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The Life History, Behavior, and Ecology of *Etheostoma sagitta* (Jordan and Swain)

John Eldon Lowe Jr
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by John Eldon Lowe Jr entitled "The Life History, Behavior, and Ecology of *Etheostoma sagitta* (Jordan and Swain)." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology and Evolutionary Biology.

David A. Etnier, Major Professor

We have read this thesis and recommend its acceptance:

Gordon M. Bughardt, M. C. Whiteside

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

L. Evans Roth
Vice Chancellor
Graduate Studies and Research

THE LIFE HISTORY, BEHAVIOR, AND ECOLOGY OF ETHEOSTOMA SAGITTA (JORDAN AND SWAIN)

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

John Eldon Lowe, Jr.

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ABSTRACT

The life history, behavior, and ecology of *Etheostoma sagitta* (Jordan and Swain) were studied in the Cumberland River system in Tennessee. Diving equipment was utilized in making observations on macrohabitat, microhabitat, distribution, seasonal and diurnal activity, feeding behavior, migration, territoriality, associated species, competition, and population density and structure. Courtship, reproductive behavior, and diurnal activity were studied primarily in an experimental raceway. Feeding behavior and territoriality were studied in the raceway and in a 77.5-l. (20-gal.) aquarium. Parasites, longevity, age and growth, ova numbers and maturation, sex ratios, and food habits were examined in the laboratory.

Etheostoma sagitta was found in clear as well as turbid streams. Habitats ranged from intermittent pools to small rivers. It more frequently occurred in streams with small rubble bottoms, but microhabitat varied with size class and season. Adults more frequently inhabited mid-channel portion of the stream while juveniles inhabited the periphery during fall, winter, and spring. Migration was only noted in No Business Creek. Associated species and competition are discussed, with special reference to other *Etheostoma*.

Quantitative diurnal activity studies indicated that activity peaked in late morning (1100 hrs.) and probably ceased by 1900 hrs. Large males and females were more active than smaller fish.

Juvenile fish fed mainly upon copepods, cladocerans, and dipteran larvae. E. sagitta is sexually dimorphic. Males reached the height of coloration in spring. The color pattern was retained throughout the year in adults but intensity faded after the breeding season. Females were only slightly brighter in the spring. Courtship and reproductive behavior began with construction of a gravel depression by an adult male. During this activity, territorial behavior was centered upon the gravel nest area. This was the only time that territorial behavior was observed.

E. sagitta attains its greatest growth increment during the first year. Over the period of study, population densities did not change drastically; longevity was 4 years. A sex ratio of 1.04 males per females was observed.

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INTRODUCTION

Etheostoma sagitta (Jordan and Swain) is a geographically restricted percid fish found only in certain headwaters of the upper Cumberland and Kentucky River systems. Although it has been reported mainly in Kentucky, Kuehne and Bailey (1961) suggested its occurrence in the tributaries of the upper Cumberland River system in Tennessee. Comiskey and Etnier (1972) recorded its occurrence from one location in Tennessee. A complete listing of the Tennessee collections can be found in the Appendix.

Etheostoma sagitta is found in headwater streams as well as fast-flowing rivers. Headwater streams may be reduced to intermittent pools during the dry months. The creeks, streams, and rivers range from clear to extremely turbid due to strip mining in the area. One-year-old and older specimens are strikingly sexually dimorphic (Figure 1). Breeding males are colorfully patterned in blues and reds. It is a large darter, reaching a total length of 105 mm.

Etheostoma sagitta has received little attention biologically since its description by Jordan and Swain (1883) as *Poecilichthys sagitta* from a single specimen they collected from Wolf Creek, tributary to the Cumberland River system in Kentucky. This particular specimen had a single anal spine; an unusual character since all species of

Figure 1. Photograph of male and female (below) *Etheostoma sagitta*.

Poecilichthys normally have 2 anal spines. Jordan and Evermann (1896) considered the single spine of marked significance. They erected the subgenus Torrentaria for the inclusion of Etheostoma sagitta and a Mexican fish, Etheostoma australe Jordan. Jordan, Evermann, and Clark (1930) elevated Torrentaria to generic rank including the same two fish. Hubbs (1936) noted that Torrentaria Jordan and Evermann is preoccupied and proposed the substitute Austroperca for the Mexican species only. He regarded the status and relationship of Etheostoma sagitta as uncertain.

Etheostoma sagitta was compared with species of Poecilichthys by Kuehne and Bailey (1961) as well as the nominal genera Nanostoma, Nothonotus, Rafinesquillus, Oligocephalus, Ninicola, Claricola, Catonotus, Torrentaria (in part) and Boleichthys (in part) of Jordan, Evermann, and Clark (1930) and Bailey (1948). Bailey (1948) redescribed Etheostoma sagitta incorporating it with Etheostoma nianguae Gilbert and Meek from the lower Missouri River system and Etheostoma spilotum into the subgenus Litocara. Subsequently (Bailey and Gosline, 1955; Bailey, Winn and Smith, 1954) Poecilichthys was merged with Etheostoma, and Litocara submerged into the subgenus Oligocephalus, in which Etheostoma sagitta and its relatives are regarded as a species group. Bailey (1948) suggested that Etheostoma spilotum was derived from Etheostoma sagitta by differentiation following its entrance into the Kentucky system by stream capture. Kuehne and Bailey (1948), after examination of additional specimens of *Etheostoma spilotum*, compared the morphological characteristics. They referred to the group as belonging to the subgenus *Oligocephalus*. The group has two species and three forms. *Etheostoma sagitta* consists of two subspecies—*Etheostoma sagitta sagitta*, an endemic form of the upper Cumberland basin, and *Etheostoma sagitta spilotum* of the upper Kentucky drainage. The other member is *Etheostoma nianguae* of the lower Osage River system in Missouri. The present subgeneric status of *Etheostoma sagitta* is uncertain. Many authors place the group in the subgenus *Litocara*.

Etheostoma sagitta has low population densities and its distribution is limited. This may be the reason why other authors have confined themselves to brief notes on its occurrence, morphology, taxonomy, and/or habitat. Other authors who have mentioned *E. sagitta* were Collette (1965), Collette and Knapp (1967), Eddy (1969), Comiskey (1970), Comiskey and Etnier (1972), Etnier (1974), and Lotrich (1975). These few references form a nearly complete bibliography of *E. sagitta*. The paucity of knowledge concerning the biology of this fish, its limited range, and the threat to its habitat posed by strip mining formed the motivation for this investigation.

The purpose of this investigation was to learn, as completely as possible, the life history of *E. sagitta* and to describe aspects of its behavior and ecology. This was achieved by laboratory as well as field observations. A 77.5-l. aquarium and a raceway were utilized. Field observations were made by using diving equipment. Its range near The University of Tennessee and its preference for clear mountain streams enabled underwater observations to be made, and the raceway permitted studies under seminatural conditions and allowed more detailed observations to be made on particular aspects of behavior such as courtship and mating. The study was limited by low population density of the fish, spotty distribution, and scarcity of preserved samples. The latter precluded the use of large, homogeneous samples for laboratory investigations.

The pattern for the investigation was modified from procedures used in several other ichthyological life history studies and from suggestions presented in Koster (1955) and Howell (1972). The traditionally separate Results and Discussions chapters will be grouped and treated together since several aspects of the life history are inseparable.

CHAPTER I

MATERIALS AND METHODS

I. GENERAL

Underwater Observations

Diving equipment has gained considerable favor in studies of the life histories, behavior, and populations of freshwater fishes (Ellis, 1961; Keenleyside, 1962; Northcote and Wilkie, 1963; Cooper, 1966; Reed, 1967; Heard and Vogele, 1968; Reed, 1971; and Howell, 1972). For this study, a snorkle and face mask were used for observations in the field. Some limitations did exist. Among these were: cold water which limited winter observations, turbidity and depth of streams which precluded observations in Hickory Creek, and low water conditions during the dry months which interrupted snorkeling.

Descriptions of Study Areas

Most investigations were conducted in the field. Field investigations were in the upper Cumberland River system in Tennessee and Kentucky. The sites were Stinking Creek, No Business Creek, Mud Creek, White Oak Creek, Tackett Creek, Perkins Creek, and Pine Mountain Branch in Tennessee, and Brownies Creek in Kentucky. One site on Stinking Creek was studied through an annual cycle. All sites were characterized by diverse lotic environments. Typical *E. sagitta* habitat (Figure 2) consists of pristine, fast flowing water during the wet months although healthy populations have been found in turbid strip mine bounded streams that have a continuous flow.

The various sites have diverse substratums, but *E. sagitta* was primarily found in areas with rubble and sand substrates. The rock diameter classes used in the descriptions of substrates are: gravel, less than 2.5 cm; small rocks, between 2.5 and 7.6 cm; medium rocks, between 7.6 and 12.7 cm, and large rocks, between 12.7 and 22.9 cm.

The rich insect fauna present usually included mayfly nymphs, caddisfly larvae and pupae, midge and other dipteran larvae, coleopterans, and stonefly nymphs. Most of the natural observations were made at four stations even though periodical observations were made at the other sites.

Station 1. Latitude 36°31'30" north, longitude 84°04'00" west, 370.7 m above sea level on U.S. 25W, Campbell County, Tennessee, 12.8 km west of Jellico city limits. This station is located on No Business Creek below a culvert where it drains into Stinking Creek. Pool areas normally ranged in depth from 30.5-106.7 cm, riffles 2.5-61.0 cm and the transition zone between the two from 61.0-121.9 cm. Normal stream widths at this station ranged from 1.24-2.48 m. Predominant substrate materials were medium to large rocks

Figure 2. Photograph of Station 2.

and sand. Annual water temperatures during 1963-1969 ranged from 0-20° C (United States Geologic Survey, 1969).

Station 2. Latitude 36°00'00" north, longitude 84°12'30" west, 330 m above sea level off Interstate I-75, exit 124, Stinking Creek Road toward Pioneer, Tennessee, 16 km turn right travel 0.8 km, Campbell County, Tennessee. Depths of pools at this site ranged from 20.3-91.4 cm, riffles 5.1-45.7 cm, and the transition zone 15.4-91.4 cm. Normal creek widths at this station ranged from 2.4-3.7 m. Annual 1973-1975 water temperatures ranged from 0-35° C. This area was bordered by small farms. The nearby interstate had caused severe siltation. Sand covered a field to depths of one meter. However, a large population of *E. sagitta* was found.

Station 3. Latitude 36°00'00" north, longitude 84°12'30" west, 330 m above sea level. Off Interstate I-75, exit 124, Stinking Creek Road toward Pioneer, Tennessee, Campbell County, 8 km turn right, stop at wooden bridge 0.4 km from Liberty Baptist Church. Pool areas were 45.8-137.0 cm deep, riffles 15.2-91.4 and the transition zones 30.5-122.0 cm. This station normally ranged in width from 4.6-9.2 m. Predominant substrate material was medium to large gravel and sand. The area was 400 m in length and bordered by hemlock and hardwood trees with rhododendron undergrowth.

Station 4. Latitude 36°00'00" north, longitude 84°12'30" west, 330 m above sea level. Off Interstate I-75, exit 124, Stinking Creek Road toward Pioneer, Tennessee, Campbell County, on Pine Mountain Branch. Go on Stinking Creek Road one mile turn right down dirt road, and proceed for 0.8 km. The site is across from the Elbert Meredith's residence. Pool areas ranged from 0.3-1.2 m deep, riffles from 10.2-61.0 cm, and the transition zones 10.2-91.4 cm. The branch ranged in width from 1.5-6.1 m. Substrate material was small to medium gravel. The area was bounded by a hemlock and hardwood forest with rhododendron undergrowth.

An artificial raceway (Figure 3) was designed after that of Howell (1972). It was constructed of 1.3 cm plywood. Two 2.4 by 1.2 m sheets were joined end to end. They were separated into two sections by small mesh screens. The side boards were 0.6 m high. Side boards were fitted with two one-way glasses. The glasses were secured with silicone rubber. Each end of the raceway was also fitted with mesh screens. Ends were constructed with 2.5 × 5.1 cm pieces of wood to form slots. Two 5.1 × 10.2 cm pieces of wood could be placed in the slots to maintain different water depths. Two holes were drilled in each end. Spikes were driven into the ground to secure the structure. The raceway was prepared for receiving fish by the addition of sand and gravel and small to medium size rocks from the natural habitat.

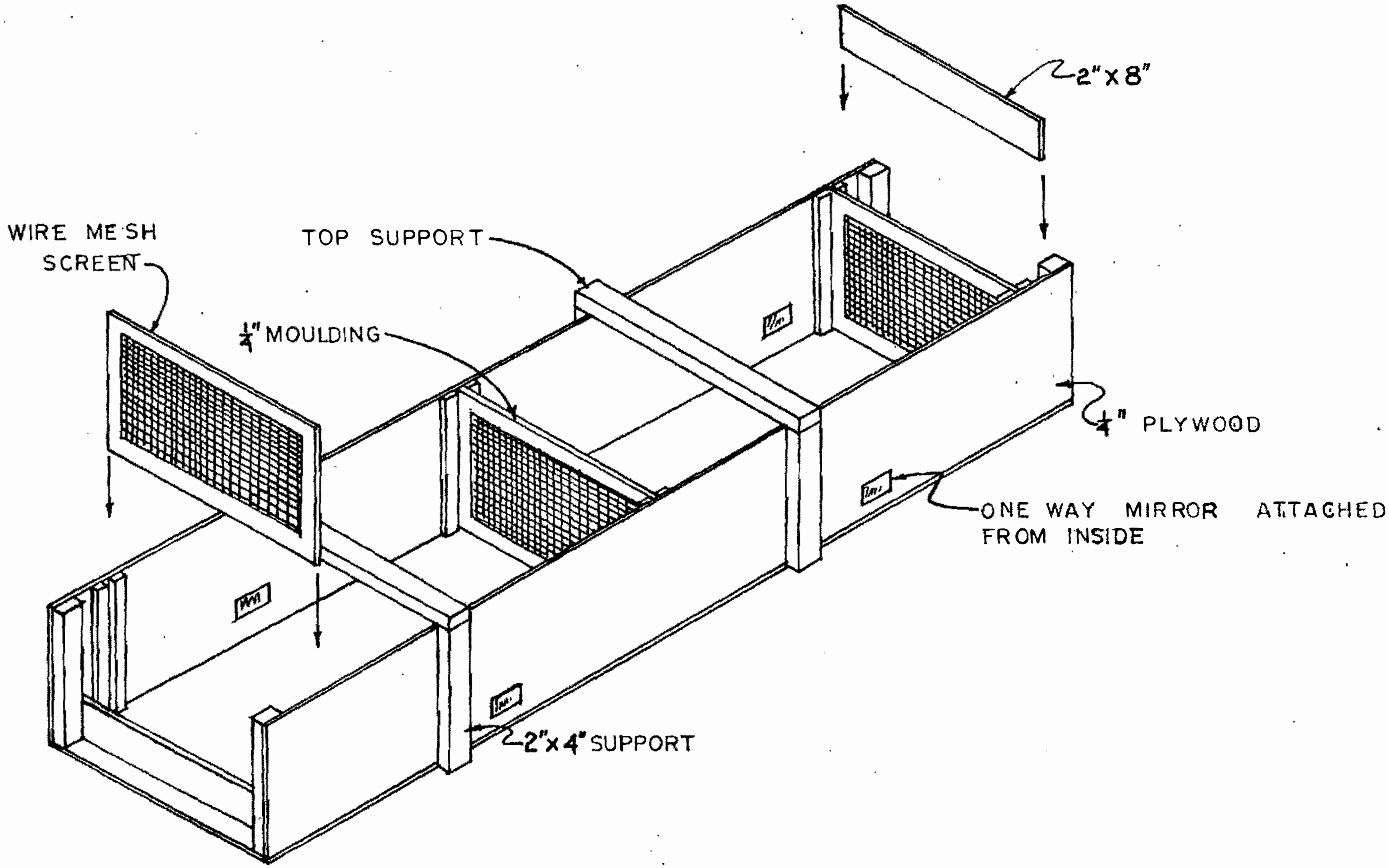

Figure 3. Experimental raceway design.

The raceway was placed 6.1 m below the origin of McCampbell spring (Figure 4). The spring is the chief source of White's Creek. It is located northwest of the East Tennessee Tuberculosis Hospital, 0.6 km from Tazewell Pike, Knox County, Tennessee, at latitude of 36°03' north and longitude 83°53'00" west, and at an elevation of 323.3 m. It normally has a steady flow rate. A flow of 5292 l per minute was recorded (Vancil et al., 1971) May, 1971 and 4536 l per minute July, 1971. Temperatures of the stream ranged from 13-15° C during the spring and summer, pH ranged 7.205-7.212 May, 1971, and a total hardness of 155 ppm was recorded.

Vegetation of the raceway site was examined by Howell (1972). He recorded watercress (*Nasturtium officionale*), green algae (*Stigeoglonium* sp., *Spirogyra* sp., *Ulothrix* sp., *Microspira* sp., and *Comarium* sp.), and diatoms (*Melogira* sp., *Meridion* sp., and *Cymbella* sp.), red algae (*Batrachospermum* sp.), and yellow algae (*Tribonema* sp. and *Vaucheria* sp.). Bethic fauna included numerous midges, several genera of mayflies, stoneflies, caddisflies, isopods, salamanders, and crayfish.

E. sagitta were introduced in the raceway on March 15, 1975. A hard rainfall on March 30, 1975 destroyed the screens. After repairs fish were placed in the raceway on April 15, 1975. The population was removed by July 5, 1975.

Figure 4. McCampbell Spring origin.

A 75.7-l. aquarium was used for behavioral studies in the laboratory. The aquarium dimensions were .31 × .31 × .93 m. A substrate of sand and gravel taken from the habitat of the fish was placed in the aquarium. The fish were fed a diet of insects taken from the stream at the raceway, and brine shrimp.

Collection of Specimens

Etheostoma sagitta is a difficult species to collect due to its habitat and low population densities. The most common method of specimen capture was by seining. A 3.0 × 1.5 m seine with 61 mm mesh was employed. The seine was lined with cheesecloth after the spawning period in order to capture juveniles. Snorkling with a hand net was very successful during the months with rapid flow. During dry months creeks were reduced to a series of intermittent pools. A hand and dip net were used to scoop up fish from water only inches deep. This was a very successful method. Laboratory specimens were preserved in 10% formalin for at least 1 week. They were later transferred into water for 2 days and permanently stored in 40% isopropyl alcohol. Specimens to be used in the raceway and aquarium were placed in 19-l. plastic buckets and acclimatized before release.

II. BEHAVIORAL EXPERIMENTS AND OBSERVATIONS

Purpose

The purpose of the experiments and observations was to determine what behavioral aspects of *E. sagitta* were important to its survival, and to compare its behavior to other species of *Etheostoma*.

Diurnal and Seasonal Activity Studies

On May 15-17, 1975, a diurnal study was made on 4 males and females in the raceway. Observations were made from 0600 to 2100 hours for 5 minutes each hour. A 6-volt Eveready underwater light was used to view crepuscular and nocturnal activity. Activity recorded (on a General Electric cassette player) was amount of time spent in the open, in sheltered areas, or under rocks, the sequence of activity, and any other behavioral patterns. Data for individual fish were recorded, and activity for a/l fish was summarized. Individual fish were recognized by sexual dimorphism, size, and distinguishing color patterns.

Stations 1 and 2 were the sites of most seasonal activity studies, but other stations were examined. After preliminary observations, general seasonal activities of both sexes and juveniles were determined. A by-product of a seasonal population study was the seasonal microhabitat and distribution of each group. This was recorded by observational dives and seining.

Feeding Habits

Feeding habits were studied primarily in the natural habitat. Feeding habits in the raceway and aquarium were also recorded. Several food selectivity studies were made in the aquarium. Food items such as mayflies and caddisflies were taken from McCampbell Springs and the results of feeding behavior were recorded.

Mating Behavior and Territoriality

Courtship and mating behavior were described from matings in the raceway. Sequential events, including territoriality, were noted during mating periods. Nonreproductive territoriality was described from observations made in the natural habitat and in the aquarium.

III. LIFE HISTORY AND ECOLOGICAL INVESTIGATIONS

Purpose

The purpose of these investigations was to describe biological aspects important in the life history of *E. sagitta*. Materials and methods during these studies are in general use in ichthyological investigations and require little specialized equipment.

Sex Ratio, Longevity, and Age at Maturity

The sex ratio was determined by dissecting and sexing the fish using a 30× binocular dissecting microscope.

Sexually dimorphic specimens were readily identified. However, gonads of juveniles had to be closely examined. Young females could usually be discerned by granular appearance associated with developing ovary, appearance of the urogenital papillae, and/or the more posterior joining of the mesenteries between the gonads compared to that of males. Fish for which sex could not be discerned were not included in the sex ratio.

Longevity was determined by examining scale slides made for each available specimen. Slides were prepared by mounting scales removed from above the lateral line at the junction of the spiny and soft dorsal fins. Ten to twenty scales were wet mounted between two microscope slides and ends were taped. Longevity determinations were made using a Scale Projector at 80×.

Age at maturity for each sex was determined by field examination and physical examination of the gonads of each sex. The indices used included overt sexual behavior, development of sexual dimorphism, formation of mature eggs by females, enlargement of male testes, and milt formation. Determinations of age at maturity of each sex were made using these factors in conjunction with parameters such as length, weight, and season taken.

Age, Growth, and Weight

Fish used in age and growth study were taken throughout the year from the stations. Scales were prepared in the manner described in the previous section. A map of the collections appears in Figure 8 in the Appendix.

Length (mm) from focus of the scale to the scale edge between the two most anterior radii was measured with use of the scale projector. Body length-scale length relationships were recorded for each fish and plotted as a scatter diagram. The ordinate intercept and slope were determined by a standard linear regression analysis.

Separate scatter diagrams were produced for males and females. The appearance of the three scatter diagrams indicated that no serious errors would result from using the expressed linear relationships in determining annual growth.

Growth calculations were made on the scales using strips of paper and a nomograph similar to that described in Carlander and Smith (1944). No allowance was made for shrinkage due to preservation in formalin and alcohol; however, any resultant error would have been very small.

Weights were determined as a by-product of the age and growth. Each fish was toweled dry. After they were measured, weights were determined with an Ainsworth Type 28N Balance.

Food Habits

Food habits were determined from fish used in the previous study. Fish were categorized as juveniles or adults, with all fish over 1 year old considered as adults.

Stomachs from both categories were examined. The stomachs after excision were slit lengthwise and their contents were flushed into individual vials by the use of a squeeze bottle. The vials were filled with 40% isopropyl alcohol and labelled.

Stomach contents in each vial were identified and recorded on charts. Individual insect items were keyed as far as possible and at least to family using Ross (1944), Burks (1953), Usinger (1963), and Johannsen (1969). Fragmentation due to digestion made further identification difficult. Many insects such as caddisflies, dragonflies, true flies, and the larvae and pupae of bettles were usually intact while mayflies were usually greatly digested. Only identifiable heads were counted in determining the total number per individual fish and per category. Unidentifiable insect parts, vegetation, fish and insect eggs, and gravel were not included in the tabulations. After identification the insects were replaced in the vials and recorded with a number corresponding to the appropriate fish.

The total number of insects listed by family for juveniles and adults was expressed as numbers per 100 fish. Frequency of occurrence and number of empty stomach were calculated. Frequency of occurrence was determined by dividing the total number in which the food item was found by the number of stomachs in that category.

Egg Counts, Attempted Rearings, and Artificial Fertilization

Egg counts were used in determining breeding periods, age at maturity, reproductive potential, and the number of breeding females in the population.

Egg counts were attempted throughout the year at several different stations. Ovaries were removed and the eggs were counted with the aid of a 30× binocular dissecting microscope. Two categories of eggs were counted. Eggs with diameters less than 1.2 mm and usually white were classified as immature. Eggs 1.2 mm and larger and usually yellow to pale orange in color were classified as mature. The eggs were placed in a graduated cylinder in water. The volume of displacement was recorded.

Other data taken from the specimen included standard length, total length, age, fish weight, ovary weight and dimensions, estimated percent of differentiated ova, and gross appearance of the ovaries. Percent of differentiated ova was a subjective estimate.

Eggs removed from the raceway were measured with calipers. These eggs were trapped in the screen at the end of the raceway. A record of the number of eggs and dates was kept. An unsuccessful attempt at rearing those eggs was made. Several methods were tried at several constant temperatures. Some eggs were aerated and treated with malachite green to retard fungal growth. Some eggs were placed in the raceway in baby food jars, with holes in the top. Seven eggs from two different spawnings found in the faceway on April 18, 1975, were covered with fungus.

Attempts were made to artificially fertilize E. sagitta eggs. Procedures of Strawn and Hubbs (1956) were attempted on April 17, 1975. Twenty eggs from two females captured on April 15, 1975, were sprayed with milt. No successful hatchings occurred.

Population Density and Structure

The advantages of underwater censusing and the procedures for accurate sampling have been discussed by Northcote and Wilkie (1963). At station 1 and 2, where the population was studied periodically from March 15, 1975, to April 1976, underwater censusing was not possible throughout the year. However during the wet months diving was possible. Three types of habitats were sampled during 1975-1976: riffle areas, transition areas, and pool areas. During the wet months visibility was good in most areas. At station 2 the fish found in a strip 11.0 × 457.2 m were counted each day the site was visited. Each census was made as slowly as possible in an attempt to count all fish. The transition zone was censused by counting all E. sagitta in a 11.0 × 763.5 m area. Approximate length, sex, and location of each fish was estimated and recorded. During the dry months the area was censused by walking the creek and counting the number of fish.

Each strip was carefully censused in order to avoid counting fish more than once. When an individual was spotted, movement was slow in order to avoid scaring the fish away from the area. Since the species moved upstream when alarmed, censusing was done going downstream.

Associated Species

Lists of fish species associated with *E. sagitta* were obtained by underwater observations, seining, and The University of Tennessee collection summary sheets for 1968, 1970, 1971, and 1973. Associated species were listed and their preferred habitats. Relative abundance was determined by estimating occurrence in typical *E. sagitta* habitats and estimating the typical total number present. The data are applicable to the upper Cumberland River system in Tennessee, and can be found in Table 10 in the Appendix.

Parasites

During the age, growth, and food habits studies, internal and external parasites were collected when present. Notes were made concerning frequency of occurrence and points of attachment. Fish examined included preserved specimens and aquarium fish.

CHAPTER II

RESULTS AND DISCUSSION

I. MACROHABITAT AND DISTRIBUTION

The range of the arrow darter is the upper Cumberland River system in Tennessee and Kentucky and the Kentucky River system in Kentucky. The range in the Cumberland River is from tributaries of Clear Fork Creek in Campbell and northwest Claiborne counties in Tennessee and from Perkins Creek a tributary to the Big South Fork in Scott County, to Cumberland Falls in Bell County, Kentucky. Kentucky River system distribution is within Noble, Breathitt, and Knott counties in Kentucky.

Eastern Kentucky and northeastern Tennessee are heavily strip mined. The distribution of *Etheostoma sagitta* was somewhat dependent upon the degree and time of strip mining. Numerous streams showed evidence of siltation and degradation of water quality. These areas were nearly devoid of stream life. However, *E. sagitta* was found in large numbers in the continuously turbid Hickory Creek.

Distribution probably depends upon gradient and substrate topography. Cumberland Falls in Bell County, Kentucky may serve as a natural barrier to the range of the arrow darter. Since *Etheostoma sagitta* was found in the headwaters of creeks and streams, range is limited only by the natural conditions of the creeks and streams.

Substrate throughout the distribution was diverse. However, *E. sagitta* was more frequently found in riffles with small gravel, rubble and sandy substrates, transition zones of small gravel, and pools of either gravel or silty substrates on top of irregularly shaped bedrock. Areas above its habitat were typically strewn with large rocks and boulders, with substrates composed of mud, silt and sand. Downstream areas were series of deep pools.

Annual temperatures within *E. sagitta* habitats in Stinking Creek ranged from 0-37° C. High temperatures were found at station 1 and 2 on August 17, 1975. However, streams with tree cover often had a much lower temperature in the summer. Temperature is not thought to affect the distribution of the arrow darter.

II. POPULATION DENSITY AND STRUCTURE, SEASONAL ACTIVITY, AND MIGRATION

The population density and structure at various intervals from March 15, 1975, to April 17, 1976, at station 1 are shown in Table 1. Under headings "Transition Area, Riffle Area, and Pool Area," are columns giving the sex, if known, of the fish present during each censusing period. All fish in the "u" category were juvenile and sexual differences could not be determined. The column "Pool Area" included

TABLE 1

NUMBERS OF <u>ETHEOSTOMA SAGITTA</u> AT STATION 1 AND 2 MARCH 15, 1975-APRIL 17, 1976 FROM THREE HABITATS

Date	Riffle Area				Transition Area				Pool Area				Total	No./m^2 (10^3)
	♂	♀	J	Σ	♂	♀	J	Σ	♂	♀	J	Σ		
3/15	10	7	-	17	20	24	-	44	10	32	-	42	103	46
3/29	8	5	-	13	27	19	-	46	15	22	-	37	96	43
4/7	6	9	-	15	19	16	-	35	14	15	-	29	79	35
4/15	5	2	-	7	19	24	-	43	17	12	-	29	79	35
4/29	7	5	-	12	15	21	-	36	15	10	-	25	83	37
5/14	3	2	-	5	13	17	-	30	15	13	-	28	63	28
5/29	4	3	-	7	25	21	-	46	5	16	-	28	74	33
6/13	1	2	-	3	19	24	-	43	12	9	-	21	67	30
6/25	-	-	-	-	9	12	-	21	16	12	-	28	49	22
7/4	-	-	-	-	17	13	-	30	22	15	33	70	100	44
7/19	-	-	-	-	11	8	-	19	20	25	37	82	101	45
8/5	-	-	-	-	16	17	-	33	13	8	42	63	96	43
8/19	-	-	-	-	15	13	-	28	21	22	27	70	98	44
9/3	-	-	-	-	9	12	-	21	17	16	23	56	77	34
9/18	-	-	-	-	14	15	-	29	13	17	32	62	91	40
10/16	-	-	-	-	17	12	-	29	17	11	21	49	78	35
10/30	-	-	-	-	12	18	-	30	13	13	25	51	81	36
11/6	7	5	-	12	12	13	-	25	21	16	13	50	87	39
11/21	8	7	-	15	11	15	19	45	14	15	15	34	94	42
12/29	7	9	4	20	9	13	11	33	16	12	-	28	81	36
1/17	9	5	6	20	8	9	14	31	11	14	-	25	76	34
2/7	12	10	7	29	7	6	10	23	9	5	-	14	66	29
2/21	9	12	5	26	9	5	9	23	7	7	-	14	63	28
3/13	8	7	12	27	7	13	11	31	9	8	-	17	775	33
3/27	11	13	5	29	16	15	4	35	17	19	-	36	100	44
4/17	14	12	-	26	16	19	-	35	20	21	-	41	102	45
Total	129	115	39	283	362	394	78	838	379	395	258	1012	2133	

J = Juvenile fish whose sex was undetermined.

the edges of the shoreline. On this date the sex of young-of-the-year was undeterminable, and no attempt was made to establish a sex ratio. The "Total" category summarizes all data and gives an estimate of number of fish per square meter of all sampled areas. The total sampled area of 2253 m^2 represents the sum of the two sample areas.

The microhabitat of E. sagitta at station 1 and 2 varied with the size, sex and age of the individual fish and with the season. During dry periods, riffle areas were practically nonexistent. The stream was reduced to a series of intermittent pools and transition areas. This is reflected in Table 1. From early winter to late spring, stream width and depth increased. During this period numerous large and small males and females were found in the riffle area as well as in the transition and pool areas.

During the rest of the year adults were observed with equal abundance in either pool or transition areas. Young-of-the-year fish were observed to inhabit the shoreline area at the edge of pools. In late fall young-of-the-year joined the rest of the fish in pool and transition areas. The only migratory facet of the arrow darter's life history occurred at No Business Creek. This station was observed at intervals from January 8, 1975, to April 17, 1976. Previous to February 29, 1975, no arrow darters were found by snorkeling or seining. At that date 34 arrow darters were observed at the mouth of the creek. A culvert was located upstream. If any migration occurred from upstream, the fish would not be able to return. Since the station was checked the week previously and the upstream area was void of darters, it is more likely that the fish migrated from Hickory Creek. After the breeding season the number of fish in No Business Creek decreased to two or three throughout the rest of the year. In February a mass migration occurred. An equal number of males and females, mostly one-year-old with only a few two-year-olds were found.

The population remained fairly constant during seasonal periods (Table 1). Note the total population figures for June through January in spite of recruitment.

III. DIURNAL ACTIVITY

Fish (collected from station 2) utilized in the raceway are listed in Table 2 along with some characteristics and fates. Fish noted by the superscript "d" in Table 2 are discussed and referred to in the rest of the text by their numbers 3, 4, 6, 7, 8, 9, 10, and 11 in order to avoid confusion.

Results of diurnal activity study are found in Table 3. Individual fish activity depended somewhat upon sex, size, and physical condition. A darkly colored male (No. 4) was the most active fish. His dominance was noted during daily

TABLE 2

SOME CHARACTERISTICS OF INDIVIDUAL *ETHEOSTOMA SAGITTA* PLACED IN AN EXPERIMENTAL RACEWAY, APRIL 15-MAY 1, 1975

Fish Number	Standard Length (mm)[a]	Age (Years)[b]	Date Placed in Raceway	Sq. Ft./Fish Immediately After Placement	Fate
1 Male	83	3	4/15/75	8.57	Died 4/21/75
2 Male	73	3	4/15/75	8.57	Died 4/27/75
3 Male[d]	75	3	4/15/75	8.57	Died 6/17/75
4 Male[d]	75	3	4/15/75	8.57	Died 6/29/75
5 Female	56	2	4/15/75	8.57	Removed 5/5/75
6 Female[d]	47	1	4/15/75	8.57	Removed 7/5/75
7 Female[d]	53	2	4/15/75	8.57	Died 5/1/75
8 Female[d]	57	2	4/15/75	8.57	Died 5/22/75
9 Female[d]	55	2	5/3/75	8.57	Removed 7/5/75
10 Male[d]	45	1	5/3/75	8.57	Removed 7/5/75
11 Male[d]	56	2[c]	5/3/75	8.57	Removed 7/5/75
12 Female	53	2[c]	5/3/75	8.57	Removed 7/5/75

[a]Determined prior to placement.

[b]Determined after removal.

[c]Age estimated from growth curve.

[d]Present when diurnal study was made.

TABLE 3

THREE DAYS (MAY 15, 16, AND 17, 1975) POOLED DIURNAL ACTIVITY DATA BY HOUR AND FISH[a]

	Fish Number and Sex									
	3(♂)	4(♂)	6(♀)	7(♀)	8(♀)	9(♀)	10(♂)	11(♂)		
	Standard Length (mm)									
Diel Period	73	75	43	57	57	55	55	56	Pooled Activity Times	x_1
0600	36	48	0	0	0	0	0	0	84	28.00
0700	33	45	0	0	28	0	1	4	111	37.00
0800	22	19	0	4	21	15	20	13	114	38.00
0900	3	6	12	14	14	10	14	28	101	33.67
1000	34	41	9	1	3	5	26	27	146	48.67
1100	63	71	31	3	54	7	30	26	285	95.00
1200	58	66	30	5	47	21	25	19	271	90.33
1300	45	59	23	16	31	17	25	15	231	77.00
1400	57	60	21	17	28	13	18	15	229	76.33
1500	30	51	15	15	23	16	14	9	173	57.67
1600	23	45	8	21	12	15	20	3	147	49.00
1700	36	2	1	20	2	14	3	7	85	28.33
1800	13	16	3	11	6	11	6	21	87	29.00
1900	17	23	9	6	23	3	18	26	119	41.67
2000	33	43	18	9	0	10	6	0	119	39.67
2100	3	5	0	0	0	0	0	0	8	2.67
Total	506	600	180	142	292	157	226	213	2316	772.01
x_2	29.76	35.29	10.59	8.35	17.18	9.24	13.29	12.53	144.75	48.26
Percent Total	21.85	25.91	7.77	6.13	12.61	6.78	9.76	9.20		

[a]Individual fish times per diel in seconds per five minute period per hour--three day total: pooled activity time is seconds = three days pooled value; x_1 = hourly mean time for all fish; x_2 = hourly mean time for individual fish.

observations. The next most active fish was a male, also darkly colored (No. 3).

The third most active fish was a gravid, darkly colored female (No. 8), with distended sides. She was followed in activity by fishes 10 and 11, gravid females but less intensely colored.

The total daily activity of individual fish was compared using Student's "t" test. The statistical decisions are found in Table 4.

Preliminary nonquantitative observations in the field revealed that large males were more active than smaller fish of either sex. Fish numbers 3 and 4 were significantly more active than most of the other fish. Often these fish would leave from underneath rocks and dart from rock to rock, chasing other fish in the open areas until they sought refuge underneath rocks. Another behavioral pattern was for the fish to emerge from rocks and climb upon them. The pelvic and pectoral fins were used in this activity. The fish would climb around the rock apparently searching for food. Another activity frequently displayed was swimming to the mid-stream area and hanging in the current for a short period of time.

Fish numbers 7 and 9 also had significant differences in activity from other fish. They were the smallest fish and occupied the less favorable rock cover. They were located at the periphery of the stream and had little space.

TABLE 4

DIURNAL ACTIVITY SIGNIFICANT DIFFERENCE TABLE WITH $T_{CALCULATED}$ VALUES AND DECISIONS[a]

		Fish Number							
Fish Number	Σx^2	3	4	6	7	8	9	10	11
3 (75 mm ♂)	21504	--	0.42 Accept	3.39 Reject	4.25 Reject	2.32 Reject	4.30 Reject	3.40 Reject	3.41 Reject
4 (75 mm ♂)	27560	--	--	4.02 Reject	4.25 Reject	2.60 Reject	4.38 Reject	3.58 Reject	3.58 Reject
6 (53 mm ♀)	3760	--	--	--	0.44 Accept	1.77 Accept	0.48 Accept	0.74 Accept	0.72 Accept
7 (46 mm ♀)	2073	--	--	--	--	2.20 Reject	0.16 Accept	1.24 Accept	1.21 Accept
8 (57 mm ♀)	9952	--	--	--	--	--	2.47 Reject	1.14 Accept	1.16 Accept
9 (55 mm ♀)	2232	--	--	--	--	--	--	1.35 Accept	1.32 Accept
10 (55 mm ♂)	4744	--	--	--	--	--	--	--	0.02 Accept
11 (56 mm ♂)	4695	--	--	--	--	--	--	--	--

[a]H0: $u_1 = u_2$, D. F. = 32, C. I. = 5%, $T_{table} = 2.04$.

Upon entering an open area or an area occupied by a larger fish, the larger fish would erect its soft and spiny dorsal fins. If the smaller fish did not retreat, it would be chased away by the larger fish. If these fish were chased from their rocks by the larger fish, they immediately returned upon vacancy of the larger fish. Much of the smaller fish's time was spent underneath rocks.

Males in their spawning colors were more active than any class of fish in the natural habitat as well as in the raceway. Gravid females were the next most active, nongravid and nonbreeding colored fish were next in activity, and immature males and females were least active.

Total activity of the 4 males and 4 females did not differ significantly. Calculated t value was 0.682 and the table t value was 2.4196.

Mean hourly activity for all fish in seconds per 5-minute period per hour is shown in Figure 5. One standard deviation was plotted around each mean. The sunrise and sunset times for the 3 days varied only 2 to 3 minutes.

IV. FEEDING BEHAVIOR AND FOOD HABITS

A large proportion of the feeding behavior of *E. sagitta* in the natural habitat was that of continuous searching. Searching was most prevalent in spring, summer, and early

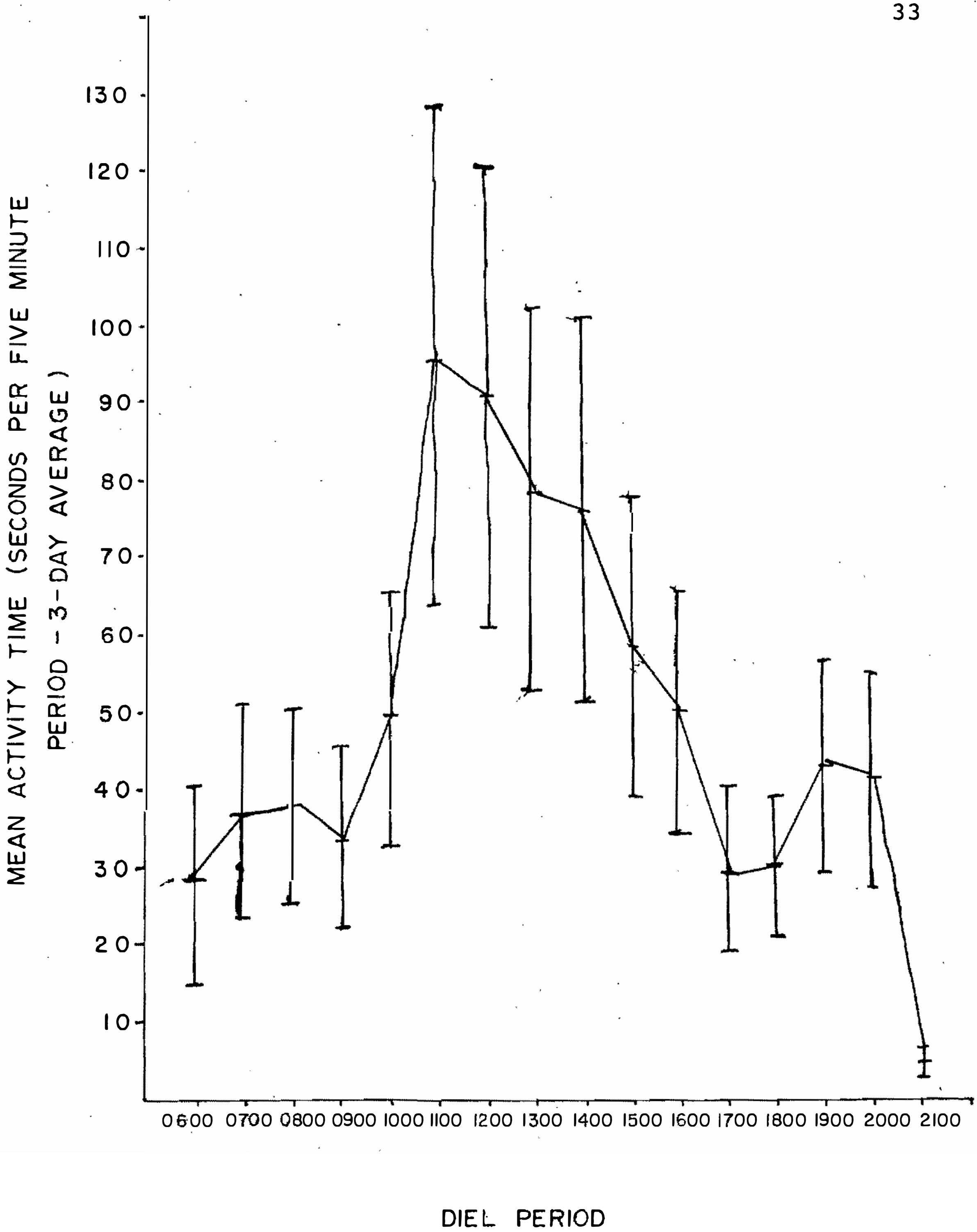

Figure 5. Mean hourly activity for all 8 fish in seconds per 5-minute period per hour.

fall. During winter, activity decreased tremendously. A typical pattern in feeding behavior of the adults would be to swim to the mid-stream area and settle on the substrate. Here it would remain stationary for a short period of time. Adults would begin an active search for food items, probing underneath and around rocks and chasing organisms. Upon spotting prey, E. sagitta would pick it off the rock. If a mayfly nymph would travel across a rock, the fish would follow the organism until it was able to capture its prey. Often the pelvic and pectoral fins were used to aid in climbing over rocks. When an unwanted food item was obtained, it was expelled by a spitting motion. This spitting motion also often occurred when the fish was engaged in obtaining food items stirred up by feeding activity of other fish.

Generally E. sagitta did not depend upon drift items as an important food source. If drift items were floating downstream, it would move to the item. Then the fish would either move upstream or drift downstream and settle on the substrate. Success in capturing drift items occurred only if the prey was in close priximity. The co-occurring species, Campostoma anomalum, Nocomis micropogon, and Semotilis atromaculatus are considered more efficient drift feeders. These species were observed traveling several feet to obtain a drift item.

An unusual feeding habit was observed at station 2 throughout several times of the year. Adults were observed following *Nocomis micropogon* and *Semotilis atromaculatus* upstream as they stirred up the gravel to obtain food. Food items loosened by this activity were taken by *E. sagitta* as they drifted downstream.

Feeding encounters were observed in the aquarium and raceway. When an item was placed in the aquarium, a fish was chased or nipped if it obtained the item first. Often the chase took place the length of the aquarium. A similar pattern occurred in the raceway, but the frequency was lower due to abundance of natural food. These types of encounters were observed in the natural setting.

Artificial conditions which confined space and increased density seemed to modify behavior of the fish. Aquarium population density ranged from one fish per 0.4 to 0.8 m^2. These densities were higher than found in natural assembledges (Table 1, p. 25) in natural environments.

Food habits of 107 specimens (94 adults and 13 young-of-the-year) are shown in Table 5. The prey items in the table are identified to families. The column "Number per 100 Fish" was used to compare the unequal number of specimens.

There is a difference in diet between juvenile and adult. Main food items of juveniles were copepods, cladocerans, and diptera immatures. Several *Chydorus* sp. were among the cladocerans taken. Cyclops was among the copepods taken. These organisms can inhabit the pools, where juveniles were

TABLE 5

FOOD HABITS OF *ETHEOSTOMA SAGITTA* OF THREE SIZE CLASSES TAKEN FROM THE CUMBERLAND RIVER SYSTEM

Taxa	Juvenile (%)	(n)	No. Per 100 Fish	1-2 Year (%)	(n)	No. Per 100 Fish	3-4 Year (%)	(n)	No. Per 100 Fish
Ostracoda	4.4	3	23.1						
Copepoda	30.9	21	233.3	4.33	23	328.6	0.30	1	3.1
Cladocera	20.6	14	108.0	2.82	15	24.1	2.00	7	3.1
Diptera Immatures	22.0	15	115.4	18.20	108	174.2	17.60	62	193.8
Simuliidae	10.3	15	53.8	3.20	19	30.6	3.10	11	34.4
Total	32.3	22	179.2	21.40	127	204.8	20.70	73	228.2
Isopoda				1.50	9	14.5	2.00	7	21.8
Hydracarina	1.5	1	7.7	0.50	3	4.8			
Ephemeroptera Immatures									
Ephemeridae				7.30	43	69.3	8.20	29	90.6
Baetidae	1.5	1	7.7	24.10	143	230.6	24.10	85	265.6
Heptageniidae	7.3	5	38.5	24.90	147	237.1	30.90	109	340.6
Total	8.8	6	46.2	56.30	333	537.1	63.20	222	696.9
Trichoptera Immatures									
Hydropsychidae	1.47	1	7.7	1.3	8	12.9	2.0	7	21.8
Rhyacophilidae				0.5	3	4.8	0.6	2	6.2
Leptoceridae				0.3	2	1.6			
Total	1.47	1	7.7	2.2	13	20.3	2.6	9	28.0
Plecoptera Immatures									
Pteronarcidae							1.4	5	15.6
Coleoptera									
Elmidae				0.8	5	4.8	1.1	4	6.3
Decapoda							1.7	6	12.5
Miscellaneous									
Fish							0.3	1	3.1
Eggs				0.5	3	4.8			

restricted until movement to transition areas in late fall (Table 1, p. 25). Caddisflies, stoneflies, and mayflies formed a small percentage of their diet.

As the fish became larger with maturity, habitat changed and mayflies became the most significant food item (Table 5). Immature dipterans were also a frequent food item. Baetidae and Heptageniidae were the most prevalent Ephemeroptera. Stenonoma sp. and Baetisca sp. were the most frequently found genera that were identifiable. Caddisflies again made up only a small proportion of the diet. Hydropsyche, Rhyacophila, and Brachycentrus were among the genera found. The main difference between the two age categories of the adults was the occurrence of larger food organisms in larger adults. Crayfish and a small fish were among the larger items found (Table 5). Victor Lotrich (1972), in his summer analysis of several species of fish, found similar results. Lotrich proposed that the larger adults are able to utilize this higher energy source with greater efficiency.

Feeding preference trials were made in the aquarium. Twenty-five specimens of Stenonema, Hydrophyche, Pteronarcys and five specimens of crayfish were placed in the aquarium four times. Stenonema was consumed first, followed by Hydropsyche, the crayfish and the Pteronarcys. Only the larger fish consumed the crayfish and the stoneflies. Often the stoneflies were attacked, mouthed and then rejected.

V. SEX RATIO, AGE COMPOSITION, AND LONGEVITY

Page and Smith (1970) found 1.50 males per females ratio for P. phoxocephalus, and 1.20 females per male for P. sciera. I found a ratio of 1.04 males per female (n = 94). This ratio may be biased by the small sample and sample selectivity. Juveniles were only collected during July through September due to water conditions and large males were only obtained during spring.

Ninety-four mature specimens and 28 sexually undeterminable specimens were examined to determine age structure. Sixty (49%) were young-of-the-year fish, 30 (25%) were 1-year-old-fish, 22 (18%) were 2-year-old fish, and 10 (8% were 3-year-old fish. Sampling bias influenced these percentages. During courtship and spawning studies younger fish were overlooked for breeding fish. However, this was the largest collection available for study and was collected throughout the year at various locations.

Etheostoma sagitta lives to a maximum of 4 years. This is assuming that the April 10, 1974, specimens would have lived beyond the breeding season. Six of the 10 4-year-old fish were male and four were female. Due to lack of adequate sample size, sexual influences on longevity were undeterminable.

VI. REPRODUCTIVE CYCLE OF THE MALE

Jordan and Swain (1883) first described *E. sagitta* in its breeding condition. Most arrow darters reach sexual maturity and spawn when one year old; however, the intensity of coloration described below is more apparent for older males. Males changed from a dull olive green of the anterior parts to a dullish black green in spiny and soft dorsal fins. The sides are patterned with 8 to 11 narrow vertical bars. These bars are dark orange-red and are bordered with light. The bars are most conspicuous on the caudal peduncle. Here they are narrow and high. At the lower ends the bars are fused to form a longitudinal ventrolateral bar of orange-brown. The belly is dirty white and the breast dusky. Red-orange spots are scattered over the upper sides. Dull olive green above the head is brightened on the lower surface by the irridescent purple of the mandibles and the white of the branchiostegal membranes. The blackish scapular bar is inconspicuous. A narrow golden rim borders the pupil. A narrow submarginal band of bright red-orange in the spinous dorsal fin is separated by a narrow clear area from the bright green bar which covers the median half of the fin. The basal fourth is white peppered with dusky. Small red-orange spots are irregularly aligned in three rows on the dusky second dorsal fin. The green on the basal part of the caudal is best developed on the lower lobe of the fin where it covers one-fourth of the fin. Otherwise the caudal is faintly olive-dusky with 2 or 3 irregular ventral red-orange bars or series of spots on the distal two-thirds of the fin. The basal two-thirds of the anal fin is green. The outer third of this fin is dirty white. Pectoral fins are full olive and pelvic fins are dusky. Genital papillae of males are short, thin, blunt, and nonpigmented. A visible thickening of the papillae could be seen in several males just before and during the breeding season. Breeding colors faded during the winter months.

Due to limited sample size and variability of fish due to size and age, seasonal comparisons of testis sizes were difficult. Of the samples collected, enlargement of testes were observed as breeding season approached. During late winter and early spring, a change in color of the testes was observed from white to light yellow and dark yellow-orange as the breeding season progressed. Males obtained from station 1 on February 29, 1975, extruded milt upon application of a small amount of pressure to the abdomen. Large amounts of milt were present in 3- and 4-year-old males in early April.

Bailey (1948) and Collette (1965) noted breeding tubercles on male E. sagitta. The tubercles occur on the ventral surface of the body. They start at the posterior half of the belly extending up to 6 scale rows on the side and on 2 rows on either side of the base of the anal fin and on 6 or 7 rows of scales on the lower edge of the caudal peduncle. Most of the tubercles are low and rounded but those near the midventral line anterior to the vent and on the caudal peduncle are bluntly conical. The tubercles are pale, not contrasting with the ground color. Structurally the nuptial tubercles are superficially excreascent like the pearl organs of the cyprinid fishes. Their function is discussed later. *E. nianguae* has a similar pattern. Several other members of the subgenus *Oligocephalus* have more weakly developed breeding tubercles.

VII. REPRODUCTIVE CYCLE OF THE FEMALE

The anterior body of the female is straw colored deepening to a dark olive on the caudal peduncle. Lateral patterns are not uniformly dark like that of the male and are diamond shaped. The diamond shapes have a dorsal light spot that is either encircling or merges with the ground color above. Vertical bars on body and caudal peduncle are less developed than in males and sides are orange instead of deep red-orange. The sides are covered with dull yellowish gold. Except for a narrow submarginal bar of red-orange, membranes of the spinuous dorsal fin are clear. A few faint orange spots break the otherwise clear second dorsal fin. The caudal is dusky with weak orange bars. Anal and pelvic fins are clear. Pectoral fins are pale washed with olive. From the chin to behind the anal fin the ventral surface is clear white. Cheeks are shining white and more conspicuous than in adult males. Females genital papillae are long, fleshy, pointed, nonpigmented, and prominent only during the breeding season. Two well-defined characteristics, size and color, were used in determining ova maturation states. The smallest eggs were less than 1.2 mm, white, most numerous, contained no oil globules, and were near the center of the ovary. The larger eggs were greater than 1.2 mm, yellowish, contained oil globules, and were found near the periphery of the ovary. During the spawning period they formed yellow streaks through the dorsal portion of the ovarian wall. These eggs were more concentrated toward the posterior one-third of the ovary. Both mature and immature eggs were spheroid. Spawned mature eggs in the raceway were pellucid, demersal, adhesive, and spherical after water hardening. They averaged 1.9 mm (n = 56). Dissected eggs showed off-center oil droplets.

Ovarian changes occurred during the spawning season. February ovaries were white with slight tinges of yellow. May ovaries were a dark orange-yellow. Eggs were being reabsorbed in the May sample. Later samples revealed small pieces of material, presumably the unlaid eggs.

Table 6 presents some characteristics of ova. During late February eggs were present, but mature eggs were not

TABLE 6

PHYSICAL AND EGG MATURATION CHARACTERISTICS OF FEMALE ETHEOSTOMA SAGITTA COLLECTED IN 1975

				Differentiated Ova				
				Immature		Mature		
Date Collected	Station No.	Standard Length (mm)	Age (Years)	No.	Percent	No.	Percent	Total
2/29	2	39	1	402	100.0	0	0.0	402
2/29	2	41	1	385	100.0	0	0.0	385
2/29	2	36	1	367	100.0	0	0.0	367
2/29	2	45	1	429	100.0	0	0.0	429
2/29	2	49	1	512	100.0	0	0.0	512
3/17	3	45	1	478	79.9	120	20.1	598
3/17	3	46	1	493	68.5	127	31.5	620
3/17	3	43	1	392	85.4	67	14.6	459
4/15	6	54	2	570	77.8	163	22.2	733
4/15	6	55	2	707	77.9	201	22.1	908
4/15	6	56	2	632	73.7	225	26.3	857
4/15	6	63	3	783	74.7	265	25.3	1048
5/15	1	54	2	351	100.0	0	0.0	351
5/15	1	55	2	378	100.0	0	0.0	378
5/15	1	56	2	412	100.0	0	0.0	412
6/14	4	42	2	7	100.0	0	0.0	7
6/14	4	46	2	0	0.0	0	0.0	0
6/14	4	46	2	0	0.0	0	0.0	0

found until March (Table 6). Spawning was a possibility at that time. A high proportion of eggs were present until early May. On May 15, three specimens were examined and revealed no mature eggs, indicating the probable end of the breeding season. By June 14, spent ovaries indicated that spawning had ended (Table 6).

The mean egg numbers for 14 darter species (Winn, 1968b) were found to increase within a species with size and age. This trend was true for E. sagitta (Table 6).

Other facets of the female reproductive cycle include a pronounced elongate, broadened, tube-like, urogential papillae and a markedly shorter left ovary in gravid females. The sinestral stomach compressed the eggs in the anterior portion of the left ovary. Right and left ovaries of immature females were of equal length and did not reach to the stomach.

VIII. REPRODUCTIVE BEHAVIOR

Several papers have been written describing the reproductive behavior of the genus Etheostoma (Reeves, 1907; Lake, 1936; Atz, 1940; Fahy, 1954; Winn, 1958a, 1968b; Mount, 1959; Winn and Picciolo, 1960; and Braasch and Smith, 1967).

Etheostoma sagitta spawned in the raceway on April 17, 1975. Water temperatures in the natural habitat and the raceway were 13° C. These fish had been transferred to the raceway three days earlier. Light intensity and duration, although believed not to be important (Hubbs and Strawn, 1957), were similar in the natural habitat and raceway.

The mating behavior in the raceway lasted for 3 hours. During this time period nine specific spawning acts were recorded from two sets of mating pairs. Spawning acts were of 3-5 second duration. These time intervals correspond closely with those found by Scalet (1972) for *E. radiosum*.

Courtship occurred at the downstream end of the raceway. The area was clear of rocks and had a sandy substratum. Nest building occurred under 15-18 cm rocks. The substratum consisted of sand and small gravel 0.6-1.2 cm in diameter. This site was chosen over other available spawning sites such as: open areas with similar substratum, larger rocks with similar shape, larger size gravel, clay bottoms, and silt deposition areas. *Etheostoma radiosum* was found by Scalet (1972) to spawn in patches of 3-5 mm gravel downstream from large rocks in moderate current.

Males involved in the courtship and spawning were fish numbers 1 and 3 (Table 2, p. 28). These fish were intensely colored and had tubercles. Bailey (1948) and Collette (1965) suggested tactile stimulation as the function of these tubercles. Tubercles were restricted to the early April males and they may serve as a stimulus to the female.

Females involved in the study were numbers 5 and 9 (Table 2). They were also intensely colored for females.

The iniation of courtship and spawning began with males swimming from rock to rock. The rocks were placed so that small openings were available for hiding, similar to the natural habitat. The males fanned under the rocks quite intensely. The silt and debris stirred up by their action were conveyed downstream by the action of the current. In this manner a small depression was formed. During this nest building period any males intruding were immediately chased from the area.

After the nest was complete, the male left and chased the females from the surrounding rocks. The females drifted to the clear downstream end of the raceway. Males began their courtship display by rapid dashes across the raceway. After a pause, this action was continued. After a series of passes, the male would nudge the female. The nudges were directed to the abdominal area. After a series of nudges the male stopped by the side and in front of the female. The male erected his spiny and soft dorsal fins and began an intense quivering motion. This display occurred several times. Finally the female made a similar response and led the male to a nearby rock with a depression.

The female then rose off the bottom 1-2 cm and buried the ventral half of her body in the sandy substratum. The male immediately mounted her (Figure 6). His pelvic fins were placed on her back, ahead of her relaxed pelvic fins.

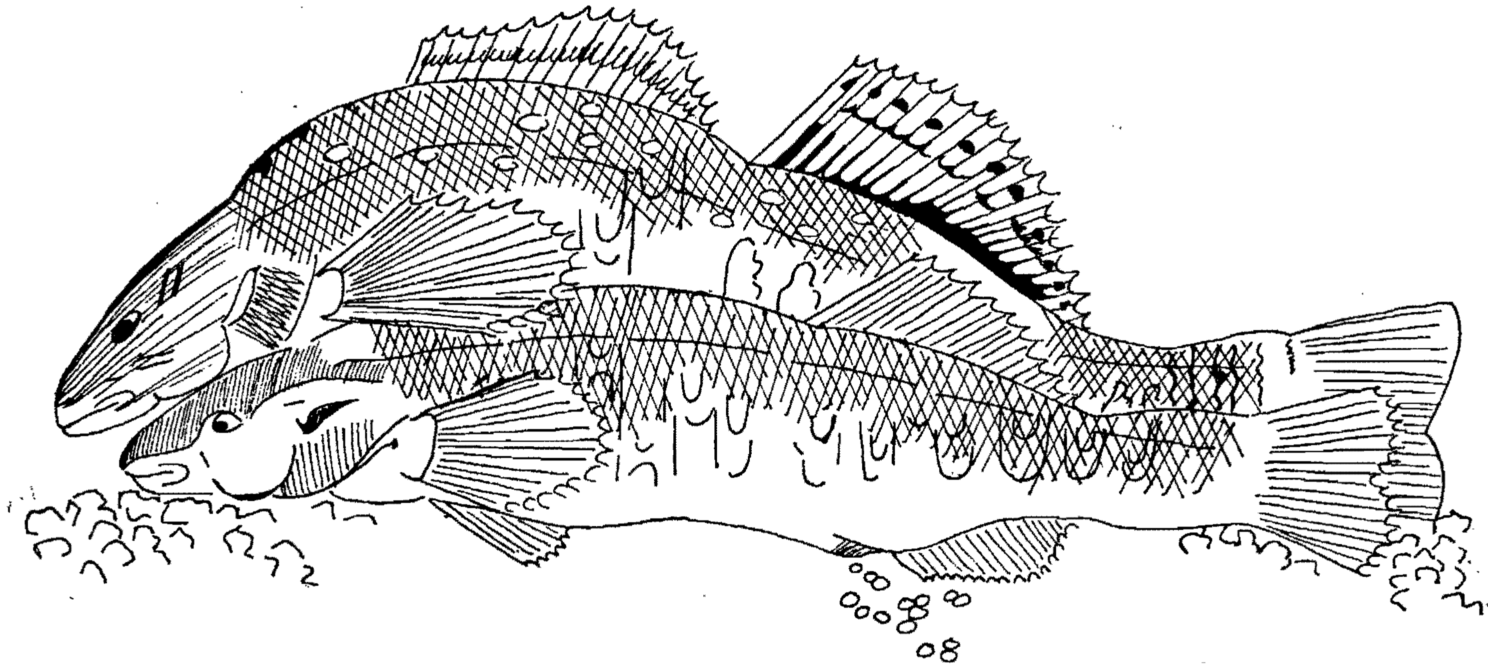

Figure 6. Spawning position of Etheostoma sagitta (male on top).

His pectoral fins were spread out for balance, and his anal region was bent down beside the anal fin of the partner. They were momentarily in a firm position with urogenital openings near each other. The male quivered first, followed by the female. As the eggs are released, the pair may move forward in the gravel due to their quivering actions. The female may perform another spawning act or prevent further egg laying by moving downstream from the nest. The egg-laying sequence lasted from 3-5 seconds. The spawning sequence is like that of E. caeruleum (Winn, 1958b) and E. radiosum (Scalet, 1972).

There may have been several releaser mechanisms involved in the courtship and spawning sequence. The completed nest could have served as the releaser mechanism for the courtship display. The nudges and quivering of the male could have been a releaser mechanism for the female to lead the male to the nest area and bury herself in the gravel. The motionless female may have been the releaser mechanism in eliciting the male to mount the female. If the spawning sequence was interrupted it was completed only when the female reburied herself in the gravel.

Intraspecific territoriality was exhibited during the spawning period but was not evident the rest of the year. Interspecific territoriality was not examined. Winn (1958b) found that E. caeruleum and E. spectabile were slightly pugnacious and limited their territoriality to a large rock in a gravel area. He also found strong territoriality in *E. nigrum*. In *E. sagitta* territoriality was limited to a rock in the gravel area during the nest building and spawning period. The rest of the year the arrow darter was only slightly pugnacious. When another darter entered the area of the nest *E. sagitta* erected his soft and spiny dorsal fins. The vivid breeding colors were clearly visible. If this response did not repel the intruder, the defender would butt the lower part of the intruding darter with his snout. If a pair was in a spawning activity, the male waited until spawning was completed, then chased away the intruder.

Counts made of eggs impaled on the screen and those remaining in gravel nests indicated the mean number of eggs laid per spawning act to be less than seven.

The courtship and spawning behaviors of *E. sagitta* are very similar to that recorded by Scalet (1972) for *E. radiosum* and quite similar to those reported by Winn (1958b). Courtship, spawning behavior, egg counts, selection of spawning sites, time of year of spawning, territoriality, breeding tubercles, size of eggs, and extreme sexual dimorphism in *E. sagitta* are some of these characteristics. Several of these characteristics are typical for advanced groups of fishes (Winn, 1958b). Current practice is to consider *Littocara* as a valid subgenus, or as a synonym of

Oligocephalus with E. sagitta and E. nianguae comprising a species group. Whatever scheme is followed, similarities in nuptial tubercle development and reproductive behavior suggest a close relationship of E. sagitta with the subgenus Oligocephalus.

IX. AGE, GROWTH, AND WEIGHT

A scale length-body length regression line shown in Figure 7 was formed by using the standard lengths and scale lengths of 94 specimens of E. sagitta taken from the Cumberland River system (Figure 8 in the Appendix). Sexual differences in growth relationships could be determined. The ordinate intercept of the regression line was 8.512 in females and 8.783 in males. This intercept value was necessary before annuli lengths corresponding to standard lengths could be determined. Nomographs were used for this determination.

The growth history of E. sagitta is summarized in Table 7. E. sagitta males obtained 34% of their 4-year growth during the first year while females obtained 32%.

From Table 8 the relationship between standard length (SL) and total length (TL) was calculated. For males, SL was .8908 Tl, while in females, Sl was 0.8702 TL. The collective relationship was SL = 0.8814 TL.

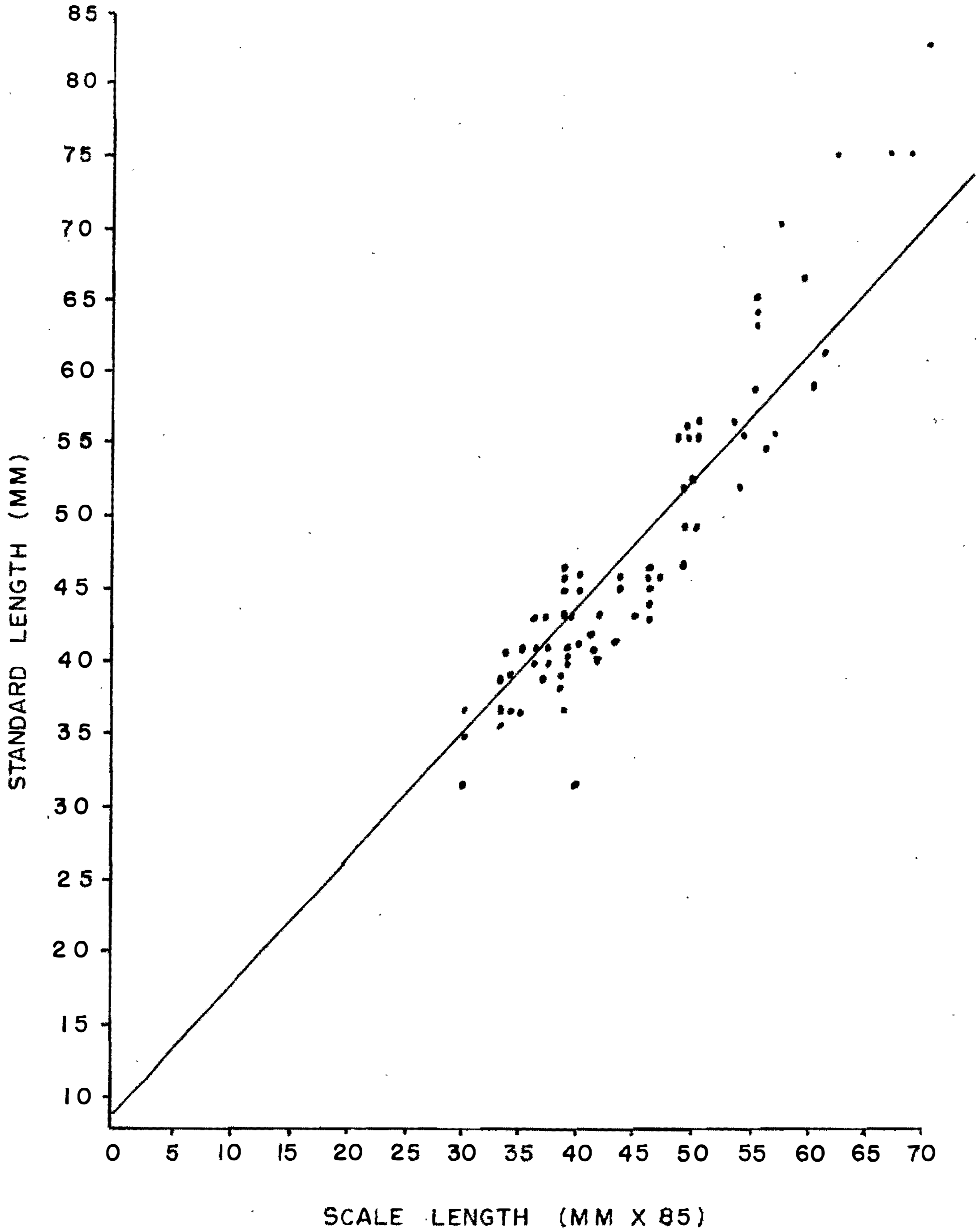

Figure 7. Body-scale relationships of *Etheostoma sagitta*, Cumberland River specimens, 1975-1976.

TABLE 7

GROWTH SUMMARY FOR *ETHEOSTOMA SAGITTA* FROM THE CUMBERLAND RIVER, 1975[a]

Year Class	1	2	3	4
n	32	30	22	10
Mean	41.7	44.3	55.2	69.8
95% C. I.	39.3-44.1	41.9-46.7	52.8-57.6	67.4-72.4
Yearly Increments	41.7	2.6	10.9	14.6
Percent of All Fish in Year Class	33.9	31.0	23.4	10.6
Percent Estimated Maximum Growth (95 mm) Reached	43.9	46.9	64.4	73.5

[a]Entries are in numbers of individuals and mm in standard lengths at the end of each year of life.

TABLE 8

LENGTH AND WEIGHT CHARACTERISTICS, BY AGE CLASS AND SEX, OF *ETHEOSTOMA SAGITTA* TAKEN FROM CUMBERLAND RIVER SYSTEM, 1975-1976[a]

Age Class	Sex	No.	Standard Length Mean	Standard Length Range	Total Standard Length Mean	Total Standard Length Range	Weight Mean	Weight Weight
0	Female	28	24.4	12-28	28.0	18-33	0.160	0.034-0.255
0	Male	18	44.1	40-47	50.4	47.54	0.940	0.619-1.158
0	Female	14	37.3	32-48	43.4	36-55	0.500	0.302-1.220
1	Male	9	47.0	46-49	53.6	51.56	1.110	0.976-1.285
1	Female	21	43.2	38-46	49.6	44-53	0.810	0.578-1.104
2	Male	15	57.9	52-59	63.6	60-68	1.900	1.603-2.570
2	Female	7	53.8	49-58	61.3	56-65	1.640	1.150-2.254
3	Male	6	73.8	65-83	82.3	75-95	5.070	3.346-5.467
3	Female	4	63.8	62-67	73.0	71-77	3.060	2.709-3.640

[a]Lengths are in mm; weights are in grams.

Parasites

Ninety-four adult and 28 3-month-old juveniles were examined for parasites on livers, gills, gonads, stomachs, and all body surfaces. One leech of the order Rhynchobdellida was removed from the caudal fin area of one specimen. No other parasites were found in *E. sagitta*. Metacercaria of an undentified digentic trematode were noticed on several specimens of *P. maculata*, *Nocomis micropogon*, and *C. anomalum* collected with *E. sagitta*.

X. TAXONOMIC STATUS AND SUGGESTIONS FOR FURTHER STUDY

Etheostoma sagitta is one of the 21 species of the subgenus *Oligocephalus*. Collette (1965) placed these species into species groups based on tubercles. Males of the *nianguae* group (*E. sagitta* Jordan and Swain, and *E. nianguae* Gilbert and Meek) have conical tubercles on the ventral sides. The *radiosum* group of *E. radiosum* (Hubbs and Black), *E. whipplii* (Giard), and *E. caeruleum* (Storer) has less numerous tubercles than the *nianguae* group. Collette (1965) places eight other tuberculate species in a loosely arranged group of *E. punctulatum* (Agassiz), *E. fricksium* (Hildebrand), *E. hopkinsi* (Fowler), *E. paravipinne* Gilbert and Swain, *E. pallididorsum* Distler and Metcalf, *E. cragini* Gilbert, *E. spectabile* (Agassiz), and *E. luteovinctum* Gilbert and Swain. Two of the species in this group have tubercles only on the anal fin, while the others have them in additional areas. The residue of eight nontuberculate species consists of E. asprigene (Forbes), E. swainni (Jordan), E. mariae (Fowler), E. juliae Meek, E. pottsii (Girard), E. lepidum (Baird and Girard), E. exile (Girard), and E. grahami (Girard).

Etheostoma sagitta and E. nianguae are more similar to the radiosum group in tubercles. E. sagitta is also similar to the two members of the radiosum group for which life history studies have been conducted. Courtship, spawning behavior, egg counts, time of year of spawning, territoriality, spawning sites, breeding tubercles, size of eggs and extreme sexual dimorphism in E. sagitta are very similar to those of E. radiosum recorded by Scalet (1972) and E. caeruleum as reported by Winn (1958b). However, E. sagitta differs from these two species in numerous morophological characteristics. At this time I support Collette's ranking of E. sagitta and E. nianguae as a species group in the subgenus Oligocephalus.

Future study of the other species of Oligocephalus is important for understanding taxonomic relationships in the subgenus. Particular importance is placed upon a life history study of E. nianguae.

Strip mining occurs near many streams which contain E. sagitta. Numerous sterams visited were devoid of fish life. Etheostoma sagitta only occurs in the Hickory Creek system in Tennessee except for Perkins Creek. Presently *E. sagitta* is listed on the endangered species list of Tennessee. Careful monitoring should be undertaken so any change in status can quickly be detected.

CHAPTER III

SUMMARY

1. Life history observations were made on *Etheostoma sagitta* utilizing in situ observations in their natural habitat, a plywood raceway, and an aquarium.

2. *Etheostoma sagitta* in the upper Cumberland River system was found in headwater streams as well as small rivers. Apparent water quality varied from extremely turbid to clear streams. Flow in some headwater streams was intermittent during dry weather.

3. Population density varied with season. Habitat of the fish varied with their size, age, and season of the year. Large males and females were found in riffles as well as transition zone and pools in the spring and late winter. By late May they were found only in pools and transition zones. Immature males and females were found along the stream edge during spring and late summer. By late winter they had joined the larger fish in pools and transition zones.

4. Migration was noted only into No Business Creek from Hickory Creek.

5. Large males were more active than smaller fish of both sexes. Adult fish were more active than juveniles.

6. Most activity occurred between 0600 and 1100. Crepuscular and possible nocturnal territoriality probably existed. Activity in the raceway decreased significantly by 2200.

7. *Etheostoma sagitta* feeds primarily upon Ephemeroptera nymphs and Diptera larvae. Immatures feed primarily upon Diptera larvae and cladocearans.

8. The sex ratio was 1.05 males per female. *Etheostoma sagitta* lives a maximum of four years.

9. Secondary sexual characteristics and breeding colors were discussed. Egg counts, coupled with observations in the field, indicate that the peak of the spawning season occurred from early April to early May. Ovary and egg characteristics, egg numbers, and facets of the female reproductive cycle were discussed.

10. Courtship and spawning behavior were discussed from two spawning sequences which occurred in the raceway on April 17, 1975.

11. A scale length-body length regression line was plotted. Scale lengths and a nomograph were used to calculate a growth summary.

12. Associated species and competition were discussed, with special reference to other *Etheostoma*.

13. Parasites were recovered and discussed.

14. Suggestions for further study on the biology of *Etheostoma sagitta* were presented.

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LITERATURE CITED

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APPENDIX

TABLE 9

<u>ETHEOSTOMA</u> <u>SAGITTA</u> SPECIMENS STORED IN THE UNIVERSITY OF TENNESSEE COLLECTIONS

Date Collected	Number of Specimens	U. T. Museum Number	Collecting Locality
2/18/68	4	91.144	Jellico Cr. at junction of Cr. and Gum Cr. Rd., Scott Co., Tenn.
5/26/68	2	91.213	I mile north of Winfield School, Scott Co., Tenn.
4/26/68	4	91.415	3 miles east of U.S. 27, off road, Scott Co., Tenn.
6/11/69	11	91.320	Hatfield Cr. below Trammel Cr., Campbell Co., Tenn.
4/26/73	6	91.839	Elk Cr. at junction Little Elk Fork Cr. Rd. mile 2345, Campbell Co., Tenn.
6/14/73	6	91.219	Brownies Cr. near Cubage, Bell Co., Ky.
10/23/73	5	91.839	Stinking Cr. 0.9 Rd. mile west of New Liberty Baptist Church, Stinking Cr. Rd., Campbell Co., Tenn.
2/29/75	15	91.1447	No Business Cr., 3 miles south-west of Jellico off U.S. 25 W, Campbell Co., Tenn.
2/29/75	9	91.1448	Stinking Cr. 0.9 Rd. mile west of New Liberty Baptist Church, Stinking Cr. Rd., Campbell Co., Tenn.
4/7/75	10	91.1449	Same as above.
4/14/75	14	91.1450	Same as above.
4/14/75	1	91.1451	Perkins Cr. 0.75 miles north of Winfield on U.S. 27, Scott Co., Tenn.
5/13/75	3	91.1452	Brownies Cr. 1 mile from Cubage, Bell Co., Ky.

TABLE 9 (continued)

Date Collected	Number of Specimens	U. T. Museum Number	Collecting Locality
6/18/75	8	91.1453	Stinking Cr. 0.9 rd. 5 mile west of New Liberty Baptist Church, Stinking Creek Rd., Campbell Co., Tenn.
7/18/75	4	91.1454	Mud Cr., 2 miles north of Jellico Tenn., Whitley Co., Ky.
7/18/75	5	91.1455	Mud Cr., 3 miles north of Jellico Tenn., Whitley Co., Ky.
7/18/75	4	91.1456	Stinking Cr. 2 miles from I-75 Campbell Co., Tenn.
7/18/75	5	91.1457	Tackett Cr. state highway 90, off rd. 1 mile from Morley, Campbell Co., Tenn.
9/25/75	5	91.1458	Stinking Cr. 3 miles from I-75, Campbell Co., Tenn.
9/25/75	8	91.1459	White Cr. off state highway 90 1/2 mile from White Oak, Campbell Co., Tenn.
9/25/75	6	91.1460	Tackett Cr. off state highway 90 near Ewing School, Campbell Co., Tenn.
9/25/75	5	91.1461	Rose Cr. off state highway 90, Eagan, Claiborne Co., Tenn.

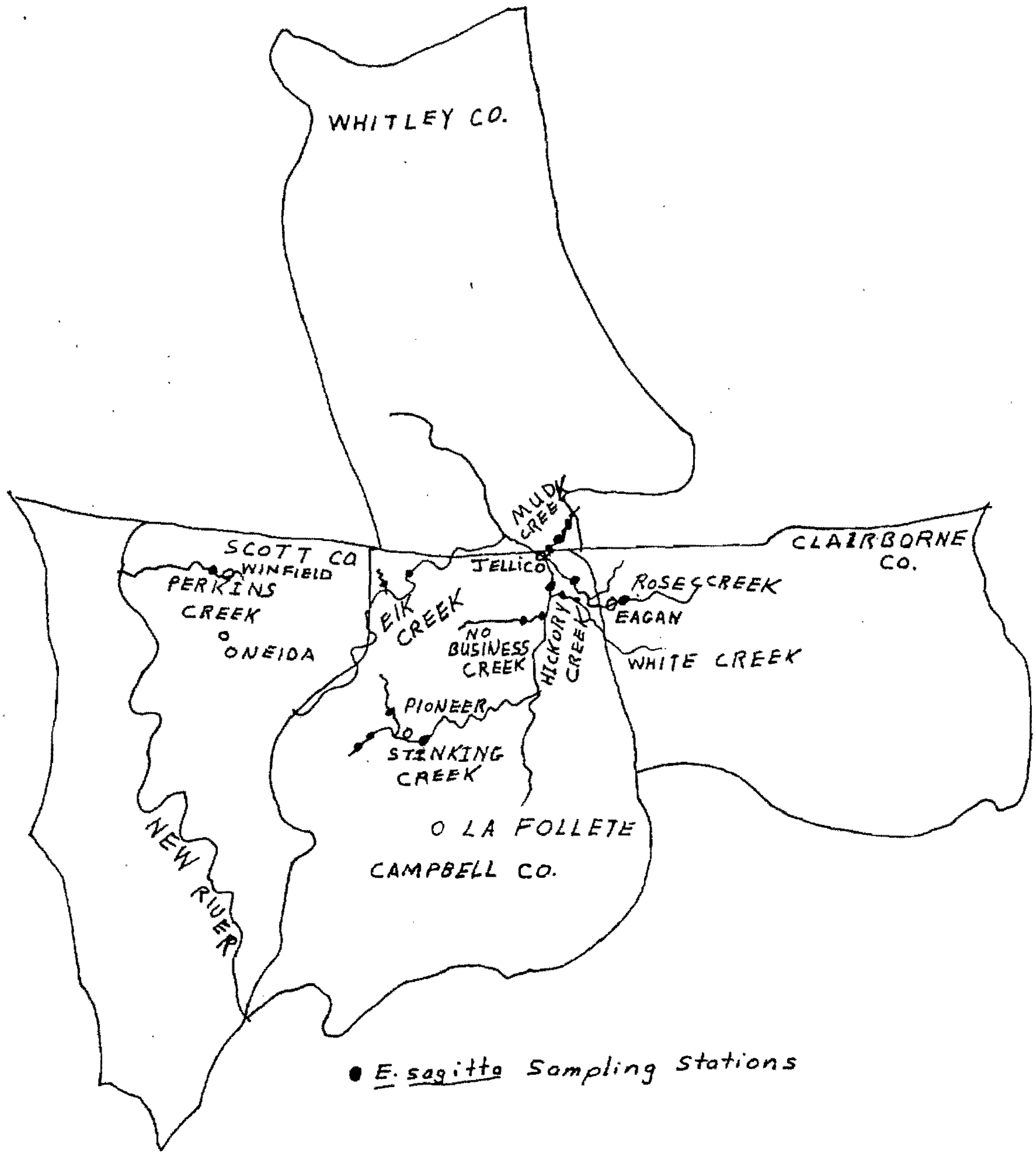


Figure 8. Map of the upper Cumberland River system showing Etheostoma sagitta collecting sites, 1975-1976.

TABLE 10

CUMBERLAND RIVER *ETHEOSTOMA SAGITTA* ASSOCIATED SPECIES

Species	Common Name	Abundance Classification	Preferred Habitats Riffle	Transition	Pool
Etheostoma sagitta	Arrow Darter	S	X	X	x
Etheostoma kennicotti	Stripe Tail Darter	C	X	X	X
Etheostoma caeruleum	Rainbow Darter	I	X	X	X
Etheostoma blenniodes	Greenside Darter	R			X
Percina maculatum	Blackside Darter	R			X
Campostoma anomalum	Stoneroller	S	X	X	X
Hypentelium nigricans	Northern Hogsucker	R			X
Rhinichthys atratulus	Blacknose Dace	R		X	X
Pimephales notatus	Bluntnose Minnow	R		X	X
Semotilus atromaculatus	Creek Chub	C	X	X	X
Nocomis micropogon	River Chub	C		X	X
Notropis cornutus	Common Shiner	S			X
Notropis leuciodus	Tennessee Shiner	S		X	X
Ichthyomyzon bdellium	Ohio Lamprey	R		X	
Ictalurus punctatus	Channel Catfish	R		X	
Ictalurus natalis	Yellow Catfish	R		X	
Micropterus dolomieui	Smallmouth Bass	R		X	X
Micropterus salmoides	Largemouth Bass	R		X	X
Lepomis auritus	Redbreast Sunfish	R			X
Lepomis macrochirus	Bluegill	R			X

TABLE 11

STATISTICAL PARAMETERS DERIVED FROM DATA PRESENTED IN TABLE 8, PAGE 53

Age Class	Sex	N	Standard Length			Total Length			Weight		
			X	S	$S_{\bar{X}}$	X	S	$S_{\bar{X}}$	X	S	$S_{\bar{X}}$
0	Undet.[a]	28	24.4	3.63	0.69	28.0	3.24	0.61	0.16	0.01	0.01
0	Male	18	44.1	2.40	0.56	50.4	2.62	0.62	0.94	1.00	0.24
0	Female	14	37.3	2.65	0.80	43.4	3.11	0.94	0.50	0.12	0.04
1	Male	9	47.0	1.17	0.39	53.6	2.13	0.71	1.11	0.12	0.04
1	Female	21	43.2	2.35	0.51	49.6	2.82	0.62	0.81	0.15	0.00
2	Male	15	57.9	4.64	1.20	63.6	2.90	0.75	1.90	0.37	0.10
2	Female	7	53.8	2.79	9.06	61.3	3.15	1.19	1.64	0.31	0.12
3	Male	6	73.8	6.01	2.45	82.3	7.02	2.86	5.07	0.91	0.37
3	Female	4	63.8	2.22	1.11	73.0	2.70	1.35	3.06	0.40	0.20

[a]Undet. = undetermined sex due to immaturity; S = standard deviation; N = sample number; X = mean; $S_{\bar{X}}$ = standard error of mean.

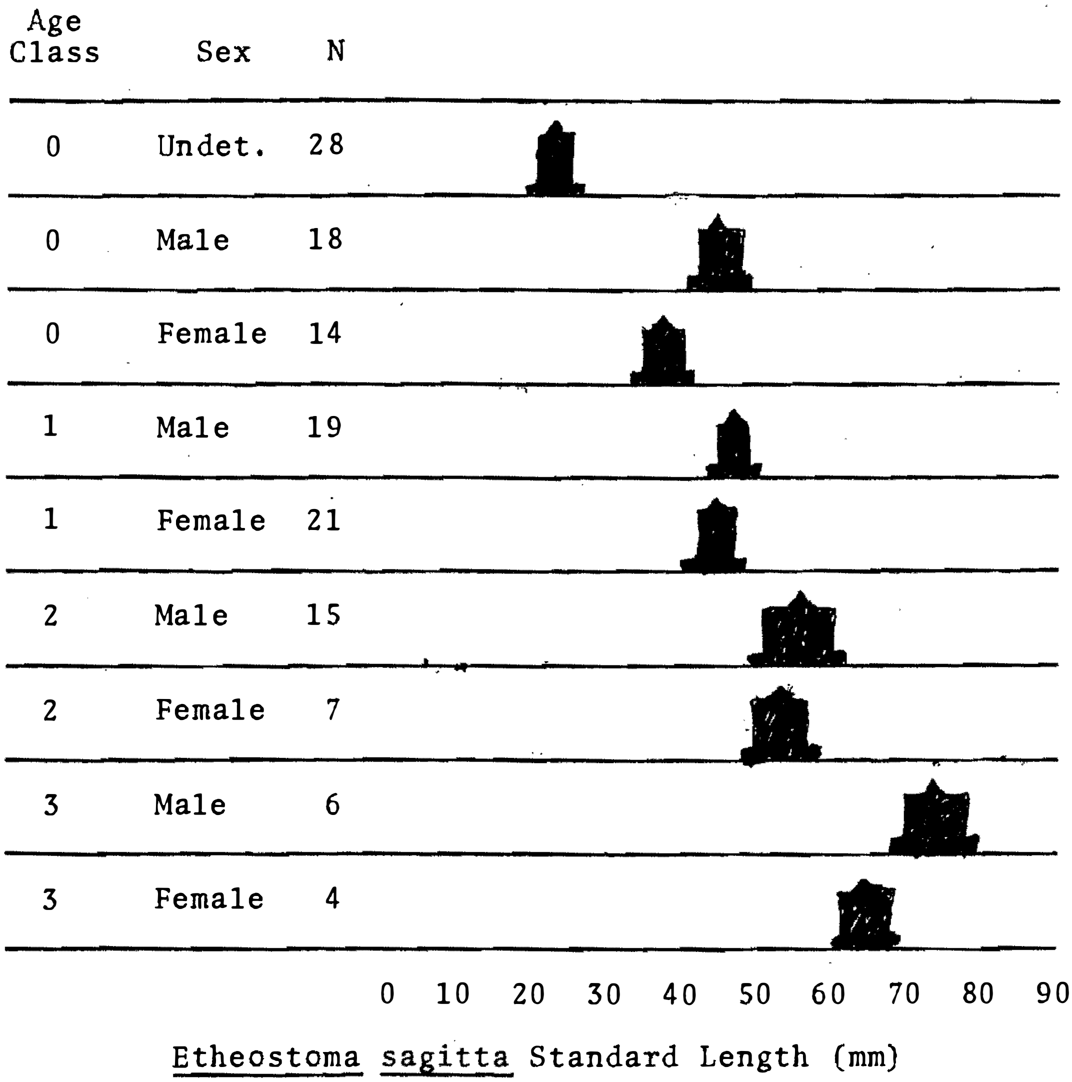
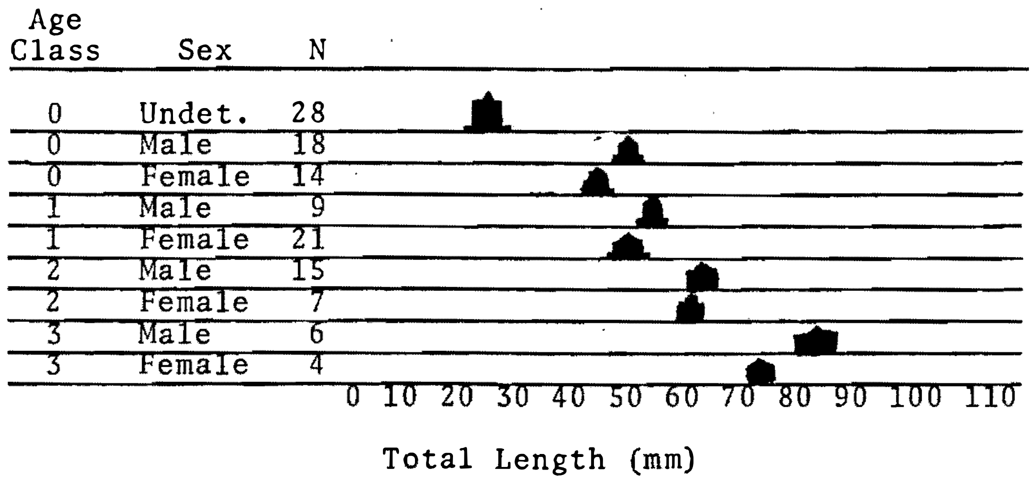


Figure 9. The relationship of the mean (small black triangles), range (heavy black line), standard deviation (unshaded areas), standard error (shaded areas—two standard errors on each side of the mean) with respect to standard length, total length, and weights of specimens of *E. sagitta*.



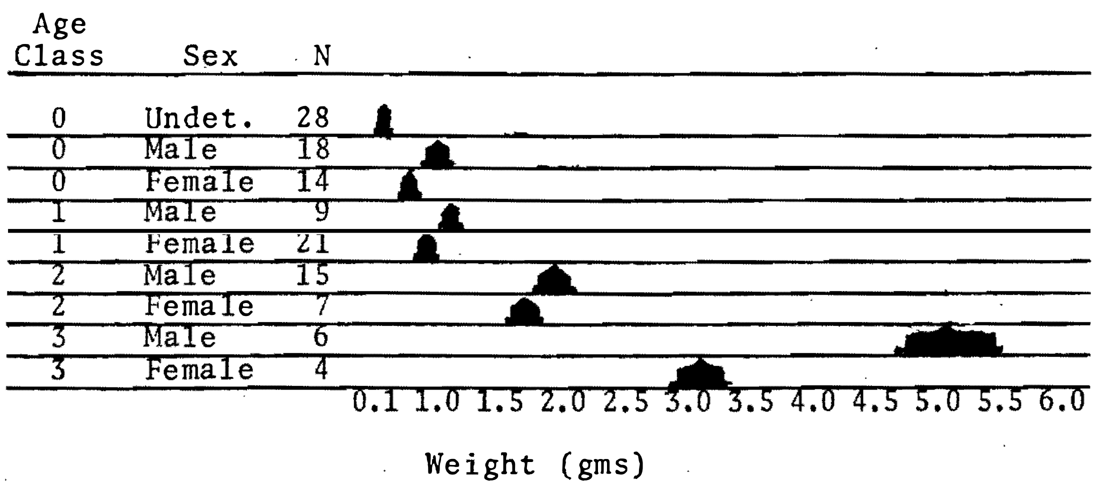


Figure 9 (continued)

VITA

John Eldon Lowe, Jr., was born in Knoxville, Tennessee, on October 27, 1951. He attended grade school in Madisonville, Tennessee, and graduated from Madisonville High School in 1969. He attended The University of Tennessee, Knoxville (1969-1973), obtaining a Bachelor of Science in Zoology in 1973.

He entered the Graduate School of The University of Tennessee, Knoxville, in September, 1973, and received the Master of Science degree with a major in Ecology in June 1977. During this time he worked as a biological aide for the Tennessee Valley Authority. He is presently employed by the West Knox Utility District in water quality.

Mr. Lowe is married to the former Karen Sue Wise of Seymour, Tennessee.