THE ECOLOGY, AGE AND GROWTH RATE OF THE CENTRAL JOHNNY DARTER, _ETHEOSTOMA NIGRUM NIGRUM_ (RAFINESQUE), AUGUSTA CREEK, MICHIGAN

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Edward Phelps Speare

1958

THESIS

This is to certify that the

thesis entitled

The ecology, age and growth rate of the central Johnny Darter *Etheostoma nigrum nigrum* "Rafinesque" Augusta Creek, Michigan.

presented by

Edward P. Speare

has been accepted towards fulfillment of the requirements for

Ph. D. degree in Zoology

Peter I. Tack
Major professor

Date November 14, 1958.

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by

EDWARD PHELPS SPEARE

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of Michigan State University in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Zoology

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Approved Peter I. Tack

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AN ABSTRACT

Seining collections were made during 1957 and 1958 at ten stations in Augusta Creek, Michigan. Three ecological groups were set up by combining stations with similar habitats. Records of the numbers and kinds of associated fish reveal that in E-I (pools) the Johnny darter constituted 60% of the fish population; E-II (riffles), 33%; and E-III (rapids), 20%. The next most abundant fish in the stream were Rhinichthys and Semotilus.

Certain ecological factors of the Johnny darter were studied, including the associated fish, aquatic plants, aquatic insects, and algae. Monthly tests were also conducted for temperature, alkalinity, pH, and oxygen concentrations at each station during 1957. "Envirographs" of the ecological factors show that the Johnny darter has an ecological preference in the Augusta Creek for quiet areas with dense aquatic plants.

There is evidence to suggest homogeneity of the darter population for the stream and differences in sex ratios for all age-groups are not significant. First year darter growth is equal for both sexes, after which the males exceed the females by 2.5 mm. The coefficient of condition is slightly higher for young-of-the-year than for older fish but is equal for both sexes. Values for the length-weight relationship are also given.

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Fall age-group proportions showed 8% for the 1956 year class, 43% for 1957, and 49% for 1958. Growth rates of 1957 and 1958 young-of-the-year were compared and no significant difference was found despite an earlier 1958 spawning date. The mean survival rate was determined as 2.0 years. The oldest fish taken was a male, age-group IV, 58.2 mm.

Ovaries develop slowly from June through September and reach full maturity by January. Ovary counts showed three classes of eggs: ripe, developed, and immature, all in about equal numbers. The three-year-old females lay approximately 60 eggs per ovary and may spawn twice in one season. About 65% of the one-year-old males and 86% of the females were mature in their first spawning season. The spawning period is from May 1 to June 1, but may vary by as much as two weeks in the spring. Field studies of egg-batches revealed that about 15% of the eggs laid die before hatching. Saprolegnia was commonly found on the unviable eggs.)

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ACKNOWLEDGMENTS

The author gratefully acknowledges the scientific and personal assistance given him throughout this study by Dr. Peter I. Tack, committee chairman. Sincere thanks are due many members of the Michigan State University teaching staff, but especially to Dr. Clarence Schloemer who guided my field work at the Kellogg Biological Station, to Dr. Eugene W. Roelofs for his help with respect to the scale critique, and to Dr. George A. Petrides for his suggestions concerning the population studies and random sampling.

For all photographs of the stream, equipment, and prepared slides, the author is indebted to Mr. Roger Tharp of Olivet College.

My particular thanks go to my wife, Patricia, for her constant encouragement and literary criticism without which this study could not have been finished.

TABLE OF CONTENTS

T

TABLE OF CONTENTS, continued

TABLE OF CONTENTS, continued

able Number

LIST OF TABLES

Table Number Page Number

LI.T

LIST OF TABLES, continued

LIS

LIST OF TABLES, continued

Table Number Page

Figure Number

LIST OF FIGURES

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LIST C

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LIST OF FIGURES, continued

A. Early darter

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INTRODUCTION.

(A. Early darter studies. The Central Johnny darter was first described by Rafinesque in 1820 (Jordan, Everman, and Clark, 1930) and previously was considered by those writing on fish to be the young of some perch or bass (Jordan and Copeland, 1876). Rafinesque named, and first described, the genus as *Etheostoma* but it was later changed to *Boleosoma*, from the Greek meaning "dark-body". Bailey (1956) has again adopted the term Etheostomidae to include all of the darters in the subfamily Percinae.

Jordan and Copeland (1876) described the general behavior of the darters and Forbes (1880) listed their food. Seal (1892) wrote about the breeding habits while Moenkhaus (1898) did a limited study on darter variation. A further study on darter breeding was done by Reeves (1907).

B. Recent darter studies. It was not until the third decade of the twentieth century that darters were again studied intensively. The breeding habits of such fish as the Iowa darter, Log-perch, and the Eastern Johnny darter were reported by Jaffa (1917), Reighard (1913), and Adams and Hankinson (1928), respectively.) Lake (1936) made a detailed study of the life history of the fan-tailed darter (*Catonotus flabellaris flabellaris*) in New York. The least darter (*Mic*

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least darter (Microperca punctulata (Putnam)) was studied by J. Petravicz (1936) and W. Petravicz (1938) reported on the breeding habits of the black-sided darter (Hadropterus maculatus). The next year, Raney and Lachner (1939) published their study on the spotted darter (Poecilichthys maculatus.)

For nearly five years, little or no work was done on the darters until 1942 when Raney and Lachner (1942) studied the predation on the eastern Johnny darter (Boleosoma nigrum olmstedi) by the yellow pike perch and the northern small mouth bass. Gosline (1947) reported on the variation of darters and Stone (1947) on their speciation. Distribution studies were carried out by Larimore, Pickering, and Durham (1952). Fahy's work (1951) on the Northern greensided darter (Etheostoma blennioides blennioides Rafinesque) is, to the best of my knowledge the most recent darter life history study.

C. Purpose of this paper. This is a detailed study of the ecology of the Central Johnny darter in Augusta Creek, Michigan. It considers such environmental factors as water chemistry, associated fish, bottom types, aquatic plants, algae, and insect larvae, and their effectiveness in determining the distribution and abundance of this darter.

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A further objective of this study has been to consider the age and rate of growth of _Etheostoma nigrum nigrum_ and the limiting factors found, first within the stream as a whole and secondly within specific ecological units.

This work is justified because of little previous work on so conspicuous a segment of our fish fauna.

STREAM DESCRIPT

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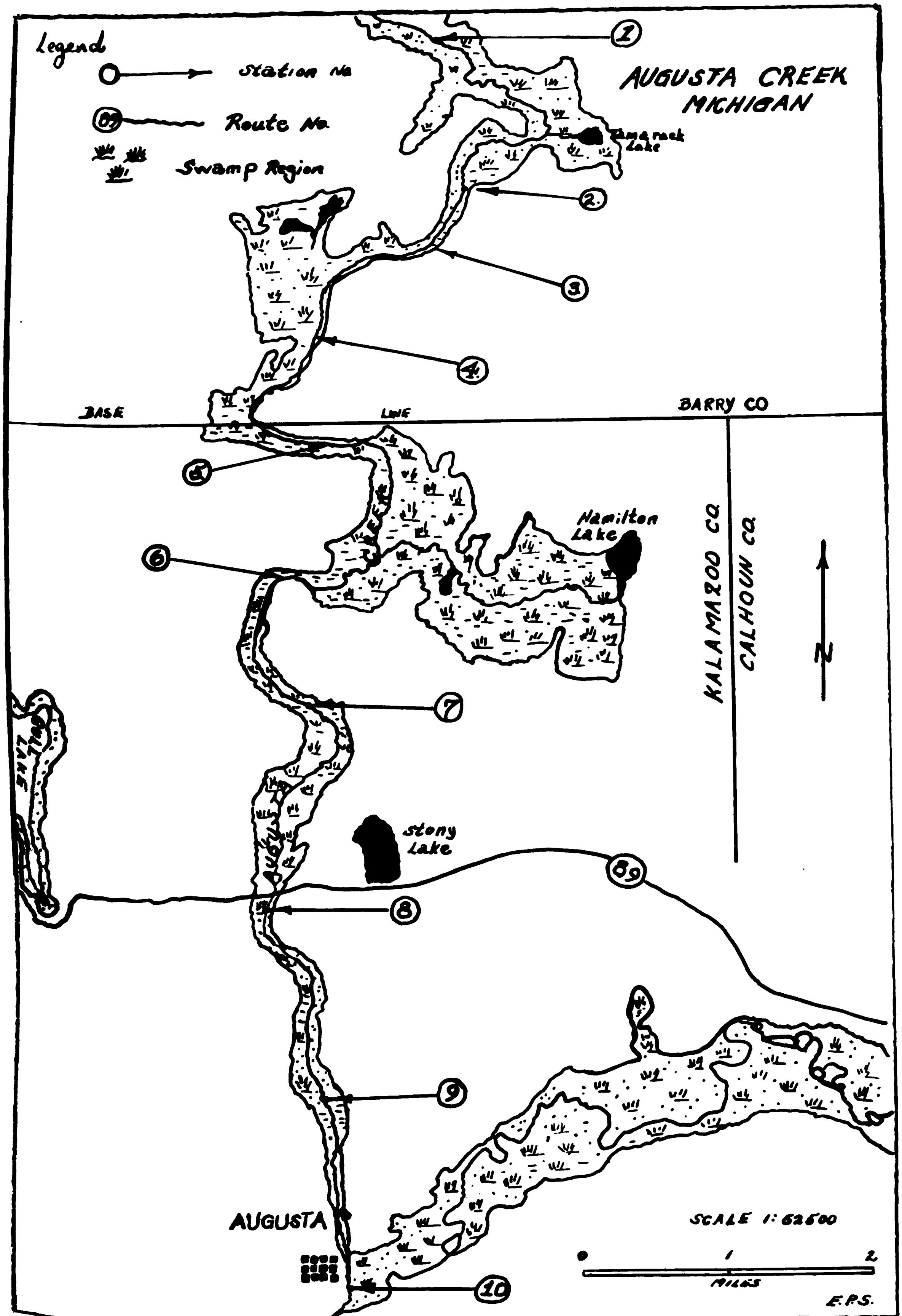
AUGUSTA CREEK

A. STREAM DESCRIPTION. This study was confined to the Augusta Creek, a tributary of the Kalamazoo River in southwestern Michigan. The present day topography of the Lower Peninsula is the result of continental glaciation. The glacier retreated from this part of the state approximately 12 to 15 thousand years ago. The valley of the Augusta Creek is thus a post-glacial development cut into an area of sorted glacial outwash material. The size of the stream may have been somewhat larger than it is today, when draining glacial water into the Kalamazoo River.

The area drained by the Augusta Creek consists of a chain of lakes near its headwaters and a series of large swamps, extending from the Kalamazoo moraine of the Saginaw Lobe to the valley of the Kalamazoo River at Augusta. The total length of the stream is approximately 14.6 miles.

The gradient of the stream is not steep at any point along its length. There is a drop of 117 feet from its origin in Little Gilkey Lake to its outlet in the Kalamazoo River. (See map on page 5.) The stream is small, meandering through fields and pasture land. The banks are muddy and the stream bottom is rocky where swift, sandy in the deeper pools, and muddy to sand-silted in the slower parts. Emergent vegetation is abundant only in certain areas of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the stream while algal growth is profuse in the swifter riffles. The headwater is that of Little Gilkey Lake, and the entire stream is subject to till drainage. In the lower third, the stream passes through a well-defined valley whose width is about 4 miles and whose depth is approximately 70 feet.

B. LIMNOLOGICAL FACTORS. Water analyses were made on samples taken throughout 1957 on or near the 15th of each month. A few selected samples were also taken in 1958. For purposes of comparison, several collections were made in streams entering the Augusta Creek, the Gilkey Lake series, and in the headwater at Balker Lake. Field and laboratory procedures were adapted from Welch (1948), Theroux, Eldridge, and Mallmann (1943), and Ellis, Westfall, and Ellis (1948). (Tables 1.1-4) Tests were made on conductivity during the summer of 1957. pH readings made in the field with a Hellige pH meter and those by the electrometric method made in the laboratory were comparable.

1. Temperature. Water temperature readings taken during the growing season ranged from near freezing in April to 27°C. in June. In 1958, spawning temperatures were reached on April 9, about four weeks earlier than in 1957. The immediate return of cold weather, however, with its retardation of spawning activity, resulted in a spawning period

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of normal duration. Selected temperature readings over the course of the stream within one hour (12:00 a.m., July 11) showed a difference of only 2°C. from head waters to outlet. Diurnal variations were about 10°C. during the summer, and shaded woodlots were consistently 0.5°C. cooler than open sunny areas. During June, the water temperature exceeds the normal upper limits of a trout stream reaching as high as 27°C.

2. Oxygen. Any ecological pressure exerted by oxygen variation is very slight. Oxygen values never fall below the critical amount of 5 ppm. (Lagler, 1956). There is sufficient oxygen available at all times of the year and particularly during the spring months. In January and February, the ice cover is not complete and large areas remain exposed as bubbling rapids. The lowest reading was taken in June at Station 1, and readings of supersaturation were recorded at several stations for the month of April. (Table 1.2)

The normal oxygen concentration for this stream is approximately 95% saturation and this agrees well with expected average stream conditions. (Ellis, Westfall, and Ellis, 1948)

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3. <u>Alkalinity.</u> Tests for alkalinity were made regularly and recorded in Table 1.3. The water is very hard and the alkalinity increases but slightly from the head waters to the outlet at Augusta. There is some evidence to suggest an increase in alkalinity below the fall-out of Tamarack Lake, probably due to the high alkalinity of this lake. Variations within the stream are very slight, and do not appear to affect the ecology of the Johnny darter.

All phenol-phthalein determinations were negative.

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4. pH. In July, a check was made on the accuracy of the pH determination conducted in the field. Water samples were brought into the laboratory directly after pH readings had been taken. Here they were tested by the electrometric method and the two data were compared. The results showed that readings made in the field with the Hellige pH meter were in complete agreement with those made in the laboratory.

Table 1.4 shows the pH range for the stream to be 7.1 - 8.8. The water becomes slightly harder as it nears Augusta.

5. Special tests. Work was begun on the determination of chemical variations affected by smaller streams flowing into the Augusta Creek, from swamps, hardwater lakes, and factories at Augusta. Water samples were thus taken from the Gilkey Lakes, Tamarack Lake, and above and below the junction of this lake's outlet with the Creek. The data suggest no temperature change resulting from water from Tamarack Lake, but there is a slight increase in water hardness below the junction. Also, the extensive water surface of the Gilkey Lake series warms the water at the upper limits of the stream. (Table 1.5)

TABLE 1.5

WATER TEMPERATURES GIVEN IN DEGREES CENTIGRADE FOR LAKES ADJOINING AUGUSTA CREEK, MICHIGAN, 1957 AND 1958

Date	Pitchfork Swamp Sta. 1	Tamarack Lake Above Junct.	Tamarack Lake Below Junct.	Gilkey Series Big Gilkey	Gilkey Series Shallow Gilkey	Gilkey Series Little Gilkey	Augusta Creek*
July 1, 1957	19	17	17	24	23	24	18
July 20, 1957	--	18	18	24	24	25	21
Aug. 9, 1957	20	--	19	25	24	25	19
Sept. 20,1958	16	14	14	19	19.5	19.5	14.5
Sept.28,1958	19	18	18	21	21	22	17

* Data given as stream average for that particular date.

TABLE 1.6

AVERAGES OF MONTHLY CHEMICAL READINGS MADE ON AUGUSTA CREEK, MICHIGAN, 1957

Data	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Range
Temp. °C.	0	0.5	6	4	12	26	23	23	20	12	3	2	0 - 26
pH	7.8	7.8	7.9	8.0	8.0	7.9	7.9	7.9	7.6	8.3	8.6	7.9	7.6-8.6
M.O.	205	163	213	188	163	201	204	215	224	177	191	204	163-224
O_2	11.8	12.3	11.3	12.4	9.0	7.2	6.8	8.0	9.0	11.2	13.4	13.4	6.8-13.4

C. STATIONS. The stream was divided into ten stations nearly equally spaced over the 14.5 mile course. Each station was identified with a bridge-crossing and extended up or down stream approximately 100 yards. The upper limit was determined by a sharp change in the stream bottom, depth, or other natural occurrence. Thus each station was limited to a particular habitat type. (Figs. 1.1-12)

Station 1. Origin: upper end of stream; NW $\frac{1}{4}$ Sec. 23, T. 1 N, R. 9 W, Barry Co.; westward from bridge on Litts Rd. 150 yds. to margin of Pitchfork Swamp; rate slow, 1/3 ft. per sec.; width 12'; depth 8"; bottom sandy; Sparganium, Etheostoma, and Tendipedidae all very abundant.

Station 2. Origin: bridge crossing on Co. Road 400; NE $\frac{1}{4}$ Sec. 26, T. 1 N, R. 9 W, Barry Co.; northward 200 yds.; rate slow, $\frac{1}{2}$'/sec.; width 20'; depth 10"; bottom sandy; Etheostoma abundant among Typha, Potamogeton, and Sparganium; insects Notonecta and Anax common; Spirogyra in small eddies.

Station 3. Origin: 400 yds. below bridge on Mann Road; SW $\frac{1}{4}$ Sec. 26, T. 1 N, R. 9 W, Barry Co.; southward 100 yds. through woodlot; rapids; rate 1'/sec.; width 12'; depth 5"; bottom gravelly; Poecilichthys abundant; Nasturtium and Iris at the margins only; mold and algae on submerged rocks

Fig. 1.1 Head waters

Fig. 1.2 Station 1

Fig. 1.3 Station 2

Fig. 1.4 Station 3

making bottom dark in color.

Station 4. Origin: bridge on Sheffield Road; SE ¼ Sec. 34, T. 1 N, R. 9 W, Barry Co.; southward 150 yds. to Aorn's fence line; rapids; rate 1'/sec.; width 15', depth 7"; bottom gravelly; Semotilus, Rhinichthys, and Etheostoma predominant; Typha and Scripus at margins only.

Station 5. Origin: bridge on Lepper Road, NW ¼ Sec. 3, T. 1 S, R. 9 W, Kalamazoo Co.; westward 200 yds.; some riffles; rate 1.3'/sec.; width 21'; depth 8"; bottom pebbly to gravelly; Poecilichthys abundant among Johnny darters; tufts of Potamogeton natans within stream proper; silt greatly reduced.

Station 6. Origin: bridge on Lepper Road, NW ¼ Sec. 10, T. 1 S, R. 9 W, Kalamazoo Co.; northwest 100 yds.; rapids; rate 2'/sec.; width 25'; depth 7"; bottom gravelly; Etheostoma very few as are aquatic plants. Hyborhynchus predominates.

Station 7. Origin: bridge on C Ave. E., SW ¼ Sec. 10, T. 1 S, R. 9 W, Kalamazoo Co.; westward 200 yds.; riffles; rate 2'/sec.; width 18'; depth 13"; bottom gravelly to pebbly; Etheostoma and Rhinichthys abundant. Scattered Potamogeton.

Fig. 1.5 Station 4

Fig. 1.6 Station 5

Fig. 1.7 Station 6

Fig. 1.8 Station 7

Station 8. Origin: bridge on Route 89 southward 25 yds. and northward 80 yds. from Lookout Point Bridge in Kellogg Forest Tract; NE ¼ Sec. 21, T. 1 S, R. 9 W, Kalamazoo Co.; bottom sandy, rate moderate, 1'/sec.; width 18'; depth 25". Many species of associated fish.

Station 9. Origin: bridge on EF Ave. E., SW ¼ Sec. 27, T. 1 S, R. 9 W, Kalamazoo Co.; northward 100 yards; strong rapids; rate 2'/sec.; width 30'; depth 11"; bottom gravelly; *Catostomus* in deep holes, *Cottus* in silt margins. *Etheostoma* in specialized areas only.

Station 10. Origin: dam site below Augusta, SW ¼ Sec. 34, T. 1 S, R. 9 W, Kalamazoo Co.; southward 80 yds. to junction with Kalamazoo River by-pass; rate variable depending upon position of dam gates; no aquatic plants; alga *Cladophora* in swifter parts.

Fig. 1.9 Station 8

Fig. 1.10 Station 9

Fig. 1.11 Station 10

Fig. 1.12 Stream outlet

D. <u>ECOLOGICAL GROUPS</u>. By correlating the data on stream characteristics given in Table 1.7, the ten stations were then combined into three ecological groups identified as E-I, E-II, and E-III. Consideration was given to the following factors as they collectively constituted a particular ecological setting in which the Johnny darter found its niche: rate of flow, bottom type, silt deposition, aquatic plant abundance, species of associated fish, algae, and aquatic insects. Separate species lists are given under Ecological Analysis. (See chapter on Ecological Analysis.)

<u>E-I (Stations 1, 2, 8)</u> This ecological group characteristically has a slow rate of flow ($\frac{1}{2}$'/sec.), a sandy-silt bottom, and is covered with snail shells of *Planorbis*, *Amnicola*, and the tiny white broken parts of the clam *Sphaerium*. Fine soft silt piles up at the margins shifting frequently as the depth of water and consequently the rate of flow varies. *Sparganium*, *Sagittaria*, and *Anacharis* form dense mats at the center of the stream in the upper portions and at the silt-laden sides of the lower section. The width averages 12' and the depth 6". In September filamentous algae *Spirogyra* and *Cladophora* form long "algal ropes" and cover the larger stones in small riffled areas.

TABLE 1.7

ECOLOGICAL COMPARISON OF 10 STATIONS ON AUGUSTA CREEK 1957

	Depth		Width			Bottom				Rate			Cover		Mar-gins		Bottom Cover		Aqua-tics		Algae		Fauna			
																							Insects			Fish
Stations	Deep	Moderate	Shallow	Wide	Modrate	Sandy	Pebbly	Rocky	Debris	Slow	Moderate	Rapids	Sunny	Shady	Sandy	Silty	Light	Dark	Abund.	Common	Abund.	Common	Abund.	Common	Abund.	Common
1	-	-	x	x	-	x	x	-	-	x	-	-	x	-	-	x	x	-	x	-	x	-	x	-	x	-
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8	x	-	-	-	x	x	-	-	-	-	x	-	x	-	-	x	x	-	-	x	-	-	-	-	-	-
9	-	-	x	x	-	-	x	-	-	-	-	x	x	-	x	-	x	-	-	-	-	-	-	-	-	-
10	-	x	-	x	-	-	x	-	-	-	x	-	x	-	x	-	x	-	-	-	-	-	-	-	-	x

This represents the optimum of conditions for reproduction, protection, and food sources, this latter being supplied first in the form of algae for the fry (Coelosphaerium, Closterium, Scenedesmus) and secondly as insect larvae for the adults (midges). Their natural fish predators, the large and small mouth bass, are very rare. From this ecological setting, approximately 50% of the 2000 darters used in this study were taken.

E-II (Stations 5, 7, 10.) This group is characterized by their scattered deeper holes. These render an abundance of associated fish but because of the shallowness of the rest of the station and its resultant swifter current and rocky bottom, the Johnny darter is found in isolated areas only. Here the bottom is pebbly to sandy. Depth is 8" and the width averages 15'. Larger rocks break the surface and form backeddies. Silt is reduced at the edges and the aquatic plants are not abundant, consisting mostly of Potamogeton and Nasturtium in isolated areas. Algae such as Cladophora and molds are profuse on the larger rocks. The aquatic insects are not abundant as in E-I. Present also are Planorbis, Amnicola, and Cambarus but in reduced numbers. The western black-nosed dace Rhinichthys and Semotilus are the most abundant associated fishes. Often lumber, iron wire, and hardware debris litter the blackish, firm pebbly, unchanging bottom.

Fig. 1.13
Ecological Group I

Fig. 1.14
Ecological Group II

The lack of aquatic plants is reflected in the reduced kinds and numbers of the "desired" aquatic insects such as Chironomids and Ostracods. There are few breeding areas supplied with stones large enough for satisfactory egg-laying.[1] The gravelly, pebbly bottom is less effective in providing a natural cover than is a speckled sandy bottom. Here the Johnny darter constituted only 33% of the catch taken at these stations.

E-III (Stations 3, 4, 6, 9) This ecological group is typified by its rapids and broken surface water. The bottom is stony and gravelly. A blackish mold and blue-green algae grow on most of the stones. The sand has washed away and there is little silt at the sides of the stream. It averages 5" in depth and 24' in width. This group is devoid of aquatic plants in the stream proper. *Nasturtium*, *Pontederia*, and *Decodon* are found at the sides in the quieter regions. Small patches of *Potamogeton* exist at Station 9. There is very little muck and consequently few aquatic larvae (Table 6.4). *Semotilus*, *Notropis*, and *Rhinichthys* are the predominant associated fish. Of the total catch for this group, *Etheostoma nigrum nigrum* com-

1. Only six of the ten "nesting plants" were used in 1957 while 13 of the 15 were used in E-I. Those utilized were in back-eddies at the extreme edges of the stream in quiet water.

Fig. 1.15

Ecological Group III

prised only 23%. Dense shade from surrounding woodlots render the bottom a dark color. Wild roses and red osier dogwood crowd the banks. From all standpoints, this would be considered a less favorable habitat for the Johnny darter.

METHODS AND MATERIALS

A. COLLECTING TECHNIQUES

1. Johnny darters. This study is based on seining collections made in Augusta Creek, Michigan, between Sept. 15, 1956 and Sept. 28, 1958. Nearly 2000 darters were taken and of these, 1200 were studied for such factors as age and rate of growth, sexual dimorphism, age groups, mortality rates, spawning ecological preferences within the stream and seasonal changes in the condition factor K.

All collections were made with a one-man darter-net, (fig. 2.1), except the collections made at Station 2 in September of 1957 and 1958. These were made with a two-man

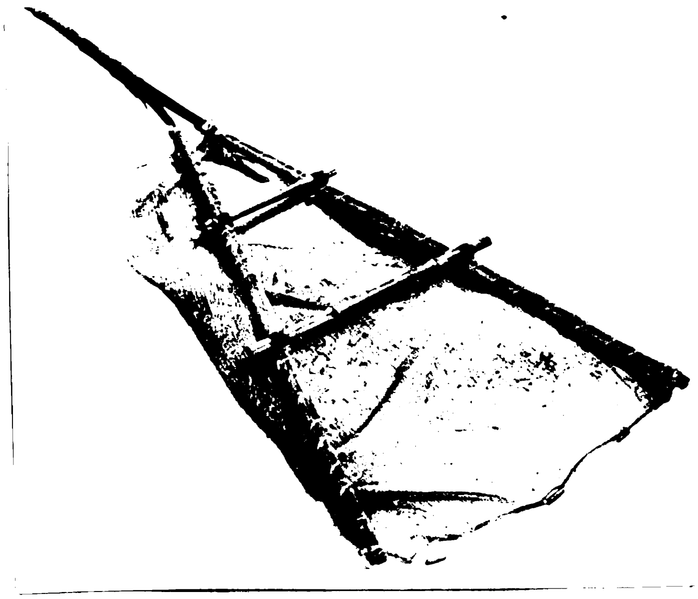

Fig. 2.1 Darter-net

six-foot common-sense-seine of $\frac{1}{4}$" mesh. These collections were used for population studies as the entire number of 245 fish (1957) and 300 fish (1958) were taken from one small area of the stream 80 yards long. Use of traps and two-man seines were generally ineffective. By means of the darter-net, fish lying on the bottom, between rocks, and among roots were successfully taken.

Most of the seining was done downstream, but in some of the quieter waters, individual fish were sought by seining upstream. The latter method was used almost exclusively at Station 10 due to the debris of iron, lumber, and wire on the stream bottom.

That the fish of this study represent a random sample is suggested by the fact that no effort was made to avoid rocky places, brush, shallow or deeper holes. The entire area of a given station was carefully seined. Fish of all lengths and ages were taken from nooks and crannies, in deep and shallow water, throughout the entire growing season. Due to the heavy matting of the algae which formed on the inner surface of the net, fry as small as 20 mm. were easily taken. At the same time, the technique used was adequate to capture the older and larger fish of 50 mm.

The average length of the station was 100 yards. The majority of fish in this study were taken on the silt margins and sandbars located in six to nine inches of water.

2. <u>Associated fish</u>. Representatives of all associated fish were kept in proportion to the numbers actually captured. For example, in August 1957 several score of yellow bullheads (<u>Ameiurus natalis natalis</u>) were picked up in the normal seining activities at Station 1. Only a few handfuls of these were retained. The above method applies to <u>Notropis cornutus frontalis</u> of most deeper stations and to <u>Poecilichthys caeruleus caeruleus</u> in the swifter rapids. These associated fish were identified by the use of Hubbs and Lagler's <u>Fish of the Great Lakes Region</u> (1949), then were wrapped in cheese cloth and preserved in 10% formalin.

B. <u>METHODS AND MATERIALS</u>

1. <u>Sex determination</u>. The sex of each darter was determined by examination of the external genitalia and then by dissection of the gonads. The males have a single palp or labium directly behind the vent; the females, two palpi (fig. 5.1). These palpi were not easily distinguishable in fish less than 20 mm. in length. Body color aided in identification only during the spawning period.

All fish measured were also examined for gonad development. The method of rating the gonad growth as suggested by W. C. Beckman and found in Lagler's <u>Freshwater Fisheries Biology</u> (1956:141) was used. This evaluates the condition of the gonads during the spawning season as immature, ripe, or spent, and during the post-spawning season as immature and mature.

2. <u>Weight</u>. All fish were weighed to within one-tenth of a gram on a Fisher platform balance. Before weighing, each fish was dried in cheese cloth for one-half minute (see validation of techniques). Newly hatched fry and fish less than 20 mm. long were below the accurate range of this scale and were thus recorded as weighing 0.1 gram. (fig. 2.2)

Fig. 2.2 Fisher platform balance

3. <u>Length</u>. The fish were measured to within one-tenth of one millimeter with a modified vernier (fig. 2.3). This consisted of a vernier calipers fastened to a standard so that the movable arm might pass over a fish supported on a block and located between the measuring arms. Each fish was placed on the support with the snout just touching the "zero-arm". The slider was then moved over the fish so

that its "indicator arm" was directly over the tip of the tail and then over the vertebral column terminus. These limits were read directly from the vernier scale and recorded as total body length and as standard length.

4. Preserving: Darters, Aquatic Plants, Insects, Algae. The darters were preserved in 10% formalin. The same solution was used for the aquatic insects. Some herbaria mounts were made of the less abundant aquatic plants for future study on this stream. Most of them were identified in the field. Fassett's A Manual of Aquatic Plants (1940) was used for this identification. Algae were collected at various times of the year and preserved in 6-3-1. Prescott's keys in Algae of the Western Great Lakes Area (1951) served for the identification of these plants.

5. Validation of Techniques. To determine the validity of the methods for measuring the fish, control tests were conducted. The questions of how much excess water remained on the fish at the time of weighing and how much of the original body length and weight are lost due to preserving are answered in Table 2.1 and 2.2. Before weighing, each fish was wrapped and dried in cheese cloth for about 20 seconds. This removed the excess water without drying out the body. To test this method, five fish, all of different weights, were successively dried and weighed five different

times. Table 2.1 shows that the greatest difference between any two weighings of the same fish is 0.1 grams -- and because the scales read accurately to only one-tenth of a gram, it was assumed that this method of drying before weighing provided good and consistant data throughout this study.

TABLE 2.1

VARIATION IN WEIGHTS OF THE SAME FISH WHEN WEIGHED SEVERAL TIMES ONE AFTER THE OTHER*

Fish No.	Weighing tries: First	Second	Third	Fourth	Fifth	Greatest difference
1	3.8	3.7	3.7	3.8	3.7	.10
2	3.1	3.05	3.1	3.1	3.1	.05
3	1.3	1.3	1.2	1.3	1.3	.10
4	1.1	1.1	1.1	1.1	1.1	.00
5	0.2	0.21	0.2	0.1	0.11	.10

*Data given in grams.

A second study measured the differences in length and weight between living fish and the same fish when preserved. The weight and length of a living fish were recorded and then redetermined once each month for four months in the preserved state. Table 2.2 shows that preserving the fish causes it to lose about 1% of its original length and about 3% of its original body weight. While these results are in agreement with what Van Oosten (1929) found for the lake herring and Shetter (1936) for trout, it should be noted that these observed differences could be accounted for as human errors and as limitations of the scales and vernier. No effort was made to compensate in this study for this loss of weight and length -- but whenever length or weights are compared, the fish are taken all from the same collection.

TABLE 2.2

BODY SHRINKAGE AND WEIGHT LOSS DUE TO PRESERVING. FISH TAKEN FROM STATION NO. 2 ABOVE COMPOUND I ON SEPTEMBER 28, 1957

	Standard length in mm.						Weight in grams					
Fish No.	Sept. Alive	Oct. Pres.	Nov. Pres.	Jan. Pres.	June Pres.	MM. Lost	Sept. Alive	Oct. Pres.	Nov. Pres.	Jan. Pres.	June Pres.	Grams Lost
1	49.2	48.8	48.0	48.0	48.8	.40	1.36	1.40	1.40	1.20	1.30	.06
2	45.0	45.5	45.1	44.2	44.5	-	1.20	1.20	1.22	1.15	1.10	.10
3	40.0	39.9	39.4	38.8	39.2	.80	0.80	0.80	0.90	0.74	0.80	.00
4	41.0	41.0	41.0	40.7	41.0	.00	0.85	0.90	0.90	0.74	0.80	.05
5	39.8	39.5	29.5	38.9	39.0	.80	0.80	0.90	0.85	0.74	0.80	.00
6	39.5	39.7	39.3	39.2	39.4	.10	0.80	0.90	0.90	0.74	0.80	.00
7	41.6	41.5	41.7	41.0	41.2	.40	0.90	1.00	1.00	0.70	0.92	--
8	39.5	39.4	39.3	39.0	39.5	.00	0.76	0.80	0.80	0.82	0.72	.04
9	28.5	28.0	28.5	28.0	28.0	.50	0.30	0.38	0.30	0.20	0.20	.10
10	29.8	28.6	28.7	28.8	28.4	.40	0.30	0.38	0.30	0.20	0.20	.10

Average percent loss of original body length = 1%

Average percent loss of original body weight = 3%

6. Scale sampling. Scale samples were taken from the mid-body on the left side at the tip of the pectoral fin just below the lateral line (Carlander, 1943). Other areas were test sampled, but this one gave the largest scale size with uniform shape. Approximately ten scales were removed and placed in scale envelopes. During the early part of the investigation, permanent mounts were prepared for reading. Later the scales were studied directly by placing them in water and reading them under the low power of a compound microscope. A fish was considered to be one year old when taken in its second summer. It would thus have one annulus and would have passed through one winter. It was considered to be in Age-group I and of a Year-class one less than the year of capture. Young fish taken before the first of January showed no annulus and were regarded as being in Age-group O.

Fig. 2.3 Vernier calipers

CENTRAL JOHNNY DARTER

A. GENERAL DESCRIPTION

(1. Etheostomidae. Bailey (1956:369) lists the major characteristics of the genus Etheostoma as follows: Breast, interpelvic space, and belly variously marked or covered with normal scales, but never with a median series of enlarged and modified scales. (Pelvic fins separated by a space which varies from nearly as wide as the pelvic base to less than half that distance. Caudal fin forked, truncated, or rounded posteriorly. Lateral line, infraorbital canal and supratemporal canal complete or incomplete. Vertebrae 32 to 41).)

2. General description of the Central Johnny darter. (The Central Johnny darter is a small awl-like fish living on the bottom of streams among aquatic plants in riffles of moderate swiftness. The body is brownish above with small black or dusky "W" markings on the sides and caudal peduncle. The mouth is inferior and the lips are prominent in the larger fish. The overly large pectoral fins and well-developed pelvic fins serve as "resting" organs of support. This fish moves with swift darting motions and often buries itself with only the large dorsally located eyes protruding above the sand. The body is somewhat depressed, being

flattened above and below. The body surface feels rough to the touch, this characteristic giving to the species the nickname of Sandpaper darter. During the spawning season the males are a deep velvet black and display various wigwagging activities as part of the mating behavior. Many who have fished a stream for years are never aware of their presence.)

3. Taxonomy. (Considerable study has been made of the serial and proportional characteristics of this fish, and the following generalizes its taxonomy sufficiently well: lateral line complete or nearly so (Bailey 1956:369); there are more than 10 pored-scales and the scale rows on the body exceed 40; pores of the preoperculomandibular canal are 9 or more; anal spine very thin, single and flexible; premaxillae protractile. There is a dark bridle on the snout which is interrupted at the midline. Breast, naked; cheek naked or with few small scales behind eye; nape naked or with few scales.

The scales of the Johnny darters completely cover the body except for the head, parts of the cheeks, and fins.) The eastern subspecies Etheostoma nigrum olmstedi (Storer) shows only the cheeks scaly, with the nape and breast unscaled. The western form found at the base level of the Great Lakes, Etheostoma nigrum eulepis (Hubbs and Greene), has the breast completely scaled; cheeks usually moderately scaled, and na

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B. <u>SYNONOMY</u>

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scaled, and nape completely scaled (Bailey 1956). (The darter concerned with in this study is the Central Johnny darter, Etheostoma nigrum nigrum, and it shows both cheeks, breast, and nape as naked. It is usually upon these two criteria -- geographic location and nakedness of the cheek, breast, and nape -- that these subspecies are separated from one another.)

B. SYNONOMY

(The following synonomy is taken from Check List of Fishes of North and Middle America by Jordan, Evermann, and Clark, 1955, page 287. It gives well enough the early generic changes.

Boleosoma nigrum (Rafinesque). Johnny darter; Blind Simon. Eastern United States, Ohio Valley, Great Lakes region, and upper Mississippi, west to Colorado and north to Manitoba.)

Etheostoma nigra Rafinesque, Ichth. Ohiensis, 1820, 37, Green River, Ky.

Boleosoma maculatum Agassiz, Lake Superior, 1850, 305, Lake Superior.

Boleosoma olmstedi brevipinnis Cope, Jour. Acad. Nat. Sci. Phila., VI, 1868, 214, Kiskiminitas River, Pa.

Poecilichthys beani Jordan, Proc. U.S. Nat. Mus., VII, 1884, 479, Tabo Creek, Mo.

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C. GEOGRAPHIC

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In 1956 Bailey (1956) proposed the return to the original genus of Etheostoma and he has included all of the Johnny darters under this heading.

C. GEOGRAPHICAL DISTRIBUTION.

There are three subspecies of the Johnny darter: the Central darter (E. n. nigrum), the Eastern darter (E. n. olmstedi), and the Western darter (E. n. eulepis). These are found most typically throughout the eastern United States (Forbes and Richardson, 1920). Here they are abundant and ubiquitous in their habitat selection. The two subspecies Etheostoma nigrum olmstedi and Etheostoma nigrum eulepis have, however, accepted widely different habitats and are thus localized in their distribution.

Etheostoma nigrum olmstedi has the more easterly distribution extending from the Canadian Maritime Provinces southward to the Ottowa River. In the United States it includes the eastern part of the Lake Ontario drainage, where in the lower elevations it intergrades easily with Etheostoma nigrum nigrum. Its southern range extends along the Atlantic Coast east of the Alleghenies to North Carolina, inhabiting the quiet waters and riffles of the smaller streams. (Hubbs and Lagler, 1949).

Etheostoma nigrum nigrum occupies the central area of this darter distribution. Its range extends from Saskatchewan to western Quebec along the northern United States and throughout

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and throughout the Great Lakes region, except in those areas pre-empted by *Etheostoma nigrum eulepis*; eastward to the Appalachian Mountains; south to the Gulf of Mexico, then westward through the Arkansas River drainage systems to the eastern slopes of the Rocky Mountains. (ibid.)

Etheostoma nigrum eulepis is confined quite specifically to the northern lakes of the Mississippi River drainage and to the base-level lakes marginal to Lake Michigan in Wisconsin, Indiana, and both peninsulas of Michigan. It is further limited to Lake St. Clair and the Detroit River; also to inlets and bays near the islands of Lake Erie in Ontario, Ohio, and Pennsylvania. (ibid.)

D. DARTER HABITAT

1. General habitat. (The Central Johnny darter inhabits small streams and lakes, differing from other darters such as the Iowa darter which prefers larger lakes and streams (Eddy and Surber, 1947). Occasionally the Johnny darters are found in small rivers or shallow parts of glacial lakes (Adams and Hankinson, 1928; Forbes and Richardson, 1920) but in Michigan they tend to inhabit the small inland streams and brooks whose depth is only a few inches in the summer and whose bottom is dense, soft, silt-sand. Larimore, Pickering, and Durham (1952) found the Johnny darter in deeper waters than the other darters they collected, and in greatest numbers in those areas where it was

associated with sandy bottoms.) Starrett (1950) in his study of Boone County, Iowa, reports Boleosoma nigrum nigrum (Etheostoma) as being the most abundant and widely distributed darter in the county, and that this species showed no particular habitat preference.

In the Augusta Creek, however, this species does show a strong habitat preference. It was observed at Stations 4, 5, and 6, that above the bridge construction which determined one limit of the station, there was a distinct shift in habitat type from that of the area below the bridge. (Upstream the water is deeper, slow-moving, the bottom sandy, and aquatic plants and insect larvae are abundant. Here the darters abound.) Downstream the water is swifter in character, shallow with rocky bottom. The shade is dense and there are no aquatic plants, few insect larvae, and the silt margins typical of the weed matted sides of the area above the bridge are gone. Here the darters are rare. Thus within a distance of 100', darters

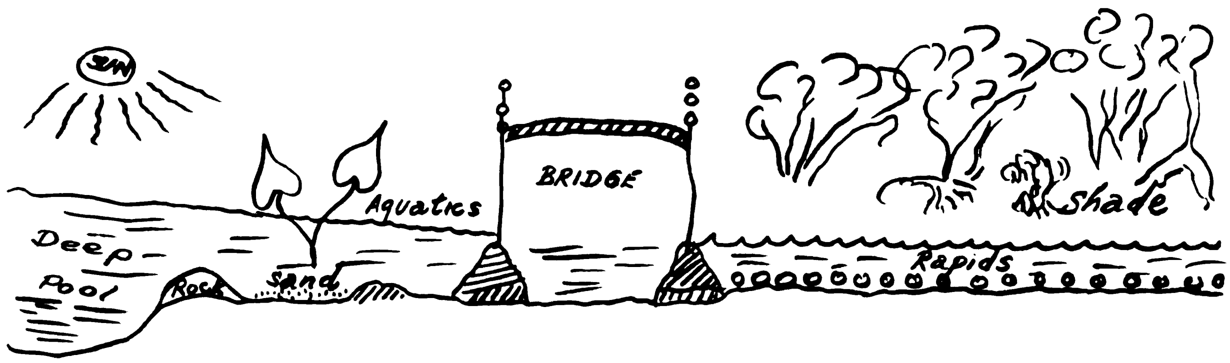

Fig. 3.1

may be taken in goodly numbers or not at all. They do not appear to cross these habitat barriers. (Fig. 3.1)

Forbes (1909) further supports this concept of habitat preference. In his work on the distribution of fishes in Illinois, he gives ten different habitat types under which he lists the number of Johnny darters captured. Three were taken in large rivers, 25 in small rivers, and 53 in creeks. Other large collections of 68 and 89 were taken in streams of moderate rate of flow, and over rocky-sandy bottoms.

In contrast to the slow-moving, quieter streams of which the Johnny darter is an inhabitant, Lachner et al. (1950) list the following fish as riffle-inhabiting species: Poecilichthys variatus (Kirtland); Poecilichthys zonalis zonalis (Cope); and Etheostoma blennioides blennioides (Rafinesque).

E. MICRO-HABITAT

During the early weeks of June there is an abundance of very small newly hatched fry on the silt shelf. Here the water averages 2" in depth, is very slow moving and bright and sunny. The bottom is jet black, silty, and easily roiled. The average length of fish is 16 mm. By July 15, the fish have moved off the shelf to the very narrow strip of sandy bottom directly below the stream's side margin. Here the water is faster moving, is about

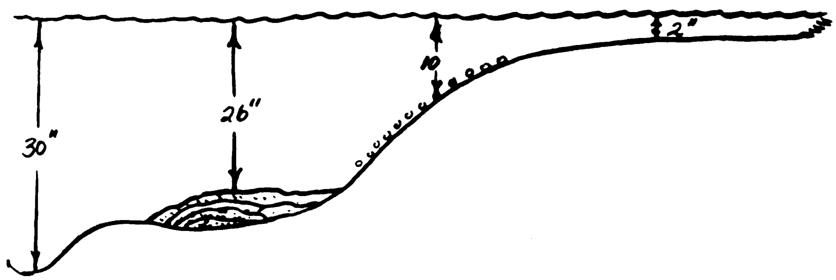

Fig. 3.2 Micro-habitat

6" in depth, clear, has a whiter background and fine to small pebbles. Farther out, the bottom has fine stones, snail shells, many roots from the marginal plants, the water is clear, sunny, and the surface shows ripples in some areas.

As the fish reach a mean length of 55 mm., they have moved sideways from the silt shelf to the center of the stream with its sandy bottom, depth of 30", and associated swifter-moving channel. (Fig. 3.2)

AGE AND RATE OF GROWTH

A. SCALE METHOD

1. Perch family. Etheostoma is in the family Percidae. Fish of this genus therefore have scales much like the "perches" and the scale method for the determination of age and rate of growth has been used extensively for related fish of this family. Adamstone (1922) worked on rates of growth of the blue and yellow pike-perch. Harkness studied the pike-perch in 1928 and Deason (1933) the same fish in 1933. The scale method was proven valid in the age and rate of growth studies on the yellow perch by Hile and Jobes (1940), Jobes (1933), and then later by Schneberger (1935). The more recent studies on the darters by Raney and Lachner (1943) and Fahy (1951) also showed the validity of the scale method for members of the subfamily Etheostomidae.

Raney and Lachner (1943) were the first to use the scale method for the determination of age and growth in darters. Previous to this study, Lake (1936) and Raney and Lachner (1939) used length-frequency data to determine age groups in the barred fantail darter, Catonotus flabellaris flabellaris and the spotted darter Poecilichthys maculatus respectively.

(2. Scale taxonomy. The percid scale is subquadrate, ctenoid with nucleus apicad of the middle, and strong basal radii, (Cockerell, 1913); stomatinae, are strongly ctenoid, thin, eliptical in the anterior portions of the fish and roughly rhomboidal in the posterior regions. They are slightly concavo-convex with concentric ridges or circuli grouped on the upper surface (Lagler, 1949; Cockerell, 1913). Apical teeth rather long, the greater part free from the marginal membrane; subapical elements below the teeth, transversely elongated and usually in four rows, (Cockerell, 1913).) Raney et al. (1943:231) state that the scales of Etheostoma are much like those of Stizostedion, but differ from them in having no annulus on the lateral field, such as occur in the yellow perch and centrarchid scales. The radii are somewhat more numerous than in Perca flavescens or Stizostedion vitreum (Evans, 1915.)

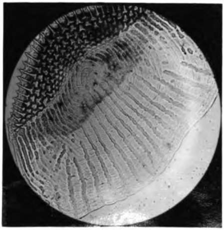

Fig. 4.1. Scale of Central Johnny darter

3. Annulus formation. It can be shown that a new annulus is formed each year in the spring and there is evidence to suggest that the time of this formation is dependent upon three factors: (1) temperature of the water -- at least 17°C. (Hankinson 1919), (2) latitude (Raney et al. 1943), and (3) degree of maturity. Raney and Lachner (1943) found that the annulus did not form until after spawning in the older fish of Etheostoma olmstdi (Storer) and Etheostoma longimanum (Jordan). (Table 4.1)

That a new annulus is formed each spring is clearly evident from a study of scales taken on advancing dates from the first of March to the last of September. These data suggest that the annulus is completed by March 15th (see Table 4.2). Scales of fish taken from the same location (Station 2) throughout the year show wide circuli in the spring and early summer when growth is more rapid; closer circuli in the winter when growth is reduced or at a standstill. (See fig. 4.4 and 4.5 of Plate I.) Secondly, from a study of the newly-hatched young it was observed that during the first spring and summer, the young showed the type of circulus pattern which is seen in the anterior parts of older scales, namely between the focus and the first year-mark (see fig. 4.2). Raney and Lachner (1943:231) have interpreted "the point on the anterior field of the scale which is laid down between the cessation of growth in

TABLE 4.1

THE TIME OF ANNULUS FORMATION OF DIFFERENT DARTERS OF DIFFERENT LATITUDES WITH VARYING SPRING TEMPERATURE

Stream System	Location	Species	No. Studied	Worker and Dates	Growth Period	Spawning Period	Annulus Date
James River System	James River System of Virginia	*Boleosoma long.*	102	Raney and Lachner (1943)	1st wk. in Apr.	Not yet spawned April 1	Before 1st wk. in April
Tributaries of upper Susquehanna River System	Candor New York	*Boleosoma nigrum olmstedi*	845	Raney and Lachner (1943)	1st 2 wks. in May. 1 –14th	Last days of April	1st 2 wks. of May. May 1-14
Fair Haven Bay Lake Ontario	New York	*Boleosoma nigrum olmstedi*	"a series of fish"	Raney and Lachner (1943)	May 25-29. Some growth	Last of May	Before May 25. May 25-29
		Catonotus flabellaris flabellaris	4	Forbes & Richardson(1920)		4 ready to spawn in last of May	
Black Creek, tributary of Genesee River System	Near Rochester, N.Y.	*Catonotus flabellaris flabellaris*	800 (approx.)	Lake (1936)		Apr. 15	
Augusta Creek	Battle Creek, Mich.	*Etheostoma nigrum nigrum*	800	Speare (1957)	Mar. 15	May 1-June 1	Feb. 1

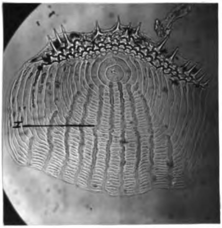

Fig. 4.2 showing spring and fall growth of circuli

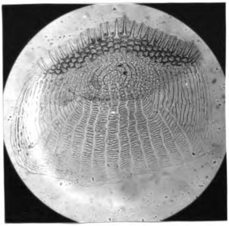

Fig. 4.3 showing key characteristics of three rows of subapical cells

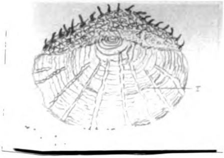

*Fig. 4.4 showing rapid growth of male, Age-group I

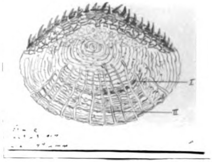

*Fig. 4.5 showing slower growth of female, Age-group II

PLATE I

*Figures 4.3 and 4.4 are reproductions of drawings of scales the

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the fall and just before the resumption of growth in the spring...as an annulus, or year mark." I have followed his interpretation and have designated these marks by Roman numerals.

Scale data taken from fish of approximately the same length and of different age groups show the relative rates of growth between the two sexes. The fish start out at approximately the same rate of growth. Soon, however, the male exceeds the female so that a male in its second summer is as long as a female in its third summer. This difference in rate of growth continues until they are both in their fourth summer. Then the rates level off and death ensues.

4. Circuli analysis. The circuli are laid down with irregular spacing throughout the year (Cooper 1951). Such factors as water temperature and food availability alter their deposition. The first circulus space following the annulus is quite wide and is followed by two other such spaces. Each space is approximately three times as wide as the circuli spaces of August, and four times the spacing of November and December. On or near May 1, growth is slowed down for a period of approximately 30 days. This is during the spawning period when the number of circuli laid down per unit of time seems to remain the same but they are much closer together. Seventy fish, taken on June 6, showed no

TABLE 4.2

TIME OF NEW ANNULUS FORMATION AND RESUMPTION OF SPRING GROWTH OF UNSPAWNED MALES AND FEMALES, 1956

	Age-group I			Age-group II			Age-group III		
Date	Sex	S.L. mm.	Scale margin	Sex	S.L. mm.	Scale margin	Sex	S.L. mm.	Scale margin
March 1	M	34.2	No growth						
	M	34.8	" "						
	F	24.6	" "						
March 9	M	25.1	Annu. formed	M	50	Annu. formed	F	50	Annu. formed
	M	26.6	" "	F	44.5	" "	F	47	" "
	F	29.6	" "	F	44	" "	F	47	" "
March 16	M	33.2	Growth slight	M	44.9	Growth slight	M	56	No new growth
	F	34.1	" "	F	45.0	1 circulus	M	53	" " "
	F	32.5	" "	F	40.7	1 circulus	F	50.6	" " "
March 24	M	33.7	Growth strong	M	54.5	Well devel.	M	54.0	New growth just started
	M	33.5	" "	F	44.5	" "			
	M	33.0	" "						

statistical difference between spawned and unspawned individuals in the average number of circuli laid down for both sexes. There is no evidence to suggest that growth begins after spawning. Rather it seems to begin earlier and is slowed down during spawning, as suggested by the closeness of the circuli. Further retardation of this growth is suggested by fig. 4.8 showing the mean length of Age-group I males for each month of the growing season. At the onset an increase of 0.3 mm. per day is normal. Thus an increase of 7 mm. for the period of May 9 to June 1 would be expected as shown by the dotted line. The actual growth achieved, 2 mm., indicates a near standstill. Following the spawning period, the normal "seasonal" rate of increase returns. Thus, on either side of the May growth period, there are single large circuli spaces. One of these spaces, that anterior to the May circuli group, is formed about June 1 immediately following the spawning activities.

Normal summer growth continues throughout July and August with a reduction in number of circuli and spacing between them. Then in August there seems to be a jump in the growth rate. This I have called a "Bumper-circuli-space". (See Plate II.) This new growth is probably due to the increase in the abundance of insect larvae. Then begins the fall and winter growth period. Here the circuli crowd in upon one another and become greatly reduced in number. Finally by February, the year mark starts to form and is com-

PLATE II

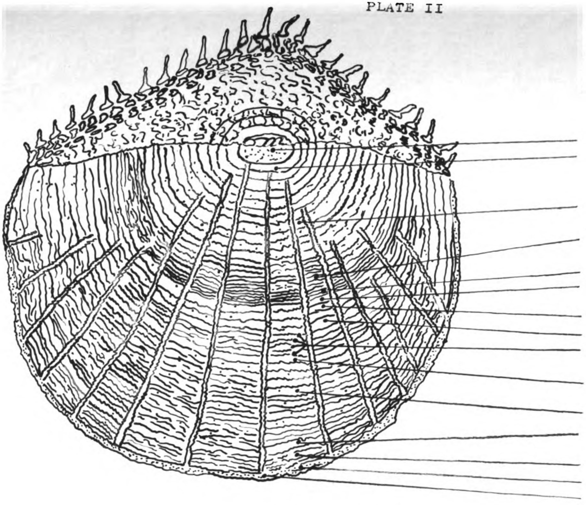

Fig. 4.6 Circuli analysis of synthesized scale: 45 mm. S.L. taken throughout the second growing season. Augusta Creek, Mich.

pleted by March 1. (Creaser 1926)

B. AGE AND RATE OF GROWTH

1. Population study. Fish (1935) reports the new-born fry as being 5 mm. in length. At the end of the first week, it is approximately 6.6 mm. and by the end of the first month, 10.20 mm. Hubbs (1921) gives the figure of .34 mm. as the rate of increase per day for a month. Spring-of-the-year fish taken in June 1958 showed a mean length of 16.9 mm. with a range of 14.5 to 18.2 mm. when both sexes were grouped. Figure 4.6 shows that there is little difference between the males and females in the rate of growth for the first year. At the end of the first growing season, the mean standard length for the males is 28.5 mm. and 27.6 mm. for the females. This difference increases, however, throughout the second year and remains about constant for the third and fourth year if this latter upper age limit is achieved. Two-year-old males average 2.5 mm. longer than females of the same age. (fig. 4.5)

While the males show an advantage in growth size over the females, the latter appear to show greater survival power. Thus Table 4.12 indicates that there is an increase in the proportion of females per age group as the fish grow older. At the end of the first summer, the males constitute 51% of the first-year-fish, the females 49%. But by the end of the third summer, the females make up 60% of the Age-group II population. It should be noted, however, that while the figures suggest a slight increase in the proportion of females, these differences are not significant at the 5% level when tested with Chi-square.

That this is the normal population change, however, may be indicated by comparing the sex ratios of other darters with that of Etheostoma nigrum nigrum. Thus Raney and Lachner (1943) in their studies of Boleosoma nigrum olmstedi throughout New England collected fish which included all four age groups. The percentage of females for Age-group O in New England was 43%, for Augusta Creek, 49%; Age-group I New England 43%, Augusta Creek 51%; and Age-group II New England 57%, Augusta Creek 60%. It can be seen that these ratios show the same tendencies as that of the Augusta Creek fish.

The upper maximum longevity of Etheostoma nigrum nigrum seems to be four full years of life, i.e. four completed summers and perhaps the fourth winter. Of the 612 fish taken by Raney and Lachner, three were of Age-group III and these were all females. A similar collection of 357 fish made in Augusta Creek in the spring of 1957 contained eight males and eight females of Age-group III. A male, S.L. 58.2 mm., believed to have completed its fourth winter, was the oldest fish captured during this study. It is interesting to note that the longest and oldest fish taken by

Raney and Lachner in Connecticut in 1943 was also a male, S.L. 88 mm.

In September of 1957, a large collection was made at Station 2 and the mean lengths for each age-group per sex are given in Table 4.3. It was found that the mean length for the three-year-old females was far above that expected. Thus two more collections, one on October 12 and a second on November 23, were made at this same station. From among the approximately 200 additional fish, 6 two-year-old females were taken. These showed an average standard length of 43.0 mm. and a range of 5 mm. extending from 41 to 46 mm. These data fit more closely the mean length for Age-group II females as suggested in Figure 4.7. Because of the closeness of this fit, it is improbable that the inclusion of still larger samples would change this mean significantly.

TABLE 4.3

LENGTH FREQUENCIES FOR EACH AGE-GROUP OF 249
JOHNNY DARTERS, AUGUSTA CREEK, MICH. 1957

Standard Length Millimeters	Age-groups							
	0		I		II		III	
	M.	F.	M.	F.	M.	F.	M.	F.
23	2	3	-	-	-	-	-	-
25	16	13	-	-	-	-	-	-
27	16	16	-	-	-	-	-	-
29	4	14	-	-	-	-	-	-
31	10	-	-	1	-	-	-	-
33	-	1	-	-	-	-	-	-
35	4	2	-	-	-	-	-	-
39	-	2	2	7	-	-	-	-
41	-	-	8	18	-	-	-	-
43	1	-	10	15	1	3	-	-
45	-	-	12	7	4	5	-	-
47	-	-	5	2	3	4	-	-
49	-	-	3	1	2	2	-	-
51	-	-	-	-	-	1	-	-
53	-	-	-	-	1	-	-	-
55	-	-	1	-	-	-	-	-
No. of Specimens	55	51	51	65	11	15	-	-
Mean	28.5	27.6	43.1	41.3	46.8	46.1*		

*This value was lowered to 44.5 when additional fish from October and November were added to the September data

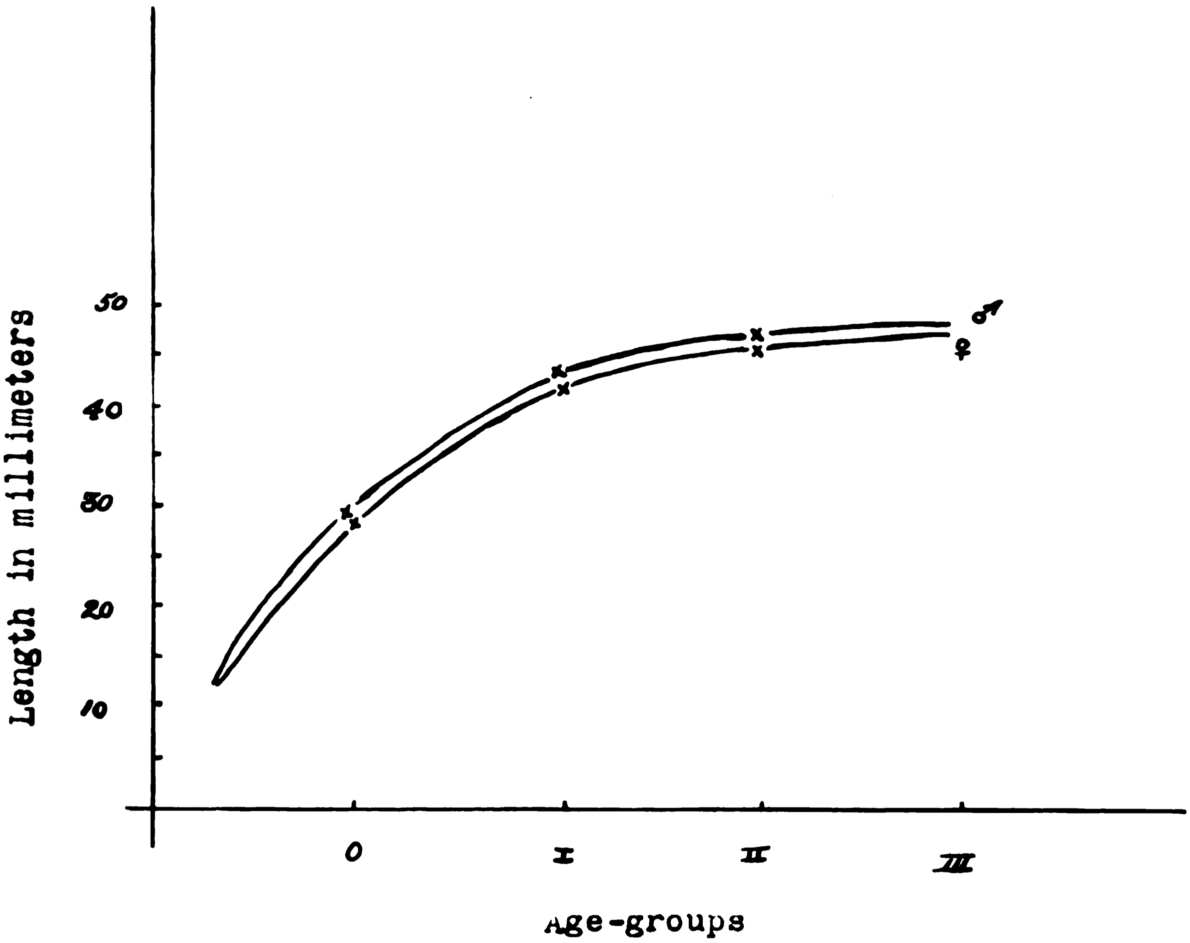

Fig. 4.7 Growth rate of Central Johnny darter

2. Geographical influence on mean length of age-groups

The mean length by sex for age-groups varies greatly among subspecies, i.e. fish of the same species but from different localities, and from different river systems. By taking the data of Raney and Lachner in their New England collection and arranging the different mean lengths of females in descending order, each with their appropriate river system indicated, it can be shown that those from the Susquehanna River in N.Y. and those from the Otter River in Massachusetts are approximately 8 mm. longer than females from Ontario, New York, the Miller River in Massachusetts, and Oneida, New York. Males from these same two groups of river systems are separated by a 10 mm. difference. It would appear that fish taken from the larger river systems show a greater mean length per age group for both sexes.

3. Seasonal growth. Fig. 4.8 suggests that spring growth is renewed about the middle of March. This is supported by observations on circuli growth made on March fish. These data showed that both males and females renewed growth on approximately March 15, 1957.

(The average overall growth achieved for the summer was 16.2 mm., 50% of which was accomplished by June 15th. Growth is retarded during the latter part of May and the first week of June during the spawning period. (fig. 4.8) Again, during July and August very little growth takes place and in

TABLE 4.4

MEAN LENGTH FOR EACH AGE-GROUP OF JOHNNY DARTER

Species	Worker	Three Age-groups					
		I		II		III	
		M.	F.	M.	F.	M.	F.
Boleosoma nigrum olmstedi	Raney and Lachner (1943)	34.9	32.8	51.2	43.4	58.0	48.6
Boleosoma longimanum	Raney and Lachner (1943)	37.6	35.4	54.9	46.3	-	-
Etheostoma nigrum nigrum	Speare (1957)	43.1	41.3	46.8	44.4	-	-

Data given in millimeters.

TABLE 4.5

MEAN SUMMER GROWTH OF CENTRAL JOHNNY DARTER
AGE-GROUP I, AUGUSTA CREEK, 1957

Date (Month)	No. Exam.	Mean Length in mm.	Range of Growth	σ mm.
April	35	27.8	22 - 40	4.40
May 18	21	33.9	31 - 38	1.87
May 28	38	34.9	29 - 42	3.03
June	42	35.6	32 - 48	3.73
July	26	44.4	37 - 50	3.58
Aug.	24	44.2	39 - 50	3.38
Sept.	46	44.0	37 - 50	2.94

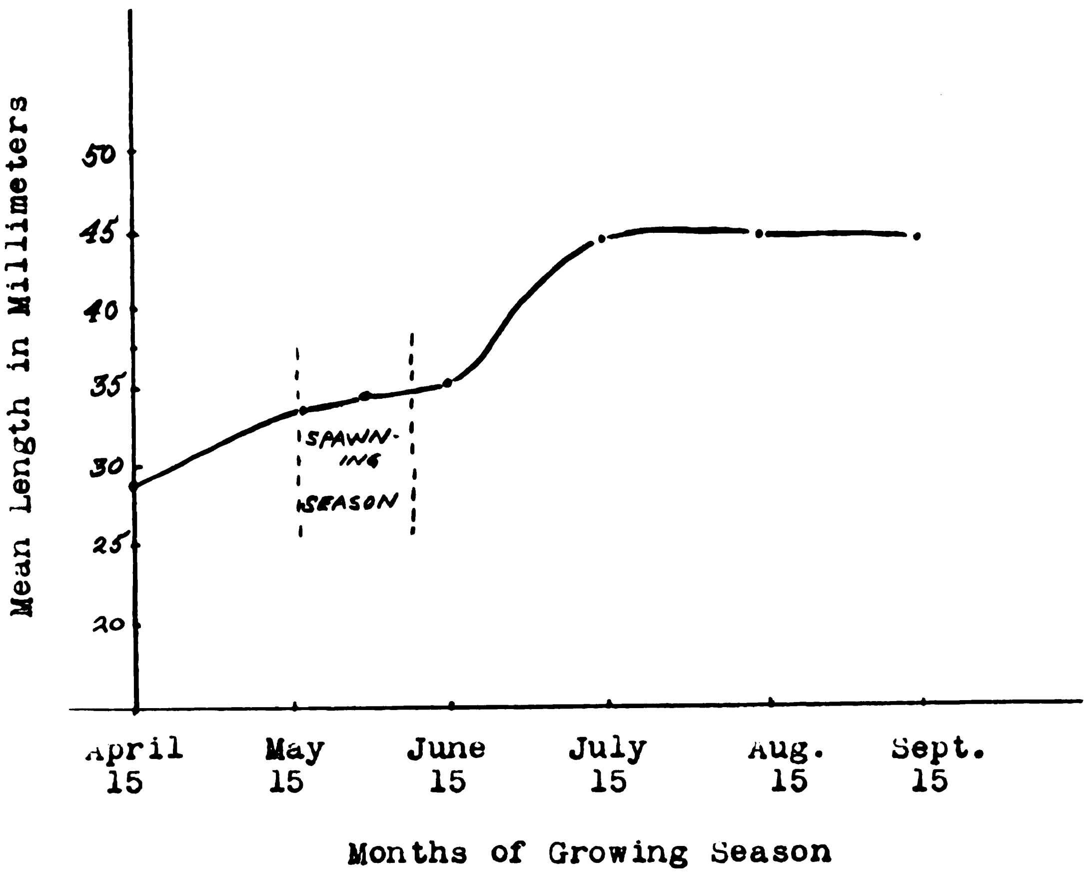

Fig. 4.8 Mean monthly growth of males Age-group I
Points plotted from data in Table 4.5

September increase in length is virtually stopped.)

4. Homogeneity of ecological groups and stations. During June, July, and August of 1957, some 273 young-of-the-year were collected from among the three ecological groups, and their mean standard length for both sexes combined are recorded in Table 4.6. It was found that there is no significant difference between the rate of growth for the two sexes within a given ecological group during the first growing season. (Both sexes grow at the same rate at all stations.) Thus on July 17, 1957, the mean length for both sexes combined for Station 3 was 23 mm.; for Station 4, 24 mm.; and for Station 6, 23 mm. Similar results were observed for other groups of stations. Data pertinent to either sex, any station, or any combination of stations indicate a homogeneous population for young-of-the-year throughout the stream for the first growing season.

It is thought that the early growth is equal throughout the stream due to the fry's diet of algae, which are abundant at all stations. Later in the summer, as the diet shifts from algae to midges, more severe competition results and this lack of food becomes a limiting factor. Field observations, regarding "insects as food for the Johnny darter", showed that at E-I there is an abundance of these midges, at E-II a relatively good supply, and at E-III a very reduced amount. This difference in food availability

TABLE 4.6

YOUNG-OF-THE-YEAR COLLECTED FROM ALL STATIONS, SPRING, SUMMER, FALL 1957
AUGUSTA CREEK, MICHIGAN. BOTH SEXES GROUPED. (S.L. IN MILLIMETERS)

Ecological Groups and Stations	June 27 No. Exam.	June 27 Mean Length	July 17 No. Exam.	July 17 Mean Length	August 9 No. Exam.	August 9 Mean Length
1	12	21.10	48	22.80	41	27.25
2	5	18.30	7	22.70	20	25.90
3	-	-	7	23.20	10	26.30
Totals E-I.........	17	20.20	62	22.90	71	26.48
5	-	-	-	-	7	25.08
7	-	-	8	22.90	17	26.05
10	-	-	-	-	16	29.58
Totals E-II........	-	-	8	22.90	40	26.90
3	-	-	10	22.90	24	24.65
4	-	-	6	24.30	19	23.39
6	-	-	6	22.70	6	24.41
9	-	-	3	30.30	4	29.75
Totals E-III.......	-	-	25	24.00	52	25.30

is not reflected in the growth achieved in the one-year-old fish as it is in the sunfish, for instance, but rather it shows up in the abundance of darters supported by any station or ecological group. There seemed to be no difference in growth achieved by all age groups at the end of the growing season regardless of the station considered. Thus two-year-old males at Station 2 averaged 43 mm. and those at Station 7, 44 mm.

5. Post-hatching growth, 1957 vs. 1958 It was desired to know if the young-of-the-year in 1958 had an advantage over the same age-group fish in 1957, this advantage accruing from the 20-day advance of the spawning season in 1958. In 1958, spawning began early in April but was followed after a few days of high warm temperatures by the normal cold nights and rainy days. Thus not until the middle of May were the expected spawning temperatures (18°C.) recurrent in the stream. Table 4.7 suggests that this early period of hatching did not aid the fish, and that growth was retarded until normal spring temperatures prevailed. Thus had they continued growing during this 20-day period, they would have accomplished a 10 mm. increase over the expected average for that date. The data, however, show that on June 27, 1957, the mean length for the young-of-the-year was 20.2 mm., and that on June 27[1] of 1958, the aver-

1. Some fish taken on June 25 were averaged into this data.

age length was only 17.8 mm. Comparison of the July and August collections for the same dates in 1957 and 1958 substantiates the statements above.

(Thus it may be inferred that early or late spawning does not greatly affect the mean length for a given age group for the first year. Where cold weather follows the early warm spells which set off spawning, growth is checked until normal temperatures continue through the early weeks of spring and summer.) Ten to fifteen days bonus at the beginning or at the end of the growing season does not affect the overall growth pattern. (See Table 4.7)

C. SURVIVAL RATES

1. Theoretic natality. The fecundity of the Central Johnny darter is not high as regards fish in general, but is amply sufficient to maintain an abundant population in the Augusta Creek. The average number of eggs per female is given in Table 5.3. (The older females lay two to three times as many eggs as the smaller one-year-olds. Thus a small one-year-old female would average 60 eggs laid and a large three-year-old, 160 eggs.) At Station 2, within a run of 50 yards, in a stream area abundant with fish, some twenty possible nesting sites were observed. Assuming that each of these were utilized by an average-sized female of 40 mm. laying 76 eggs, this area of the stream would produce 1520 eggs. Actual field studies show this manner of

TABLE 4.7

COMPARISON OF GROWTH RATES OF YOUNG-OF-THE-YEAR TAKEN IN 1957 AND 1958, MAY THROUGH SEPTEMBER, AUGUSTA CREEK, MICH.

1957			1958		
Date	Total No. Exam.	Mean S.L. MM.	Date	Total No. Exam.	Mean S.L. MM.
May 10[1]	500	0	Apr. 15[1]	500	0
May 20[2]	200	5	May 10[2]	500	0
June 6	8	13.6	June 10	7	11.4
June 17	25	16.8	June 19	25	16.8
June 27	17	20.8	June 27	17	17.8
July 17	95	24.0	July 17	68	22.8
Aug. 9	161	26.3	Aug. 9	41	25.5
Sept. 28	106	28.1	Sept. 27	28	28.9

1. Mean spawning date
2. Mean hatching date

reckoning to be inaccurate as the egg deposits are made more abundantly in certain areas than in others, such as ahead of rapids or small water falls. A further note of interest lies in the observation that when 10 tile pieces were placed in this same run of 50 yds., some 6,500 eggs were laid in a period of three weeks. While it is not known what porportion of ripe females successfully find "spawning rocks", and thus the real theoretic natality remains unknown, the data does suggest that where these spawning places are available, an enormous number of eggs can be laid within a short length of stream.

2. Ecological natality. (Only about 85% of the eggs laid ever reach the hatching stage. Strawn and Hubbs (1956) have suggested that 90% of the eggs would normally be fertilized, and field observations support this concept.) Of the eggs laid, approximately 1% develop a growth of Saprolegnia within the first ten days. By the 14th day, only 85% of the original eggs are still viable. (Table 4.8) (Large losses may be experienced from predation of the blunt nose minnow (Hyborhincus notatus) which uses the same nesting site.) A second factor, that of storage of spawning sites, lowers the ecological natality. Actual stream studies showed that many yards of the stream bed were inhabited by the darters with only one or two small pieces of wood, clam shells, or sunken stones to serve as nesting sites. In those areas

TABLE 4.8

PERCENTAGE OF VIABLE EGGS OF ORIGINAL BATCH.
CENTRAL JOHNNY DARTER, AUGUSTA
CREEK, MICHIGAN. 1957

Approx. No. days old	Date	Batch No.	No. of eggs	No. of Moldy Eggs	No. of Dead Eggs	No. of Unviable Eggs	Av. Per Cent Viable End of "X" Days	%
5	May 19	6	100	0	13	13		
5	May 19	8	100	1	3	4		
4	May 19	9	60	0	0	0	4	94.1
5	May 19	10	60	0	7	7		
2	May 24	12	100	0	9	9		
2	May 24	15	240	0	6	6		
12	May 19	1	70	0	4	4		
12	May 19	2	200	3	4	7		
10	May 24	13	200	39	5	44	11	90
12	May 24	14	260	70	9	79		
10	May 24	16	600	0	0	0		

Approximate percentage of viable eggs at hatching, after 14 days of development = 85%

abundant with nesting shelters, such deterrents as hovering crayfish, blunt nose minnows, and nest-guarding males served to keep females from laying their eggs.

Thus it may be shown that from a female in Age-group II, S.L. 39 mm., there would be laid approximately 80 ripe eggs, 15% of which would become unviable due to mold, lack of fertilization, or predation. Thus from batches of 150, only 127 would be expected to hatch successfully.

3. Mean survival rate. (The mean survival rate is 2.0 years. This would suggest that few fish pass through a third winter or even see a fourth summer.) The oldest fish taken was a male at the end of its fourth summer showing three annuli and a summer's growth. Table 4.12 shows the percentage ratios of males to females for each of the age groups. (It can be seen that after the second year, the females predominate over the males.)

D. POPULATION STRUCTURES

1. Proportion of age-groups at end of growing season. In 1957 several large collections were taken at Station 2 during September, October, and November. These combined collections provided a sample large enough to determine the relative proportions of each age-group as it occurred at the end of this growing season. The data of Table 4.9 suggest that the 1956 year class may have been more successful than that of 1957, inasmuch as this former class represents a very high proportion of the fall collection. Thus the young-of-the-year show about 49% of the total population, and the 1956 class (Age-group I), 43% -- despite the expected normal attrition which occurs through the spring and summer months. If a curve of age-group proportions is established, based on the percentages of Age-groups O, II, III, and IV, the expected percentage for Age-group I would be approximately 20%. That is, year class 1956 would normally represent 20% of the fall population. This difference between the observed 43% and the expected 20% indicates the success of this year class.

2. Proportion of age-groups in spring vs. fall seasons. The differences between the abundance of the various age-groups as found in the spring and fall seasons is indicated by comparing the data of Tables 4.9 and 4.10. Thus it may be understood that during the winter -- and perhaps direct-

TABLE 4.9

PERCENTAGE OF EACH AGE-GROUP OF 389 JOHNNY DARTERS COLLECTED IN THE FALL, AUGUSTA CREEK, MICHIGAN, 1957

Date 1957	Total Catch	Age-groups							
		Year Class 1957-0		Yr. Cl.1956-I		Yr.Cl.1955-II		Yr.Cl.1954-III	
		No. Exam.	%	No. Exam.	%	No. Exam.	%	No. Exam.	%
Sept. 28	248	106	43	116	46	26	11	-	-
Oct. 12	71	57	80	14	20	-	-	-	-
Nov. 23	70	28	41	37	54	4	4	1	1
Totals	389	191		167		30		1	
Averages			49%		43%		8%		0.2%

TABLE 4.10

PERCENTAGE OF EACH AGE-GROUP OF JOHNNY DARTERS IN THE SPAWNING SEASON
AUGUSTA CREEK, MICHIGAN, 1957

Date 1957	Total Catch	Age-groups 0 No.	%	I No.	%	II No.	%	III No.	%
March	67	0	-	38	57	17	25	12	18
April	91	0	-	58	64	30	33	3	3
May	177	0	-	162	92	14	8	1	0
Totals	335	0		258		61		16	
Averages			-		77		18		5

ly after the early frosts of October[1] -- the three-year-old fish tend to die off and be removed from the population.

Two-year-olds of late September, October, and November, if they had lived through the winter to March 15th, would at this time be classed as three-year-olds; and the three-year-olds of the previous fall would become fish with four annuli. The number of three-year-old fish per 100 collected in the spring is far fewer than the two-year-old fish captured per 100 in the fall. The two-year-olds of the fall represent approximately 8% of the population while the three-year-olds (after the new annulus formation of February) make up only 5% of the spring population.

1. Following the first hard frosts of late October, I began to experience fewer and fewer large fish in the collections made in the same routine manner as in the summer and fall.

3. Sex ratios. Twenty-three collections were made between March 1 and May 18, and 287 Age-group I fish were taken from selected stations representing each ecological group. These were studied with a view to determining if the sex ratio was different between the ecological groups or was essentially the same for the stream as a whole. Table 4.11 shows these relationships. Chi-square tests show that for fish of Age-group I, there is no reason to suspect that the sex ratio is other than one to one, either within groups, between groups, or for the entire stream.

The same seems now to be true of the older age groups. Thus while the percentage of females within Age-group II and III is higher than for Age-group I, the sex ratios for these age-groups is not significantly different at the 5% level. (Table 4.12)

TABLE 4.11

NUMBER OF MALES AND FEMALES AGE-GROUP I IN THREE ECOLOGICAL GROUPS WITH NUMBERS EXPECTED UNDER A 1:1 HYPOTHESIS AND VALUES OF CHI-SQUARE

"E" Group	No. Fish	No. Males	No. Females	Expected Males	Expected Females	Chi-Square	d.f.
E-I	159	92	67	80	79	3.6	1
E-II	72	30	42	36	36	2.0	1
E-III	56	28	28	28	28	0.0	1
Sum of chi-squares						5.6*	3
Total	287	150	137	144	143	0.5*	1
$X^2_{(het.)}$ 5.6 - 0.5 =						5.1*	3

*Not significant at the 5% level.

TABLE 4.12

CHANGE IN SEX RATIOS WITH ADVANCING AGE-GROUPS

		Age-groups					
		O		I		II	
Date 1957	No. Exam.	% Males	% Females	% Males	% Females	% Males	% Females
Sept.	248	52	48	43	57	42	58
Oct.	71	56	44	43	57	-	-
Nov.	69	35	65	54	46	25	75
Average percent		51%	49%	49%	51%	40	60%
Chi-square		.08*		.86*		1.20*	

*Not significantly different from a 1:1 expected ratio at the 5% level.

E. COEFFICIENT OF CONDITION

The coefficient of condition K_{SL} was determined for each age-group for both sexes, using the formula $K = {}^{W}/_{L^3}$ (Lagler 1956:159). Age-groups O, I, and II for both male and females were collected from Station 2 on September 28, 1957. Table 4.13 shows that the coefficient of condition changes slightly with increase in age and that both males and females exhibit a firm robust condition throughout life.

TABLE 4.13

COEFFICIENT OF CONDITION K_{SL} FOR JOHNNY DARTERS TAKEN AT THE END OF THE GROWING SEASON AUGUSTA CREEK, MICHIGAN, 1957

Male		Female	
Age Group	K_{SL}	Age Group	K_{SL}
O	1.8	O	1.9
I	1.5	I	1.5
II	1.5	II	1.5

F. LENGTH-WEIGHT RELATIONSHIP.

The length-weight relationship was determined for fish selected at random from all three age-groups taken on September 28, 1957 at the end of the growing season. When separate curves for males and females are drawn, they coincide closely. Thus curve B of figure 4.10 shows the length-weight curve when both sexes are plotted simultaneously. This curve is based on the absolute values and curve A upon the log-log transformation.

The formula $\text{Log } W = \log a + n \log L$ was used to determine the intercept and true slope of the length-weight line of regression where values of a and n were .00002207 and 2.8983 respectively. The following formulae were used to determine the above two unknowns:

$$\text{where } n = \frac{\sum\left[(\log W)(\log L)\right] - \dfrac{(\sum \text{Log } W)(\sum \log L)}{N}}{\sum\left[(\log L)^2\right] - \dfrac{(\sum \log L)^2}{N}}$$

$$\text{and } \log a = \frac{\sum(\log W) - n\left[\sum(\log L)\right]}{N}$$

Thus where a given fish length is known and its weight is desired, the formula $W = a\,L^n$ gives a reasonably close fit for values between 20 and 60 mm.

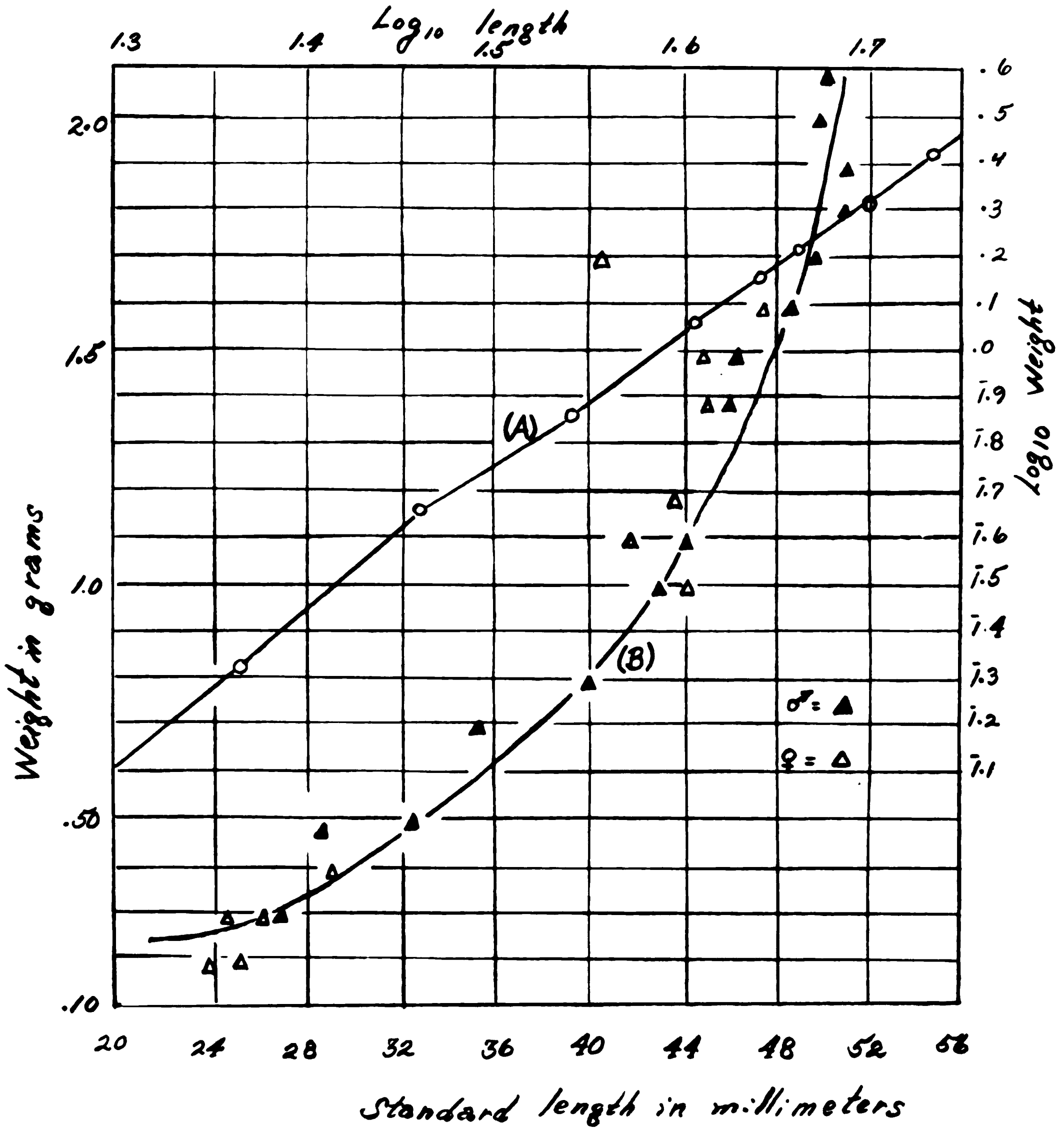

Fig. 4.9 Length-weight relationship in Johnny darter of Augusta Creek, Michigan, 1957. Curve B shows the absolute values; curve A the log-log transformation.

REPRODUCTION

A. SECONDARY SEXUAL CHARACTERISTICS

1. Spawning coloration. During the last two weeks of March, the males begin to take on their characteristic spawning colorations. The cheeks, lips, breast, and back of the head become a deep bluish-black. The ventral and dorsal fins look slate-like in color, except the very tips of the spinous and soft rays. The caudal fin deepens to a grayish-black and the scales along the belly become spotted with black pigment. The female does not take on this black coloration but becomes browner generally. The seven dark bands upon the back blend into one another and extend slightly downward along the flanks and the "W" markings become broader. The caudal peduncle turns a depper olive green.

In April 1958, pairs of ripe individuals were placed in battery jars at stream temperature of 12°C. These were allowed to come to room temperature slowly and observations were made on the behavior and coloration changes. Several pairs were kept at 4°C. as controls.

Males whose fins were only slightly darkened when in the stream now became very black and showed intense sexual behavior of wigwagging and territorial guarding. Approximately 12 hours after the temperature had reached 20°C., males and females spawned.

Several hours after spawning, a certain male had lost its blackish color and became a speckled brownish-gray. When, however, he was put into another aquarium containing a ripe female, the darker coloration returned within several hours. It would appear that this spawning coloration was a highly variable trait, capable of being "turned on" or "off" as a special sexual response.

2. Genitalia. By April 15th, the genitalia of both sexes become distended. The two palps of the female become erect, being pushed upward by an enlarged bursa which lies between the genital pore and the ventral fin. The body wall is enlarged and the scales slide pass one another. The male palp likewise is swollen, densely speckled with black pigment at the tip, and is somewhat erect. The genital bursa if present is much reduced.

Fig. 5.1 Genitalia of the Johnny darter seen from the ventral surface. Left: Female Right: Male

Fig. 5.2 Male 40 mm. showing sexual coloration April 15, 1958

Fig. 5.3 Female 40 mm. showing sexual coloration April 15, 1958

B. GONAD DEVELOPMENT

1. Seasonal changes. Following the spawning act of May, there is a period of nearly three months before the gonads begin to redevelop to the point of producing grossly visible eggs. In the female there are present at the time of spawning three "sets" of eggs each at a different stage of development. During the spawning act or acts, approximately one-third of these eggs are laid. This leaves one-third to be ripened by next spring and one-third as undeveloped. In the smaller fish there are fewer ripe eggs. (Table 5.3) Cooper (1935) found in the Golden Shiner (Notemigonus crysoleucas auratus) that maturity was apparently related to size at the end of the first year of life, and that within any one locality, maturity was dependent upon size rather than upon age. This same characteristic of gonad development seems to be true with the Central Johnny darter. Of the 174 fish examined in March, April, and May, all in their first spawning year and between 22.9 and 45.9 mm., 35% of the males and 14% of the females were immature. All fish, male and female,

TABLE 5.1

PERCENTAGE OF MATURE AND IMMATURE MALES AND FEMALES IN THEIR FIRST SPAWNING SEASON

Males Age-group I					Females Age-group I				
No. Exam.	No. Mature	% Mature	No. Immat.	% Immat.	No. Exam.	No. Mature	% Mature	No. Immat.	% Immat.
118	77	65	41	35	56	48	86	8	14

over 31 mm. were mature in their first spawning season.

One-year-olds, taken in the spring of 1957, all born in the spring of 1956, showed a length variation of some 23 mm. This difference is a result of at least three ecological factors which collectively serve as a strong deterrent to growth.

a) Spawning date. The spawning season is a month and a half long. Some fish may have hatched by May 15, while others are not free from the egg until June 15. Thus a fish born on the 10th of June as compared to that born early in May has a shorter total growth period until May of the next year.

b) Spring-growth period. Since the biggest part of the first year's growth is in the early spring, a difference in birth dates is influential. Not only has the fish born on June 15 a shorter total growth period, but he misses the rapid growth which takes place in the May 15 fry before the later ones are hatched. This results in sharp differences in total fish length among the one-year-olds. Variations thus appear as differences in length, weight, and the state of gonad development.

c) Interspecies competition. The area inhabited by the post-hatched Johnny darter is the same habitat as that of the young of Cottus bairdii bairdii, found in abundance throughout the stream and occupying the same habitat as the Johnny

darter generally. This competitor has, however, an ecological advantage over the darter because it hatches before the first of the darters. The two species remain closely associated until the middle of July, at which time the Johnny darters move to the more sandy areas and the Cottus to those of muddy bottoms.

2. Gonad regeneration. In order to determine the rate at which regeneration of the gonads takes place, a standardized method for comparing the size of the gonads was established. Thus two sets of comparator tubes were set up, the one bearing testes, the other ovaries. Each set of twelve tubes contained gonads taken from fish captured in April through March of the following year. Spawned gonads removed in July were rated as 1 and those in April as 10. These two dates represent the minimum and maximum stages of development. After these two terminal criteria were established, the remaining 10 tubes were ordered according to gonad development. Fish studied throughout the late fall, winter, and spring months were then evaluated according to their degree of ripeness by comparing their gonads with those in the tubes. Thus a two-year-old male, taken in September, would be identified as: male, II, mature; (devel. -5). Figure 5.4 shows that most of the regeneration takes place after September of the spawning year. Gonad development is slow through the summer but speeds up rapidly during the

TABLE 5.2

AVERAGE GONAD DEVELOPMENT BASED ON 20 REPRESENTATIVE FISH TAKEN DURING EACH MONTH, APRIL 1957 THROUGH MARCH 1958

Comp. Tube No.	12	1	2	3	4	5	6	7	8	9	10	11
Month	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Propor. of dev.	10	4	1.7	1.9	3.1	5.5	9.5	10	10	10	10	10

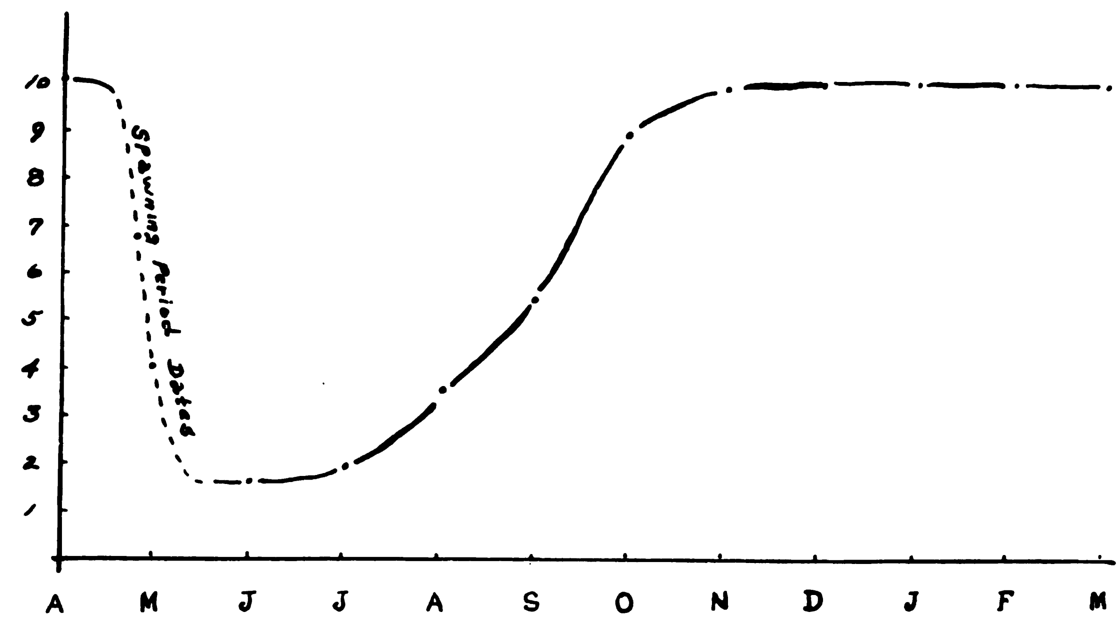

Fig. 5.4 showing monthly gonad regeneration

fall. During February, March, and April, the eggs enlarge, food supplies are increased, and approximately one-third of the eggs become ripe.

3. Fecundity. Eggs become grossly visible during late August and early September. They continue to develop through January and become fully ripe by April 15. The eggs in unspent ovaries may be divided into three classes: Class I, eggs fully ripe, possessing a large oil-droplet, orange in color and 1.5 mm. in diameter; Class II, eggs smaller (1 mm. in diameter), lighter orange and with little food supply, no visible oil droplet; Class III, eggs less than .5 mm., whitish in color and without oil or food material. Table 5.3 shows the average number of eggs of each class for various fish sizes. In general the larger fish lay more eggs, and my findings suggest that only the larger two-year-olds and some three-year-olds spawn twice. Data taken from actual field count suggest that 50 to 100 eggs

TABLE 5.3

AVERAGE NO. OF UNSPAWNED EGGS IN FISH OF DIFFERENT SIZES TAKEN APRIL 13 THROUGH MAY 18, 1957-58. (DATA GIVEN FOR ONE OVARY.)

Size Group	Total per Ovary	Class I	Class II	Class III
31-35 mm.	96	30	27	38
36-40 mm.	113	38	27	48
41-45 mm.	164	59	36	68

are laid in one batch, depending upon the size of the female. (Tables 9 - 11)

C. SPAWNING

1. Field studies. In the spring of 1957, a number of "nesting plants" were placed at different areas in the stream. Pieces of broken drainage tile, numbered 1 through 25, were deposited in groups of five at the odd numbered stations. In addition, ten more pieces were used at Station 2 and were lettered A through J, and a third set labeled S through Z was used within a stream enclosure. In 1958, the nesting plants at Station 2 were again studied. Tables 5.4 and 5.5 show the results of these spawning observations. Seining collections and field observations were also made on the breeding grounds during April and May 1958 in order to observe breeding behavior.

Early in April, the males move out of the areas of deeper and swifter water to those which are shallower and slower moving. They investigate the new habitat and locate a flat stone under which they swim and take up their vigil. (Raney and Lachner (1939) and Atz (1940) suggest that in *Etheostoma nigrum nigrum* there is only one male to a nesting site or stone,) and that this is in contrast to *Etheostoma nigrum olmstedi* which may permit three males to share the same nesting stone at the same time. I found that any male of *Etheostoma nigrum nigrum* which has located his "breeding

TABLE 5.4

RESULTS OF FIELD OBSERVATIONS ON NESTING PLANTS 1957

Egg Batch No.	Nesting Plant No.	Date Found	Field Count	Approx. Date Laid	Approx. Date Hatched	Final Date Checked	Number Days to Hatching	Average Water Temp. °C.
1	9	May 9	70	May 1	May 16	June 3	16	17
2	14	May 9	100	May 1	May 10	May 11	10	17
3	16	May 11	50	May 1	May 25	May 28	24	17
4	17	May 11	400	May 1	(Died in the laboratory.)			
5	B	May 18	50	May 13	June 1	May 28	18	16
6	G	May 18	15	May 13	May 27	May 28	14	16
7	J	May 18	170	May 13	May 27	May 28	14	16
8	U	May 18	200	May 14	June 1	June 3	18	17
9	V	May 18	50	May 14	June 5	June 3	22	17
10	W	May 18	50	May 14	June 1	June 3	18	17
11	Y	May 18	60	May 14	June 1	June 3	18	17
12	Z	May 18	230	May 14	June 1	June 3	18	17
13	X	May 28	250	May 14	June 1	June 3	18	17
14	S	May 28	60	May 14	(All dead in inclosure on June 3)			
15	14	June 6	250	May 25	June 10	June 17	16	20

Total number of nests (successful): 16

Av. number of eggs per nest: 125

Av. number days to hatching: 17.5

TABLE 5.5

RESULTS OF FIELD OBSERVATIONS ON NESTING PLANTS 1958

Egg Batch No.	Nesting Plant No.	Date Found	Field Count	Approx. Date Laid	Approx. Date Hatched	Final Date Checked	Number Days to Hatching	Aver. Water Temp. °C
1	A	April 25	500	April 20	May 10	May 16	20	16
2	B	April 17	400	April 15	May 10	May 16	25	16
3	B	April 25	200	April 20	May 10	May 16	20	16
4	C	April 17	600	April 15	April 25	April 25	10	18
5	C	May 2	50	April 27	May 14	May 16	17	16
6	C	May 2	50	April 27	May 14	May 16	17	16
7	C	May 9	120	May 1	May 14	May 16	14	17
8	E	May 2	10	April 27	May 8	May 9	11	15
9	F	April 17	600	April 15	April 25	April 25	10	18
10	F	April 17	200	April 15	April 25	April 25	10	18
11	F	May 2	130	April 27	May 8	May 9	11	15
12	G	April 25	400	April 21	May 1	May 2	10	15
13	G	May 2	12	April 27	May 12	May 16	15	15
14	G	May 9	120	May 5	May 15	May 16	10	17
15	H	April 17	300	April 15	May 14	May 16	21	16
16	H	April 25	300	April 20	May 14	May 16	24	16
17	J	April 17	600	April 15	May 1	May 2	16	16
18	J	May 2	500	May 1	May 15	May 16	15	17
19	J	May 16	60	May 8	May 21	May 25	13	18

stone", guards it against all intruders and drives off with ferocious attack all other males who wander near his acclaimed territory.

The site for the nest is usually upstream from a small or slow-moving rapids, at the side of the stream, and at a depth of approximately 8". Fish (1935) reports finding nests in water approximately 1' in depth in the Great Lakes. The bottom may be gravelly, marly shoals (Hankinson 1908), or stony and shallow (Hankinson 1932). Raney and Lachner (1939) found sandy bottoms best. "Nesting plants" placed on one inch of mud in the Augusta Creek at Station 1 were not used. Those on sandier bottoms were most frequently employed and those over gravelly bottoms only occasionally. No effort is made by the male to excavate further the natural nesting site. Something a little more than the thickness of the body is all that is required. Eggs have, however, been laid on tile-channeling raised well over 1½" from the stream bed.

The eggs are most commonly attached to flat stones about 5" across. Hankinson (1919) reports finding eggs on wooden splinters, mussel shells, and pieces of tile. Several hundred eggs may be laid in one or more clusters. The egg "patches" are about 3" in diameter. These are all closely packed and sometimes have one layer upon the other. Field observations suggest that the same nest is often used by several females and that polygamy is probably the case. Hankinson (1932) reports having made similar observations.

Between May 9 and June 17, 1957, some 28 nesting plants were studied about every 7 days. Fifteen of these were successful and 2,000 eggs were observed in the field or brought into the laboratory. Observations were also made on aquaria-spawning individuals.

2. Spawning dates. The spawning period for the stream begins around April 25, when the water temperature is approximately 18°C., this temperature having been maintained for about four days prior to the early spawning date. Spawning continues until approximately June 10 with most of the actual egg-laying taking place between May 1 and May 28. (See Table 5.6) Some one-year-olds spawned in the first

TABLE 5.6

SPAWNING DATES OF BOLEOSOMA NIGRUM BY VARIOUS AUTHORS

Name of worker	Year	Location	Egg-laying dates
Hankinson	1908	Walnut Lake South Mich.	May 16 - June 19
Forbes and Richardson	1909	Illinois	Last day of April to first of June
Hankinson	1919	Charleston Illinois	May 1 - June 17

week of May but no two-year-olds spawned as early as this. By May 18, all the one-year-olds had spawned and the two- and three-year-olds spawned after this date only. By May 28, all mature fish had spawned once and some of the older fish twice. (Table 5.7)

3. Number of eggs spawned. When one compares the number of ripe eggs of the different age groups with the number of eggs per batch as found in the field, there is observed a good correlation. The observations made on the pieces of tile showed that the eggs were laid in batches of 50 or multiples thereof. Often several sets were found together, each at a different stage of development, suggesting that several females had used the same nesting site. (Table 5.8)

TABLE 5.7

PERCENTAGE SPAWNED OF 267 MALES AND FEMALES BETWEEN MAY 9 AND JUNE 6 TAKEN IN AUGUSTA CREEK, MICH. 1957

Date	No. Observed	% Spawned	Percentage spawned by age-group					
			I		II		III	
			No. Exam.	% Sp.	No. Exam.	% Sp.	No. Exam.	% Sp.
May 9	32	46	31	48	1	0	-	-
May 18	44	86	39	97	5	0	-	-
May 28	85	92	78	94	6	83	-	-
June 6	76	95	61	97	12	83	1	100
June 17	30	99	28	96	2	100	-	-

TABLE 5.8

EGG-BATCH COUNTS OF JOHNNY DARTER AS OBSERVED ON NESTING TILE PIECES, 1957

Lab. Counts	Field Counts			
No. Ripe Eggs Both Ovaries	Small Single Batches	Large Single Batches	Double Batch Counts	Total Count
Age-group I (60)	50 hatching 50 hatching		50 near hatching 200 developing	250
Age-group II (100)		100 hatching 170 developing 170 developing	130 near hatching 130 near hatching	260
Age-group III (200)	200 developing		200 near hatching 200 near hatching	400

TABLE 5.9

EGG COUNTS IN RIPE FEMALES, STANDARD LENGTH 31 TO 35 MM.*

Station No.	Date	Age-group	Stand. Length	Ripe Eggs Class I 1.5 mm.	Devel. Eggs Class II 1.0 mm.	Immature Eggs Class III 0.5 mm.	Total Per Ovary
1	May 9	I	35 mm.	28	19	20	67
1	May 9	I	35.8 mm.	39	23	37	99
1	May 9	I	32.0 mm.	21	13	26	60
1	May 9	I	35 mm.	36	32	35	103
1	May 9	I	34.1 mm.	24	22	42	98
9	Mar. 28	I	33.8 mm.	38	41	28	107
1	Apr. 13	I	33.2 mm.	41	23	67	131
1	Apr. 13	I	32 mm.	29	25	35	87
1	Apr. 13	I	32 mm.	11‡	35	38	-
2	May 2	I	35 mm.	29	38	55	122

*Fish were collected in 1957 and data is given for one ovary.
‡Once spawned.

TABLE 5.10

EGG COUNTS IN RIPE FEMALES, STANDARD LENGTH 36 to 40 MM.*

Station No.	Date	Age-group	Stand. Length	Ripe Eggs Class I 1.5 mm.	Devel. Eggs Class II 1.0 mm.	Immature Eggs Class III 0.5 mm.	Total Per Ovary
1	April 13	II	38 mm.	50	48	60	158
3	May 18	II	39 mm.	36	24	57	117
3	May 18	II	39 mm.	34	12	43	89
3	May 18	II	40 mm.	41	14	40	105
2	May 9	II	39 mm.	45	30	34	109
2	May 9	II	38 mm.	30	24	40	94
1	May 18	II	37 mm.	30	27	30	87
9	March 28	II	37 mm.	42	27	60	129
2	April 13	II	36 mm.	36	27	50	113
2	April 13	II	38 mm.	33	23	53	109
2	April 13	II	40 mm.	36	28	48	112
2	May 2	II	39 mm.	44	44	63	151

*Fish were collected in 1957 and data is given for just one ovary

TABLE 5.11

EGG COUNTS IN RIPE FEMALES, STANDARD LENGTH 41 to 45 MM.*

Station No.	Date	Age-group	Stand. Length	Ripe Eggs Class I 1.5 mm.	Devel. Eggs Class II 1.0 mm.	Immature Eggs Class III 0.5 mm.	Total Per Ovary
1	April 13	II	41.1 mm.	62	44	61	167
1	April 13	II	41.0 mm.	87	53	92	282
9	March 28	II	47 mm.	69	46	65	180
2	April 13	II	42 mm.	60	40	77	177
2	April 13	II	44 mm.	44	27	67	138
2	April 13	II	47 mm.	43	35	66	144
2	April 13	II	45 mm.	55	46	70	171
2	April 25	II	42.5 mm.	64	55	90	209
2	May 2	II	41 mm.	47	39	52	138
2	May 2	II	45 mm.	68	24	80	171
3	May 18	II	43 mm.	62	9	30	101
4	May 18	II	43 mm.	42	5	69	116

*Fish taken during 1957 and 1958, and values given for one ovary only.

4. Egg viability. Between May 19 and May 24, eleven new egg batches were discovered over a half mile strip of the stream above Station 2. All the eggs in each batch were recorded. This included the living eggs, those with a mold on them, plus those which were completely dead and white in color. For batches of 150 eggs there averaged 2 eggs with mold and 6 which were dead. The former were identified by the long white filaments which grew on the egg, and the latter were white and milky in color. During the first 5 days about 5.9% of the eggs become unviable and by the 10th to 12th day this has increased to 10%. Thus at hatching on the 14th day, about 85% of the original batch are still living and hatch successfully. (Table 4.8)

In the laboratory, once a mold had started, it ran quickly over all the eggs and destroyed the entire batch within 6 days. This was at temperatures of approximately 20°C. In the field (natural waters) it was observed that only a very few of the eggs develop the mold and that it does not spread throughout the other growing eggs. Occasionally, however, a batch of 60 to 100 eggs was found, all eggs of which were milky white and dead. These were undoubtedly unfertilized.[1]

1. In the laboratory, females unattended by ripe males laid eggs in the normal way under rocks, and where there were no stones, upon the bottom of the aquarium.

5. Number left unspawned. A short study was made on the number of ripe eggs left as unspawned in the body cavity of spent females. Twenty fish were examined and all had spawned completely.

6. Spawning act of laboratory matings. Preliminary to the spawning act and as part of the courtship, the male in the presence of a ripe female begins wigwagging his pectoral fins. This is done slowly at first, only several times a minute. Later the wigwagging becomes more rapid and vigorous. Often this act of courtship is initiated from within the "nesting house". Then with short violent jerky motions, the male nudges the female toward the nesting quarters. This he does by biting at her caudal fin and butting his head against her caudal peduncle. After several failing attempts to inveigle her to enter, he may return to the nesting site only to begin the courtship activities again.

Once inside, the female then makes several passes upside down along the surface of the nest roof. She may either brace herself with the stiff dorsal fins, or by the action of her pectoral fins remain for a brief moment pressed against the mid-roof without support. The male meanwhile keeps up his sporadic wigwagging. After several moments rest, the female then inverts her body against the undersurface of the "nesting rock" and deposits several minute orange eggs. The male follows her in an inverted position and fertilizes the eggs as she moves about. Once initiated, the egg-laying may continue for several hours.)

(The eggs are about 1.5 mm. in diameter and are laid side-by-side very closely packed together. Several batches containing 600 eggs are sometimes laid without over-lap. In areas too small to accommodate all the eggs to be laid, a double layer is employed.

At the completion of the spawning act, the male guards the nest and cares for the eggs. (Hankinson, 1908, 1932; Adams and Hankinson, 1928; Seal 1892; Atz 1940) This guarding continues unceasingly and he drives from the area all other males. Adams and Hankinson (1928) suggest that this guarding is really territorial defense rather than an actual guarding of the eggs. While engaged in this care, the male directs himself in such manner as to have his tail lie under the eggs. He then moves his tail back and forth while holding his position with his pectorals (Atz 1940). This stirring action apparently aeriates the water and cleanses the eggs. Newly laid eggs brought into the laboratory and left unaeriated quickly developed a white mold (Saprolegnia).)

TABLE 5.12

LABORATORY SPAWNING TIME AND EGG COUNTS

Tank No.	Time	Date	Fish No.	H_2O Temp.	Coloration Male	Coloration Female	Wig-wag	Time Egg Laying	Total Eggs Laid	S.L.	Eggs Per Ovary
1	10 a.m.	April 18	5	22°C.	Deep bl.	Brown	12 a.m.	3 a.m.	110	42 mm.	55
2	10 a.m.	April 18	6	22°C.	Deep bl.	Brown	-	-	(No results)		
1	9 a.m.	April 19	7	18°C.	Very bl.	Dark br.	2 p.m.	3 p.m.	122 (26 laid next morn.)	48.3mm.	74
2	9 a.m.	April 19	8	22°C.	Black	Dark br.	-	-	(No results)		
1	12 a.m.	April 21	9	22°C.	Light br.	Brown	-	-	(No results)		
1	10 a.m.	April 26	11	7°-17°C.	Black	Brown	4 p.m.	6 p.m.	130	46 mm.	65
2	10 a.m.	April 26	12	17°C.	Black	Brown	6 p.m.	-	103	44.5mm.	52
2	12 a.m.	April 29	14	6°-15°C.	Very bl.	Light br.	-	-	(No results)		
1	9 a.m.	May 3	15	18°C.	J.darter	R. darter	(Would not mate. Male tried but female refused; later male took no interest in Rainbow darter.)				
2	9 a.m.	May 3	16	18°C.	J.darter	R. darter	(Would not spawn. Male died on May 4th. He tried hard for 12 hours to get her to spawn.)				

D. HATCHING

1. Embryonic development. In the spring of 1957, several nesting plants bearing freshly fertilized eggs were brought into the laboratory and their embryonic growth was studied. Every day until hatching, one or two eggs were preserved for future study. Following hatching, samples were removed every second day. Upon study, the details of their development were recorded. (See Table 5.13 for summary of this development.)

(The ripe Central Johnny darter egg measures approximately 1.5 mm. in diameter. There are present a large oil droplet, yellow yolk material, and a thin egg membrane which swells quickly in the presence of water. The eggs require constant circulation of the surrounding water in order to receive a sufficient oxygen supply. This is usually accomplished by the male who beats his fins and tail while guarding the eggs. Both unfertilized eggs and unaeriated eggs quickly develop the mold Saprolegnia. Strawn and Hubbs (1956) found that normally about 90% of the eggs laid in their natural habitat were fertilized. The percentage of growing embryos within batches of 100 or more eggs which the author studied in the field compared favorably with this figure. Not all the eggs laid remain attached to the substrate, for the male knocks off many while struggling to keep at the side of the moving female.

TABLE 5.13

EMBRYONIC DEVELOPMENT OF CENTRAL JOHNNY DARTER. LABORATORY OBSERVATIONS 1958.

Stage of Development	Time of the Development	Temp. Degrees C.	Embryonic Characteristics
Spawning	0 days	15	Eggs a light color of orange; oil droplet large; dia. 1.5 mm.
Blastopore	1 day		
Eye-ring	4 days	17	Eye-rings just beginning to form; oil droplet much reduced; pigment beginning to appear.
Heart beat	7 days	18	Movement is strong; eyes thicker; heart beat is strong and blood is circulating.
Fin-fold	10 days	18	Egg now very dark; pigment in dorsal body wall; fin-fold is well developed.
Near hatching	12 days	20	Body movement strong; color black; oil droplet small; egg case broken.
Hatched	14 days	20	Length 5 mm.; mouth large and ventral; pectoral fins large; eyes black and more dorsal; myomeres average 35 for the total body length.

Further, some eggs may be eaten by the male or female immediately after being laid.) This was observed several times in the laboratory.

The incubation period is approximately 17 days depending upon the water temperature. Jaffa (1917) gives the incubation period of the Iowa darter in the laboratory when the temperature was 13°C. to 16°C. as approximately 18 to 26 days. These darters were 3.4 mm. long when hatched. (During the incubation period of the Johnny darter, the egg remains round and it soon appears a darker orange. Two prominent black spots are the embryonic eyes at 8 days. The body trunk is conspicuous and the myotomes become visible at 10 days. Prior to hatching, the oil droplet becomes reduced and is very nearly absorbed by hatching time.)

(2. Post-hatched fry. Fish (1935) lists the following as characteristic of the post-hatched larvae: fry are about 5 mm. in length; mouth very inferior with the upper jaw projecting; a large silvery black eye; myomere count of 15 to the vent plus 19 to 22 behind the vent, and an embryonic marginal fin fold which originates directly behind the head.

At the 5.6 mm. stage, the fish is characterized by very large pectorals extending past the middle of the yolk) region and by large well-imbedded eyes which have moved higher upon the head.

In the more advanced stages, the protractile premaxillaries and single anal spine help to distinguish the individual. The adult characters do not become apparent until the 15 mm. stage is reached, but by the time the young females reach the 35 mm. stage, adulthood is attained.)

ECOLOGICAL ANALYSIS

A. ASSOCIATED SPECIES

1. Associated fish. Fish were collected from each of the ten stations during a ten month period, extending from April 15 to Nov. 20, 1957. Unusually high water prevented some stations from being sampled once each month. The species were sorted and recorded for each station. A longitudinal distribution of these fish is shown in Table 6.2. By lumping together the total catch of those stations making up a given ecological group, the three most abundant species in any ecological group was determined, Table 6.1. It can be seen that E-I with its slow-moving waters, sandier bottom and abundant aquatics, stands in direct contrast to E-III in its capacity to produce Johnny darters. This latter is characterized by rapids and gravel covered with fungal and algal growths. E-II, having ecological differences halfway between E-I and E-III, shows an abundance intermediate to the two above groups.

Etheostoma nigrum nigrum was by far the most abundant fish taken, constituting 41% of the total catch. Then follow *Semotilus*, *Rhinichthys*, and *Notropis* in that order. Ecological Group I produced 63% of all the Johnny darters; E-II, 24%; and E-III only 13%. This shows that *Etheostoma*

TABLE 6.1

THREE MOST ABUNDANT SPECIES WITHIN EACH ECOLOGICAL GROUP, AUGUSTA CR. 1957

Ecological Group	Total Catch	Three most abundant Species per group	% of total catch within E-Group
E-I	1101	*Etheostoma nigrum nigrum*	60%
Sites 1,2,8		*Cottus bairdii bairdii*	8%
		Semotilus a. atromaculatus	6%
E-II	771	*Etheostoma nigrum nigrum*	33%
Sites 5,7,10		*Rhinichthys atratulus meleagris*	23%
		Semotilus a. atromaculatus	13%
E-III	697	*Semotilus a. atromaculatus*	23%
Sites 3,4,6,9		*Etheostoma nigrum nigrum*	20%
		Notropis cornutus frontalis	16%

TABLE 6.2

LONGITUDINAL DISTRIBUTION OF ASSOCIATED FISH OF AUGUSTA CREEK, MICHIGAN, 1957. (STATIONS NEARLY EQUALLY SPACED.)

Stations / Species	1	2	3	4	5	6	7	8	9	10
Micropterus dolomieu dolomieu	x									
Micropterus salmoides	x									
Pomoxis nigro-maculatus	x									
Umbra limi	x									
Esox americanus vermiculatus	x									
Erimyzon sucetta kennerlii	x	x	x	x						
Ameiurus natalis natalis	x	x					x			
Etheostoma nigrum nigrum	x	x	x	x	x	x	x	x	x	x
Poecilichthys caeruleus caeruleus	x	x	x	x	x	x	x	x	x	x
Hyborhynchus natatus	x	x	x	x	x	x	x	x	x	x
Cottus bairdii bairdii	x	x	x	x	x	x	x	x	x	x
Notropis cornutus frontalis	x	x	x	x	x	x	x	x	x	x
Semotilus atromaculatus atromaculatus	x	x	x	x	x	x	x	x	x	x
Rhinichthys atratulus meleagris		x	x	x	x	x	x	x	x	x
Catostomus commersonnii commersonnii		x	x	x	x	x	x	x	x	x
Hypentelium nigricans			x	x	x		x	x	x	x
Hadropterus maculatus					x				x	x
Lepomis macrochirus										x

nigrum nigrum exhibits an ecological preference for sandy, weedy areas in contrast to shallow, rocky rapids.

2. Aquatic Plants. Aquatic plant collections were made during the summer of 1957 and the spring of 1958. The species, relative abundance, and their distribution throughout the stream were recorded. Table 6.3 lists the more common forms found in the stream proper.

(Reference to envirograph (a) of figure 6.1 shows a strong correlation between the Johnny darter and aquatic plant abundance. The rotting root stalks of Typha, Nuphar, and Sagittaria provide good areas for hiding when being pursued. Also the plant parts of Anacharis, Nasturtium, and Potamogeton form a deep organic medium in which the insects abound. Thus these contribute indirectly to the food source.) In such stations as 6 and 9 where the aquatic plants of the stream proper are reduced to a few scattered, isolated plants, the Johnny darter population is likewise limited to a few individuals.

TABLE 6.3

COMMON AQUATIC PLANTS OF AUGUSTA CREEK, MICH. 1957

EQUISETACEAE *Equisetum fluviatile*	ARACEAE *Peltandra virginica*
TYPHACEAE *Typha latifolia*	LEMNACEAE *Lemna minor*
SPARGANIACEAE *Sparganium angustifolium* *Sparganium chlorocarpum*	PONTEDERIACEAE *Pontederia cordata*
NAJADACEAE *Potamogeton illinoensis* *Potamogeton natans*	IRIDACEAE *Iris virginica var. Shrevei*
ALISMATACEAE *Sagittaria latifolia*	NYMPHAEACEAE *Nuphar advena* *Nymphaea odorata*
HYDROCHARITACEAE *Anacharis canadensis*	CRUCIFERAE *Nasturtium officinale*
CYPERACEAE *Eleocharis calva* *Scripus acutus*	LYTHRACEAE *Decodon verticillatus*
	LABIATAE *Mentha arvensis*

[illegible]

3. <u>Aquatic Insects</u>. The common and more abundant aquatic insects are given in Table 6.4. No quantitative study of abundance or distribution has been made but records for each seining station have been kept. Because of the variety of ecological niches within each station, many families restricted to gravelly bottoms, or muck, or slower waters, or sandy bottoms appear in the same collections. (Only a very few of the fauna types collected play any important ecological role in the life history of the Johnny darter. Such forms as diatoms, Cyclops, and diptera larva are used as food, with the latter making up most of the adult food diet.) (See Table 6.6) Most of the larger insects such as Agrion, Corixa, Anax, and Hexagenia, although abundant among large darter populations do not compete with the Johnny darter for food, space, or oxygen. Rather they occupy micro-habitats just outside those used by the darters.

(It is significant to note that the use made of the aquatic fauna varies with the age and the size of the darters. Thus the diatoms and Entomostraca are used by the young to supplement the early algae diet of the fry, and the adults, averaging 42 mm., use Tendipedidae almost exclusively (Pearse 1921). This would suggest that the larger three-year-old fish found in the day-time on light, sandy bottoms in the deeper holes must at sometime move to the silt-bottoms for feeding.) These sandy bottoms used during the sunny hours do not support the midges found in their stomachs.[1]

The wide distribution of the Tendipedidae throughout the stream is directly correlated with the data given in Table 6.1 in which it was observed that the Johnny darter, despite the ecological differences in the separate collecting stations, remained highly abundant fish within each of the ecological groups.

1. Only a few selected stomach analyses have been made to date. The problem of night-time feeding and diurnal movement is now being considered and studied.

TABLE 6.4

COMMON AQUATIC INSECTS OF AUGUSTA CREEK, MICH. 1958

PLECOPTERA
- Perlidae
  - *Perlesta*
- Acroneuriinae
  - *Acroneuria*

EPHEMEROPTERA
- Ephemeridae
  - *Hexagenia*
  - *Ephemera*
- Heptageniidae
  - *Stenonema*

ODONATA
- Gomphidae
  - *Hagenius*
  - *Gomphus*
- Aeschidae
  - *Anax*
  - *Aeschna*
  - *Basiaeschna*
  - *Epiaeschna*
- Libellulidae
  - *Libellula*
- Agrionidae
  - *Agrion*
- Coenagrionidae
  - *Ischnura*
  - *Argia*

HEMIPTERA
- Corixidae
  - *Corixa*
- Notonectidae
  - *Notonecta*
- Nepidae
  - *Ranatra*
- Belostomatidae
  - *Belostoma*
  - *Lethocerus*
- Gerridae
  - *Gerris*

TRICHOPTERA
- Helicopsychidae
  - *Helicopsyche*
- Hydropsychidae
  - *Hydropsyche*
- Brachycentridae
  - *Brachycentrus*
- Limnephilidae
  - *Limnephilus*
  - *Astenophylax*
  - *Pycnopsyche*

COLEOPTERA
- Hydrophilidae
  - *Hydrophilus*
- Psephenidae
  - *Psephenus*

DIPTERA
- Tipulidae
  - *Tipula*
- Tendipedidae
  - *Tendipedes*

4. Algae. The common algae of the stream have been treated in much the same way as the insects. Those common to the entire stream are listed in Table 6.5. There seems to be no major shift in abundance or kinds of algae throughout the growing season for any particular station. The filamentous forms do, however, become more conspicuous during September and October as they collect on the stalks of *Sparganium* and *Sagittaris*. While no quantitative study has been made on their abundance per unit surface of stream bottom, the kinds of "food-type" algae are included in Table 6.5.

(It was further noted that where the algae were abundant as at Stations 1 and 2, the darters also were abundant. At Stations 3 and 4 the abundance and kinds of algae were limited as were the darters.) These stations support few but larger fish.

TABLE 6.5

COMMON ALGAE FORMS OF AUGUSTA CREEK, MICHIGAN 1957

Sub-division CHLOROPHYCEAE	Sub-division BACILLARIOPHYCEAE
Cladophora	*Diatoma*
Scenedesmus	*Navicula*
Spirogyra	*Amphora*
Zygnema	*Meridion*
Mougeotia	*Cymlella*
Cylindrospermum	*Synedra*
Chara	*Pinnularia*
Sub-division MYXOPHYCEAE	*Gomphonema*
Chroococcus	*Opephora*
Oscillatoria	

B. ENVIROGRAPHS

The effectiveness of the relative abundance of seven environmental factors within the stream is shown graphically in fig. 6.1 a-d. The graphs show a strong correlation between abundance of aquatic plants, a sandy-silt bottom, moderate rate of flow and depth, as opposed to rapids with a dark, gravelly bottom. Other factors making up the environment such as temperature, oxygen concentration, pH, and water hardness seem less effective in determining darter abundance.

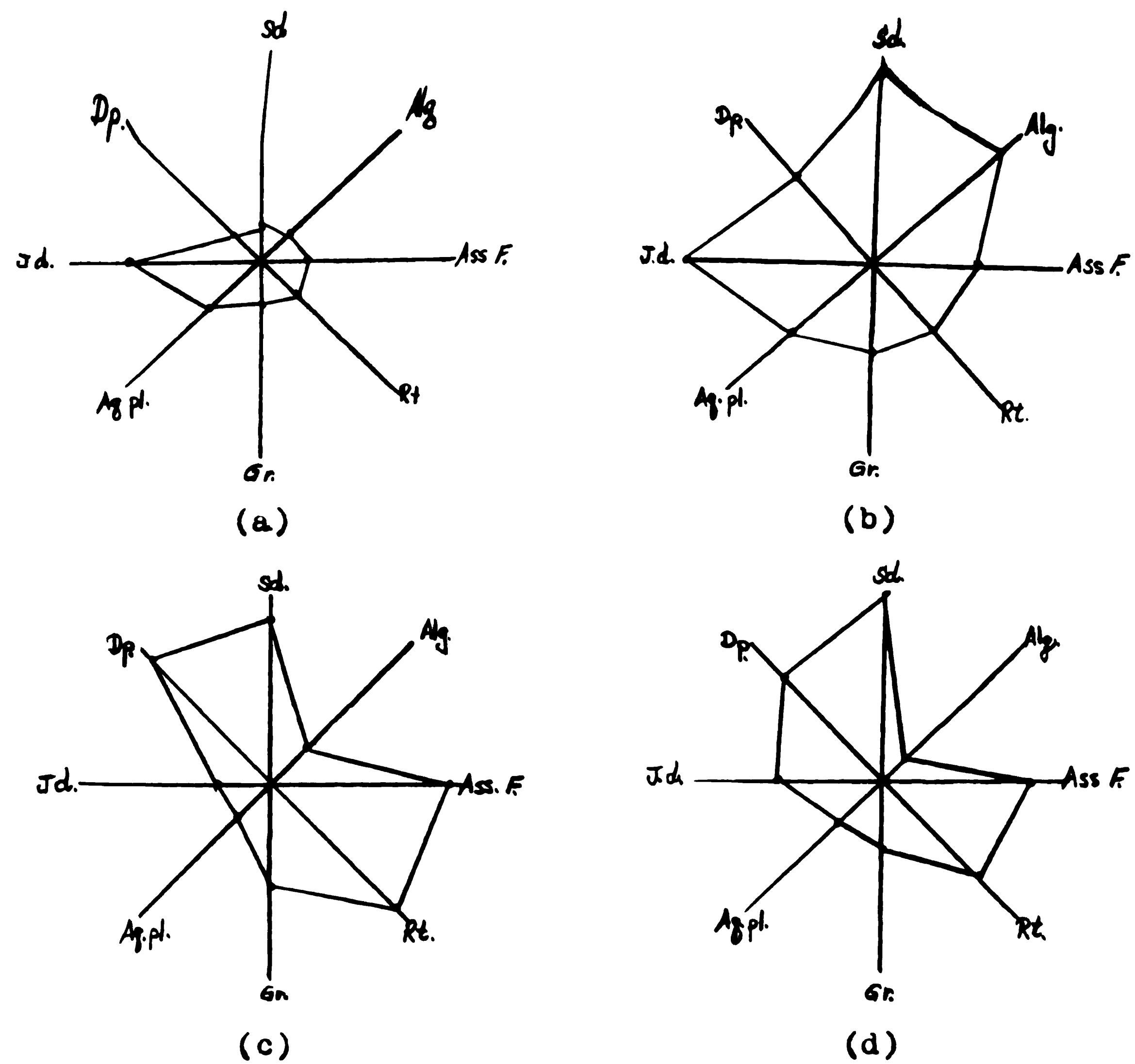

Fig. 6.1 showing envirographs of various ecological habitats. (J.d. Johnny darter; Dp. depth; Sd. sandy bottom; Alg. algae; Ass. F. associated fish; Rt. rate of flow; Gr. gravel bottom; Aq. pl. aquatic plants)

C. ABUNDANCE

(Despite the very high numbers of successfully hatched eggs per spawned female, the darters do not become overly abundant, due, I think, to shortage of food for the newly-hatched fry. They cannot successfully eat even the smallest of midges. Food for these fry must consist primarily of algae or large infusoria, both of which are available in limited amounts in those areas where the fry are hatched. These areas are usually sandy or silty with a slight current under the nesting stone. Thus there is considerable competition for the limited amount of food.

Because they are hatched in only a few inches of water, they are not eaten by other associated fish, as these latter seek out the center of the stream with its deeper channel. The rainbow darter remains in the deeper rapids, the blunt nose minnow in the stream channel, and the black sided dace in the shallower rapids. There is, however, evidence to suggest that these fry are eaten by the larger darters frequenting these areas. As the fry hatch out and begin moving around upon the silt shelf or leave the egg case in the presence of the guarding male, they are quickly eaten. Once beyond 15 mm. they continue on to maturity or death from disease or perhaps crayfish predation.)

D. DISTRIBUTION

The most limiting factor of distribution is that of stream gradiant and secondly, texture of bottom material. The stream gradient introduces three controlling factors simultaneously: (1) the swiftness results in a broken surface and rapids-like environment which is strongly inhabited by the larger, more aggressive rainbow darter[1]; (2) the bottom contains neither sand nor silt but remains very pebbly to stony which bottom is avoided by the Johnny darter; and (3) the aquatic plant abundance is reduced. Thus a rapids affords competition for food, and territory; lack of protective coloration from the background; and a more limited source of food dependent upon the muck of decaying plants. (The most perfectly adapted habitat in the Augusta Creek for the Johnny darter is thus a quiet to slow-moving area, about 6" to 8" deep, over a sandy to sand-silt bottom, at the sides and margins of the stream, in areas brightly lighted near heavy bottom vegetation.) The larger fish tend to occupy the deeper, more sandy holes (Table 6.2) but the bulk of the population is found in areas as described above. This habitat preference varies somewhat from what Trautman (1950) found in Ohio. While the larger fish both in the

1. Laboratory observations made on these two fish in the same aquarium showed the rainbow darter *Poecilichthys caeruleus c.* to be more aggressive and to defend a larger territory.

Augusta Creek and smaller Ohio streams seem to prefer a sandy-gravelly bottom first, he suggests that in the Ohio stream they accept a "gravel-boulder-bedrock" secondarily, and in preference to a silt bottom. I, however, found few to none on the large rocky-boulder type of bottom, and took tremendous numbers, particularly spring-of-the-year fish off the silty margins. This would suggest that "preference habitats" are correlated with size.

There seems to be no severe competition from the associated fish. There may, however, be slight predation upon the fry from Northern small mouth bass, *Micropterus dolomien dolomien* (Raney and Lachner 1943) and from the pickerels, *Esox spp*. (Hunter and Rankin 1939) which use the Johnny darter as supplementary food. Competition may also occur between the Northern Common Shiner, *Notropis cornutus frontalis*, *Hyborhynchus*, and the Johnny darter at the time of spawning. The former spawn at about the same time and in relatively similar habitats. Because of the multitude of possible spawning sites, however, this competitive pressure is very low.

Perhaps of least ecological importance is the variation in chemical and thermal factors from the source to the outlet. Table 1.6 shows very little variation in such critical factors as temperature, oxygen availability, and pH concentrations. All remain within tolerable limits. Normal lower limits of oxygen at 5 p.p.m. (Lagler 1956:254) were never exceeded. Jewell and Brown (1929) recorded pH readings of 8.0, 8.2, 8.4, and 8.6 in Michigan where darters were captured and Coker (1925) took specimens at concentrations of 7.2 to 7.4. Jewell and Brown (op. cit.) felt that a range of pH 7.2 to 8.6 as found in natural waters did not affect the distribution of fresh-water fish. The other chemical factors measured were alkalinity and CO_2 and these remained relatively constant throughout the three year period of study. While there is a slight gain in alkalinity from head waters to outlet, this shift is slight and offers no limiting pressure.

That the darters are found in such chemical environments should not suggest that these factors determine their distribtution -- but rather that they have wide ranges of tolerance.

E. FOOD OF JOHNNY DARTER

(A number of investigators have studied the basic foods of the Johnny darter, (Forbes 1880). None, however, have done so extensively and this study yet remains to be done. Thus there is little known about the differences in food preference between the young and older fish, between the availability of the food and their chosen habitat. There is, however, some evidence to suggest that the shift in micro-habitat as a lateral movement experienced during July and August is correlated in the younger fish with their new food requirements as they grow during their first summer.

Thus Fletcher (1957) has suggested that the newly hatched fry require infusoria for the first week, while Kidd (1929) reports finding colonies of algae and diatoms in the stomachs that he examined, among them being Gomphosphaeria, Coelosphaerium, Closterium, Scenedesmus, Melosira, Stephanodiscus, and Fragilaria. It should be noted that these are found in the small eddies, inlets, and upon the silt shelf; the exact micro-habitat of the newly-hatched fry. Heimburger (1913) found that the food of the adult Central Johnny darter consisted almost entirely of the larvae of chironomidae, while the young eat mostly Entomostraca. He further noted that the young eat more of the chironomidae as they become larger. An early study made by Pearse in 1921 concerned 10 specimen taken in June and July from Wisconsin lakes upon sandy shores, and he lists their stomach contents as being 78% chironomid larvae, 3% Helea larvae, 2% maggots, 3.5% cyclops, 13% ostracods, and some sand making up about 0.5%. The insect data collected over a three year period from all ten stations shown in Table 6.4 shows the availability of this food in Augusta Creek.)

TABLE 6.6

BASIC FOOD OF JOHNNY DARTER AS GIVEN BY VARIOUS AUTHORS

Investigator	Year	Species	Food	%
		Larvae		
Fletcher	1957	Boleosoma nigrum	Infusoria	
Kidd	1929	Boleosoma nigrum	Different algae and diatoms	
Heimburger	1913	Boleosoma nigrum	Entomostraca	
		Adults		%
Heimburger	1913	Boleosoma nigrum	Chironomidae	
Pearse	1921	Boleosoma nigrum	Chironomid larvae . .	78
			Helea larvae. .	3
			Maggots	2
			Cyclops	3.5
			Ostracods . . .	13

F. PREDATORS

(In their study of predation on the Johnny darter Boleosoma nigrum olmstedi (1942) and in their investigation of stomach contents of the fish of streams of Central New York (1942), Raney and Lachner found that in 31 stomachs of the Yellow pikeperch Stizostedion vitreum vitreum, 81.6% had recognizable Johnny darters (Boleosoma nigrum olmstedi) and this quantity constituted 80.6% of the estimated volume of all food. Further, these darters represented 61.4% of the frequency of occurrence of all food. They also found it as an important item in the diet of the northern small mouth bass (Micropterus dolomieu dolomieu) where these two occurred together in the streams of Central New York. Hunter and Rankin (1939) found it as the food of the pickerels (Esox spp.). Embody (1910) observed that Boleosoma nigrum nigrum served as food for the King Eider.)

Of the 2,569 associated fish taken throughout the entire stream, only two specimens of the northern small mouth bass (all immature) and two small specimens of the mud pickerel (Esox americanus vermiculatus) were captured. Therefore it is concluded that predation from such fish is slight.

(Real predation pressure may, however, be experienced from the blunt nose minnow (Hyborhynchus notatus) which Hankinson (1908) reports as a most persistent predator of

the Johnny darter eggs. This fish was taken abundantly throughout most of the stream.

Abbott (1873) reports finding Boleosoma olmstedi in the claws of a crayfish where it was captured when hiding. This is perhaps the one important source of predation.) In the Augusta Creek, the crayfish are as abundant as the darters. Any weakened specimen or any specimen which is morphologically handicapped is quickly eaten by this ever present death trap. The darter's defensive pattern of scurrying under stones increases its vulnerability to capture. Into the waiting claws of these crayfish the darters swim as an avoidance reaction to some lesser outside danger.

Thus the population is constantly being reduced and the weak and dying are quickly eaten. That this is so is seen in the fact that of the 65 fish tagged, clipped, or in some other way impaired, none were ever recaptured.

G. DISEASES

(Little is known of the diseases attacking the darter group. Atz (1940) found Ichthyophythiruis maltifillis (Fouquet) to be the cause of death of a darter which he had in his aquarium. Many trematodes, particularly in their earlier stages, attack the Johnny darter.) Among these are Neascus vancleavei and Azygia angusticauda. Cestodes such as Ligula intestinalis and Proteocephalus amblopl itis and acanthocephalans such as Neoechinorhynchus cylindratus and Leptorhynhoides thecatus have been reported in darters by Van Cleave and Mueller (1934).

(The well known "Black pinhead" parasitizes the Johnny darter and two and three-year-old fish are heavily infested. The older females appear to be more densely covered than males of the same age.) Fish taken from stations of E-I are more heavily infested than those of E-II. (It would seem from this that the slower-moving waters of Station 1 and 2 plus the heavy silt bottom harbor this parasite to a more prominent degree than the swifter and sandier bottoms of Station 8 and 10.)

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TABLE 1.1

TEMPERATURE VALUES, AUGUSTA CREEK, MICHIGAN, 1957. (DEGREES C.)

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Stations												
1	0	0	4	0	11	25	20	21	22	12	1	2
2	0	0	6	2	11	24	20	21	20	12	1	2
3	0	0	6	3	12	25	20	21	20	13	1	2
4	0	0	6	3	12	27	21	23	20	13	3	3
5	0	0	7	4	12	27	22	23	20	13	3	2
6	0	0	8	4	13	27	23	22	19	13	3	2
7	0	0	7	5	13	27	24	22	18	14	3	2
8	0	0	7	5	13	25	25	22	19	13	4	3
9	0	0	6	5	13	25	26	22	20	13	4	3
10	0	1	6	5	13	25	25	22	21	12	4	3
Sta. Aver:	0	0	6	4	12	26	23	22	20	12	3	2

Range for the stream: 0 - 27

TABLE 1.2

OXYGEN VALUES, AUGUSTA CREEK, MICHIGAN, 1957

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Stations												
1	11.6	10.7	10.8	11.5	9.3	6.7	6.4	7.6	8.6	13.0	13.0	12.0
2	10.8	10.5	10.6	10.1	8.7	6.3	6.6	7.6	11.8	11.0	14.0	12.6
3	12.2	14.4	12.0	12.3	9.3	7.0	6.4	8.0	10.0	11.4	13.2	13.6
4	12.2	14.4	12.1	13.6	9.8	7.4	6.6	8.0	9.4	11.2	13.4	14.2
5	11.9	12.4	10.8	13.0	10.0	7.4	7.2	7.6	8.4	10.4	13.2	13.4
6	11.9	11.6	12.0	13.6	7.4	7.4	7.2	8.2	8.4	10.8	12.8	13.6
7	12.0	11.6	12.0	12.7	7.8	7.4	7.4	8.2	8.2	10.8	13.8	13.6
8	11.9	11.9	11.0	12.5	8.7	7.4	6.8	8.2	8.4	10.6	12.6	13.6
9	11.7	13.5	11.0	12.6	10.2	7.5	7.0	8.2	8.2	11.2	13.8	13.6
10	11.7	12.4	10.8	12.8	9.1	7.5	6.8	8.2	8.2	11.6	13.8	14.0
Average	11.8	12.3	11.3	12.4	9.0	7.2	6.8	8.0	9.0	11.2	13.4	13.4

Range for the stream 6.3 - 14.2

TABLE 1.3

TOTAL BICARBONATES, AUGUSTA CREEK, MICHIGAN, 1957

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Stations												
1	199	142	180	172	164	161	180	212	210	204	160	164
2	227	162	200	201	141	207	200	180	229	208	185	194
3	211	167	218	211	180	205	208	230	230	160	191	210
4	203	167	222	205	190	229	220	230	235	230	191	215
5	214	167	220	198	192	210	205	225	231	160	207	215
6	199	172	211	196	137	212	208	225	234	155	202	207
7	206	163	219	170	170	201	215	210	230	164	195	224
8	197	165	219	182	140	196	218	216	224	164	191	205
9	194	165	220	202	170	190	210	216	210	155	198	205
10	199	162	218	165	145	198	180	210	208	167	188	200
Average	205	163	213	188	163	201	204	215	224	177	191	204

Range for the stream: 140 - 235

TABLE 1.4

pH VALUES AUGUSTA CREEK, MICHIGAN, 1957

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Stations												
1	7.8	7.4	7.9	7.6	8.3	7.4	7.6	7.2	7.8	8.4	8.6	7.4
2	7.9	7.6	7.2	7.7	8.4	7.4	7.8	7.1	7.9	8.6	7.6	7.8
3	7.6	7.7	7.2	7.7	8.8	7.6	7.8	7.9	7.4	8.2	8.8	7.6
4	7.4	7.8	7.3	7.6	8.8	7.8	7.8	7.8	8.2	7.6	8.8	8.0
5	7.6	7.9	7.9	7.9	8.1	7.9	7.9	7.8	7.4	8.0	8.4	8.1
6	7.6	7.8	7.8	7.8	7.9	7.8	7.9	7.8	8.1	8.5	8.8	7.8
7	7.9	7.8	8.6	7.9	8.8	7.8	8.1	8.0	8.0	8.5	8.8	7.8
8	7.8	7.9	8.6	8.6	8.1	8.1	8.2	7.6	7.2	8.2	8.8	8.0
9	7.8	8.0	8.4	8.6	8.4	8.1	8.1	7.4	7.2	8.3	8.8	8.2
10	7.9	8.2	8.5	8.6	8.1	8.2	7.6	7.6	7.2	8.5	8.8	8.1
Average	7.7	7.8	7.9	8.0	8.0	7.9	7.9	7.6	7.6	8.3	8.6	7.9

Range for the stream: 7.1 - 8.8

ROOM USE ONLY

~~NOV 2~~

OCT 16 1961

OCT 30 1961

~~MAY 1963~~