madison Co., Ala.; el. 600 ft.; flow fluctuates from 0.5 to 14.5 million gallons per day; aqf. Tuscumbia Limestone (Malmberg and Downing, 1957); temp. 16° C; bottom sand, gravel; depth to 8 ft.; width to 40 ft.; 17 July 1966. Formerly a watercress farm. UAIC 1958. Species: 9, 10, 13, 15, 20, 41, 44, 45.

STATION 47. Unnamed spring, NW ¼ Sec 27, T 2 S, R 1 E, Madison Co., Ala.; el. 600 ft.; flow approx. 1,000 gpm.; aqf. Tuscumbia Limestone (Malmberg and Downing, 1957); temp. 17° C; bottom sand, silt; depth to 3 ft.; width to 15 ft.; watercress, mint, *Spirodela* abundant and some *Callitriche;* 10 September 1966. Formerly a watercress farm, the spring complex covers approx. one acre. UAIC 1967. Species: 10, 32, 37, 38, 47.

STATION 48. Unnamed spring, NE ¼, SE ¼ Sec 25, T 2 S, R 1 W, Madison Co., Ala.; el. 600 ft.; flow approx. 300 gpm.; aqf. probably Tuscumbia Limestone (Malmberg and Downing, 1957); temp. 16° C; bottom gravel, rock, sand; depth to 1 ft.; width to 25 ft.; no vegetation; 17 July 1966. Water flows from beneath pump house. UAIC 1959. Species: 9, 10, 33, 37.

STATION 49. Unnamed spring, SW ¼ Sec 12, T 2 S, R 1 E, Madison Co., Ala.; el. 600 ft.; flow approx. 75 gpm.; temp. 14° C; bottom sand, chert; depth to 10 inches; width to 2 ft.; watercress abundant, some *Batrachospermum;* 6 April 1967. UAIC 1998. Species: 9, 13, 32, 33, 37, 38.

STATION 50. Unnamed spring, 1.5 mi. S. Lincoln on county road, Lincoln Co., Tenn.; el. 800 ft.; flow approx. 75 gpm.; aqf. probably Fort Payne Chert (Theis, 1936); temp. 14° C; bottom soft sand, chert; depth to 6 ft.; width to 4 ft.; watercress abundant; 17 December 1966. Water flows from beneath pump house. UAIC 1972. Species: 10, 32, 33, 37, 46.

STATION 51. Unnamed spring branch, 1.4 mi. SE of Flintville on county road between Flintville and Lincoln, Lincoln Co., Tenn.; el. 900 ft.; flow approx. 125 gpm.; temp. 11° C; bottom flat rock, chert; depth to 1 ft.; width to 3 ft.; some watercress; 17 December 1966. UAIC 1973. Species: 9, 13, 15, 20, 33, 38, 41.

STATION 52. Unnamed spring, 0.5 mi. NE of Flintville, Lincoln Co., Tenn.; el. 900 ft.; flow approx. 150 gpm.; aqf. Fort Payne Chert (Theis, 1936); temp. 14° C; bottom rock, chert; depth to 4 ft.; width to 12 ft.; watercress present; 17 December 1966. UAIC 1974. Species: 9, 10, 13, 20, 33, 37, 38, 41, 44, 45, 46.

STATION 53. Unnamed spring, SE ¼, SE ¼ Sec 23, T 3 S, R 4 E, Jackson Co., Ala.; el. 675 ft.; flow approx. 275 gpm.; temp. 13° C; bottom sand, gravel; depth to 6 ft.; width to 12 ft.; no vegetation; 16 April 1966. UAIC 1946. Species: 9, 10, 13, 15, 18, 33, 41, 42, 44.

STATION 54. Unnamed spring, NE ¼, SE ¼ Sec 28, T 2 S, R 3 E, Jackson Co., Ala., el. 675 ft.; flow approx. 2,000 gpm.; temp. 13° C; bottom gravel; depth to 1 ft.; width to 3 ft.; some watercress and rooted aquatic vegetation; 16 April 1966. UAIC 1945. Species: 13, 15, 20, 22, 33.

STATION 55. Unnamed spring, NE ¼, SW ¼ Sec 30, T 2 S, R 4 E, Jackson Co., Ala.; el. 675 ft.; flow approx. 500 gpm.; temp. 13° C; bottom gravel, sand; depth to 1 ft.; width to 6 ft.; watercress abundant along margin of spring; 16 April 1966. Water issues from pump house. UAIC 1942. Species: 10, 13, 15, 20, 33, 41, 44.

STATION 56. Unnamed spring, SW ¼, SE ¼ Sec 19, T 1 S, R 5 E, Jackson Co., Ala.; el. 675 ft.; flow approx. 100 gpm.; temp. 14° C; bottom soft sand, organic detritus; depth to 1 ft.; width to 2 ft.; rooted aquatic vegetation in spring; watercress along margin of spring run; 16 April 1966. UAIC 1944. Species: 15, 20, 33, 39, 44.

STATION 57. Unnamed spring, SE ¼, NW ¼ Sec 21, T 1 S, R 5 E, Jackson Co., Ala.; el. 675 ft.; flow approx. 125 gpm.; temp. 13° C; bottom soft sand; depth to 1 ft.; width to 2 ft.; no vegetation; 16 April 1966. UAIC 1943. Species: 13, 15, 20, 33, 41.

STATION 58. Smith Spring, SW ¼, SE ¼ Sec 7, T 8 S, R 3 E, Marshall Co., Ala.; el. 630 ft.; flow approx. 75 gpm.; temp. 14° C; bottom gravel; depth to 1 ft.; width to 3 ft.; watercress and mint along margin of spring run; 11 June 1966. UAIC 1947. Species: 9, 33.

STATION 59. Big Spring at Big Spring Community, SW ¼ Sec 26, T 9 S, R 2 E, Marshall Co., Ala.; el. 750 ft.; flow approx. 3,000 gpm.; temp. 16° C; bottom silty clay; depth to 3 ft.; width to 15 ft.; *Myriophyllum* abundant, some mint along margin of spring run; 15 April 1967. UAIC 2532. Species: 7, 8, 9, 13, 19, 32, 33, 37, 44.

STATION 60. Unnamed spring, SE ¼ Sec 2, T 2 S, R 7 E, Jackson Co., Ala.; el. 600 ft.; flow approx. 50 gpm.; temp. 14° C; bottom chert; depth to 1 ft.; width to 6 ft.; some algae and *Fontinalis* in spring run; 14 April 1967. UAIC 2526. Species: 33, 38, 45.

STATION 61. Unnamed spring, 3.8 mi. S. Sherwood on Tenn. Hwy. 56, Franklin Co., Tenn.; el. 600 ft.; flow approx. 50 gpm.; aqf. probably Warsaw Formation (Theis, 1936); temp. 14° C; bottom sand and chert; depth to 1 ft.; width to 12 ft.; some watercress and mint present along margin of spring run; 14 April 1967. UAIC 2527. Species: 33, 34, 44.

STATION 62. Unnamed spring, 0.9 mi. S. of Sherwood on Tenn. Hwy. 56, Franklin Co., Tenn.; el. 600 ft.; flow approx. 300 gpm.; aqf. probably Warsaw Formation (Theis, 1936); temp. 13° C; bottom chert; depth to 1 ft.; width to 10 ft.; some watercress; 14 April 1967. UAIC 2528. Species: 12, 13, 14, 15, 33, 34, 44, 45.

STATION 63. Unnamed spring, SW ¼ Sec 23, T 2 S, R 8 E, Jackson Co., Ala.; el. 500 ft.; flow approx. 300 gpm.; temp. 13° C; bottom sand and chert; depth to 1 ft.; width to 15 ft.; mint, *Fontinalis,* and algae present in spring run; 15 April 1967. UAIC 2531. Species: 33, 37, 44.

STATION 64. Gray Spring, NE ¼ Sec 9, T 2 S, R 9 E, Jackson Co., Ala.; el. 550 ft.; flow approx. 150 gpm.; temp. 13° C; bottom sand, chert; depth to 1 ft.; width to 10 ft.; no vegetation; 15 April 1967. UAIC 2530. Species: 33.

STATION 65. Unnamed spring NE ¼ Sec 15, T 2 S, R 9 E, Jackson Co., Ala.; el. 600 ft.; flow approx. 300 gpm; temp. 13° C; bottom sand, chert; depth to 1 ft.; width to 5 ft.; *Fontinalis* on rocks; 15 April 1967. UAIC 2529. Species: 34.

STATION 66. Unnamed spring, off Old U. S. Hwy. 64-11, 3.6 mi. N. junction with U. S. Hwy. 72, Marion Co., Tenn.; el. 600 ft.; flow approx. 200 gpm.; temp. 13° C; bottom sand, chert; depth to 1 ft.; width to 10 ft.; some algae in spring run; 14 April 1967. UAIC 2525. Species: 13, 33, 34, 44.

STATION 67. Martin Spring at Martin Springs Community, Marion Co., Tenn.; el. 600 ft.; flow approx. 1,500 gpm.; temp. 12° C; bottom chert; depth to 1 ft.; width to 20 ft.; some watercress and mint around shore margin; 14 April 1967. Water issues from a cave with a low dam across its entrance making a pool approx. 40 by 50 ft. UAIC 2000. Species: 13, 33, 34.

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A BEER'S LAW TEST FOR CHARGE-TRANSFER ABSORPTION SPECTRA*

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ABSTRACT

A simple procedure is presented for determining the concentration dependence of electronic absorption spectra of molecular complexes. Absorbance values for complexes of tetracyanoethylene with hexamethylbenzene and with fluorene, and 9-dicyanomethylene-2,4,7-trinitrofluorene with hexamethylbenzene are found to vary linearly with concentration.

INTRODUCTION

The vast majority of experimental investigations of molecular-complex systems have employed optical absorption measurements. Association constants and other thermodynamic properties of these systems are computed from spectral data by algebraic methods in which it is assumed that the complex species obeys Beer's law.[1] The validity of this assumption has been questioned, and it has been suggested that discrepancies reported between optical absorption results and other experimental methods may arise because of deviations from Beer's law.[2] Since a complex exists in solution only in rapid equilibrium with uncomplexed donor and acceptor, any attempt to evaluate its absorbance as a function of absolute concentration is inextricably bound to a determination of the corresponding association constant.

With a major portion of the work in this area subject to question, a rapid, sensitive procedure for determining the concentration dependence of the absorbance of molecular complexes is desirable. We present here a simple Beer's law test which should be applicable to most donor-acceptor systems.

If an electron acceptor, A, and a large excess of electron donor, D, interact in solution to form a 1:1 complex, C.

$$A + D \rightleftharpoons C$$

the association constant, K may be represented as

$$K = \frac{[C]}{([A]_o - [C])[D]_o} \quad (1)$$

where [C] is the equilibrium concentration of complex and $[A]_0$ and $[D]_0$ are initial concentrations of acceptor and donor respectively. From eq (1)

$$[C] = \left(\frac{K[D]_o}{1 + K[D]_o} \right) [A]_o \quad (2)$$

so that for a fixed donor concentration, [C] is directly proportional to $[A]_0$. *Assuming* Beer's law to be obeyed

* From the Ph.D. Thesis of D. D. Holder, Memphis State University, 1970.